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Zulkifli Ahmad (a) Manap · Mohamad Zairi Baharom ·
Nasrul Hadi Johari · Ummu Kulthum Jamaludin ·
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Human-Centered Technology for a Better Tomorrow

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Editors
Mohd Hasnun Arif Hassan
Faculty of Mechanical and Automotive
Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

Mohamad Zairi Baharom
Human Engineering Research Group
(HUMEN), Faculty of Mechanical
and Automotive Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

Ummu Kulthum Jamaludin
Human Engineering Research Group
(HUMEN), Faculty of Mechanical
and Automotive Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

Idris Mat Sahat
Human Engineering Research Group
(HUMEN), Faculty of Mechanical
and Automotive Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

Zulkifli Ahmad (a) Manap
Human Engineering Research Group
(HUMEN), Faculty of Mechanical
and Automotive Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

Nasrul Hadi Johari
Human Engineering Research Group
(HUMEN), Faculty of Mechanical
and Automotive Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

Muhammad Hilmi Jalil
Human Engineering Research Group
(HUMEN), Faculty of Mechanical
and Automotive Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

Mohd Nadzeri Omar
Human Engineering Research Group
(HUMEN), Faculty of Mechanical
and Automotive Engineering Technology
Universiti Malaysia Pahang
Pekan, Pahang, Malaysia

This book is dedicated to the late Associate Professor Dr. Zakri Ghazalli.

Preface

Human and technology can never be separated. Humans can no longer exist without the help of technology. The influence of technology on human's daily lives is inevitable. Understanding the relation between humans and technology is key to responsible development and acceptance of future technologies in almost every application field, be it energy, mobility, health, work, living, learning or entertainment. We need to understand better how past technologies have fundamentally changed human existence, and how future technologies may impact human beings and their society. This reflection will help to design technologies with maximal value and minimal friction in a responsible way.

Universiti Malaysia Pahang (UMP) values technological advancement towards improving human lives. Therefore, UMP is planning on establishing a Centre of Excellence, whose research and development is focused on the application of technology for humans. There is a wide area of research in this field of human technology, such as biomechanics, medical technology, ergonomics and human safety, health and rehabilitation, sports technology, bio-inspired technology, among others.

This inaugural Human Enginering Symposium (HUMENS) 2021 is vital to put UMP on par with other universities that have already embarked on this field of research. Through a symposium like this, it is hoped that researchers from all over Malaysia and abroad can have a platform to discuss ideas and findings, in addition to fostering professional relationships for future collaborations among institutions.

This book gathers the papers submitted to HUMENS 2021, which was conducted online due to the COVID-19 pandemic that has affected the whole world. These papers were categorized into four parts: Artificial Intelligence and Biosimulation, Biomechanics, Safety and Sports, Design and Instrumentation, and Ergonomics. On behalf of the editors of this book, we believe that the papers will be of interest to researchers in fields related to human engineering and technology. Let technology enhances human's life, and not worsens it. Thank you.

Pekan, Malaysia

Mohd Hasnun Arif Hassan
Corresponding Editor

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Artificial Intelligence and Biosimulation

Heart Rate Variability (HRV) as a Physiological Marker of Stress Among Electronics Assembly Line Workers

Kamarulzaman Mahmad Khairai, Muhammad Nubli Abdul Wahab, and Auditya Purwandini Sutarto

Abstract The increase in the prevalence of workplace stress is closely related to adverse effects, such as reduced organizational performance, damage to overall employee performance, high employee turnover, and absences due to health problems. On the other hand, the stress response can be expressed by a change in a physiological index, that is, heart rate variability (HRV). Therefore, the main purpose of this article is to assess the impact of workplace stress on HRV, and how HRV is assessed compared to stress self-reports. Participants are 36 assembly line workers, divided into high and low DASS scores. The name with the highest DASS score is the treatment group, consisting of 18 workers who admitted to experiencing extremely high levels of self-reported depression, anxiety, and stress (DASS) measures. Among 301 participants with normal to moderate DASS scores, 18 were randomly selected as the control group. Both groups participated in the HRV measurement meeting using EmWavePro computer system equipment. The results showed that compared with the control group (1.28), it was more difficult for the participants in the treatment group to achieve a high coherence rate (0.69). A follow-up analysis using Mann-Whitney statistics showed that there was a significant difference between the two groups ($p < 0.001$). These findings indicate that the use of DASS for self-reported stress assessment is parallel to HRV measurement, indicating that participants have a comprehensive understanding of the psychological and physical conditions. Further research using HRV biofeedback mechanisms to improve HRV continuity may help reduce negative emotional symptoms among high-stress operators.

Keywords Depression anxiety and stress scale (DASS) · Heart rate variability (HRV)

K. Mahmad Khairai (✉) · M. N. Abdul Wahab
University Malaysia Pahang, Pekan, Malaysia

A. P. Sutarto
University of Qomaruddin, Gresik, Indonesia

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1 Introduction

In today's world, the pressure in the workplace is increasing, and it has become a common challenge for organizations and employee productivity [1]. Workplace stress can be defined as the difference between the physiological needs of the workplace and the amount of control that employees manage or respond to such work needs [2]. Some common workplace stressors are low wages, excessive workload, few growth opportunities, no challenging work, and lack of social support, lack of control, conflicting needs and natural environment [3]. As we all know, due to health problems such as anxiety and emotional disorders, work stress may lead to a decline in organizational performance, impaired overall employee performance, high error rates, poor work quality, high turnover rates and absenteeism. Work-life imbalance, depression and other forms of illness [4]. In order to deal with these adverse effects, many efforts have been made to identify potential factors and find effective stress management techniques.

An internal company conducted a survey called the "Employee Engagement Survey" (EES) at an electronics manufacturing plant and found that the pressure occurrence rate among assembly line operators was relatively high, and assembly line operators accounted for the largest proportion in the factory. There are also reports of increasing absenteeism, overtime, turnover and low productivity. These results are consistent with [5, 6], who believe that stress is more common among lower-ranking employees in the workplace because they have less control over their work status. A follow-up self-assessment of stress using the Depression, Anxiety and Stress Scale (DASS) showed that of the 319 assembly line female workers, 18 suffered from severe depression, anxiety and stress.

On the other hand, stress is a physical and psychological response, mainly affected by the autonomic nervous system (ANS) [7]. Heart rate variability (HRV) is a very important indicator for evaluating ANS function. HRV is defined as the variability between beats and the change between beats [8]. The traditional view is that heart rate (HR) is a product of emotional reactions or stress. However, recent studies have found that the interval between beats (ie, HRV) is a sign of the ability to regulate internal and external demands [9]. The HRV index indicates the supervisory capabilities of individuals under pressure. A poor HRV score indicates weaker mental and physical vulnerability, while a higher HRV is related to mental flexibility, and has better emotional, cognitive, and physical abilities to control stress [10–12].

The frequency domain measurement that reflects the autonomic balance can be used to quantify the HRV measurement [13]. According to the HRV power spectrum, there are three types of HRV frequencies, which affect the ANS through the sympathetic nervous system or the parasympathetic nervous system. The very low frequency (VLF) frequency range is 0.005–0.05 Hz, which means that sympathetic nerve activation or parasympathetic nerve suppression is reduced. Low frequency (LF) HRV (0.05–0.15 Hz) is affected by the sympathetic nervous system and the parasympathetic nervous system. High frequency (HF) HRV in the range of 0.15–0.4 Hz, inhibits and activates fuzzy nerves by breathing at a normal rate [8]. Many studies have shown

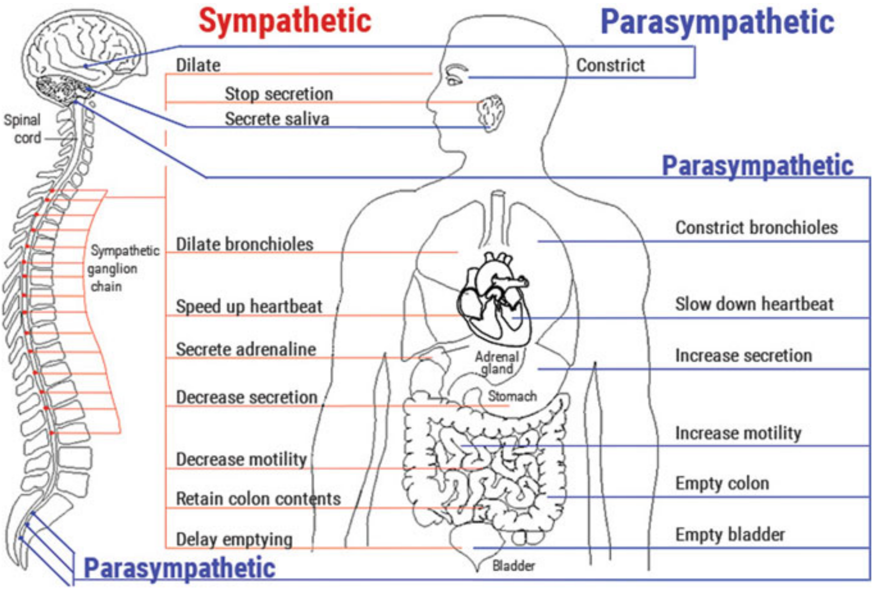


Fig. 1 Relationship between nervous system and the heart and brain

that emotional stress is related to the increase of sympathetic nerve activity and the decrease of parasympathetic nerve activity [7]. Figure 1 depicts the nervous system connection between the heart and the brain. The sympathetic nerve branches speed up the heart rhythm, while the parasympathetic nerve slows it down. Heart rate variability is caused by the interaction between the two branches of the nervous system and the incoming signals sent from the heart to the brain (baroreceptor network) [1].

It has been proposed that a good HRV score is considered to be above 0.04 Hz for LF and below 0.26 Hz for HF. On the contrary, the reason for the poor HR score is that the sympathetic activity in the VLF frequency band or the LF frequency band below 0.04 Hz is very low, or the parasympathetic activity in the HF frequency band above 0.26 Hz is very high [10, 11, 14]. Figure 2 illustrated the HRV power spectrum and its respective indicator.

Research by the Institute of Heart Mathematics has shown that two different emotions will produce different HRV patterns, as shown in Fig. 3 [15]. The irregular heart rhythms and irregular waveforms shown in the figure above are related to stress and negative emotions. The image below shows the coherent heart rhythm patterns that a person usually observes when experiencing sustained positive emotions. The coherent pattern is characterized by its relatively harmonic sinusoidal waveform. This mode corresponds to very narrow high-amplitude peaks (easy to be visualized as 0.09–0.1 Hz) in the LF region of the HRV power spectrum, while there are no major peaks in the VLF and HF bands [16]. McCraty and colleagues proposed the coherence ratio as a general indicator of HRV, and its formula is: (peak power/[total power-peak power]) or LF/(VL + HF). Coherence is a dynamic system approach dedicated

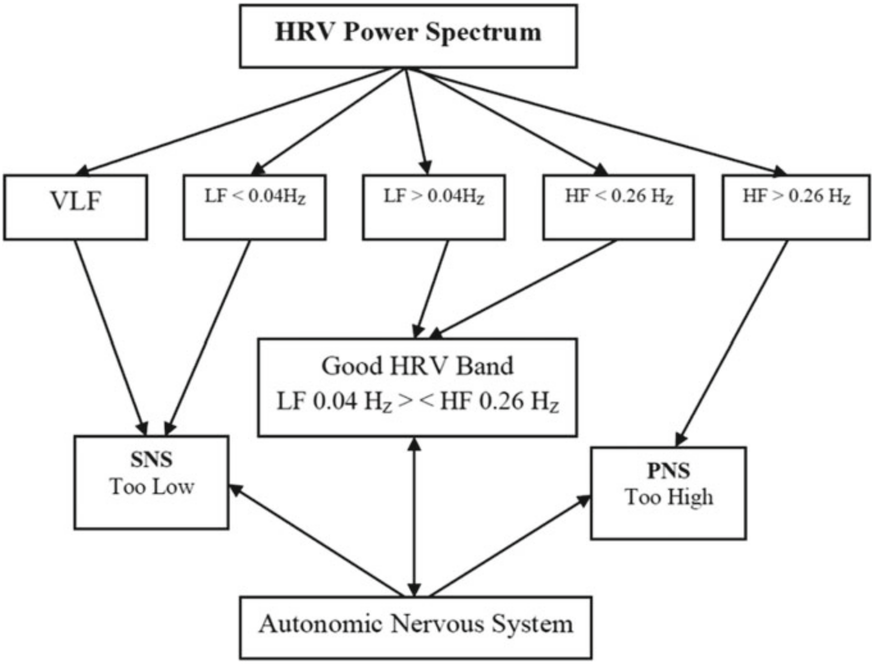
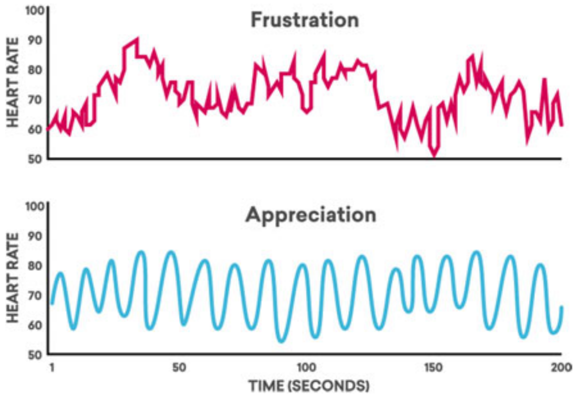


Fig. 2 HRV power spectrum indicator

Fig. 3 HRV patterns between two types of emotions



to improving the self-regulation ability of individuals by inducing physiological changes reflected in the heart rhythm.

In addition, in the field of stress measurement, Lazarus [17] believes that the best technique to effectively measure stress is to combine psychological measurement methods with physiological evaluation methods, so as to provide researchers with more comprehensive information about the subjective experience and state of participants. Mauss et al. [18] found that HRV is a powerful and objective biomarker. It is non-invasive and easy to assess stress in the workplace. Therefore, the main purpose of this article is to find the impact of workplace stress on HRV. It also aims to explore ways to compare HRV with self-report of stress. A more comprehensive evaluation is expected to help management find the best stress management method for the target audience.

2 Research Method

2.1 Participants

Participants were 36 female assembly line workers from an electronics manufacturing industry in Kuantan. They are divided into high pressure group and low pressure group. The high-stress group consisted of 18 workers who admitted that they had experienced severe depression, anxiety, and stress scores in the DASS measures they reported and were referred to as the treatment group. Among 301 participants with normal to moderate DASS scores, 18 were randomly selected as the control group. Table 1 shows the demographic characteristics of participants in each group.

2.2 Self-report Depression, Anxiety, Stress Scale

DASS-42 is a self-report assessment scale designed to measure the negative emotional state of depression, anxiety and stress [19]. The three DASS scales each contain 14 items, which are divided into subscales of 2–5 subscales, with similar content. The depression dimension assesses depression, life devaluation, interest or participation, and lack of pleasure and inertia. The anxiety dimension is to observe the influence of automatic stimulation, muscle changes, anxiety and anxiety on the situation, while the stress dimension studies the level of non-specific stimuli, such as sedation, neurostimulation and stress assessment, depression and lack of patience. Table 2 shows the general criteria for DASS classification scoring. In this study, DASS was delivered in Bahasa (BM), Malaysia, and it has been validated against the Malaysian population. For depression, anxiety, and stress, the Cronbach alpha values are 0.84, 0.74, and 0.79, respectively [20].

Table 1 Demographic characteristics of the participants

Category	Frequency (Percentage %)	
	Treatment group	Control group
Age		
19–29	8 (44.4)	6 (33.33)
30–39	4 (22.2)	5 (27.78)
40–49	4 (22.2)	5 (27.78)
50–61	2 (11.1)	2 (11.11)
Working experience		
Less than 5 years	11 (61.1)	2 (11.1)
5–10 years	1 (5.55)	31 (16.67)
11–20 years	0 (0)	9 (50.00)
21–30 years	3 (16.7)	2 (11.1)
More than 30 years	3 (16.7)	2 (11.1)
Department		
Agilent	1 (5.55)	2 (11.1)
ASL	1 (5.55)	1 (5.55)
Keysight	2 (11.1)	1 (5.55)
Magnetics	11 (61.1)	11 (61.1)
Moulded	3 (16.7)	3 (16.7)

Table 2 Cut-off scores for depression, anxiety, and stress scale of DASS

Category	Scale		
	Depression	Anxiety	Stress
Normal	0–9	0–7	0–14
Mild	10–13	8–9	15–18
Moderate	14–20	10–14	19–25
Severe	21–27	15–19	26–33
Extremely severe	28	20+	34+

2.3 Heart Rate Variability Measurement

The HRV measures used in this study are quantified by the EmWavePro system equipment developed and designed by Heartmath Research Institute [15]. It is a computer software program that collects pulse data through a pulse sensor that can be connected to a computer (Fig. 4). Studies have shown that the use of EmWavePro tools for HRV assessment and training is effective and effective in many areas such as work and performance improvement, stress and anxiety reduction [15, 21].

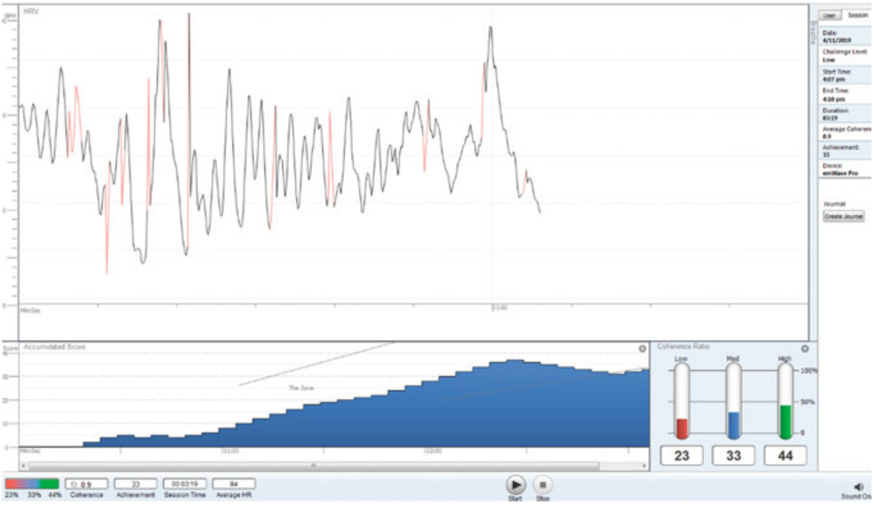


Fig. 4 EmWavePro computer hardware and HRV monitor reading

2.4 Measurement Procedure

Before collecting data, each participant read and signed the informed consent form, and then described how to use the software for 30 min. After the introductory meeting, participants were taken to a room with a controlled physical environment and showed them how to log in to the computer, start the HeartMath software, and place sensors. Then, each subject was asked to follow the continuous bar graph (CBC) displayed on the computer screen, and the breathing rate was slower and deeper than normal, but at a comfortable pace. CBC has three colors, representing the states of (red), calm (blue) and personality (green). All participants are encouraged to fill in as many blue and green bars as possible to achieve a high degree of consistency. The average duration of each HRV test session is 5 min.

2.5 Data Analysis

Descriptive characteristics and analysis of the difference HRV measures (coherence ratio) between high and low stress groups were performed using the SPSS Version 20.0. Due to violation of normality assumptions, Mann-Whitney test were conducted to assess whether any significant different on the coherence ratio between high and low stress group at significance level $p < 0.05$.

3 Results

Table 3 provides the DASS score for both group. Descriptive statistics of the HRV measurement for each indicator is revealed in Table 4. As shown, overall findings

Table 3 DASS score for treatment and control group participants

Participants	Treatment			Control		
	Depression	Anxiety	Stress	Depression	Anxiety	Stress
1	30	32	40	4	7	12
2	42	60	48	0	6	2
3	38	40	46	8	12	10
4	48	40	48	0	8	0
5	40	50	52	4	4	6
6	56	44	46	4	4	6
7	58	40	66	0	4	2
8	38	46	46	0	6	6
9	66	42	66	4	6	8
10	34	32	38	4	4	8
11	30	36	40	4	6	0
12	28	36	40	4	6	5
13	36	34	38	0	4	4
14	32	26	42	8	8	6
15	32	22	36	8	2	6
16	32	42	46	0	4	2
17	74	60	52	0	2	6
18	28	30	36	4	0	2

Table 4 Descriptive statistics of HRV measurement for treatment and control groups

HRV measures	Group	Mean (std dev)	Median
Coherence ratio	Treatment	0.7	0.7
	Control	1.3	1.0
Achievement	Treatment	22.7	20.5
	Control	48.2	32
Red-color	Treatment	52.61	59.5
	Control	18.6	21.5
Blue-color	Treatment	24.3	23.0
	Control	31.8	32.0
Green-color	Treatment	23.1	26.0
	Control	47.0	47.0

were in the expected direction. The Treatment Group got worse scores coherence ratio (0.69) compared to Control Group (1.28).

They were also experiencing more stresful states (red-color code) than the blue or green phase as depicted in Fig. 5. On the opposite, participants in Control Group were able to shift their HRv into higher blue and green areas (Fig. 6). Further analysis

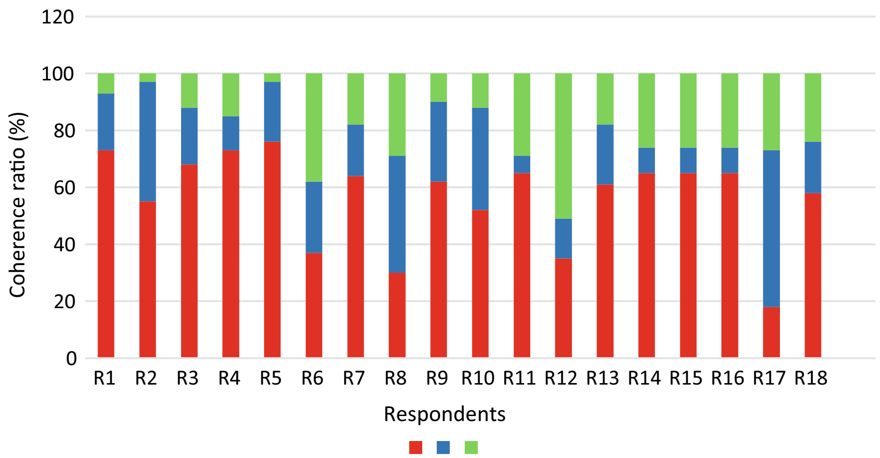


Fig. 5 Distribution of coherence ratio based on color-code code among treatment group

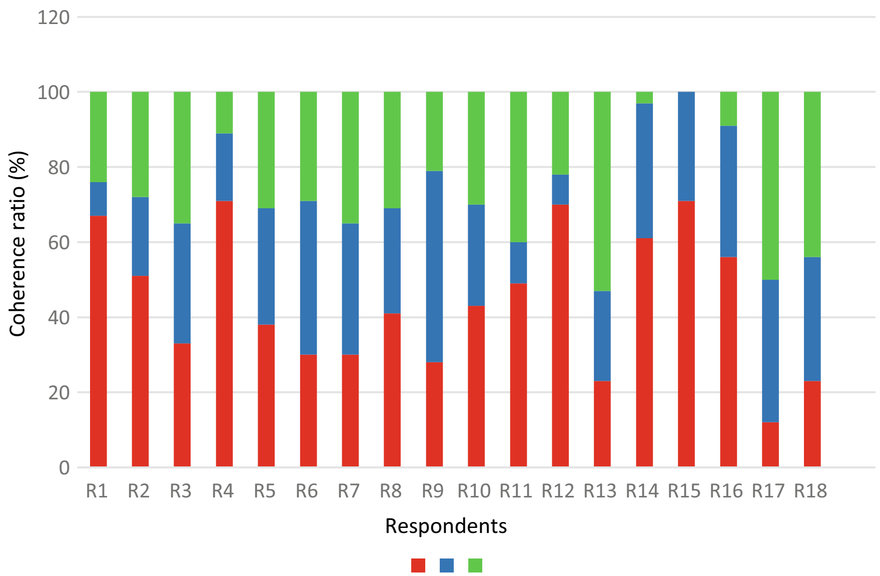


Fig. 6 distribution of coherence ratio based on color-code among control group

using Mann-Whitney test confirmed the significant difference on the coherence ratio between two groups ($U = 43.5$, $p < 0.001$).

4 Discussion

The results of this study can show the impact of workplace stress on HRV. Compared with the control group, the participants in the treatment group had significantly lower agreement. HRV data confirms that there are obvious self-reported negative emotional symptoms among high-stress workers. The HRV coherence rate range obtained in this study is consistent with other previous studies [21–23]. Fujimura and Okanoya [24] proposed that compared with unhealthy employees, healthy employees (low-stress groups) can better regulate their emotional stress. People use her/his emotion regulation process (including fuzzy neural intonation) to manage positive and negative emotions, as shown by HRV continuity. Reynard et al. [25] it is believed that low HRV may indicate poor physical and mental health and other life problems.

Since the results of this study support the association between HRV and self-regulation, it may be important to implement stress management procedures involving HRV through biofeedback mechanisms. Biofeedback technology is a behavioral intervention method and an effective method to achieve HRV coherence [26]. The technology uses the HRV indicators of a person and provides feedback so that the person can learn to control these indicators and adjust their occurrence state to the best HRV state. HRV biofeedback can help promote emotional regulation by increasing the continuity of HRV, which is related to reducing stress, anxiety and depression and improving cognitive ability [22, 26–29]. As a cheap, safe and non-invasive technique, HRV-related biofeedback may be an effective training method to reduce stress-related symptoms of assembly line workers [30].

5 Conclusion

Further exploration of the relationship between HRV and self-regulation could be conducted in several directions. Can HRV coherence biofeedback training improve self-regulation? By increasing HRV, high stressful workers could be helped to combat with all of the negative emotional symptoms.

This study has some important limitations. The relatively small sample size and sample characteristics reduce the general application in other settings. Need to address the relationship between self-reported stress, HRV and objective job performance evaluation.

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References

1. Ramos-Galarza C, Acosta-rodas P (2018) Stress and productivity in workers of textile companies. J Fashion Mark Manag 23(1):17–29
2. Kivimäki M, Kawachi I (2015) Work stress as a risk factor for cardiovascular disease. Curr Cardiol Rep 17:630
3. American Psychological Association (2012) The different kinds of stress. Available at: http://www.apa.org/helpcenter/stress-tips.aspx. Last Retrieved on 12 Oct 2019
4. Sauro MD, Jorgensen RS, Teal Pedlow C (2003) Stress, glucocorticoids, and memory: a meta-analytic review. Stress 6(4):235–245
5. Beheshtifar M, Nazarian R (2013) Role of occupational stress in organizations. Inst Interdisc Bus Res 4(9):648–657
6. Sutherland VJ, Cooper CL (1996) Working paper stress prevention in the offshore oil and gas exploration and production industry, Geneva. Available at: https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_250121.pdf. Last retrieved on 19 Aug 2019
7. Yu B, Funk M, Hu J, Wang Q, Feijs L (2018) Biofeedback for everyday stress management: a systematic review. Front ICT 5:23
8. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiol. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Eur Heart J 17(3):354–381
9. Young H, Benton D (2018) Heart-rate variability: a biomarker to study the influence of nutrition on physiological and psychological health? Behav Pharma 29:140–151
10. Hansen AL et al (2004) Heart rate variability and its relation to prefrontal cognitive function: the effects of training and detraining. Eur J Appl Phys 93(3):263–272
11. Shaffer F, McCraty R, Zerr CL (2014) A healthy heart is not a metronome: an integrative review of the heart's anatomy and heart rate variability. Front Psychol 5:1–19
12. Beauchaine TP, Thayer JF (2015) Heart rate variability as a transdiagnostic biomarker of psychopathology. Int J Psychophys 98(2):338–350
13. Berntson GG et al (1997) Heart rate variability: origins, methods, and interpretive caveats. Psychophysiology 34(6):623–648
14. Appelhans BM, Luecken LJ (2006) Heart rate variability as an index of regulated emotional responding. Rev Gen Psychol 10:229–240
15. Institute of Heart Math. Em wave pro tour user manual 2016. https://www.heartmath.com/support/knowledgebase/?article=kA180000000CsvqCAC%20and%20t=emWave+Pro+Tour+User+Manual. Last retrieved on 3 July 2019
16. McCraty R, Childre D (2010) Coherence: bridging personal, social, and global health. Altern Ther Health Med 16:10–24
17. Lazarus RS (1990) Theory-based stress measurement. Psychol Inquiry 1:3–13
18. Mauss D, Jarczok MN, Fischer JE (2016) The streamlined allostatic load index: a replication of study results. Int J Biol Stress 19:553–558
19. Lovibond SH, Lovibond PF (1995) Manual for the depression anxiety stress impact of a new emotional self-management program on stress, emotions, heart rate variability. Integr Physiol Behav Sci 33(2):151
20. Musa R, Fadzil MA, Zain Z (2007) Translation, validation and psychometric properties of Bahasa Malaysia version of the depression anxiety and stress scales (DASS). ASEAN J Psychiatry 8(2):82–89

21. Reiner R (2008) Integrating a portable biofeedback device into clinical practice for patients with anxiety disorders: results of a pilot study. Appl Psychophysiol Biofeedback 33(1):55–61
22. Burch JB, Melannie A, Pallavi B, Jameson S, James W, Venkat K, Ginsberg JP (2019) Shift work and heart rate variability coherence: pilot study among nurses. Appl Psychophysiol Biofeedback 44(1):21–30
23. Berry ME, Chapple IT, Ginsberg JP, Gleichauf KJ, Meyer JA, Nagpal ML (2014) Non-pharmacological intervention for chronic pain in veterans: a pilot study of heart rate variability biofeedback. Glob Adv Health Med Improving Healthc Outcomes Worldwide 3(2):28–33
24. Fujimura T, Okanoya K (2012) Heart rate variability predicts emotional flexibility in response to positive stimuli. Sci Res 3:578–582
25. Reynard A, Gevirtz R, Rustin B, Milton B, Kerri B (2011) Heart rate variability as a marker of self-regulation. Appl Psychophysiol Biofeedback 36(3):209–215
26. Lehrer PM, Gevirtz R (2014) Heart rate variability biofeedback: how and why does it work? Front Psychol 5
27. Goessl VC, Curtiss JE, Hofmann SG (2017) The effect of heart rate variability biofeedback training on stress and anxiety: a meta-analysis. Psychol Med 47(15):2578–2586
28. Morgan SJ, Mora JM (2017) Effect of heart rate variability biofeedback on sport performance, a systematic review. Appl Psychophysiol Biofeedback 42(3):235–245
29. Sutarto AP, Wahab MNA, Mat Zin N (2013) Resonant breathing biofeedback technique for stress reduction among manufacturing operators. Int J Occup Safety Ergon 18(4):549–561
30. Low A, McCraty R (2018) Heart rate variability: new perspectives on assessment of stress and health risk at the workplace. Heart Mind 2:16–27

Dynamic Propagation Area to Simulate Soft Tissue Deformations Using Mass Spring Method

Mohd Nadzeri Omar and Muhammad Hilmi Jalil

Abstract Modeling soft tissues during deformation is a real challenge in the development of a surgical simulation. Modeling techniques must be able to model deformations accurately in real-time interactions. Mass Spring Method (MSM) is one of the well-used modeling techniques. Most MSM models were developed via force propagation, where the definition of the propagation area is crucial for realism and optimum computational efficiency. In this paper, a new technique for establishing the area of propagation is proposed in which the area of propagation is determined by identifying a distance from contact point where minimum displacement occurs. The distance is calculated using the Bossiness equation, which considers the material properties and the magnitude of the subject load. Implementation of the proposed method and validation with Finite Element Method (FEM) assessments show that the proposed method provides better rationale for the area of propagation and optimized computational efficiency.

Keywords Surgical simulation · Soft tissue deformation · Mass spring model · Dynamic propagation area

1 Introduction

In the development of surgical simulation, researchers have had trouble modeling soft tissue behaviors during deformation. It is caused by the complexity of the properties and structures of soft tissue [1, 2].

There are two main criteria for modeling soft tissues, namely accuracy in modeling and real-time computing to update soft tissue deformations. These two conditions are in conflict with each other [3]. Highly accurate modeling techniques usually involve

M. N. Omar (✉) · M. H. Jalil
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: nadzeri@ump.edu.my

M. H. Jalil
e-mail: muhammadhilmi@ump.edu.my

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complex mathematical formulas leading to longer computational time. Often additional computing resources, such as higher memory capacity and high-performance graphics processing unit (GPU), are used to minimize computational time [4, 5]. These additional resources substantially increased the cost of computation.

Simplification, on the other hand, is often an alternative for real-time computation at a lower cost. The Mass Spring Method (MSM) is part of this group. MSM-based models are based on a physics-based approach that discretizes a soft body into several nodes interconnected by mass-less springs. Commonly, spring links are either in the form of hexahedron [6] or tetrahedron [7] structures. The MSM-based model has simplified the complex definition of soft tissue deformation by using spring reactions, often combined with damping forces to withstand external disturbances. While each spring has its material properties, it does not have a direct relationship to the soft tissue properties. As a result, MSM-based model requires an optimization process to accurately simulate soft tissue deformation [8].

In order to simulate soft tissue deformations, the MSM-based model will distribute the reaction force between the connected nodes. The distribution of force in MSM models can be divided into two categories. The first group of MSM models used the maximum and minimum spring length as distribution constraints. The next adjacent nodes will be shifted only after one of the spring constraints has been met. It is the conventional method of MSM models that has many limitations, such as difficulty in identifying limitations and restriction in the selection of geometry [9].

The propagation method was used by another group of MSM models. Based on the change in the spring length due to external disturbances, the measured reaction force is propagated to the next adjacent nodes and the location of each node is changed by solving a dynamic equation that is often Newtonian dynamic. This second method offers better accuracy, but involves the determination of the propagation area to avoid excessive deformation.

Several methods for determining the propagation area have been suggested in the literature. The simplest approach for generating the propagation area is to use the pre-set method as stated in Qiao et al. [10], Huangfu [11] and Farhang et al. [12]. In this method, nodes that will be affected are manually identified by the user prior to the simulation. On the other hand, Choi et al. [13] have been recorded to monitor the propagation area by selecting the number of nodes involved, which are manually selected on the basis of a trade-off between computational efficiency and accuracy. In relation to this, Chang et al. [14] suggested an algorithm to find an effective propagation area but still depends on the number of nodes that can provide realistic visualization.

Among the methods available, the propagation area was created without considering any material properties, rather than relying solely on geometrical properties to achieve realism. In addition, the available methods are static, the size of the propagation area being the same for every amount of input load. It is well accepted on the basis of Hooke's law, with a larger input load resulting in a larger displacement, thus the static type of propagation area can lead to unrealistic deformation and can consume unnecessary computational resources.

This paper proposes a new approach for generating the propagation area by considering the material properties of the simulated soft tissues. In addition, the proposed method also determines the propagation area based on the magnitude of the applied load which the size of the propagation area will be adjusted on the basis of the load applied to that instance. The results of the performance evaluations show that the proposed method produced different propagation areas under different material properties and applied loads. It therefore provides a more realistic deformable model and optimizes computational efficiency.

2 Methodology

In this study, soft tissue is assumed to be an isotropic and linear elastic material. With the assumptions, the proposed propagation area is founded upon linear elastic theory, where the Boussinesq equation is used. With selection of an arbitrary value that represents the minimum displacement value, the distance at which the value occurs is calculated and the area of propagation is established. The following subsections describe the technique used to generate the propagation area.

2.1 Displacement Estimation

The Boussinesq equation is a well-known method in soil mechanics for estimating stress and displacement within soils subject to a normal load on the surface of the soil. According to Verruijt [15], based on the Boussinesq equation, the vertical displacement inside an isotropic and linear elastic material can be determined using the following equation

$$u_z = \frac{P(1+v)}{2\pi E\rho}\left[2(1-v) + \frac{l_z^2}{\rho^2}\right] \tag{1}$$

where u_z represents vertical displacement, l_z is the vertical distance from the contact point, $\boldsymbol{P}$ denotes the normal load while E and v are the elastic modulus and Poisson's ratio respectively. The term ρ is the spherical coordinate described as

$$\rho = \sqrt{l_x^2 + l_y^2 + l_z^2} \tag{2}$$

where l_x and l_y are the horizontal distances from the contact point. By considering only points located at $l_x = 0$ and $l_y = 0$ which is located vertically underneath the contact point, Eq. (1) can be rewritten as

$$u_z = \frac{P(1+v)}{2\pi E l_z}[2(1-v)+1] \tag{3}$$

Hence, by using Eq. (3), vertical displacement value along l_z can be estimated.

2.2 Propagation Threshold

Propagation threshold is a value that is used to calculate the size of the propagation area. It defines the number of spring layers in the MSM model that will be affected.

In this study, the propagation threshold is determined by using the Boussinesq equation given in Eq. (3). The concept is to select an arbitrary minimum displacement value $u_{\min z}$ and estimates the location where the $u_{\min z}$ value occurs. To find the location where the $u_{\min z}$ occurs, Eq. (3) is reorganized as follows

$$l_z = \frac{P(1+v)}{2\pi E u_{\min z}}[2(1-v)+1] \tag{4}$$

The calculated l_z gives the vertical distance from the contact point where $u_{\min z}$ occurs. The l_z is then converted to the propagation threshold z by evaluating it with respect to the initial length of the springs l_{spring} as shown in Eq. (5)

$$z = \frac{l_z}{l_{\text{spring}}} \tag{5}$$

2.3 Force Propagation

To implement the force propagation, a HashMap data structure is used to store information of all nodes and spring connections between those nodes. Breadth-first searching method is used to locate the next adjacent nodes following the layout presented in Fig. 1.

The subjected node is at Level 0 and nodes connected to it are at Level 1. The succession continues until the propagation threshold z is achieved. A constraint is placed to avoid multiple calculations on the same node. The number of nodes N involved is arbitrary which depends on the current propagation threshold z and can be calculated using the following Eq. (6)

$$N = 3z^2 + 3z + 1 \tag{6}$$

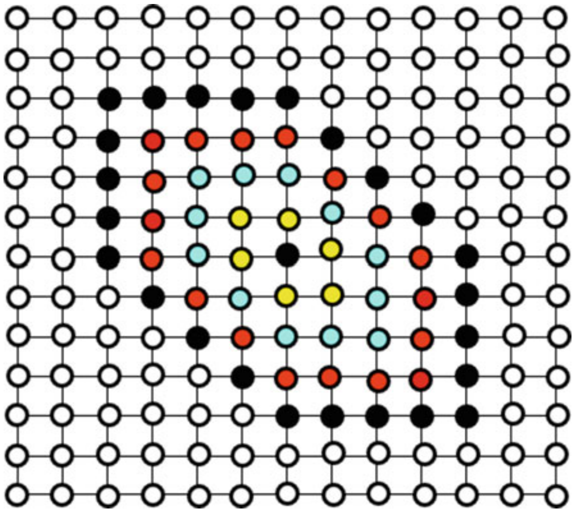


Fig. 1 Top view of nodes layout that form layers starting from the subjected point at the center. The number of layers involved depends on the propagation threshold z

2.4 MSM Model Generation

The proposed propagation area was implemented on an MSM model for performance analysis. The MSM model used Hooke's law to define spring resistance and was combined with damping force in the form of the Maxwell viscoelastic model. The reaction force acting between two nodes i and j that are connected by a spring is described as

$$f_{ij}^{reaction} = k_s\left(\left|x_{ij}\right| - l_{ij}\right)\frac{x_{ij}}{\left|x_{ij}\right|} + k_d\left(v_{ij}\right) \tag{7}$$

where k_s is the spring stiffness, $\left|x_{ij}\right|$ and l_{ij} represents the current and original length of the spring respectively, k_d is the damping coefficient, while x_{ij}. and v_{ij} is the distance and velocity between the two nodes.

The nodes in the MSM model were connected to each other in the form of a tetrahedron structure, and therefore the reaction force acting on a node i is the summation of the springs connected to it presented as

$$F_i^{reaction} = \sum_{n=n_1}^{n_q} f_{ij}^{reaction} \tag{8}$$

where $n_1 \ldots n_q$ are nodes that are connected to node i through springs.

Dynamic equation of the MSM model is described using the Newtonian dynamics which at node i the equation is written as

$$m_i a_i = F_i^{total} \tag{9}$$

where m_i is mass and a_i is acceleration at node i respectively. The F_i^{total} is described as

$$F_i^{total} = F_i^{reaction} + F_i^{external} \tag{10}$$

To solve the dynamic equation, the explicit Euler integration method is used where the location of the node i is updated using the following equations

$$v_i(t + \Delta t) = v_i(t) + \Delta t \cdot \frac{F_i^{total}(t)}{m_i} \tag{11}$$

$$x_i(t + \Delta t) = x_i(t) + \Delta t \cdot v_i(t + \Delta t) \tag{12}$$

2.5 Computational Algorithm

The computational algorithm used in this work is illustrated as in Fig. 2.

3 Results

3.1 Displacement Distribution

The behavior of the displacement distribution within a linear isotropic material was analyzed by comparing the value calculated using Eq. (3) with the value obtained from an FEM model. A linear and isotropic FEM model was developed using commercial software called ABAQUS with a mass density of 1000 kg/m^3, elastic modulus $E = 90$ kPa and Poisson's ratio $v = 0.4$. The model was generated as an axisymmetric model with fixed bottom and outer edges. As shown in Fig. 3, when both models were subjected to 10 N of normal load, similar behavior was observed. The displacement value is getting smaller further away from the contact point.

However, at any distance from the contact point, Eq. (3) generates a larger displacement value compared to the FEM model. The variation between the two models is small near to the point of contact and increases with the distance. At the furthest point of measurement, the variation is around 30%.

When comparing the displacement distribution for different elastic modulus, similar behavior is observed and the percentage of variation is also equivalent to less than 30% at the furthest point of measurement as shown in Fig. 4. In addition, it should be noted that different displacement values have been reported compared to Fig. 3. A larger displacement value was observed at the same position for a model with a smaller elastic modulus. It explains that a greater displacement would take

MSM with dynamic propagation area

Input: Model parameters
Material properties of the simulated soft tissue
Minimum displacement value $u_{min\,z}$

For $t = 0$ to Stop **do**
$t = t + \Delta t$
get $\boldsymbol{F}_i^{external}$
calculate $\boldsymbol{F}_i^{reaction}$
calculate propagation threshold z
$\boldsymbol{v}_i = \boldsymbol{v}_i(t) + \Delta t \cdot \boldsymbol{F}_i^{total}(t)/m_i$
$\boldsymbol{x}_i = \boldsymbol{x}_i(t) + \Delta t \cdot \boldsymbol{v}_i(t + \Delta t)$
For $k = 1$ to z **do**
determine total force on nodes in the k-neighbour
$\boldsymbol{v}_j = \boldsymbol{v}_j(t) + \Delta t \cdot \boldsymbol{F}_j^{total}(t)/m_j$
$\boldsymbol{x}_j = \boldsymbol{x}_j(t) + \Delta t \cdot \boldsymbol{v}_j(t + \Delta t)$
propagate the force to the next adjacent nodes
Loop
Update nodes position
Loop
End

Fig. 2 Algorithm for the MSM model with dynamic propagation area

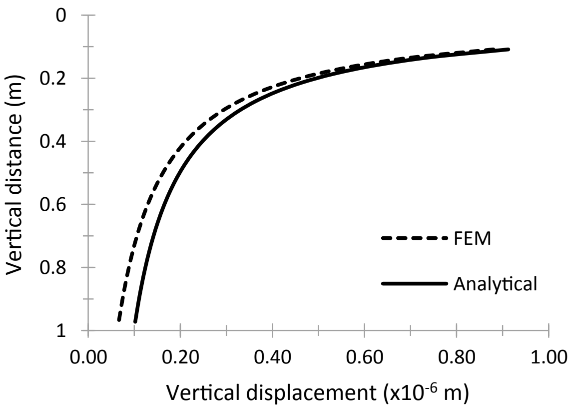


Fig. 3 Vertical displacement distribution measured vertically underneath the contact point with elastic modulus $E = 50$ GPa

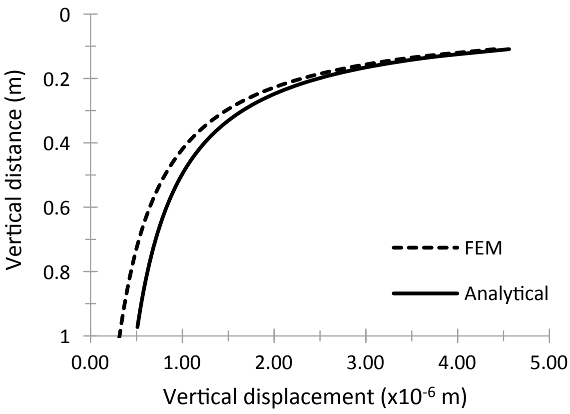


Fig. 4 Vertical displacement distribution measured vertically underneath the contact point with elastic modulus $E = 10$ Gpa

place for a softer material under a similar loading environment. The result follows Hooke's law, which is valid for linear elastic content.

3.2 Propagation Area

The proposed propagation area was implemented in an MSM model. The MSM model consisted of 1331 nodes connected by springs in the form of tetrahedral structure. The spring stiffness, damping coefficient, and mass density are 10, 8 and 1000 kg/m^3 respectively.

The first analysis was conducted to observe the effect of different elastic modulus values to the propagation area. A node located on the top surface of the MSM model was subjected to a compression load of 30 N and the minimum displacement value $u_{\min z}$ was set to 0.15 mm. The Poisson's ratio was set at a constant of 0.4 and two elastic modulus values of 30 and 10 kPa were used. As depicted in Fig. 5, under a similar loading condition, different propagation areas were recorded. A smaller propagation area was observed in the MSM model with a larger elastic modulus.

The observation was compared to an FEM model for validation. The FEM model was generated as described by Nikishov [16]. Figure 6 shows the deformation area of the FEM model when assigned with different elastic modulus. Only deformation contours are shown for visualization purposes. It is found that the size of the deformation area is influenced by the elastic modulus and the proposed approach has therefore been validated.

Next, the same analysis was performed to study the effect of the subject load on the propagation area. The elastic modulus and minimum displacement value $u_{\min z}$ was set to $E = 10$ kPa and 0.15 mm respectively. The MSM model was subjected to two different applied loads of 30 and 10 N as shown in Fig. 7. The deformation area for the larger load can be seen to be wider in both tension and compression loads. Similar observations are obtained in the FEM model shown in Fig. 8.

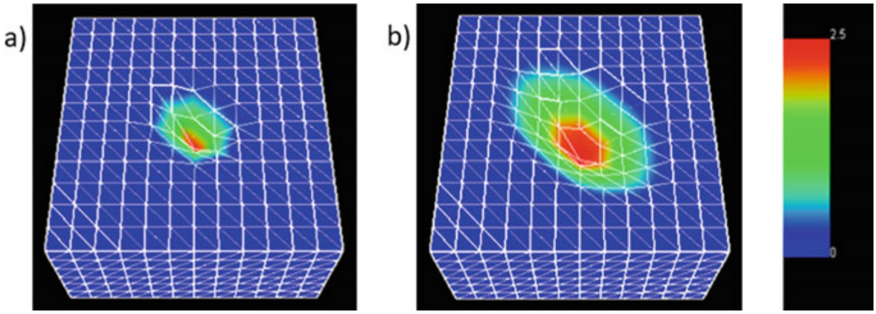


Fig. 5 Image of the MSM model during deformation when different elastic modulus values are used to generate propagation area. The color contour described the propagation area. **a** Elastic modulus $E = 30$ kPa and **b** Elastic modulus $E = 10$ kPa

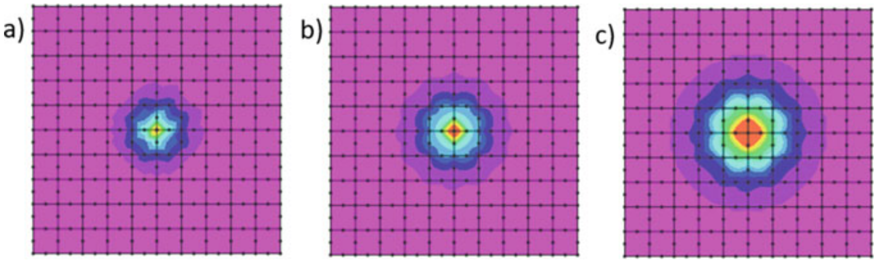


Fig. 6 Deformation area of the FEM model assigned with different elastic values subjected to 30 N of compression load. **a** $E = 30$ kPa, **b** $E = 20$ kPa and **c** $E = 10$ kPa

Furthermore, the analysis was repeated again but with different minimum displacement values $u_{\min z}$. Two values of 0.15 and 0.20 mm were used. As shown in Fig. 9, different sizes of deformation area were observed. The larger $u_{\min z}$ gives a smaller propagation threshold leading to a smaller deformation area.

3.3 Computational Performance

The computational performance of the proposed method has been observed using the computational time. The recorded computational time was measured with respect to the time taken for the program to determine the propagation area and to update the location of nodes within the propagation area. The simulation was run on a Windows 7-based personal computer (Processor: Intel Core 2 Duo 2.26 GHz, RAM: 4.00 GB, Graphics adapter: ATI Mobility Radeon HD 3400 Series) with no parallel computation. As shown in Fig. 10, the computational time is proportional to the propagation threshold and the area of the propagation. This is due to the amount of

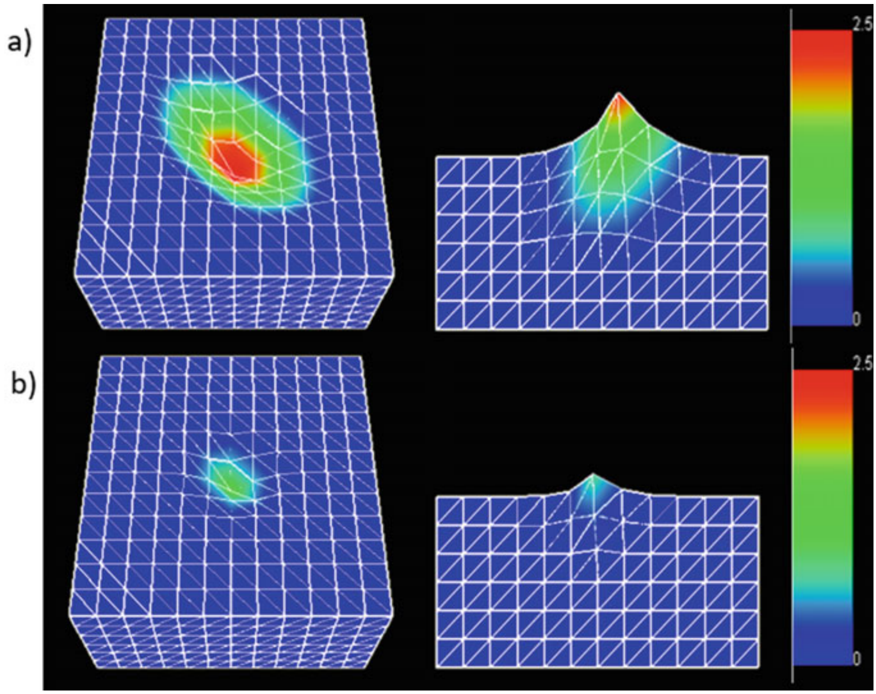


Fig. 7 Image of the MSM model during deformation with the elastic modulus and minimum displacement value are 10 kPa and 0.00015 m respectively. The MSM model was subjected to different loads, **a** 30 N and **b** 10 N

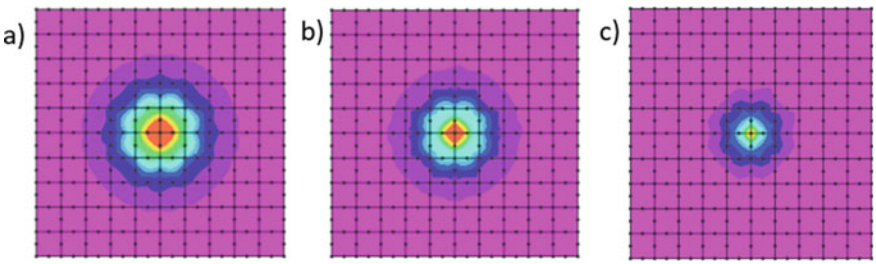


Fig. 8 Deformation area of the FEM model with elastic modulus $E = 10$ kPa and was subjected to different applied loads, **a** 30 N, **b** 20 N and **c** 10 N

the affected nodes. With a larger propagation area, more nodes are affected, resulting in a higher computational time.

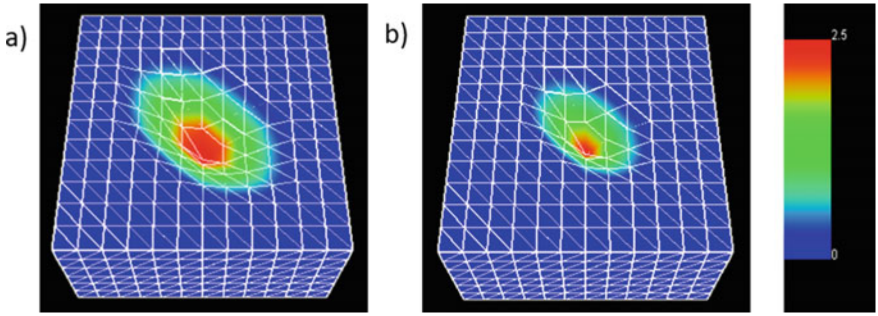
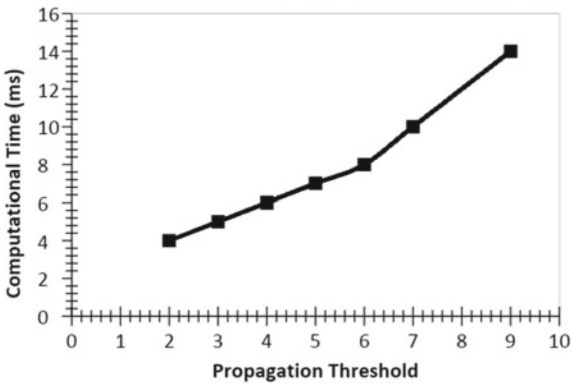


Fig. 9 Image of the MSM model during deformation with the elastic modulus and applied load value are 10 kPa and 30 N respectively. **a** The MSM model with $u_{\min\,z} = 0.15$ mm and **b** the MSM model with $u_{\min\,z} = 0.20$ mm

Fig. 10 Computational time taken by MSM model with the proposed propagation area at different propagation threshold



3.4 Discussion

In this study, the propagation area is generated by considering the elastic modulus of the subject material and the magnitude of the load being subjected to it. In the case of isotropic and linear elastic materials that follow the Hooke's law, as shown in Figs. 6 and 8, both the elastic modulus and applied load are the crucial factors that influence its deformation. By considering these two factors, the proposed propagation area has improved the previous methods which consider only geometrical properties.

Static propagation method has a fixed propagation area which the size of the propagation area stays the same for different applied loads and elastic properties. The static propagation area could lead to unrealistic deformation and unnecessary computational resources. The proposed method overcomes the problem with its dynamic capability where, at each time step, the propagation threshold is modified on the basis of the applied load at that instance as illustrated in Fig. 7. With this dynamic capability, the size of the propagation area will be parallel to the magnitude of the applied load contributing to the optimization of the computational resources.

FEM is considered to be the most accurate simulation method. Comparison with the FEM validates the accuracy of the proposed method. As indicated in Figs. 3 and 4, even though the variance, particularly at the furthest measured point is around 30%, which is high, in this application, the variation is appropriate as the value is used to estimate the propagation area not to reflect the deformation. Importantly, the behavior of the displacement distribution for both models is equivalent.

Despite the improvements, the proposed method still requires optimization in finding the best minimum displacement value $u_{\min z}$. The value is essential to the accuracy and efficiency of the simulation. The best option is to find the minimum displacement value through computational analysis using commercial software such as ABAQUS. Moreover, the Boussinesq equation used here is fundamentally on linear elastic theory. Therefore, its implementation can be inaccurate for soft tissues during large deformation where nonlinear deformation is displayed. Nevertheless, with consideration of the material properties, the proposed method still offers better justification for the area of propagation.

4 Conclusion

This paper focuses on improving the MSM models that used force propagation to simulate soft tissue deformation. The key requirement of the simulation is to define the size of the propagation area. A novel method for defining the size of propagation area has been proposed where the propagation area is determined by identifying a location from the contact surface where minimum displacement occurs using the Boussinesq equation that considers the simulated soft tissue properties and the magnitude of the applied load. The proposed method enhances the solutions available that consider only geometrical properties. Moreover, the proposed method has the dynamic capability to adjust the propagation area based on the current magnitude of the loads applied. These improvements and validation with FEM model indicate that the proposed method provides a better solution in generating the area of propagation.

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References

1. Innocenti B, Lambert P, Larrieu JC, Pianigiani S, Paolanti M, Bernardini M, Cenci A, Frontoni E (2016) Development of an automatic procedure to mechanically characterize soft tissue materials. In: 12th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA)
2. Budday S, Sommer G, Birkl C, Langkammer C, Haybaeck J, Kohnert J, Bauer M, Paulsen F, Steinmann P, Kuhl E, Holzapfel GA (2017) Mechanical characterization of human brain tissue. Acta Biomater 48:319–340

3. Li C, Ding J, Hong Z, Pan Y, Liu PX (2018) A surface mass-spring model with new flexion springs and collision detection algorithms based on volume structure for real-time soft-tissue deformation interaction. IEEE Access 6:75572–75597
4. Taylor ZA, Cheng M, Ourselin S (2008) High-speed nonlinear finite element analysis for surgical simulation using graphics processing units. IEEE Trans Med Imaging 27(5):650–663
5. Courtecuisse H, Jung H, Allard J, Duriez C, Lee DY, Cotin S (2010) GPU-based real-time soft tissue deformation with cutting and haptic feedback. Prog Biophys Mol Biol 103(2–3):159–168
6. Golec K, Palierne JF, Zara F, Nicolle S, Damiand G (2019) Hybrid 3D mass-spring system for simulation of isotropic materials with any Poisson's ratio. Vis Comput 36(4):809–825
7. Hong M, Jeon JH, Yum HS, Lee SH (2016) Plausible mass-spring system using parallel computing on mobile devices. Hum Centric Comput Inf Sci 6(1)
8. Wu D, Lv C, Bao Y (2016) An improved vascular model based on mass spring model and parameters optimization by Gaussian processes. In: IEEE International conference on mechatronics and automation, pp 2425–2430
9. Zhang J, Zhong Y, Gu C (2018) Deformable models for surgical simulation: a survey. IEEE Rev Biomed Eng 11:143–164
10. Qiao B, Chen G, Ye X (2009) The research of soft tissue deformation based on mass-spring model. In: International conference on mechatronics and automation, pp 4655–4660
11. Huangfu Z (2013) An improved mass-spring model for simulation of soft tissue deformation. J Inf Comput Sci 10(17):5551–5558
12. Farhang S, Foruzan AH, Chen, YW (2016) A real-time stable volumetric mass-spring model based on a multi-scale mesh representation. In: 23rd Iranian Conference on Biomedical Engineering and 2016 1st International Iranian Conference on Biomedical Engineering (ICBME), pp S1–S5
13. Choi KS, Sun H, Heng PA, Zou J (2004) Deformable simulation using force propagation model with finite element optimization. Comput Graph 28(4):559–568
14. Chang YH, Chen YT, Chang CW, Lin CL (2010) Development scheme of haptic-based system for interactive deformable simulation. Comput Aided Des 42(5):414–424
15. Verruijt A (2018) An introduction to soil mechanics. Springer, Cham
16. Gennadij NP (2010) Programming finite elements in Java. Springer, London

EMG Signal Segmentation to Predict Driver's Vigilance State

N. A. Ab. Rahman, M. Mustafa, N. Sulaiman, R. Samad, and N. R. H. Abdullah

Abstract Road accidents are the serious matter and need to be taken care of by certain parties. Some causes of road accidents are due to the poor driver vigilance when most drivers show signs of fatigue and loss of vigilance during long and monotonous driving. Muscle fatigue develops due to changes in the efficiency of the nervous system that can be seen in the declining the performance. This study will present a brief explanation of different methods for processing and classifying the electromyogram (EMG) signal to estimate driver's muscle fatigue. The signal was obtained by pairing the electrode to the bicep brachii for two hours. Before that, the subject will answer a set of questionnaires and the score will be calculated to determine whether the driver in non-fatigue or fatigue condition. Signals were filtered and undergone feature extraction method. Then, the extracted features were undergoing feature selection method. Finally, to evaluate the performance measure of the feature selection method and classify the driver's condition, ANN was applied. From the results obtained, ANN performance using features that undergo feature selection method produce a better classification accuracy compared to the ANN performance without feature selection method. Apart from that, EMG Signal Segmentation (ESS) methods were applied. The filtered signals were partitioned into few segments in segmentation process. The two hours signals were split into 60 and 30 min long segments for the first methodology and second methodology respectively. From each segment, the features were analysed to contemplate the progressions of the features and based on result, the change of features shows that every subject yields different result because the different person has different muscle condition. As a conclusion, relevant parameters that useful for the development of human safety by assessing muscle fatigue during the driving task were found.

Keywords Muscle fatigue · EMG · CWT · PSD · ESD · ANN · ESS

N. A. Ab. Rahman (✉) · M. Mustafa · N. Sulaiman · R. Samad · N. R. H. Abdullah
Faculty of Electrical and Electronics Engineering Technology, Universiti Malaysia Pahang, Pahang 26600 Pekan, Malaysia

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1 Introduction

Number of road accidents and car crashes are still increasing even though lots of improvements have been done in road and vehicle design for the drivers safety. Scanning for the countermeasures to decrease the measure of car crashes and upgrade the public road safety has turned into an earnest issue for the governments and automakers. A responsibility for the researchers to create an automatic system that intelligently recognizes driver's unfit status and makes warning to the drivers once necessary. Driver's vigilance is the ability of the driver to sustain attention and to remain alert in perform the tasks in period of time. Diminished in the level of vigilance, drivers will suffer in declining their ability of perception, recognition and vehicle control. Driver's vigilance level is easily distracted when in a state of fatigue and drowsiness [1]. Most drivers' shows sign of visual fatigue and loss of vigilance during long and monotonous driving. In addition, physical discomfort such as extreme ambient temperature, uncomfortable driving condition and muscle fatigue in the neck or shoulder or back area might impact driver behaviors [2]. Muscle fatigue or performance fatigue is usually referred to a reversible reduction in performance measurement that could occur in both submaximal and maximal force [3, 4].

Selecting the effective measurements in developing the automatic system to measure drivers' status is very crucial. The methods are generally divided into three main categories, which seem to be the measures of vehicle behavior, video-based measures and physiological measures [5, 6]. Measurements of vehicle behavior include acceleration, braking and steering, route position deviation, gear changes and vehicle speed [7]. Major issues with these methods depend on the type of vehicle, the capabilities, the behaviors and the competence of the drivers in the handling of the car in the real driving scenario [8, 9]. Recent researches also have investigated video-based measures using detectors to detect body movements, interpret the position of the eye gaze and assess face features [10, 11]. The device that focuses on a single visual reference can experience difficulties if the requisite visual features images have not been adequately or accurately attainable. The use of a single visual cue is that acquired visual feature is often uncertain yet cannot always reflect one's psychological disorders [12].

Recent decades, physiological parameters such as electromyograms (EMGs), electroencephalograms (EEGs), electrocardiograms (ECGs) and galvanic skin response (GSRs) have shown good accuracy recognition and have great insights into driving conditions [11]. The EEG signals are quite non-stationary and the data collection is responsive to the surroundings but very intrusive [13, 14]. In addition, long-term contact observation may lead to discomfort for drivers, which could lead to the direct implementation of the EEG in driving fatigue supervision [15, 16]. Physiological signal that can use to detect muscle fatigue is electromyography (EMG) [17, 18]. When the muscle encounters the decline in its capabilities to generate force and attain its required motion, muscle fatigue was occurred. Muscle fatigue also occurred because bodies are too tired of overwork in a long time, and can distract the daily routines. EMG is a technique used to diagnose the wellbeing of the motor neurons that influencing the muscles and nerve cells. The mechanism of motor neurons is to transmit electrical impulses that allow the muscle contractions and relax. The electrical signals will be translated into graphs and numerical values that can be interpreted by the specialist by using EMG device [19]. Tiny devices called electrode pad used to detect electrical signals and the analysis will reveal the occurrence of the muscle fatigue of the subject.

2 Methodology

The experimental procedures with ID No: IREC 2020-070 with project title Signal Analysis To Predict Driver's Vigilance State Using Emg Signal were supported by IIUM Research Ethics Committee (IREC).Sixteen healthy subjects from University Malaysia Pahang (UMP) students aged around 20 and 26 years, consisting of 9 female students and 7 male students with verified driver's licenses, have been chosen randomly [3, 6, 7]. The experiment begins with the subject answering sets of questionnaire. Fatigue Assessment Scale (FAS) is a 10-item scale that assessing chronic fatigue symptoms was used. Then, subjects were recruited to perform driving simulation in Need for Speed Game for two hours. The time of experiment chosen is in the afternoon, between 12.00 pm and 6.00 pm [6, 8, 20]. The data was collected all the time while the subjects were drove. Based on Fig. 1a show the experiment set up. SHIMMER TM Model used to collect the raw EMG data as shown in Fig. 1b from the biceps brachii muscle based on Fig. 1d. The simulator used was PXN-V3II Racing Wheel as shown on Fig. 1c which are consists of pedal, steering and gear.

The raw data of EMG signals were exported into excel after data collection, the raw data needs to be reprocess. Before undergo filtering process, the rectification process using full-wave rectification was done to translate the raw EMG signal to a signal with single polarity which is positive polarity. Next, the Band-pass "Butterworth" filter was used to remove any artifacts as well as high frequency noises with cut-off frequency between 15 and 45 Hz because low frequency band technique was a more reliable index of fatigue in fatigue tasks [21].

Next, the filtered signal undergo feature extraction process using time domain, frequency domain and time frequency domain analysis. The proposed time domain features in this project are RMS, mean and standard deviation. The frequency domain analyses applied in this project were PSD and ESD. The proposed features from PSD were total power, band power, mean frequency, median frequency and maximum power. Meanwhile, for ESD were total of signal energy, mean energy and maximum energy. Time frequency domain analysis that used was CWT and the extracted features were power and energy of wavelet coefficients.

The extracted features were undergone feature selection method by using one-way ANOVA before fed into the ANN classifier. ANOVA examines the variance of data set means and compared to within class variance of the data sets themselves. In this work, ANOVA test was performed using the software "MATLAB 2019(a)". The significance threshold was set to p-value < 0.05 for all of the case studied.

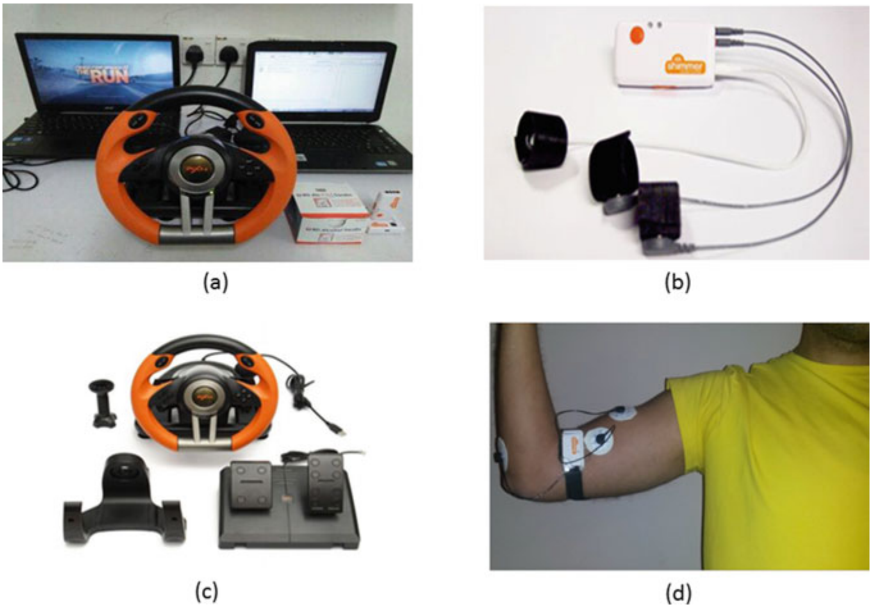

Fig. 1 Data collection; **a** Experiment set-up, **b** SHIMMER TM model, **c** PXN-V3II Racing Wheel, **d** Electrode placement on biceps brachii muscles

In order to interpret various patterns and classified it efficiently, the features derived from the signals were fed into classifier. ANN was included in this study as the classification models. Neural Network Pattern Recognition Tool in Matlab 2019(a) was used. In this study, the training data was set to 70% while the validation and testing data are 15% for both. The number of hidden neurons will be optimized in order to achieve best ANN model. The adequate parameters can be obtained by obtaining the lowest mean square error (MSE) and highest classification accuracy [22].

Lastly, EMG Signal Segmentation method applied to split the signal into two and four different windows. Signal segmentation method used to observe the changes of the features extracted in each window. Two hours of data collection with 512 Hz sampling rate were obtained 3,686,400 data points. Two hours of data was segmented into two 60 min block that contains 1,843,200 data points each blocks. For each blocks, a set of features were extracted to form the features array. For the four windows, the data were segmented into 30 min window that yield four segments of data that contain 921,600 data points for each windows. From the each window, the features extracted. Then, the changes of all the features were observed.

Table 1 Result from questionnaire

Subject	Gender	Questionnaire score	Driver's condition
1	Female	19	Non-fatigue
2	Female	28	Fatigue
3	Male	33	Fatigue
4	Male	20	Non-fatigue
5	Female	27	Fatigue
6	Female	23	Fatigue
7	Female	18	Non-fatigue
8	Male	27	Fatigue
9	Male	21	Non-fatigue
10	Male	26	Fatigue
11	Female	22	Fatigue
12	Female	18	Non-fatigue
13	Female	25	Fatigue
14	Male	20	Non-fatigue
15	Male	25	Fatigue
16	Female	25	Fatigue

3 Results and Discussion

3.1 Questionnaire Result

The experiment was carried out in APPECE lab for 2 h per subject. Firstly, subjects answered set of questionnaires on driving habits. The questionnaire consist of ten statements refer to how you usually feel. Subjects choose one out of five answer categories, varying from Never to Always. Total score will be calculated to determine the condition of driver whether in non-fatigue or fatigue state.

Based on Table 1, the driver's condition from the questionnaire result can be observed after the total score were calculated. There are 10 subjects in fatigue condition and 6 subjects in non-fatigue condition. The highest of the total score was obtained by Subject 3 with the score 33 and the lowest score by Subject 7 and Subject 12 with the score 8. In conclusion, questionnaire result yields that Subject 3 in fatigue group while Subject 7 and Subject 12 are in non-fatigue group.

3.2 Analysis for Two Hours

Figure 2a shows the raw data obtained from Subject 7 that collected for the 120 min. The amplitude of data is between −2500 and 2500 μV. Rectification of EMG signal

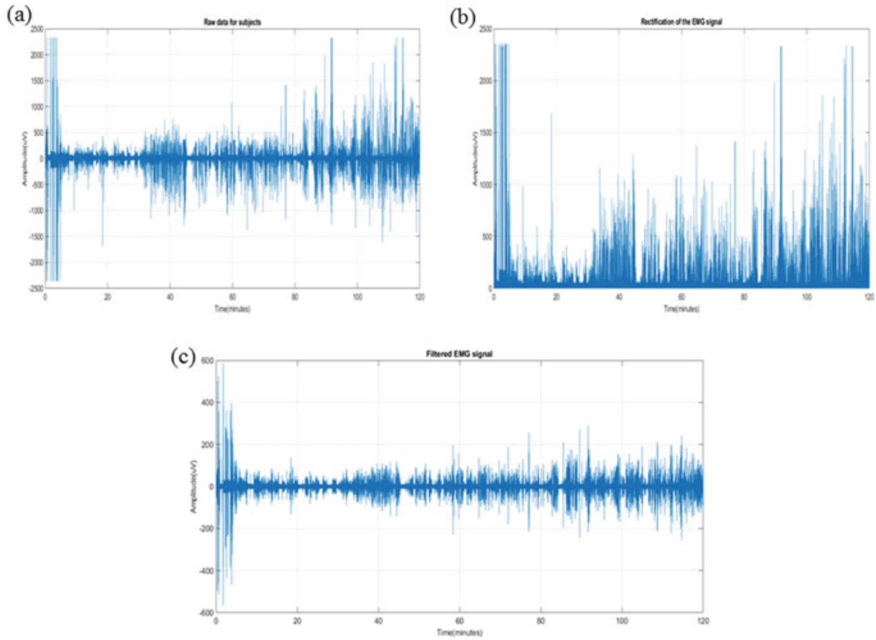

Fig. 2 Two hours processing; **a** raw signal of subject, **b** rectification of signal, **c** filtered signal

raw data shows in Fig. 2b and c shows the filtered signal of EMG. After filtering, amplitude of the signal drops between −600 and 600 μV. Then, filtered data were processed to extract the feature using time domain, PSD, ESD and CWT. From the processed data, the features extracted were mean, standard deviation RMS. From frequency domain analysis which was PSD, features were band power, maximum power, signal power, mean frequency and median frequency. While, from ESD were maximum energy, mean energy and total energy. From CWT, the extracted features were power and energy of wavelets coefficients.

Next, features undergo feature selection method yields that only six features have the significant values p-value < 0.05 which were mean, standard deviation, RMS, band power, total energy and energy of wavelet coefficients while maximum power, signal power, total power, maximum energy, mean energy and power of wavelet coefficients had no significant with p-value > 0.05. Therefore, the features were divided into two groups with one groups consists of selected features (mean, standard deviation, RMS, band power, total energy and energy of wavelet coefficients) and other group consist of all 11 features extracted. Then, those two groups were fed into ANN classifiers separately.

In addition, the optimizations of number of neurons in hidden layer were adjusted to obtain an optimized network. The result of optimization the number of neurons in the hidden layer presented in Fig. 3.

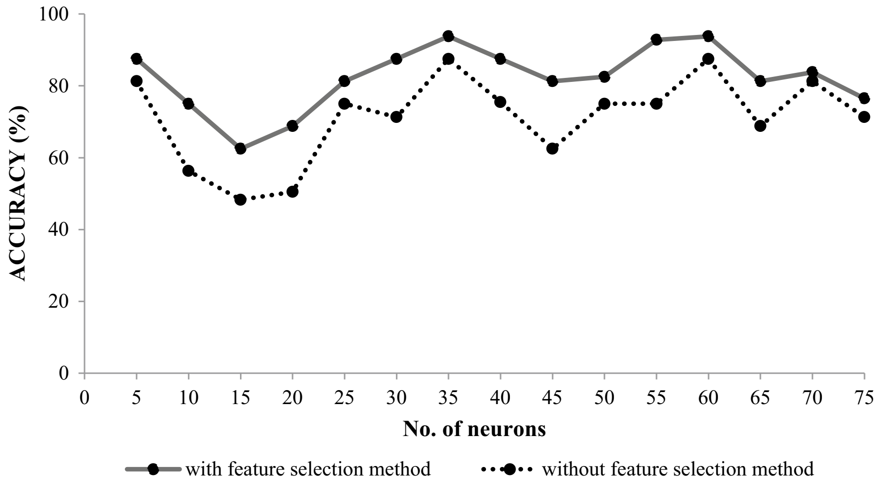

Fig. 3 ANN accuracy for varying number of neurons in hidden layer

Table 2 Overall performance comparison for ANN with and without feature selection method

Classifier	Accuracy (%)	
	With feature selection method	Without feature selection method
ANN	93.8	87.5

Based on the fact, the excellent parameters can be reached by identifying the highest accuracy rate. Based on Fig. 3, ANN with number of neurons in hidden layer which is 35 is the best number of neurons for both ANN model. The accuracy obtained after tested with 35 numbers of neurons in hidden layer by using feature selection method is 93.8% and without feature selection method is 87.5% accuracy rate as shown in Table 2.

3.3 Two Segments Data Processing, 60 min Each Segment

Figure 4a shows the first 60 min EMG filtered signal and Fig. 4b the last 60 min EMG filtered signal. Amplitude of first and last 60 min EMG signal is between $-600\ \mu V$ and $600\ \mu V$ and $-300\ \mu V$ and $300\ \mu V$ respectively.

- **Time Domain Analysis**

As shown in Fig. 5a and b, the pattern of time domain features for the first and last 60 min of driving task for Subject 4 and Subject 16 were presented. Theoretically, in early part of driving task, majority of obtainable motor units were activated and the value of motor units influenced by the prolonged time of the driving task. The

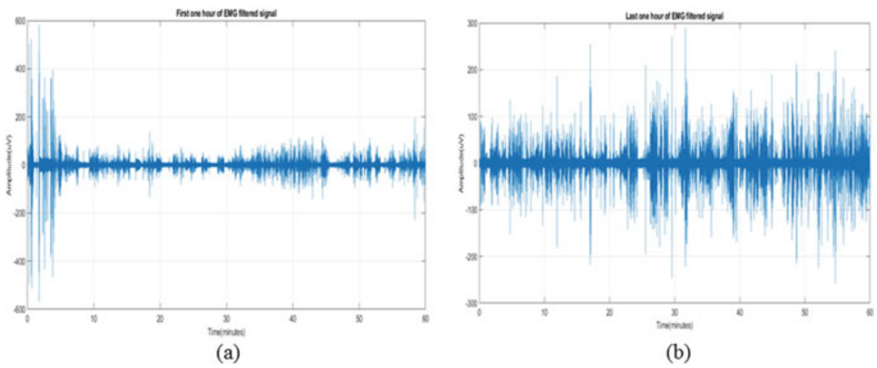

Fig. 4 **a** First 60 min of EMG filtered signal, **b** last 60 min of EMG filtered signal

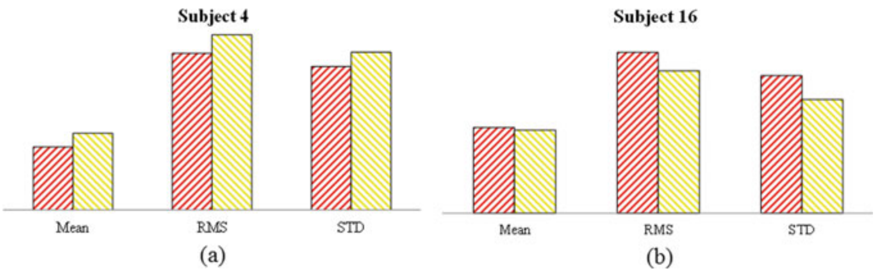

Fig. 5 **a** Changes in mean, standard deviation and RMS of Subject 4, **b** changes in mean, standard deviation and RMS of Subject 16

recruitment condition of motor units can influence the amplitude of EMG. Decrement of EMG amplitude clearly demonstrated that driver's seems to be incapable to sustain the recruitment of motor units and to acquire new motor units throughout ability to respond to fatigue. Based on result, time domain features which are RMS, mean and standard deviation of Subject 4 were increase described that subject was in non-fatigue state after two hours of driving task while for Subject 16 the features were decrease indicates that subject in fatigue group.

- **Power Spectral Density**

Frequency domain features extracted were mean frequency, median frequency, band power, maximum power and total power. Figure 6a and b were presented the features of PSD for the first 60 min and last 60 min for Subject 4 and Subject 16 respectively. As shown from the histogram, all features of Subject 4 were increase and for Subject 16 decrease after two hours of driving. In theory, the frequency was decrease in parallel with power output describes that there was a decline in motor unit recruitment and muscle fibers conduction velocity. Significant decrease in the frequency of EMG may be directly linked to excessive intramuscular acidosis and slowing muscle fibers conduction velocity that can lead to muscle fatigue [23]. Based

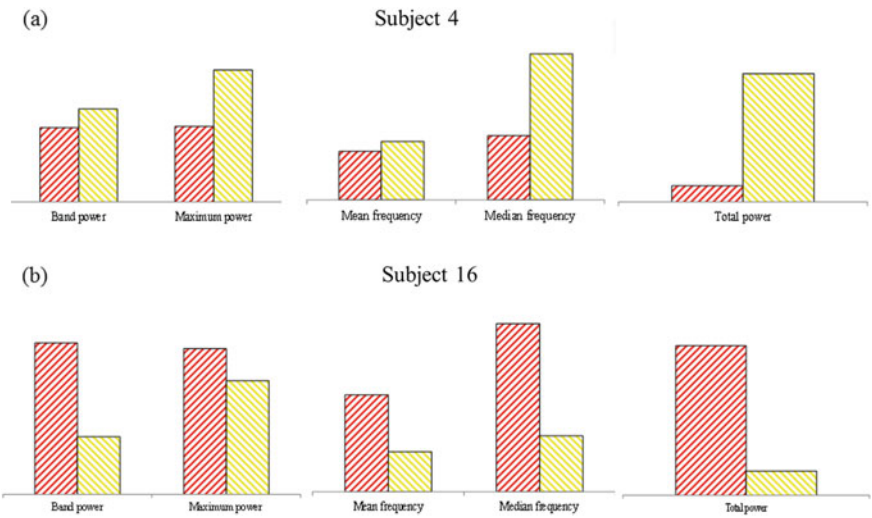

Fig. 6 **a** Changes of features extracted from PSD for Subject 4, **b** changes of features extracted from PSD for Subject 16

on result, frequency domain features of PSD for subject 4 were increase indicates that subjects were in non-fatigue state after two hours of driving. However, frequency domain features from PSD was decrease described that Subject 16 were in fatigue state after two hours of driving task.

- **Energy Spectral Density**

Frequency domain features extracted from ESD for first and last 60 min of driving were total energy, maximum energy and mean energy. Based on Fig. 7a and b, the pattern of features extracted for the first 60 min and last 60 min for Subject 4 and Subject 16 were described. Result shows that the features of Subject 4 were increase from low to high. While, for Subject 16 the features were decrease from high to low. During fatigue, large maximal motor units, might be appointed earlier and energy production would be prevented by the significantly decreased of pH content inside the fibers [24]. To summarize, the energy were decrease in the state of fatigue and increase in non-fatigue state. To be concluded, Subject 4 was in non-fatigue state while Subject 16 in fatigue state.

- **Continuous Wavelet Transform**

Based on, Fig. 8a and b shows the changes of features extracted from CWT for Subject 4 and Subject 16 respectively. Features extracted were the power and energy of wavelet coefficients. From the result, Subject 4 show the changes from low to high while Subject 16 change from high to low. In theory, for non-fatigue group, the features are rise while drops for fatigue group. This result can be approved by Shariatinasab et al. [25] as mentioned on that paper that during fatigue development,

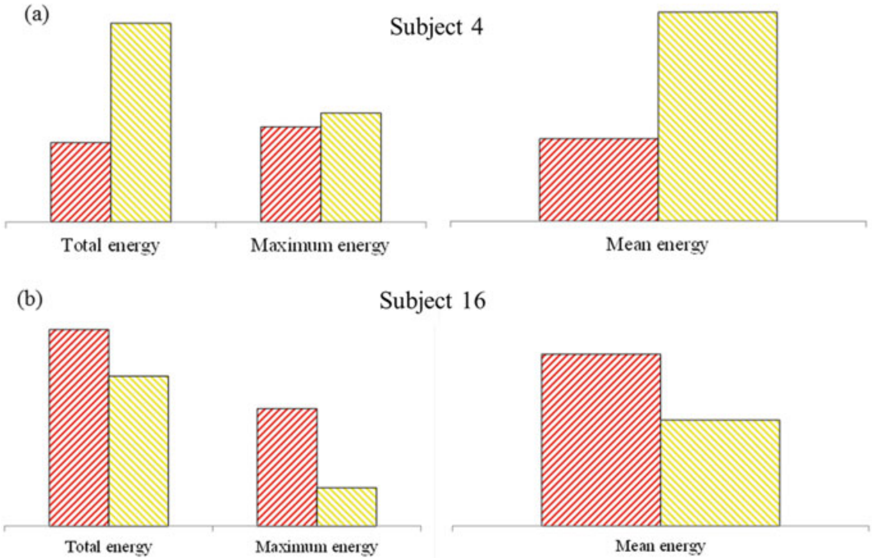

Fig. 7 **a** Changes of features extracted from ESD for Subject 4, **b** changes of features extracted from ESD for Subject 16

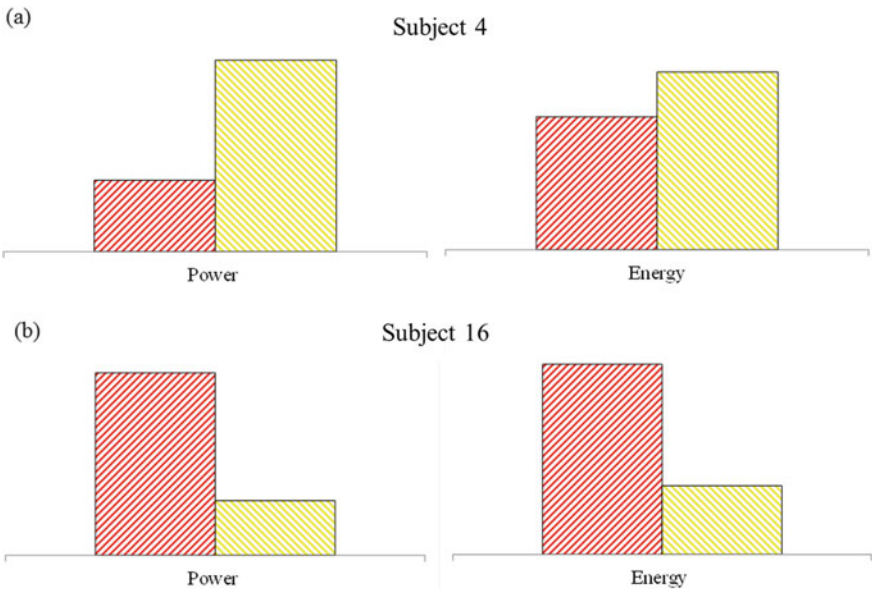

Fig. 8 **a** Changes of features extracted from CWT for Subject 4, **b** changes of features extracted from CWT for Subject 16

the wavelets coefficient values in this frequency band decreased which reflected the decrease of the high frequencies in the scalogram. To be concluded, Subject 4 was in non-fatigue group while Subject 16 was in fatigue group.

3.4 *Four Segments Data Processing, 30 min Each Segments*

Based on Fig. 9, the pattern of all features which are mean, band power, mean energy and energy of wavelet coefficients in Subject 3 was changed from high into low for the first two minutes and from 0 to 30 min. Between 30 and 60 min of driving time, the features lower but rises after 60–90 min of driving time. In 90–120 min, the features decrease indicates that the muscle gets fatigue after two hours of driving. As seen in Fig. 9, shows the same pattern of the all features.

From the analysis, the result can be concluded as Table 3. Table 3 shows the comparison of all the final results from four different methods which are questionnaire, ANN, 2 segments processing and 4 segments processing. Based on Table 3, the final condition of subject's muscle after two hours of driving task can be discovered.

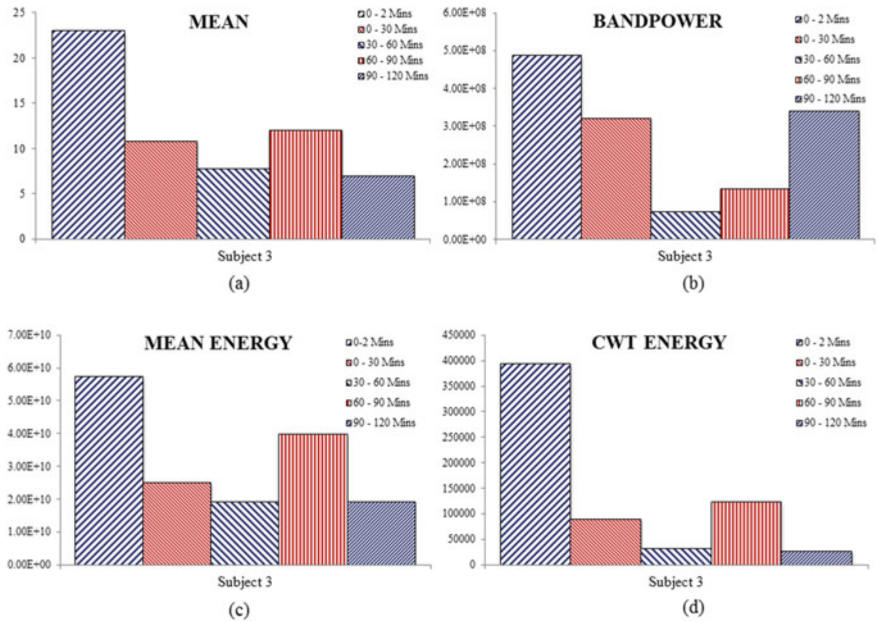

Fig. 9 Features extracted from four segments data processing for Subject 3

Table 3 Comparison of driver's condition obtained from questionnaire, ANN, two segments processing and four segments processing

Subject	Questionnaire	ANN	2 Segments	4 Segments
1	Non-fatigue	Non-fatigue	Non-fatigue	Non-fatigue
2	Fatigue	Fatigue	Fatigue	Fatigue
3	Fatigue	Fatigue	Fatigue	Fatigue
4	Non-fatigue	Non-fatigue	Non-fatigue	Non-fatigue
5	Fatigue	Fatigue	Fatigue	Fatigue
6	Fatigue	Fatigue	Fatigue	Fatigue
7	Non-fatigue	Non-fatigue	Non-fatigue	Non-fatigue
8	Fatigue	Fatigue	Fatigue	Fatigue
9	Non-fatigue	Non-fatigue	Non-fatigue	Non-fatigue
10	Fatigue	Fatigue	Fatigue	Fatigue
11	Fatigue	Fatigue	Fatigue	Fatigue
12	Non-fatigue	Non-fatigue	Non-fatigue	Non-fatigue
13	Fatigue	Fatigue	Fatigue	Fatigue
14	Non-fatigue	Fatigue	Non-fatigue	Non-fatigue
15	Fatigue	Fatigue	Fatigue	Fatigue
16	Fatigue	Fatigue	Fatigue	Fatigue

4 Conclusion

Driver's vigilance is the capability of the driver to maintain focus and remain alert in the execution of actions over time. Fatigue is an example of the factors that can reduce the attention of the driver. Detection of driver fatigue continues to be a major concern in road safety, car design and transport studies. Measurements to determine the driver's status consist of three measures are vehicle-based measurement, video-based measurement and physiological measurement. Due to drawbacks and limitations of first two measurements, the physiological measurement was chosen in this project. During this study, a comprehensive muscle fatigue measurement methodology for driving in a simulated environment is described. Good valuable information can be derived from muscles and researchers can use this information in a broad range of diagnostic and engineering applications through evaluating surface EMG signals to detect muscle fatigue.

Apart from that, in this project, the data segmentation methods were studied to analyses the changes of features in two hour of driving. First, the data were segmented into two segments and the features were extracted in each segment. Based on time domain analysis, the features extracted were mean, standard deviation and RMS. The result obtained from the project shows that the features obtained from some subjects there were increasing and also decreasing. The increment of features can be classified as non-fatigue group while the decrements of features were classified as fatigue group. This can be supported from the past research that mentioned that effect of fatigue had a decreasing with the influence of mean EMG voltage.

Lastly, data were segmented into four segments and undergo the same procedure as the two segments data. The features will be extracted from each 4 segments. Then, the features obtain will be studied. To be concluded, the result from the overall features changed during two hours of driving shows the same pattern. In this method, we can observe the initial conditions of the subjects muscle and the time for the muscle start to fatigue. As the result, there are different times for each of the 16 subjects when the fatigue state begins. In each subject, there is a fluctuation of the features. This happened due to the recovery processes in the muscles. Throughout the presence of muscle fatigue and diminished muscle performance, subjects appeared able to organize muscular and kinematic changes to sustain work performance. This finding explained the immediate response to fatigue and how the muscle response changes over the time. The fluctuations of features also occur because as individuals continue to work with signs of muscle fatigue, the adaptations to muscle fatigue change over time will happened and resulting in kinematic changes and muscle recovery.

Final conditions of subjects muscle for two segments and four segments were observed in order to compare with the result from questionnaire and the result from the classifier. As conclusion, the decrements in skeletal muscle power output are related to neural drive reductions and may lead to muscle fatigue in prolonged exercise. Muscle fatigue is a condition that diminishes the ability of your muscles to respond over time. When encounter fatigue, the energy behind the movement of your muscles reduces. Ultimately, the development of force or power relies on contractile processes within skeletal muscle fibers. However, a series of processes in the nervous system and muscles that precedes spontaneous contraction of the muscles may impede the production of force or power. To sum up, from the studies, the final results obtained from four methods, 15 out of 16 subjects show the same muscle condition after two hours of driving.

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References

1. Gruyer D, Rakotonirainy A, Vrignon J (2005) The use of belief theory to assess driver's vigilance. Australas Road Saf Res Polic Educ Conf 1:1–10
2. Chen LL, Zhao Y, Ye PF, Zhang J, Zou JZ (2017) Detecting driving stress in physiological signals based on multimodal feature analysis and kernel classifiers. Expert Syst Appl 85:279–291
3. McCrary JM, Ackermann BJ, Halaki M (2018) EMG amplitude, fatigue threshold, and time to task failure: a meta-analysis. J Sci Med Sport 21(7):736–741
4. Li L, Shin H, Li X, Li S, Zhou P (2016) Localized electrical impedance myography of the biceps brachii muscle during different levels of isometric contraction and fatigue. Sensors 16:4

5. Sahayadhas A, Sundaraj K, Murugappan M (2012) Detecting driver drowsiness based on sensors: a review. Sensors 12(12):16937–16953
6. Kang HB (2013) Various approaches for driver and driving behavior monitoring: a review. In: Proceedings of the IEEE international conference on computer vision (ICCV), pp 616–623
7. Horberry T, Anderson J, Regan MA, Triggs TJ, Brown J (2006) Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. Accid Anal Prev 38(1):185–191
8. Apostoloff N, Zelinsky A (2003) Robust vision based lane tracking using multiple cues and particle filtering. In: IEEE intelligent vehicles. Symposium proceedings, Figure 2, pp 558–563
9. Pranowo ID, Artanto D, Sulistyanto MP (2019) Non-intrusive vehicle-based measurement system for drowsiness detection. TELKOMNIKA (Telecommun Comput Electron Control) 17(2):956
10. Alioua N, Amine A, Rziza M (2014) Driver's fatigue detection based on yawning extraction. Int J Veh Technol 2014
11. Lee BG, Chung WY (2012) A smartphone-based driver safety monitoring system using data fusion. Sensors 12(12):17536–17552
12. Dababneh L, Sharaf AM, El-Gindy M (2016) Real-time non-intrusive monitoring and prediction of driver distraction. Int J Veh Syst Model Test 11(3):193–216
13. Guo Z, Pan Y, Zhao G, Cao S, Zhang J (2018) Detection of driver vigilance level using EEG signals and driving contexts. IEEE Trans Reliab 67(1):370–380
14. Mu Z, Hu J, Min J (2017) Driver fatigue detection system using electroencephalography signals based on combined entropy features. Appl Sci 7(2)
15. Zheng WL, Lu BL (2017) A multimodal approach to estimating vigilance using EEG and forehead EOG. J Neural Eng 14(2)
16. Li R, Su W, Lu Z (2017) Physiological signal analysis for fatigue level of experienced and inexperienced drivers. Traffic Inj Prev 18(2):139–144
17. Karthick PA, Ghosh DM, Ramakrishnan S (2018) Surface electromyography based muscle fatigue detection using high-resolution time-frequency methods and machine learning algorithms. Comput Methods Programs Biomed 154:45–56
18. Veer K, Sharma T (2016) A novel feature extraction for robust EMG pattern recognition. J Med Eng Technol 40(4):149–154
19. Phinyomark A, Phukpattaranont P, Limsakul C (2012) Feature reduction and selection for EMG signal classification. Expert Syst Appl 39(8):7420–7431
20. Jo J, Lee SJ, Park KR, Kim IJ, Kim J (2014) Detecting driver drowsiness using feature-level fusion and user-specific classification. Expert Syst Appl 41(4, Part 1), 1139–1152
21. Allison GT, Fujiwara T (2002) The relationship between EMG median frequency and low frequency band amplitude changes at different levels of muscle capacity. Clin Biomech 17(6):464–469
22. Mustafa M, Taib MN, Murat ZH, Sulaiman N, Mohd Aris SA (2011) The analysis of EEG spectrogram image for brainwave balancing application using ANN. In: Proceedings—2011 UKSim 13th international conference on computer modelling simulation UKSim 2011, pp 64–68
23. Hunter AM, de Vito G, Bolger C, Mullany H, Galloway SDR (2009) The effect of induced alkalosis and submaximal cycling on neuromuscular response during sustained isometric contraction. J Sports Sci 27(12):1261–1269
24. Basu B, Nagarajaiah S, Chakraborty A (2008) Online identification of linear time-varying stiffness of structural systems by wavelet analysis. Struct Heal Monit 7(1):21–36
25. Shariatinasab R, Akbari M, Rahmani B (2012) Application of wavelet analysis in power systems. Adv Wavelet Theor Appl Eng Phys Technol

Prediction of Blood Glucose Level Based on Lipid Profile and Blood Pressure Using Multiple Linear Regression Model

Q. 'A. A. Ahmad Fazil and Ummu Kulthum Jamaludin

Abstract Diabetes mellitus refers to a metabolic disorder that occurs due to insulin resistance and/or inability to produce enough insulin from islet β–cells in pancreas leads to increasing levels of blood glucose. Due to perturbation towards current diabetes screening and diagnosis procedures that require fasting, oral glucose consumption and involve invasive and finger-pricks, numbers of undiagnosed diabetes mellitus kept increasing due to hesitation of these people to take screening tests as their routine check-up. Since diabetes mellitus is closely related to blood glucose level, a multiple linear regression model for predicting the blood glucose level gives the impression as one of the alternatives. Thus, this study proposed a multiple linear regression equation for predicting the fasting blood glucose level based on independent parameters of lipid profile and blood pressure as high blood cholesterol and high blood pressure are known as risk factors for diabetes. There are 302 data collected from UMP's retrospective data via data directory from University Health Centre in 2017 to 2018. This study shows that the adjusted R^2 of 46.8% for multiple linear regression model of fasting blood glucose level was obtained to predict the possibility of pre-screening diabetes without fasting procedures. This model equation was solely based on high density lipoprotein cholesterol, triglyceride and systolic blood pressure levels with the prediction made by the model are acceptable with moderate accuracy (MAPE = 9.46%). In order to increase the accuracy of the model, future research should consider a bigger and wider cohort from different comorbidities background which can be an alternative method in screening diabetes mellitus.

Keywords Multiple linear regression · Fasting blood glucose · Screening diabetes mellitus

Q. 'A. A. Ahmad Fazil · U. K. Jamaludin (✉)
Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: ummu85@ump.edu.my

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1 Introduction

According to the International Diabetes Federation report, diabetes mellitus (DM) is a global alarming issue with increasing numbers of people being diagnosed with DM from 382 million in 2013 to 422 million in 2017, worldwide. These numbers are predicted to increase up to 642 million by 2040 [1, 2]. Based on the National Health and Morbidity Survey conducted by the Ministry of Health Malaysia in 2019, there are 3.9 million people diagnosed with DM which aged 18 years old and above with prevalence of 18.3% and the prevalence of DM is predicted to increase up to 21.6% in 2020 [3]. Type 2 DM which is commonly diagnosed among adults is defined as a metabolic disorder that occurs due to insulin resistance and/or inability to produce enough insulin from islet β–cells in pancreas [4]. Decreasing concentration of insulin leads to increasing levels of blood glucose (BG) that are referred to as DM or hyperglycaemia (i.e. high BG level) [5].

There are four current screening and diagnosing methods for DM in Malaysia which are random blood glucose (RBG), fasting blood glucose (FBG), postprandial glucose (PPG) and glycosylated haemoglobin (HbA1c). RBG is suggested to be the simplest method in measuring BG since it is fast, can be repeated everyday, the blood is drawn once at any time of the day and also requires no fasting and no glucose consumption. However, the results is unreliable for screening purposes without classic symptoms of DM (e.g. polyuria, polydipsia, weight loss and blurred vision) [6]. This is due to the randomness of the RBG test since there are no specific procedures needed in this test.

Besides, HbA1c also offers simple procedures like RBG test which also suggests greater pre-analytical stability and less day-to-day perturbations during periods of stress and illness [5]. However, HbA1c does not directly measure blood glucose. HbA1c measures glycated haemoglobin which is more related to protein [5]. This test also may vary with patients' race or ethnicity. Some individuals and ethnic groups have persistently lower or higher than the expected HbA1c levels compared to others with similar BG levels [7]. These variations are caused by genetic factors and differences in haemoglobin glycation rates such as red blood cell life-span or mean red blood cell age, in those with and without type 2 DM [8].

Despite the fact that FBG and PPG tests have a great sensitivity towards DM which directly measure blood glucose, people hesitate to uptake both tests as one of their routine check-ups due to the procedure of both tests require fasting which can lead to hypoglycaemia in certain individuals, especially diabetic patients. Meanwhile, only PPG test require glucose consumption as well as the test takes 2 h as a standard procedure. Consequently, this hesitation will contribute to a high percentage of undiagnosed DM in future. Undiagnosed DM which is prevalent among young and middle-aged is defined as subjects who meet the DM criteria but never been diagnosed or prescribed anti-diabetic medications by medical practitioners [9].

For that reason, an effective strategy is essential to identify undiagnosed DM and to prevent DM in future. After comparing the current tools, FBG test is the best option to be implemented in the predictive model for screening DM purposes. Also, high fasting BG level is reported as an independent risk in Japanese population [10]. The idea for this study is to predict blood glucose at fasting, without fasting procedures.

DM defined by American Diabetes Association (ADA) includes the condition where defects in insulin secretion and action leads to abnormalities in carbohydrate, protein and fat metabolism [5]. Thus, it shows the close relationship between blood glucose, protein and body fat. HbA1c level could also be considered independent parameter since it is related to protein, however, it will cost RM40 per test which is a bit pricey to be included in this study. Study conducted by Lee et al. [9] reported that undiagnosed DM subjects are more prevalent in uncontrolled hypertension (HTN) [HTN: blood pressure, BP $\geq$ 140/90 mmHg] and high bad cholesterol. Also, blood glucose level during fasting is significantly increase with increasing BP [11, 12].

Despite the fact that body mass index (BMI) is a well-known risk factor for DM [13], BMI cannot be considered as an independent parameter because a person with healthy BMI reading, obese or underweight may have or may not have DM due to differences in age, fitness and body composition including body fat [14, 15]. In addition, the effects of BMI have a conflict finding across different ethnic groups which may lead to different prevalence of DM in ethnicity based on BMI [16]. Therefore, only lipid profile and BP are considered as independent parameters in this study to predict blood glucose at fasting, without fasting procedure. To sum up, this study proposed a multiple linear regression (MLR) model for predicting the fasting BG level as an alternative tool to screen DM at the very early stage by using blood cholesterol and BP levels in healthy subjects.

2 Methods

The ethical approval of this study was obtained from International Islamic University Malaysia (IREC 657). Next, the retrospective data was collected from the University Health Centre, Universiti Malaysia Pahang (UMP) directory. This retrospective data was based on the collective data from yearly health screening campaigns for UMP's staff that were held back in 2017 and 2018.

2.1 Subjects

A total of 302 data (i.e. healthy subjects) available for present study after the cleaning process. Healthy subjects means that the person has not been diagnosed for DM and not been prescribed with anti-diabetic medicine by medical practitioners. Data cleaning is the tactic to detect and to correct or to remove corrupt or inconsistent data records from data collection [17]. Missing data was irreplaceable as the MLR model for predicting fasting BG level proposed in this study was purposely conducted based on the real measurements. This is to represent the true physiology of a human body behaviour and the relationship of BG, lipid and BP mechanisms. A general rule of thumbs indicated a clinical practice should have 30 subjects or more for each parameter investigated [18]. Thus, this study followed the general rule of thumbs with a total of 302 subjects since only 240 subjects needed when 8 parameters are involved.

2.2 Data Statistical Analysis

Figure 1 shows research work flow for present study. A normality test was conducted using one-sample Kolmogorov-Smirnov test via MATLAB software to determine overall data distribution. All hypotheses in this study were tested using two-tailed tests, which means the rejection region was for both sides.

This study uses three types of statistical tests via MATLAB R2016a software which are one-sample Kolmogorov-Smirnov test, Mann-Whitney U test and Kruskal-Wallis test that use a *p*-value approach to test all the hypotheses. *p*-value is the probability of the observing data set if the null hypothesis for it means (parametric test) or medians (non-parametric test) is true. Lower *p*-value can decrease the validity of the result. α-value is a subtraction of *p*-value from 1. The confidence interval used in this present study was 95% (p-value $= 0.95$), thus α-value was 0.05. If *p*-value < α-value, then the null hypothesis, H0 was rejected vice versa.

This study split the overall data to create 70% (training): 30% (testing) data due to limited numbers of data [16, 19]. Overall data was split randomly without replacement using random number generation function, '***rng***' function in MATLAB R2016a software. Training data was used for modelling a MLR BG model then the model was validated using overall 302 data [20]. After that, self-validation was done using testing data to determine the ability of the MLR BG model in estimating the BG value for a new data set. A hypothesis for paired samples was tested using a non-parametric Mann-Whitney U test. It is equivalent to Wilcoxon rank sum, W test which is available in MATLAB R2016a software. This test was used to determine whether the two data sets are separated relatively.

Then, the MLR model used to describe a relationship of one dependent parameter (BG) with more than one independent parameter (lipid profile and BP). Regression analysis computed via MATLAB software also provided R, R^2, adjusted R^2 and *p*-value. R was used as the overall correlation and the value was ranged from 0 (i.e. no relationship) to +1 (i.e. strong relationship). R^2 showed how the regression line can predict the actual values. Adjusted R^2 is the modified version of R^2, must always be lower than R^2 value and has been adjusted for the number of predictors in the model. Adjusted R^2 closed to 1 indicated the best fit. Kruskal-Wallis ANOVA table computed via MATLAB calculated median values (replacing mean function), provided similar information as ANOVA table except for F-statistics which was replaced by a chi-square statistical test. Thus, Kruskal-Wallis test was used to claim the hypothesis that all group medians were equal versus the alternative hypothesis that at least one group was different from the others.

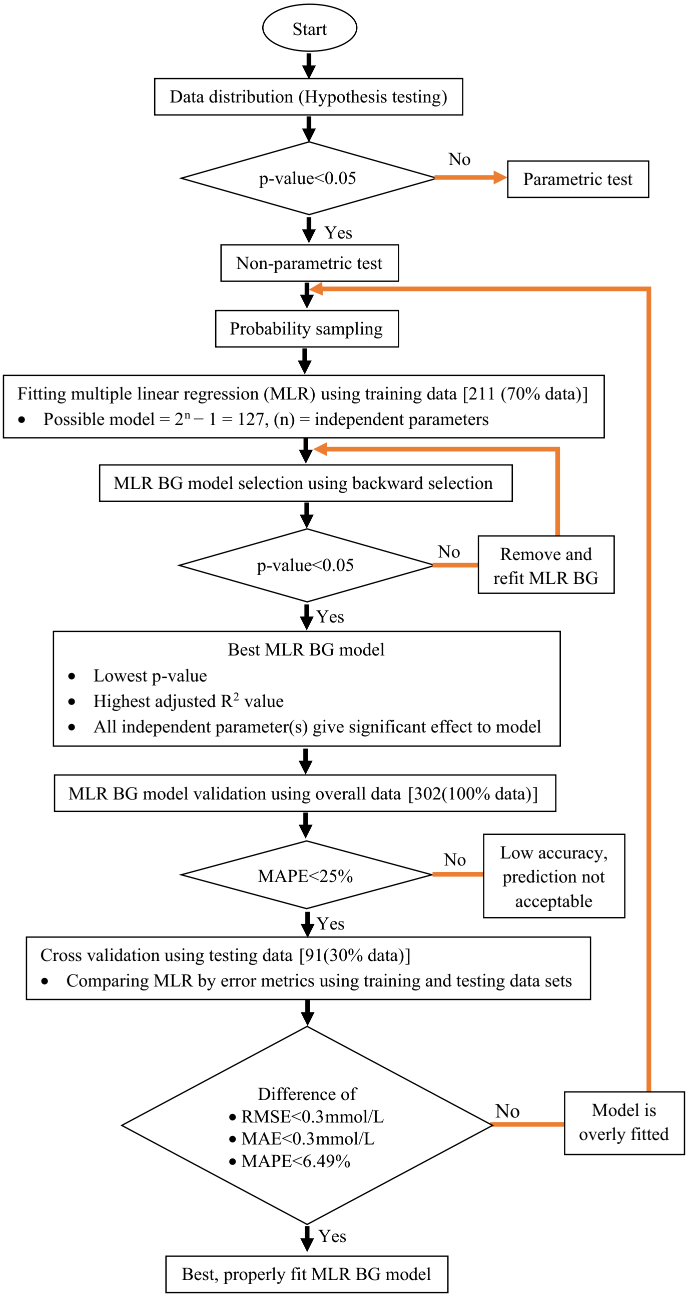

Fig. 1 Framework for data statistical analysis

There will be a total of $2^k - 1$ possible models for k independent parameters (x_1, x_2, …, x_k). Thus, selecting the best model was functionally to simplify the model by removing redundant predictors (independent parameters), removing unnecessary predictors that will add noise to the estimation of others predictors, and identifying collinearity between predictors and selecting only one parameter among them. There are various methods for model selection including backward, forward and stepwise selection. This study used backward selection since it was the simplest procedure among all which was similarly used by Pralle et al. [20] as well as Abdollahian and Gunaratne [21] studies. Starting with all independent parameters in the model, then a significant independent parameter was removed one by one according to their p-value > 0.05. In the end, the best model chosen in this study had the highest adjusted R^2 value with the smallest p-value, and all independent parameters were significant, p-value < 0.05.

The proposed MLR BG model was validated by comparing the observed and the expected BG values box plot. The expected BG value (predicted BG) was gained by solving the equation gained after the model selection process using input lipid profile and BP values from the observed data (i.e. overall data). The maximum and the minimum values of box plots gave information whether the MLR BG model overestimated or underestimated the BG value, respectively. Besides, error metrics based on residuals ($y - \hat{y}$) consisting of mean absolute error (MAE), mean absolute percentage error (MAPE), root mean square error (RMSE) and mean percentage error (MPE) were used to validate the model. Residuals were referred to as the differences between the predicted and the observed values of the validation samples.

MAE was the average magnitude of error produced by the MLR model. MAPE determined how far the MLR model's predictions were off from actual values on average. RMSE was used to measure how large MLR model's residuals were spread out. MPE was used to determine whether the MLR model was systematically overestimated (positive error) or underestimated (negative error) the actual value. At the end, MAPE was used as the benchmark for MLR BG model based on accuracy and forecast's acceptability. Table 1 shows MAPE indicator to determine accuracy and forecast acceptability as reported by Swanson [22].

For self-validation purposes, these four error metrics were used to determine whether MLR BG model proposed by this study was having the best fit or it is overly fitted. The best fit model would have similar error magnitude between training and testing data. Meanwhile, an overly fitted model would have incredibly low error

Table 1 MAPE indicator

MAPE value (%)	Accuracy	Forecast acceptability
0	Perfect	Acceptable
0.1–5	High	Acceptable
5.1–9.9	Moderate	Acceptable
10–25	Low	Acceptable
>25	Very low accuracy	Not acceptable

magnitude for training data compared to testing data due to the MLR model recognizing the data pattern from the training data. Thus, it worked poorly on the new sets of data (i.e. testing data).

3 Results and Discussion

3.1 Subjects Demographic and Data Distribution

The distribution of male 164 (54.3%) and female 138 (45.7%) subjects were almost the same, where it was dominated by the age group of 40–49 years old 145 (48%). The highest race was Malay 279 (92.4%), followed by Chinese 7 (2.3%) and Indian 3 (1.0%) subjects. Totally, up to 95.7% were Malaysians and 4.3% were foreigners. Roughly, the majority subjects have normal and pre-obese BMI which were 112 (37.1%) and 115 (38.1%), respectively. Then, it was followed by 71 (23.5%) obese and 4 (1.3%) underweight subjects. The clinical data collected to give an overview of the overall data (n = 302) is summarised in Table 2.

In general, most subjects have normal levels of dependent: BG (75.50%) and independent parameters: TC (84.44%), HDLC (81.79%), LDLC (82.45%), TG (79.80%) and BP (65.56%). All of these values were based on ADA [5]; National Cholesterol Education Program (NCEP) ATP III [23] and Bhagani et al. (2018) study [24]

Table 2 Clinical details of overall data (n = 302)

Profile	Category	Mean ± S.D.	Normal level
Dependent parameter	BG (mmol/L)	5.2 ± 0.9	4.0–5.5 (fasting BG)
Independent parameter	Total cholesterol, TC (mmol/L)	5.2 ± 0.9	<6.20
	High density lipoprotein cholesterol, HDLC (mmol/L)	1.3 ± 0.3	>1.03
	None high density lipoprotein cholesterol, non-HDLC (mmol/L)	3.8 ± 1.0	<3.4
	Low density lipoprotein cholesterol, LDLC (mmol/L)	3.3 ± 0.9	<4.11
	Triglycerides, TG (mmol/L)	1.3 ± 0.8	<1.70
	Systolic BP, SBP (mmHg)	126.2 ± 14.9	<130
	Diastolic BP, DBP (mmHg)	77.8 ± 13.0	<85

Table 3 Normality test of BG, lipid profile and BP levels (n = 302)

Parameter	*p*-value
BG (mmol/L)	<0.05*
TC (mmol/L)	<0.05*
Non-HDLC(mmol/L)	<0.05*
HDLC (mmol/L)	<0.05*
LDLC (mmol/L)	<0.05*
TG (mmol/L)	<0.05*
SBP (mmHg)	<0.05*
DBP (mmHg)	<0.05*

*: Statistical significance attributed to results when p-value < 0.05

for fasting BG, lipid profile and BP levels. However, Non-HDLC (66.56%) level in this study (3.8 mmol/L) was above the recommended value by NCEP ATP III (<3.4 mmol/L).

To ensure the normality of the model, a statistical test known as one-sample Kolmogorov-Smirnov was conducted to test the null hypothesis and claim that BG, lipid profile and/or BP levels come from standard normal distribution. Table 3 shows the normality test results of BG, lipid profile and BP levels using the '***kstest***' function computed via MATLAB software.

Overall, since p-value < 0.05, then the null hypothesis was rejected. At 5% significance level, there was no sufficient evidence to support the claim that BG, lipid profile and BP levels were normally distributed. As a result, a non-parametric statistical test known as Wilcoxon rank sum test was used for probability sampling. Besides, a non-parametric Kruskal-Wallis test was used in MLR model analysis.

3.2 Probability Sampling

Next, a hypothesis for paired samples was tested to claim that both training and testing data sets have similar medians of dependent and independent parameters. Table 4 shows the results of a hypothesis tested using Wilcoxon rank sum test computed via MATLAB software.

From Table 4, since p-value > 0.05, it failed to reject the null hypothesis. At 5% significance level, there was sufficient evidence to support the claim that both training and testing data sets have BG, lipid profile and BP levels with similar median. For that reason, it is suggested that both groups were split relatively.

Table 4 Results for rank sum test for training and testing data sets

Parameter	Training data	Testing data	*p*-value
BG (mmol/L)	5.2 ± 0.9	5.2 ± 0.9	>0.05
TC (mmol/L)	5.2 ± 0.9	5.1 ± 0.9	>0.05
Non-HDLC (mmol/L)	3.9 ± 1.0	3.7 ± 1.0	>0.05
HDLC (mmol/L)	1.3 ± 0.3	1.4 ± 0.4	>0.05
LDLC (mmol/L)	3.3 ± 0.9	3.2 ± 0.9	>0.05
TG (mmol/L)	1.3 ± 0.8	1.3 ± 0.9	>0.05
SBP (mmHg)	127.1 ± 15.0	124.6 ± 14.5	>0.05
DBP (mmHg)	78.4 ± 12.9	76.3 ± 13.0	>0.05

3.3 MLR Model Analysis

The formula of MLR model in predicting BG in this study was given by Eq. 1 as follows:

$$\widehat{\mathrm{BG}} = \hat{\beta}_0 + \hat{\beta}_1\mathrm{TC} + \hat{\beta}_2\text{Non-HDLC} + \hat{\beta}_3\mathrm{HDLC} + \hat{\beta}_4\mathrm{LDLC} + \hat{\beta}_5\mathrm{TG} + \hat{\beta}_6\mathrm{SBP} + \hat{\beta}_7\mathrm{DBP} \quad (1)$$

where $\widehat{BG}$: predicted value of dependent parameter (BG); $\hat{\beta}_0$: estimated value of plane intercept; $\hat{\beta}_1, \hat{\beta}_2, \ldots, \hat{\beta}_7$: estimated value of the regression coefficients. Table 5 shows the MLR model between dependent and independent parameters.

From the regression statistics in Table 5, the adjusted coefficient of determination (adjusted R^2) was 0.478. Hence, 47.8% of the BG level can be explained by TC, non-HDLC, HDLC, LDLC, TG, SBP and DBP levels. Figure 2 shows Kruskal-Wallis ANOVA table results of multiple comparisons between BG level and independent parameters (lipid profile and BP).

Based on Fig. 2, since p-value < 0.05, hence the null hypothesis was rejected. Thus, there was sufficient evidence to claim that at least one of the independent parameters was related to the BG level at 5% significance level.

Table 5 MLR statistics for all seven independent parameters (lipid profile and BP levels)

Regression statistics	
R	0.704
R square	0.495
Adjusted R square	0.478
Standard error	0.673
Observations	211

Kruskal-Wallis ANOVA Table

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Columns	3.63748e+08	7	51963976.8	1531.31	0
Error	3.6982e+07	1680	22013.1		
Total	4.0073e+08	1687			

Fig. 2 MLR statistics for all seven independent parameters (lipid profile and BP levels)

3.4 Model Selection

There were 127 (calculate: $2^7 - 1$) possible MLR models to be considered as the best regression model for BG. The best model was chosen to simplify the MLR model so that the BG model contained only significant independent parameters without collinearity. Multicollinearity is a condition where one independent parameter in a MLR can be linearly predicted by another independent parameter(s). Model selection process is crucial so that the best model will be able to predict well without unnecessary and redundant independent parameters that will affect the estimation of other independent parameters.

This study applied a backward selection method as it has the simplest procedures to select the best MLR model. The backward selection method started with all seven independent parameters in the model as shown in Fig. 3a. Independent parameters

a

Linear regression model:
BG ~ 1 + TC + NONHDLC + HDLC + LDLC + TG + SBP + DBP

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	5.8223	0.53583	10.866	5.6619e-22
TC	-0.86391	0.52034	-1.6603	0.098401
NONHDLC	0.71239	0.50459	1.4118	0.15953
HDLC	-0.77062	0.50129	-1.5373	0.12578
LDLC	0.031067	0.27509	0.11293	0.9102
TG	0.23522	0.10275	2.2892	0.023095
SBP	0.013758	0.0053285	2.5819	0.01053
DBP	0.00040106	0.0062172	0.064509	0.94863

Number of observations: 211, Error degrees of freedom: 203
Root Mean Squared Error: 0.673
R-squared: 0.495, Adjusted R-Squared: 0.478
F-statistic vs. constant model: 28.5, p-value = 4.05e-27

b

Linear regression model:
BG ~ 1 + TC + NONHDLC + HDLC + LDLC + TG + SBP

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	5.8205	0.53383	10.903	4.1671e-22
TC	-0.86414	0.51905	-1.6649	0.097477
NONHDLC	0.71311	0.50323	1.4171	0.15799
HDLC	-0.77174	0.49977	-1.5442	0.12409
LDLC	0.030761	0.27438	0.11211	0.91084
TG	0.23509	0.10248	2.294	0.022807
SBP	0.014028	0.0032886	4.2655	3.0508e-05

Number of observations: 211, Error degrees of freedom: 204
Root Mean Squared Error: 0.672
R-squared: 0.495, Adjusted R-Squared: 0.481
F-statistic vs. constant model: 33.4, p-value = 6.7e-28

c

Linear regression model:
BG ~ 1 + TC + NONHDLC + HDLC + TG + SBP

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	5.8167	0.53149	10.944	2.9916e-22
TC	-0.84505	0.48913	-1.7277	0.085557
NONHDLC	0.72424	0.49217	1.4715	0.14268
HDLC	-0.78678	0.48027	-1.6382	0.10291
TG	0.22639	0.066746	3.3918	0.00083307
SBP	0.013983	0.0032569	4.2934	2.7139e-05

Number of observations: 211, Error degrees of freedom: 205
Root Mean Squared Error: 0.67
R-squared: 0.495, Adjusted R-Squared: 0.483
F-statistic vs. constant model: 40.3, p-value = 1e-28

d

Linear regression model:
BG ~ 1 + TC + HDLC + TG + SBP

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	5.789	0.53265	10.868	4.8503e-22
TC	-0.12946	0.052788	-2.4525	0.015021
HDLC	-1.4463	0.17311	-8.3549	9.6226e-15
TG	0.23961	0.066325	3.6127	0.00038078
SBP	0.013751	0.0032623	4.2152	3.7346e-05

Number of observations: 211, Error degrees of freedom: 206
Root Mean Squared Error: 0.672
R-squared: 0.49, Adjusted R-Squared: 0.48
F-statistic vs. constant model: 49.5, p-value = 3.85e-29

Fig. 3 MLR analysis with **a** seven, **b** six, **c** five and **d** four independent parameters with the highest p-value > 0.05 were removed from the model as in Figs. 3a–c. From Fig. 3d, all four independent parameters give significant effect to the model with p-values < 0.05 and have moderate adjusted $R^2 = 0.48$. However, TC level was removed from the MLR BG model since TC had no correlation with BG individually (p-value > 0.05) (refer to the Appendix).

LDLC, non-HDLC and TC levels are excluded from the model since these three levels have no significant correlation with BG level (p-value > 0.05) individually, so any combination with LDLC, non-HDLC and TC levels was not preferred. In addition, LDLC level was influenced by TC, TG and HDLC levels since the determination of LDLC value was calculated using these three values [25]. Also, TC level was influenced by HDLC and non-HDLC levels because TC is the summation of all lipoprotein present in the human body consisting of good cholesterol (HDLC) and bad cholesterol (non-HDLC) [26].

Studies conducted by Stein et al. [27] and Yeboah et al. [28] also found that non-HDLC level had no significant relationship with BG level. Furthermore, increasing non-HDLC closely related with the accumulation of small dense LDL particles and TG in plasma, including chylomicron and vLDLC remnants [29]. Thus, it is suggested that non-HDLC level was influenced by LDLC and TG levels. Moreover, only few research papers have reported on non-HDLC as a parameter.

Next, the MLR model was re-fitted with three independent parameters without DBP, LDLC, non-HDLC and TC levels as shown in Fig. 4. All three independent parameters give significant effect to the model with p-values < 0.05. In addition, HDLC ($R^2 = 0.404$, p-value < 0.05) had moderate correlation with BG level (refer to the Appendix). Meanwhile TG ($R^2 = 0.186$, p-value < 0.05) and SBP ($R^2 = 0.144$,

```
Linear regression model:
    BG ~ 1 + HDLC + TG + SBP

Estimated Coefficients:
                   Estimate        SE         tStat       pValue
                   ________    _________    _______    __________

    (Intercept)      5.4417      0.51966     10.472    7.2805e-21
    HDLC            -1.5469      0.17019    -9.0893    8.2253e-17
    TG               0.1893     0.063833     2.9656     0.0033754
    SBP            0.012754    0.0032758     3.8934    0.00013335


Number of observations: 211, Error degrees of freedom: 207
Root Mean Squared Error: 0.68
R-squared: 0.475,  Adjusted R-Squared: 0.468
F-statistic vs. constant model: 62.5, p-value = 8.39e-29
```

Fig. 4 MLR analysis with three independent parameters

Table 6 Relationship between dependent parameter (BG) and independent parameters (HDLC and TG) as reported in different studies

Study	Significant correlation with BG, R^2		Subjects, n
	HDLC	TG	
Present study (2020)	0.404	0.186	211 healthy
[30]	0.020	0.032	9764 diabetic
[31]	0.030	0.050	515 healthy and 523 diabetic
[32]	–	0.130	89 healthy

p-value < 0.05) were having weak correlation with BG level (refer to the Appendix). Thus, any combination with HDLC, TG and SBP were acceptable.

Table 6 shows the variability in R^2 values reported by different studies might be due to differences in sample size and healthy condition of subjects involved. Study by Lin et al. [30] focused on the relationships between lipid profile with insulin resistance and DM. Meanwhile, Misra et al. [31] study, the aim was to determine the prevalence of DM, metabolic syndrome and cardiovascular risk factors in US Asian Indians. For Alwardata et al. [32] study, it is focused on the relationship between HTN and metabolic disorders among elderly patients in North Jordan. Despite the differences in R^2 values, all these studies reported that HDLC and TG levels are significantly correlated with BG level.

Adjusted $R^2 = 0.468$ means that there was 46.8% of the variation in the BG values that can be predicted by HDLC, TG and SBP levels and Eq. 2 was the best for predicting BG value at fasting.

$$\widehat{\mathrm{BG}} = 5.4417 - 1.5469\mathrm{HDLC} + 0.1893\mathrm{TG} + 0.012754\mathrm{SBP} \tag{2}$$

The estimated BG value was 5.4417 mmol/L when HDLC, TG and SBP input were zeros. The estimated BG value decreased by 1.5469 mmol/L for every 1 mmol/L of HDLC value when TG and SBP values were held constant. Meanwhile, the estimated BG value increased by 0.1893 mmol/L for every 1 mmol/L of TG value when HDLC and SBP values were held constant. Besides, if HDLC and TG values were held constant, the estimated BG value increased by 0.012754 mmol/L for every 1 mmHg of SBP value.

Based on Eq. 2, HDLC has a negative estimated regression coefficient which was −1.5469. This means that, decreasing level of HDLC increased the BG level. Similar results were found in He et al. [33]; Odum and Young [12], and Rkhaya et al. [34] studies. Contradict to Hassan et al. [35] study which found no significant difference ($p > 0.05$) between diabetic and non-diabetic subjects for HDLC level. This difference might be due to the differences in the number of subjects since Hassan [35] only included small data input of 30 healthy and 31 T2DM subjects.

In contrast, Eq. 2 showed TG and BP had positive estimated regression coefficients which were 0.1893 and 0.012754, respectively. This suggested that increasing the level of TG and BP increased the fasting BG level. Similarly found in Hassan et al. [35]; He et al. [33]; Odum and Young [12], and Rkhaya et al. [34] studies that also found subjects with higher TG and BP levels had higher fasting BG level. For BP level, only SBP is included in the model since SBP and DBP levels were collinear. Therefore, it is suggested to choose between SBP and DBP as both levels were previously reported having strong correlation when R = 0.62 [36].

3.5 Model Validation and Self-validation

The MLR BG model was validated by comparing the fasting BG data between the observed value and the expected value. Expected fasting BG value was gained by solving Eq. 2 using input of HDLC, TG and SBP values from the observed data (i.e. overall data).

By referring to Fig. 5, the minimum and the maximum observed fasting BG values were 4.1 mmol/L (normal fasting BG: 4.0–5.5 mmol/L) and 11.3 mmol/L (DM: fasting BG $\geq$ 7.0 mmol/L), respectively. Meanwhile, the minimum and the maximum fasting BG values for the expected were 2.9 mmol/L (hypoglycaemia: fasting BG < 4.0 mmol/L) and 7.5 mmol/L, respectively. The minimum and the maximum fasting BG value for expected box plot was lower than the observed box plot. This suggests that the MLR BG model might underestimate the actual fasting BG value. Fasting BG value which was used to screen and diagnose pre-diabetes and DM should never be underestimated as DM diseases might lead to various co-morbidities (i.e. HTN and cardiovascular diseases) and mortality. Table 7 shows the summary of four error metrics which are used to validate (overall data) and self-validate (training and testing data sets) the MLR BG model.

For overall data, the MAE value for MLR BG model in this study was 0.5036 mmol/L, which was relatively small given that this study data ranged from

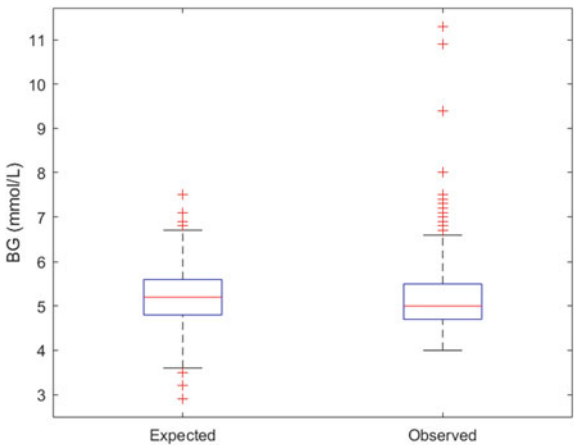

Fig. 5 Box plots of observed and expected fasting BG values (n = 302)

Table 7 Error metrics values

Error metric	Overall data (n = 302)	Training data (n = 211)	Testing data (n = 91)
MAE (mmol/L)	0.5036	0.4483	0.6319
RMSE (mmol/L)	0.7298	0.6800	0.7840
MPE (%)	+1.07	+1.06	+1.09
MAPE (%)	9.46	8.27	12.20

4.0 to 11.0 mmol/L. MAE value in this study was smaller when compared to Yan and Zhang [37] study which was 2.07 mmol/L. This difference might be due to differences of independent parameters used to predict BG level as Yan and Zhang [37] used breath samples (i.e. non-invasive, monitoring DM method) in their study.

Even if there was a chance that the MLR BG model might underestimate fasting BG value, positive value of MPE = +1.07% indicated that this MLR BG model has higher chances to overestimates actual fasting BG value with missed of actual fasting BG values by about 0.7 mmol/L (RMSE = 0.7298 mmol/L). Furthermore, the missed value was larger than the possible minimum changes of FBG value which was ±0.1 mmol/L. Even ±0.1 mmol/L could change the diagnostic status of a person, thus ±0.7 mmol/L could be even worse.

For example, Abu has normal actual fasting BG = 5.0 mmol/L (4.0–5.5 mmol/L). Due to a miss of 0.7 mmol/L, the MLR BG model might overestimate Abu's fasting BG = 5.7 mmol/L then changes the diagnostic status to pre-diabetes (5.6–6.9 mmol/L). In this case, overestimating fasting BG value can give extra awareness to Abu, as he needs to begin to consider practicing a healthy diet and lifestyle.

Another example, Bob has abnormal actual fasting BG = 6.0 mmol/L (i.e. IFG). The predictive model underestimates Bob's fasting BG = 5.3 mmol/L by 0.7 mmol/L and changes the diagnostic status to non-diabetic. For this case, suppose Bob has started to consider practicing a healthy diet and lifestyle. However, he might continue his current diet and lifestyle unknowingly his current conditions.

On top of all that, the model has moderate accuracy (MAPE < 10%) which predictions made were 9.46% (i.e. MAPE) off from the actual fasting BG value. However, since the MAPE value was <25%, it is suggested that the forecast made by the proposed MLR BG model was acceptable as reported by Swanson [22] study.

Meanwhile, for self-validation, the error metrics for testing data were higher than the training data in this study. Since both data sets showed positive MPE values, it is affirmed that the MLR BG model has higher chances to overestimate actual fasting BG value.

If the evaluation of model using training data is extremely higher than the model's evaluation using testing data, the model is said to be over-fit as it memorized the training data and works poorly on the new data. By comparing with the Zeng et al. (2020) study [38], the ratio of total subjects is 1:11 with this study. Thus, the target

Table 8 Value differences for error metrics by different studies

Metrics	Value differences		
	This study (2020)	[38]	Target
No. of subjects	302	3414	1:11
Dependent parameter	BG level	HbA1c level	
No. of independent parameter	3	4	
MAE (mmol/L)	0.2	0.03	0.3
MAPE (%)	3.93	0.59	6.49
RMSE (mmol/L)	0.1	0.03	0.3
MPE(%)	Both positive	–	–

for differences in error metric values in this study was set to be compatible with the value differences in Zeng study as shown in Table 8.

The model suggested to have a properly fit characteristics as the differences in MAE and RMSE values were lower than 0.3 mmol/L and differences in MAPE value was lower than 6.49%. Variability in error metrics values reported by different studies may be due to differences in sample size as well as dependent and independent parameters involved. Zeng et al. [38] study had bigger sample size (n = 3414) and it predicted HbA1c level using four independent parameters compared to this study which has much smaller sample size (n = 302) and predicted fasting BG level using three independent parameters.

In short, self-validation suggests that this model is a properly fit model by considering error metrics between predictive training and test in Table 7 were about the same magnitude where differences in MAE and RMSE values were lower than 0.3 mmol/L and differences in MAPE value was lower than 6.49%.

4 Conclusion

This study proposed the MLR BG model for about 46.8% of the variation in the BG values could be predicted by HDLC, TG and SBP levels. There was sufficient evidence to claim that there was significant correlation between HDLC ($R^2 = 0.404$, p-value < 0.05), TG ($R^2 = 0.186$, p-value < 0.05) and SBP ($R^2 = 0.144$, p-value < 0.05) levels with BG. Thus, all these three levels were eligible to be independent parameters for the MLR BG model. The predictions made by the model are acceptable with moderate accuracy as reported by Swanson (2015) study [22] due to its MAPE value is 9.46%. The positive value of MPE (+1.07%) indicates that this model has higher chances to overestimates actual blood glucose value at fasting with missed of actual blood glucose value (RMSE = 0.7298) was larger than the possible minimum changes of blood glucose level which is 0.1 mmol/L.

The overall sample was not representative of the whole Malaysia population as it was predominantly ethnic Malay (92.2%). In addition, this study was carried out within UMP's staff and students which was unlikely to be representative of those in other universities, other parts of countries and different ethnic. Thus, future study should involve wide variety cohorts which cover different types of demographics in Malaysia. Study should not be restricted to Peninsular Malaysia only. Higher chances to predict the variation in the fasting BG values based on lipid profile and BP levels might be achieved if widen the subjects' cohort.

Furthermore, data used in this study was collected from UMP's retrospective data which only provided limited information (i.e. BG, lipid profile, BP, age, gender and BMI levels) of subjects. Thus, this study was unable to verify the correlation between the fasting BG level and the heart rate variability as reported by Lutfi and Elhakeem [39]. For that reason, future study should consider heart rate variability as an independent parameter for fasting BG value as their correlation stated in Lutfi and Elhakeem [39] and should verify the variability of TG level since it is reported to be increased by 0.3 mmol/L when not fasting by Botet et al. [25].

To sum up, it is possible to decrease the percentage of undiagnosed DM by simplifying the procedure for the current DM screening tests in Malaysia which requires fasting and oral glucose consumption. An efficient screening test that is highly repeatable, and also requires no fasting and no glucose consumption would be more preferable to be used. This preferable test could be engineered by considering other independent parameters (i.e. risk factors) of DM by determining their relationship with BG.

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Appendix

Correation Between BG and Independent Parameters

No	Independent Parameter	*p*-value	R^2	Adjusted R^2	Regression Equation
1	TC	0.229	0.007	0.002	$\widehat{BG} = 5.6668 - 0.0825\text{TC}$
2	HDLC	3.05×10^{-25}	0.404	0.401	$\widehat{BG} = 7.7942 - 1.9184\text{HDLC}$
3	Non-HDLC	0.088	0.014	0.009	$\widehat{BG} = 4.7979 + 0.1146\text{Non-HDLC}$
4	LDLC	0.753	0.000	−0.004	$\widehat{BG} = 5.3147 - 0.0229\text{LDLC}$
5	TG	5.38×10^{-11}	0.186	0.183	$\widehat{BG} = 4.6254 + 0.4909\text{TG}$
6	SBP	1.31×10^{-8}	0.144	0.139	$\widehat{BG} = 2.2499 + 0.0235\text{SBP}$
7	DBP	1.39×10^{-7}	0.125	0.120	$\widehat{BG} = 3.2417 + 0.0255\text{DBP}$

References

1. Aguiar C, Duarte R, Carvalho D (2019) New approach to diabetes care: from blood glucose to cardiovascular disease. Portuguese J Cardiol 38(1):53–63 (2019). https://www.sciencedirect.com/science/article/pii/S2174204919300017
2. Banitalebi E, Kazemi A, Faramarzi M, Nasiri S, Haghighi MM (2019) Effects of sprint interval or combined aerobic and resistance training on myokines in overweight women with type 2 diabetes: a randomized controlled trial. Life Sci 217:101–109. https://doi.org/10.1016/j.lfs.2018.11.062
3. Malaysia Disease Control Division (2013) National diabetes registry report. Ministry of Health Malaysia (2013). https://www2.moh.gov.my/index.php/database_stores/attach_download/554/80
4. Burrin JM, Price CP (1985) Measurement of blood glucose. Ann Clin Biochem 22:237–342. https://pubmed.ncbi.nlm.nih.gov/3898972/
5. American Diabetes Association (2010) Diagnosis and classification of diabetes mellitus. Diab Care 33(1):S62–S69. https://care.diabetesjournals.org/content/33/Supplement_1/S62.full-text.pdf
6. American Diabetes Association (2020) Classification and diagnosis of diabetes: standards of medical care in diabetes-2020. Diab Care 43(1):S14–S31. https://care.diabetesjournals.org/content/43/Supplement_1/S14.full-text.pdf
7. Kavya ST, Nagaraja BS, Akila V, Mohan GC, Gowdaiah P (2014) Comparative study of glycosylated haemoglobin with blood glucose levels in the diagnosis of diabetes mellitus. J Evol Med Dent Sci 3(23):6435–6443. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7244899/
8. Kim MK, Jeong JS, Yun JS, Kwon HS, Baek KH, Song KH et al (2018) Hemoglobin glycation index predicts cardiovascular disease in people with type 2 diabetes mellitus: a 10-year longitudinal cohort study. J Diab Complications 32:906–910. http://doi.org/10.1016/j.jdiacomp.2018.08.007
9. Lee YH, Armstrong EJ, Kim G, Oh J, Kang SM, Lee BW et al (2015) Undiagnosed diabetes is prevalent in younger adults and associated with a higher risk cardiometabolic profile compared to diagnosed diabetes. Am Heart J 170(4):760–769. http://doi.org/10.1016/j.ahj.2015.07.024
10. Masanaria K, Yaswanth C, Mehmet K, Koichiro N, Ichiro H, Ana AH et al (2018) Fasting blood glucose is predictive of hypertension in a general Japanese population. J Hypertens 37(1):167–174. https://pubmed.ncbi.nlm.nih.gov/30507865/

11. Barkas F, Elisaf M, Liberopoulos E, Liamis G, Ntzani EE, Rizos EC (2019) Atherogenic dyslipidemia increases the risk of incident diabetes in statin–treated patients with impaired fasting glucose or obesity. J Cardiol 74(3):290–295. https://pubmed.ncbi.nlm.nih.gov/30910387/
12. Odum EP, Young EE (2018) Elevated cardiac troponin I, creatine kinase and myoglobin and their relationship with cardiovascular risk factors in patients with type 2 diabetes. Diab Metab Syndr Clin Res Rev 12:141–145. https://pubmed.ncbi.nlm.nih.gov/29254891/
13. Veghari G, Sedaghat M, Joshaghani H, Banihashem S, Moharloei P, Angizeh A et al (2014) The association of fasting blood glucose (FBG) and waist circumference in northern adults in Iran: a population based study. J Diab Metab Disord 13(2). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3937214/
14. Wu WC, Lin PC, Hung CC, Lin HH, Cheng CM, Lee CY et al (2015) Clinical risk factors of prediabetes in Taiwanese women without substance uses (tobacco, alcohol, or areca nut). J Formos Med Assoc 114:1233–1239. http://doi.org/10.1016/j.jfma.2014.10.007
15. Iacobini C, Pugliese G, Fantauzzi CB, Federici M, Menini S (2019) Metabolically healthy versus metabolically unhealthy obesity. Metab Clin Exp 92:51–60. https://pubmed.ncbi.nlm.nih.gov/30458177/
16. Li TC, Li CI, Liu CS, Lin WY, Lin CH, Yang SY et al (2018) Development and validation of prediction models for the risks of diabetes–related hospitalization and in-hospital mortality in patients with type 2 diabetes. Metab Clin Exp 85:38–47. http://doi.org/10.1016/j.metabol.2018.02.003
17. Han J, Rodriguze JC, Beheshti M (2008) Diabetes data analysis and prediction model discovery using RapidMiner. In: 2nd international conference on future generation communication and networking, Hainan Island. http://doi.org/10.1109/FGCN.2008.226
18. Lancaster GA, Dodd S, Williamson PR (2004) Design and analysis of pilot studies: recommendations for good practice. J Eval Clin Pract 10(2):307–312. https://pubmed.ncbi.nlm.nih.gov/15189396/
19. Li N, Tuo J, Wang Y, Wang M (2020) Prediction of blood glucose concentration for type 1 diabetes based on echo state networks embedded with incremental learning. Neurocomputing 378:248–259. https://doi.org/10.1016/j.neucom.2019.10.003
20. Pralle RS, Weigel KW, White HM (2018) Predicting blood β-hydroxybutyrate using milk Fourier transform infrared spectrum, milk composition, and producer–reported variables with multiple linear regression, partial least squares regression, and artificial neural network. J Dairy Sci 101:4378–4387. https://doi.org/10.3168/jds.2017-14076
21. Abdollahian M, Gunaratne N (2015) Low birth weight prediction based on maternal and fetal characteristics. In: 12th international conference on information technology: new generations, Las Vegas, NV, USA. https://www.researchgate.net/publication/282301969_Low_Birth_Weight_Prediction_Based_on_Maternal_and_Fetal_Characteristics
22. Swanson DA (2015) On the relationship among values of the same summary measure of error when used across multiple characteristics at the same point in time: an examination of MALPE and MAPE. Rev Econ Financ 5(1):14. http://www.bapress.ca/ref/ref-article/1923-7529-2015-03-01-14.pdf
23. United States, Department of Health and Human Services (2001) ATP III guidelines at-a-glance quick desk reference. National Institute of Health. https://www.nhlbi.nih.gov/files/docs/guidelines/atglance.pdf
24. Bhagani S, Kapil V, Lobo MD (2018) Hypertension. Medicine 46(9):509–515. https://doi.org/10.1016/j.mpmed.2018.06.009
25. Botet JP, Padial LR, Brotons C, Salán ME, Lerín AG, Pintó X et al (2018) Homogenization of the lipid profile values. Clin Investig Arterioscler 30(1):36–48. https://pubmed.ncbi.nlm.nih.gov/29274683/
26. Fernando E, Razak F, Lear SA, Anand SS (2015) Cardiovascular disease in South Asian migrants. Can J Cardiol 31:1139–1150. https://doi.org/10.1016/j.cjca.2015.06.008
27. Stein E, Kushner H, Gidding S, Falkner B (2007) Plasma lipid concentrations in nondiabetic African American adults: associations with insulin resistance and the metabolic syndrome. Metab Clin Exp 56:954–960. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1950893/

28. Yeboah J, Bertoni AG, Herrington DM, Post WS, Burke GL (2011) Impaired fasting glucose and the risk of incident diabetes mellitus and cardiovascular events in an adult population. J Am College Cardiol 58(2):140–146. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3146297/
29. Boullart ACI, Graaf JD, Stalenhoef AF (2012) Serum triglycerides and risk of cardiovascular disease. Biochim Biophys Acta 1821:867–875. https://pubmed.ncbi.nlm.nih.gov/22015388/
30. Lin D, Qi Y, Huang C, Wu M, Wang C, Li F et al (2018) Associations of lipid parameters with insulin resistance and diabetes: a population–based study. Clin Nutr 37:1423–1429. http://doi.org/10.1016/j.clnu.2017.06.018
31. Misra R, Patel T, Kotha P, Raji A, Ganda O, Banerji M et al (2010) Prevalence of diabetes, metabolic syndrome, and cardiovascular risk factors in US Asian Indians: results from a national study. J Diab Complications 24:145–153. http://doi.org/10.1016/j.jdiacomp.2009.01.003
32. Alwardata N, Renzo LD, Miranda RCD, Alwardat S, Salimei PS, Lorenzo AD (2018) Association between hypertension and metabolic disorders among elderly patients in North Jordan. Diab Metab Syndr 12:661–666. https://doi.org/10.1016/j.dsx.2018.04.011
33. He S, Wang S, Chen X, Jiang L, Peng Y, Li L et al (2012) Higher ratio of triglyceride to high–density lipoprotein cholesterol may predispose to diabetes mellitus: 15–year prospective study in a general population. Metab Clin Exp 61:30–36. https://pubmed.ncbi.nlm.nih.gov/21664631/
34. Rkhaya SA, Bulatova N, Kasabri V, Naffa R, Alquoqa R (2018) Increased malondialdehyde vs. reduced sirtuin 1 in relation with adiposity, atherogenicity and hematological indices in metabolic syndrome patients with and without prediabetes. Diab Metab Syndr Clin Res Rev 12:903–909. https://pubmed.ncbi.nlm.nih.gov/29779969/
35. Hassan AB, Salih SF, Hassan II, Saadi FS, Abdulah DM, Ahmed IH et al (2019) Circulating betatrophin in relation to metabolic, inflammatory parameters, and oxidative stress in patients with type 2 diabetes mellitus. Diab Metab Syndr Clin Res Rev 13:458–463. http://doi.org/10.1016/j.dsx.2018.11.016
36. Steyerberg EW (2019) Clinical prediction models a practical approach to development, validation and updating. http://doi.org/10.1007/978-3-030-16399-0
37. Yan K, Zhang D (2014) Blood glucose prediction by breath analysis system with feature selection and model fusion. In: 36th annual international conference of the IEEE engineering in medicine biology society. https://www.researchgate.net/publication/270658264_Blood_glucose_prediction_by_breath_analysis_system_with_feature_selection_and_model_fusion
38. Zeng Y, He H, Zhou J, Zhang M, Huang H, An Z (2020) The association and discordance between glycated hemoglobin A1c and glycated albumin, assessed using a blend of multiple linear regression and random forest regression. Clin Chim Acta 506:44–49. https://doi.org/10.1016/j.cca.2020.03.019
39. Lutfi MF, Elhakeem RF (2016) Effect of fasting blood glucose level on heart rate variability of healthy young adults. PLoS ONE 11(7):e0159820. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4956167/

Study on the Enhancement of Malaysian ICU Centre and Introduction of STAR Performance

Che Zafirah Rosly, Ummu Kulthum Jamaludin, Khalijah Khalid, Fatanah Suhaimi, Normy Norfiza Abdul Razak, Mohd Basri Mat Nor, and Azrina Md Ralib

Abstract Stress-induced hyperglycaemia commonly occurred in the ICU. It is known that the majority of the ICU centre in Malaysia is using intensive insulin therapy (IIT) protocol in order to control glucose level in critically ill patient blood within the targeted level to achieve required safety goals. However, alterations to the current practice needed to be considered to minimize the risk of hypoglycaemia and mortality while reducing the case of hyperglycaemia event. Therefore, the objective of this research paper is to weigh and evaluate the performance of a modern practice known as Stochastic Targeted (STAR) Protocol in managing blood glucose (BG) levels in Malaysia ICU cohort and to compare its performance between the three participating hospitals (HTAA, HUSM and PPUM) via MATLAB simulations. STAR is a tablet-computer based protocols that provide patient-specific glucose control framework accounting for patient variability with a stochastically derived maximum 5% risk of hypoglycaemia events. The in-silico trials were simulated with controlled goal feed (GF) and without GF. Only one type of nutrition is considered in this study, which is Glucerna. The results show that all three ICU centre with STAR simulation have a tight glycemic control with HTAA (83.6%), HUSM (76.8%) and PPUM (80.6%) in terms of BG within the targeted band of 4.0–10.0 mmol/L. Also, the median BG measurement level and insulin secretion shows decrease in percentage for all ICU cohort, HTAA (12.3%; 30.2%), HUSM (21.6%; 9.9%) and PPUM (17.9%; 13.3%). The insulin sensitivity (SI) of STAR simulations have a significant increase

C. Z. Rosly · U. K. Jamaludin (✉) · K. Khalid
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: ummu85@ump.edu.my

F. Suhaimi
Advanced Medical and Dental Institute, Universiti Sains Malaysia, 13200 Kepala Batas, Pulau Pinang, Malaysia

N. N. Abdul Razak
College of Engineering, Universiti Tenaga Nasional, Putrajaya Campus, 43000 Kajang, Selangor, Malaysia

M. B. Mat Nor · A. Md Ralib
Kuliyyah Medicine, International Islamic University Malaysia, 25200 Kuantan, Pahang, Malaysia

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when compared with IIT protocol, HTAA (26.1%), HUSM (33.3%) and PPUM (50%). The Kruskal-Wallis test was utilized to test the BG, SI and insulin secretion median. There are significant differences between IIT protocol and STAR simulations among the three cohorts ICU centre with p-value < 0.05.

Keywords Stochastic targeted · STAR · Stress induced hyperglycemia · Hypoglycaemia

1 Introduction

The Intensive Care Unit (ICU) is an exclusive department of the hospital that provides rehab and care to the critical patients. The first ICU ward in Malaysia was set up at the Pusat Perubatan Universiti Malaya (PPUM) or formerly known as Hospital University, Kuala Lumpur in 1969 [1]. During the last decade, the number of ICU wards increased and approaching the year of 2020, almost all government hospitals in Malaysia has its ICU centre. With the use of advanced technology medical devices and close monitoring from the highly specialized physicians, ICU provides continuous and specific care to rehabilitate critical patient based on their current conditions. Even though with a high quality of medical treatment, the ICU mortality rate can be considered high with approximately 20% of mortality cases reported worldwide.

In 2001, research from van den Berghe [2] initiates the role of intensive insulin therapy in controlling the patient glycaemic level and reducing ICU mortality rates. In recent years, many researchers referring to Berghe research as a fundamental study which they are focusing on improving the ICU patients' health and condition using the tight glycaemic control protocol and lowering the death rate in the ICU. A normal protocol written to control the ICU patients' BG level in the Malaysian ICU cohort is Intensive Insulin Therapy (IIT). IIT administered sliding scale practice in measuring the supply of insulin needed by the patients based on the current measured glucose content in the patients' blood sample drawn via finger prick [3]. This traditional protocol, which is a manually automated system, requires closed monitoring and frequent bedside treatment from the medical staffs. The practice of the sliding scale method indeed improving and maintaining the patient glucose level within a safety band, but the undesired event of mortality cases still occurs during the process. This method is conducted in hourly-basis and incapable of predicting the next hour BG level [4]. Therefore, it is indirectly creates clinical workload to the physicians to keep an eye and controlling patients' BG levels in the ICU setting. Thus, a BG performance simulation studies between three Malaysian ICU centre using clinically validated BG control protocol [5–8] known as STAR protocol have been conducted to analyze the suitability of the protocol with Malaysian ICU cohort.

2 Methods

2.1 Clinical Data Information

The clinical data recorded in the collected check sheet can be used in the simulation. The data needed to be extracted and screened before proceed with the simulation tests to ensure the effectiveness of the experiment. Patients' total length of stay in the ICU ward, demographics of every patients including their age, gender and weight, patients' comorbidity history; and patients' clinical data—insulin intake (U/h), BG measurement (mmol/L), enteral feeding type and feeding quantity (ml/h); are extracted data from the ICU check sheet.

2.2 Virtual Trial and Virtual Patient

The in-silico trial needs to be done first to avoid undesirable events occur during the pilot clinical trial and to ensure the safety of the ICU patient. The overall achievement of the in-silico experiment is compared with the initial results of clinical data obtained from the ICU check sheet of the selected hospitals to analyse the results and to observe the improvement in the improvised BG management by using STAR with controlled goal feed. The actual clinical data of Malaysian ICU cohort patient who underwent IIT protocol is needed to generate the virtual patient via ICING equation model. Hospital Tengku Ampuan Afzan (HTAA) have clinical data of 94 patients while Hospital Universiti Sains Malaysia (HUSM) and Pusat Perubatan Universiti Malaya have 55 and 60 patients respectively as shown in Table 1 who underwent IIT.

Enteral and parenteral nutrition are two types of nutrition that are given to the ICU patient and the parenteral nutrition is neglected in this experiment. The virtual patient simulation only considered Glucerna as the main enteral nutrition instead of giving many types of enteral nutrition (Jevity, Isosource and Novasource) as per current practice in the selected hospital. As per ESPEN [9] recommendation, the daily nutrition needed by the virtual subject is based on the specific goal feed, GF (kcal). Specific GF can be determined based on their body weight data. The use of the 25 kcal/kg/day for daily calorie intake for a virtual patient is adequate when indirect calorimetry is not available. For example, a 50 kg patient need to consume 1250 kcal in a day (i.e. 50 kg $\times$ 25 kcal/kg/day $=$ 1250 kcal/day). The glucose content in

Table 1 Patient demographics

	HTAA	HUSM	PPUM
Total patients	94	55	60
Weight, kg (mean)	67.8	67.9	74.0
Age (years—mean)	49.9	67.6	60.6
% Male	60.6	67.3	63.3

Glucerna is 0.0812 g/mL for each 1 kcal/mL. Thus, a 50 kg virtual patient requires approximately 4.23 g (or 101.5 g/day) of glucose in an hour which can be calculated as shown in Eq. (1).

$$\begin{aligned}\frac{1250\,\text{kcal/day}}{24\,\text{h/day}} \div (1\,\text{kcal/mL}) &= 52.08\,\text{mL/h} \times (0.0812\,\text{g/mL}) \\ &= 4.23\,\text{g/h of glucose} \end{aligned} \quad (1)$$

The extracted clinical data is filtered based on the patients' specific comorbidity history before converting all the data to the virtual patient simulation using Intensive Control Insulin-Nutrition-Glucose (ICING) modelling run by MATLAB software.

2.3 Physiological Modelling

Under a standard SOP from the selected hospital, a blood specimen drawn from an ICU patient can only measure their current BG level. A real-time modelling equation, the ICING model, doable to predict future patients' hourly insulin sensitivity, S_I, by simulating the patient current BG level data [10–12] which can reduce the medical staff workload. The model equations defined in Eqs. (2)–(8).

$$\dot{G} = -p_G G(t) - S_I(t)G(t)\frac{Q(t)}{1+\alpha_G Q(t)} + \frac{P(t) + EGP - CNS}{V_G} \quad (2)$$

$$\dot{Q} = n_I(I(t) - Q(t)) - n_C\frac{Q(t)}{1+\alpha_G Q(t)} \quad (3)$$

$$\begin{aligned}\dot{I} = &-n_K I(t) - n_L\frac{I(t)}{1+\alpha_I I(t)} - n_I(I(t) - Q(t)) + \frac{u_{ex}(t)}{V_I} \\ &+ (1 - x_L)\frac{u_{en}(t)}{V_I}\end{aligned} \quad (4)$$

$$\dot{P}_I = -d_1 P_1(t) + D(t) \quad (5)$$

$$\dot{P}_2 = -\min(d_2 P_2(t), P_{max}) + d_1 P_1(t) \quad (6)$$

$$P(t) = \min(d_2 P_2(t), P_{max}) + P_N(t) \quad (7)$$

$$u_{en}(t) = \min(\max(u_{min}, k_1 G(t) + k_2), u_{max}) \quad (8)$$

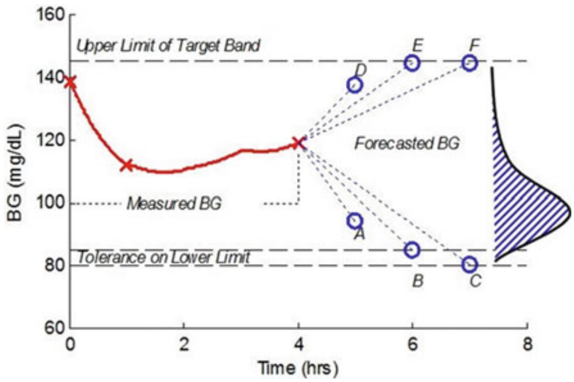

Fig. 1 The generated BG forecast (points A to F) within the target 5th–95th percentiles: 80–145 mg/dL (i.e. 4.44–8.0 mmol/L)

Above physiological model achieved low fitting and low prediction error based on prior studies [13–17] when the virtual clinical data inputs obtained from the actual patients fitted to the ICING model.

2.4 Stochastic Control Methods

The uncertainties of hypoglycaemia and hyperglycaemia cases (5% for BG < 4.44 mmol/L, ≈ 1% for BG < 4.0 mmol/L) can be minimized when using STAR protocol. This protocol uses stochastic forecasting that provides a control framework for future outcomes. As mentioned previously, ICING equation model used to simulate BG measurement from the clinical data to identify current S_I profile for the virtual patient. Then, the STAR protocol simulates the identified S_I profile to give an output of S_I values used for future forecasting. The predicted S_I is then simulated by ICING model to generate a safe range of BG results which give the most suitable therapy correlate with potential insulin rate and nutrition administration combinations. For every tolerable insulin rate, the BG outcomes are simulated between the 5th percentile (refer to Fig. 1, points A-C) and 95th percentile (refer to Fig. 1, points D-F). The outcomes of the simulation expected to stabilise clinical workload, nutrition rates, and BG variability.

2.5 Performance Metrics

There are four classes of range—hypoglycaemic (BG < 4.0 mmol/L), normal BG level (BG within 4.0–10.0 mmol/L) and hyperglycaemic (BG > 10.0 mmol/L). Every class has its respective treatment based on the patient conditions and comorbidities to stabilise patients' BG level. A high number of percentages in the normal range of BG levels and a decrease in the percentage of patients with severe hypo and hyperglycaemia when compared to the original clinical data from the ICU centre of selected hospital ensure patients' safety and proves STAR's performance. The reduced frequency of the blood specimens drawn from patients to measure their current BG levels in the patients' blood will decrease the bedside treatment as much as reduce medical staff labor. The less frequency of the blood sampling required, the better the performance of the STAR protocol.

3 Results and Discussion

3.1 Performance

Based on the insulin-glucose rates tabulated in Tables 3, 4 and 5, it shows that all HTAA, HUSM and PPUM data of STAR with controlled goal feed simulations offers tight control that stabilizes and control patient's BG level and at the same time helps to reduce hyperglycaemia incidence in the all participated ICU centre (HTAA decreases by 12.1%, HUSM decrease by 25% and PPUM decreases by 17.4%). The amount of exogenous insulin suggested to the critically ill patient by STAR simulation for all cohorts is higher when compared to the initial trial simulation for IIT, which provide an outcome of simulated BG between the 5th percentile and 95th percentile that leads to the increase of percentage of BG concentration within a safety range or percentage of desired glycaemic bands (4.00–10.0 mmol/L) with HTAA cohort increase by 9.6%, while HUSM and PPUM percentage increase by 22.4% and 15.1% respectively. This proves that STAR simulation provides an optimum amount of insulin needed by the patient. The right amount of insulin administrated to the critically ill patient maximize the capacity of glucose absorption from the bloodstream to their body effectively to achieve glucose homeostasis.

The introduction of controlled GF to the trial simulation shows an improvement for all cohorts. The amount the glucose content required by the patient and the patient's

Table 2 Nutrition information[a]

Nutrition	kcal/mL	Glucose content (g/mL)
Diabetic resource	1.06	0.0872
Glucerna	1.00	0.0812
Jevity	1.50	0.2020
IV	1.0	0.5000
Nepro	1.80	0.0863
Ensure	1.06	0.1370
Peptamen	1.00	0.0493
Diben	1.50	0.0800

[a]Full product information can be obtained from the Abbott and Nestle websites respectively

Table 3 HTAA BG performance

Whole cohort statistics	IIT	STAR	STAR Glu	STAR Glu GF
# of patients	94	94	94	94
Total hours	11,838	11,798	11,798	11,823
# of BG measurements	5608	7071	7235	6367
BG median	8.1	7.3	7.5	7.1
[IQR] (mmol/L)	[6.7–10.1]	[5.9–9.1]	[6.0–9.3]	[5.7–8.6]
Desired glycaemic bands				
% BG within 6.0–10.0 mmol/L	61.6	57.1	57.6	58.1
% BG within 4.0–5.9 mmol/L	12.4	23.4	21.8	25.5
Glycaemic bands				
% BG > 10.0 mmol/L	25.2	16.7	17.9	13.1
% BG < 4.0 mmol/L	1.1	2.7	2.6	3.3
# of patients < 2.2 mmol/L	1	8	8	8
Interventions				
Median insulin rate	1.5	4.5	5.0	4.5
[IQR] (U/h)	[1.0–3.0]	[2.0–8.0]	[2.0–8.0]	[2.0–7.5]
Median glucose rate	5.7	4.3	3.9	5.8
[IQR] (U/h)	[2.6–6.1]	[1.9–6.6]	[1.9–6.6]	[3.9–6.6]

body weight is the main factor in controlling every patient's goal feed. To ensure the ICU patients received the right amount of nutrition and to avoid the significant weight loss due to a deficient amount of nutrition given to the patient and excessive glucose content in the blood which will lead to hyperglycaemia, the GF is necessary to be determined before STAR is initiated (Tables 4 and 5).

3.2 Safety

The optimum amount of the insulin suggested by the STAR simulation which successfully decreases the cases of stress-induced hyperglycaemia in the virtual patient affect the virtual patients who initially have low BG level. Prior study [6–8] proven that ≈1% of hypoglycaemia case reported when STAR is introduced and there are three patients (≈3%) will be experiencing hypoglycaemia. Malaysian ICU cohort have higher chances of getting hypoglycaemia and hyperglycaemia when compared to the other countries that used STAR [8, 15] because of the level of comorbidities and different type nutrition given to the Malaysian patients. From the table above, all the ICU centres show slightly increased in the number of percentage of hypoglycaemia cases (BG < 4.00 mmol/L) with HTAA increase by 2.2%, HUSM increase by 2.8% and PPUM increase by 2.3%. While the case of severe hypoglycaemic

Table 4 HUSM BG performance

Whole cohort statistics	IIT	STAR	STAR Glu	STAR Glu GF
# of patients	55	55	55	55
Total hours	9884	9848	9847	9868
# of BG measurements	3113	6739	7123	5809
BG median	9.7	7.3	8.4	7.6
[IQR] (mmol/L)	[7.8–11.9]	[5.7–9.5]	[6.5–10.5]	[6.0–9.4]
Desired glycaemic bands				
% BG within 6.0–10.0 mmol/L	48.4	52.1	53.6	57.2
% BG within 4.0–5.9 mmol/L	6.0	24.9	16.6	19.6
Glycaemic bands				
% BG > 10.0 mmol/L	44.4	18.6	27.2	19.0
% BG < 4.0 mmol/L	1.2	4.4	2.7	4.0
# of patients < 2.2 mmol/L	6	17	14	15
Interventions				
Median insulin rate	0.0	4.0	6.0	5.5
[IQR] (U/h)	[0.0–2.0]	[1.0–8.0]	[2.5–8.0]	[2.0–8.0]
Median glucose rate	4.1	1.9	1.9	4.6
[IQR] (U/h)	[0.0–7.9]	[0.0–5.2]	[0.0–3.9]	[2.6–6.6]

Table 5 PPUM BG performance

Whole cohort statistics	IIT	STAR	STAR Glu	STAR Glu GF
# of patients	60	60	60	60
Total hours	7360	7336	7330	7337
# of BG measurements	2954	4801	5026	4162
BG median	8.9	7.7	8.2	7.3
[IQR] (mmol/L)	[7.3–10.9]	[6.2–9.5]	[6.5–9.8]	[5.9–8.9]
Desired glycaemic bands				
% BG within 6.0–10.0 mmol/L	57.5	59.8	60.0	58.7
% BG within 4.0–5.9 mmol/L	8.0	18.3	15.0	21.9
Glycaemic bands				
% BG > 10.0 mmol/L	33.2	18.6	22.6	15.8
% BG < 4.0 mmol/L	1.3	3.4	2.4	3.6
# of patients < 2.2 mmol/L	3	6	6	6
Interventions				
Median insulin rate	2.0	5.5	6.0	5.0
[IQR] (U/h)	[1.0–2.0]	[2.0–8.0]	[3.0–8.0]	[2.0–8.0]
Median glucose rate	4.8	3.9	2.6	4.9
[IQR] (U/h)	[1.6–7.3]	[1.9–5.8]	[1.9–4.9]	[3.6–6.6]

(BG < 2.2 mmol/L) for all HTAA, HUSM and PPUM increases by 8%, 12% and 5% respectively when compared with the IIT simulations. This might be due to the comorbidity history of the patient itself.

In the real application of STAR, there are several options of insulin rate available to be chosen by the user as a 1–3 h treatment given to the patient based on the patients' current BG level. Every option is specifically calculated based on patients' weight and comorbidity. The glucose rate options will be automatically matched with the optimum glucose rate to avoid any excess or insufficient intake of glucose. The prior pilot studies on the STAR implementation in several hospitals in Christchurch, NZ and Gyula, Hungary indicate low mortality rate of 6.4% (Christchurch) and 0% (Gyula) [8, 13]. Thus, it is believed that this outcome proves that STAR is effectively safe to be implemented in the Malaysian ICU cohort as it can reduce the risk of mortality significantly but need to be further investigate the relationship of other factor.

3.3 Clinical Effort

Tables 1, 2 and 3 shows a slightly decreasing number of total hours by almost 0.3%, but the STAR simulation also resulted in an increasing number of BG measurement by 13.5% for HTAA and 40.8% for PPUM. HUSM shows a significant increase in BG measurement (86.6%).

As mentioned earlier, the specific comorbidity history of patient which is not taken into account while running the simulations might be one of the reasons why the STAR simulations unable to improve nurses clinical workload. It is believed that the use of only one type of nutrition—Glucerna, will decrease the nurse workload. To tolerate with the patient's comorbidities in order to minimize the risk, Malaysian ICU cohort using different types of nutrition because each type of nutrition is formulated based on the targeted group. For example, a patient with acute kidney injury (AKI) required only 1.4–1.8 g/kg/day [18] of protein intake.

3.4 Kruskal-Wallis Test

Kruskal-Wallis test was conducted to examine the differences on BG measurements within the targeted band (4.0–10.0 mmol/L), insulin sensitivity, SI, and insulin secretion, U according to the given protocol mentioned above. There are statistically significant differences were found among the three cohorts (HTAA, HUSM and PPUM) as per shown in Table 6.

Table 6 Kruskal-Wallis test, *P*-value

Cohort centre	Blood glucose, BG	Insulin sensitivity, SI	Insulin secretion, U
HTAA	1.62e−11	2.40e−03	7.42e−05
HUSM	1.41e−15	2.43e−06	3.19e−02
PPUM	8.92e−15	3.91e−08	4.70e−03

4 Conclusion

The performance of STAR shows a significant reduction of the stress-induced hyperglycaemia cases for all HTAA, HUSM and PPUM cohorts. This all related to the increasing number of percentage of desired BG level band (4.0–10.0 mmol/L). There is also a slight improvement in total hours that nurses needed for the bedside treatment. However, the total BG level measurements are increased which also increases the frequency of nurses workload. The STAR simulation protocol also has increased the hypoglycaemia cases for all cohorts. The patient details of comorbidities and demographics such as the patient races, gender and location might be the factors that arise in the hospital, which are not taken into account in the study and that might affect the outcomes of the study. Thus, a larger cohort which considered every demographic and comorbidity aspect should be considered in the future study to validate the results obtained in this study.

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References

1. Ling TL et al (2017) Malaysian registry of intensive care 2016 report, pp 1–52
2. van den Berghe G et al (2001) Intensive insulin therapy in critically ill patients. N Engl J Med 345(19):9
3. Programme A, Malaysia KK, M.S.o.I. Care (2012) Management protocol in ICU. In: ICU management protocol no. 10. Blood glucose management in the intensive care unit: insulin infusion protocol. Kementerian Kesihatan Malaysia, Malaysia, p 73
4. Jamaludin UK et al (2018) Performance of stochastic targeted blood glucose control protocol by virtual trials in the Malaysian intensive care unit. Comput Methods Programs Biomed 162:149–155
5. Evans A et al (2011) Pilot proof of concept clinical trials of stochastic targeted (STAR) glycemic control. Ann Intensive Care 1:38
6. Penning S et al (2012) Second pilot trials of the STAR-Liege protocol for tight glycemic control in critically ill patients. Biomed Eng Online 11:58
7. Penning S et al (2012) First pilot trial of the STAR-Liege protocol for tight glycemic control in critically ill patients. Comput Methods Programs Biomed 108(2):844–859
8. Stewart KW et al (2016) Safety, efficacy and clinical generalization of the STAR protocol: a retrospective analysis. Ann Intensive Care 6(1):24

9. Kreymann KG et al (2006) ESPEN guidelines on enteral nutrition: intensive care. Clin Nutr 25(2):210–223
10. Chase JG et al (2011) Tight glycemic control in critical care—the leading role of insulin sensitivity and patient variability: a review and model-based analysis. Comput Methods Programs Biomed 102(2):156–171
11. Dickson J et al (2015) Evaluation of a plasma insulin model for glycaemic control in intensive care. In: 2015 37th annual international conference of the IEEE engineering in medicine and biology society, pp 4009–4012
12. Lin J et al (2011) A physiological intensive control insulin-nutrition-glucose (ICING) model validated in critically ill patients. Comput Methods Programs Biomed 102(2):192–205
13. Chase JG et al (2009) A glucose-insulin pharmacodynamic surface modeling validation and comparison of metabolic system models. Biomed Signal Process Control 4(4)
14. Griesdale DEG (2017) Intensive insulin therapy and mortality among critically ill patients: a meta-analysis including NICE-SUGAR study data. Can Med Assoc J 180(8):7
15. Thomas F et al (2014) Reducing the impact of insulin sensitivity variability on glycemic outcomes using separate stochastic models within the STAR glycaemic protocol. Biomed Eng Online 13:43
16. Fisk L et al (2012) Development and pilot trial results of stochastic targeted (STAR) glycemic control in a medical ICU. In: International federation of automatic control
17. Luqman HM et al (2016) Performance of blood glucose management protocols in HTAA intensive care unit. In: 2016 IEEE international conference on automatic control and intelligent systems, Shah Alam, Malaysia
18. Cano N et al (2006) ESPEN guidelines on enteral nutrition: adult renal failure. Clin Nutr 25(2):295–310

Modeling of Soft Tissue Deformation Using Mass Spring Method with Nonlinear Volume Force

Mohd Nadzeri Omar, Nasrul Hadi Johari, Mohd Hasnun Arif Hassan, and Mohd Amzar Azizan

Abstract Soft tissues displayed two phases of deformation, linear behavior during small deformation and nonlinear behavior during large deformation. Mass Spring Method (MSM) is one of the preferred methods for simulating soft tissue deformations. MSM-based models provide simpler calculations that allow real-time interaction. However, only a small number of MSM models are capable of simulating two phases of soft tissue deformation. This study introduces a new approach to modeling the deformation. The conventional MSM model, which is governed by Hooke's law, is coupled with the nonlinear volume force defined using the conical spring methodology. The nonlinear volume force is triggered by a change in volume in the structure of the MSM model. With the implementation, at small deformation where volume change is also small, only the Hooke's law equation is activated resulting in linear deformation. Whereas, during large deformation, nonlinear deformation occurs as a result of a large change in the MSM volume. Analyzes conducted show that the proposed model can simulate the two phases of deformation. The proposed model can also control each phase independently, which shows that it has a high degree of flexibility on modeling various of soft tissue deformation.

Keywords Nonlinear volume force · Mass spring method (MSM) · Nonlinear deformation · Soft tissue simulation

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M. N. Omar (✉) · N. H. Johari · M. H. A. Hassan
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: nadzeri@ump.edu.my

N. H. Johari
e-mail: nhadi@ump.edu.my

M. H. A. Hassan
e-mail: mhasnun@ump.edu.my

M. A. Azizan
UniKL MIAT, 43900 Sepang, Selangor, Malaysia
e-mail: mohdamzar@unikl.edu.my

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1 Introduction

MSM models have been commonly used to simulate deformation of soft materials. The MSM models are founded on discrete mechanics that discretized an object into several mass points connected by springs. The construction of the MSM models is easy and efficient to minimize computational time and has therefore been applied to numerous applications, including cloths [1], animations [2] and soft tissues [3] modeling.

However, traditionally, the MSM models can only simulate linear deformation. It is therefore very limited to model accurately soft tissue deformation, which is considered to have two phases of deformation that are linear behavior during small deformation and nonlinear behavior during large deformation [4]. Despite this, its advantages in computational time and cost encourage researchers to improvise the available MSM models.

There are several studies available in the literature that concentrate on improving MSM models, in particular on simulating nonlinear deformation. Most of the studies used quadratic function for either the load-displacement relation [5–7] or the spring reaction force [8]. Several disadvantages to this approach include the fact that nonlinearity is limited to quadratic behavior and limited to a function that may converge to linear at a small deformation.

Alternatively, San-Vicente et al. [9] and Golec et al. [10] are recorded to use combination of linear springs to form nonlinear response. San-Vicente used three linear springs; edge, diagonal and inter-diagonal springs to form a cubical structure that resembles a hexahedral element. Each spring has it owns stiffness value and behaves differently during loading, thus providing a nonlinear response. Shah and Gupta [11] also used the same approach, but they substituted the inter-diagonal springs with a cubical spring constant. The single cubical structure is then pieced up together to form any shape. A nonlinear deformation was observed but it requires high optimization process as more than one spring is used and related to each other.

Another group of researchers were reported using piecewise approach [12, 13]. The piecewise approach requires a deformation data in advance, often in the form of load-displacement curve. The load-displacement curve is then divided into several sections connected through transition points. Each phase has its individual formulation. In Basafa and Farahmand [13], the load-displacement curve is divided into two regions; the toe and linear region respectively. The toe region is guided by a third polynomial function while a linear function is used for the second region. Perhaps, this approach is the closest one that consider different phases of the soft tissue deformation. However, it has several limitations such as difficulty in defining the transition points and to find the third polynomial function that can describe linear response at small deformation. On the other hand, [14] and [15] used the combination of linear functions to describe nonlinear deformation. Their approach relies on the location and the amount of transition points. It can be seen clearly in [14] where more transition points lead to a smoother nonlinearity in comparison to [15].

Recently, Omar et al. [3] has been reported for modeling a nonlinear MSM model using conical spring methodology. The advantage of the conical spring, where different stiffness can be achieved at different displacements, generates variation in spring resistance during the deformation leading to a nonlinear response. It was observed that different nonlinear deformations can be simulated by adjusting the conical springs parameters. However, the model cannot be used for soft tissues with a longer linear region due to the stiffness variance.

In this paper, we improvised our initial model [3] to simulate the two phases of soft tissue deformation by integrating the conventional Hooke's law model with a nonlinear volume force governed by the conical spring methodology. During small deformation, where volume changes are small, the Hooke's law relation is dominant, resulting in linear deformation. Meanwhile, for large deformations, where volume changes are significant, greater resistance is introduced for the MSM model leading to nonlinear deformation.

2 Methods

2.1 Spring Force

According to Hooke's Law, the resistance force of the spring between two nodes i and j when subjected to an external force can be described as

$$\boldsymbol{f}_{ij}^{spring} = k_s\left(\left|\boldsymbol{x}_{ij}\right| - l_{ij}\right)\frac{x_{ij}}{\left|x_{ij}\right|} \tag{1}$$

where k_s is the stiffness of the spring connected the two nodes, $\boldsymbol{x}_{ij}$ represents the distance between the two nodes with $\left|\boldsymbol{x}_{ij}\right|$ gives the current length of the spring and l_{ij} represents the original length of the spring.

2.2 Damping Force

Damping force is introduced to the model to dissipate energy during deformation. The damping force is described as

$$\boldsymbol{f}_{ij}^{damping} = k_d(\boldsymbol{v}_{ij}) \tag{2}$$

where k_d is the damping coefficient and $\boldsymbol{v}_{ij}$ is the velocity difference between the two nodes.

The damping force and the spring force are combined in the form of Maxwell viscoelastic model leading to the following spring damper force $\boldsymbol{f}_{ij}^{sd}$

$$\boldsymbol{f}_{ij}^{sd} = \boldsymbol{f}_{ij}^{spring} + \boldsymbol{f}_{ij}^{damping} \tag{3}$$

Therefore, the spring damper force acting on node i is

$$\boldsymbol{F}_i^{sd} = \sum_{j=j_1}^{j_q} \boldsymbol{f}_{ij}^{sd} \tag{4}$$

where $j_1, \ldots, j_q$ are nodes with which node i is connected via springs.

2.3 Nonlinear Volume Force

The volume force is introduced in the MSM model at each node which is generated through to the change in volume of the element containing the node. The volume force is acted towards the barycenter of the element.

2.3.1 Element Type

In this study, tetrahedral element was used due to its accuracy in modeling soft tissues [16]. The nodes in the MSM are connected to each other via springs in the form of regular tetrahedral structure. Hence, volume of a tetrahedral element q can be calculated using.

$$V_q = \frac{e^3}{6\sqrt{2}} \tag{5}$$

where e is the length of the tetrahedral edge.

Meanwhile, the barycenter of tetrahedral element q is defined as follows

$$p_q = \frac{1}{4} \sum_{\forall k \in T_q : k=1}^{4} \alpha_k \tag{6}$$

where α_k is the vertices of the tetrahedral.

2.3.2 Conical Spring Methodology

Conical spring methodology adopts the fundamental determination of the cylindrical spring force described by Wahl [17] which discretized the cylindrical spring into several elementary parts and the stiffness of the spring is determined based on the distance of the active elementary part to the center of the spring which is described by its radius. Since the radius of the cylindrical spring is equivalent entirely, all the elementary parts have the same stiffness property.

On the other hand, due to conical structure, each elementary part in conical spring has a different radius leading to variation in stiffness. The variation in the stiffness induces nonlinearity in the conical spring. As mentioned in [3], the variation in stiffness can be manipulated to simulate any type of soft tissue deformation. The geometrical parameters of conical springs are as illustrated in Fig. 1.

According to Rodriguez et al. [18], conical spring force $\boldsymbol{P}(\delta)$ can be calculated based on the axial deflection δ using the following equations

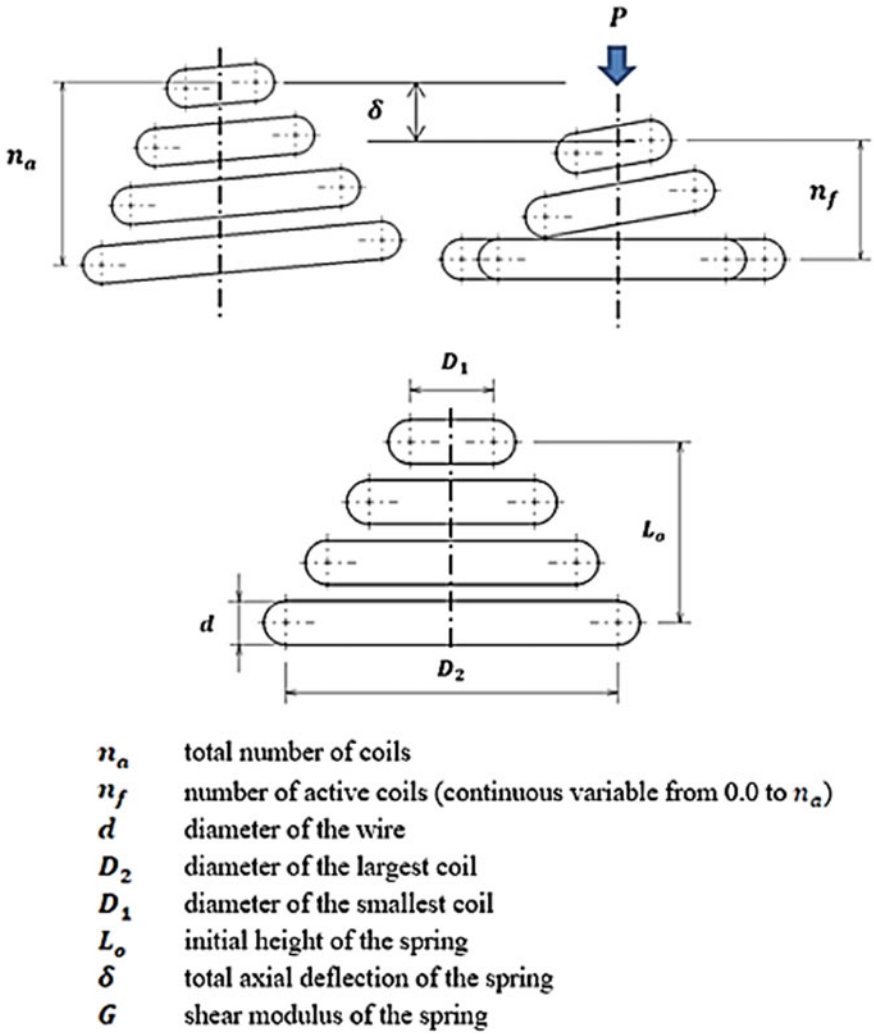

Fig. 1 Geometrical parameters of conical spring [3]

$$\boldsymbol{P}(\delta) = (K_1/2)^{\frac{3}{2}} \left[1 - \left(1 - 2\left[1 - \left(1 + \frac{K_2}{K_1^2} \right)^{\frac{1}{2}} \right] \right)^{\frac{1}{2}} \right]^3 \tag{7}$$

where

$$K_1 = K_3 - \frac{K_2}{3K_3} \tag{8}$$

$$K_2 = -\frac{K_6}{K_5} \tag{9}$$

$$K_3 = \left[\frac{K_4}{16} + [(K_4/16)^2 + (K_2/3)^3]^{\frac{1}{2}} \right]^{\frac{1}{3}} \tag{10}$$

$$K_4 = \left[\frac{(K_7 + \delta)}{K_5} \right]^2 \tag{11}$$

$$K_5 = -\frac{\left(2D_1^4 n\right)}{\left[Gd^4(D_2 - D_1)\right]} \tag{12}$$

$$K_6 = (L_0)\frac{D_2}{(D_2 - D_1)} \tag{13}$$

2.4 Nonlinear Volume Force

The nonlinear volume force is generated using Eq. (7), where the axial deflection δ is substituted with the change in volume of the active tetrahedrons. The volume force equation acting on a node i towards the barycenter is given as

$$\boldsymbol{F}_{ij}^{volume} = \sum_{\forall q \in \Omega_i}^{4} P_{\left(V_q^{cur} - V_q^{ori}\right)} \frac{x_{ij} - p_q}{\left|x_{ij} - p_q\right|} \tag{14}$$

where Ω_i represent all tetrahedrons containing node i, V_q^{cur} and V_q^{ori} are the current and original volume of tetrahedral q respectively, p_q is the barycenter of tetrahedral q defined in Eq. (6).

2.5 Propagation Method

In order to eliminate the super-elastic effect that may occur from linear spring force, the resulting force is propagated to the neighboring nodes using a fixed propagation approach called Breadth First propagation. An arbitrary value is used to define the propagation threshold. The subject node is at Level 0 and nodes connected to it are at Level 1. The sequence continues until the propagation threshold is reached. Nodes at each level are processed individually and constraint is placed to prevent repetitive processes.

2.6 Numerical Integration

Dynamic equation acting on node i can be written as

$$m_i \boldsymbol{a}_i = \boldsymbol{F}_i^{resultant} \tag{15}$$

where m_i is mass and a_i is acceleration at node i respectively. The resultant force at node i, $\boldsymbol{F}_i^{resultant}$ is the summation of the spring damper, volume and external forces

$$\boldsymbol{F}_i^{resultant} = \boldsymbol{F}_{ij}^{sd} + \boldsymbol{F}_{ij}^{volume} + \boldsymbol{F}_i^{external} \tag{16}$$

The dynamic equation is solved using explicit Euler method as reported in Huangfu [19] given as

$$\boldsymbol{v}_i(t + \Delta t) = \boldsymbol{v}_i(t) + \Delta t \frac{\boldsymbol{F}_i^{resultant}(t)}{m_i} \tag{17}$$

$$\boldsymbol{x}_i(t + \Delta t) = \boldsymbol{x}_i(t) + \Delta t \cdot \boldsymbol{v}_i(t + \Delta t) \tag{18}$$

2.7 Computational Algorithm

The computational algorithm to develop the proposed model is given in the following Fig. 2.

MSM with nonlinear volume force

Input: Model parameters
Set propagation threshold
For $t = 0$ to Stop **do**
$t = t + \Delta t$
get the external force
calculate the resultant force
$\boldsymbol{v}_i = \boldsymbol{v}_i(t) + \Delta t \cdot \boldsymbol{F}_i^{resultant}(t)/m_i$
$\boldsymbol{x}_i = \boldsymbol{x}_i(t) + \Delta t \cdot \boldsymbol{v}_i(t + \Delta t)$
For $k = 1$ to Propagation Threshold **do**
determine resultant force on nodes in the k-neighbour
$\boldsymbol{v}_j = \boldsymbol{v}_j(t) + \Delta t \cdot \boldsymbol{F}_j^{resultant}(t)/m_j$
$\boldsymbol{x}_j = \boldsymbol{x}_j(t) + \Delta t \cdot \boldsymbol{v}_j(t + \Delta t)$
propagate the force to the next adjacent nodes
Loop
Update nodes position
Loop
End

Fig. 2 Algorithm for the MSM model with nonlinear volume force

2.8 Model Generation

A cubical MSM model with 1331 nodes was generated. These nodes are connected to each other by springs in the form of tetrahedral element with distance between each node was 1 unit (see Fig. 3). For each spring, the stiffness k_s and damping coefficient k_d were 5 and 10 units respectively. Mass for each node was 1 unit while the time step was set as 0.02 s. The arbitrary value for the propagation threshold was set to 5 layers.

3 Analysis and Discussion

The MSM model as defined in the Methodology section was developed and several analyzes were carried out to investigate the performance of the proposed approach with regard to the following measures: (i) the volume force-displacement relationship; (ii) the load-displacement relationship; and (iii) computational performance.

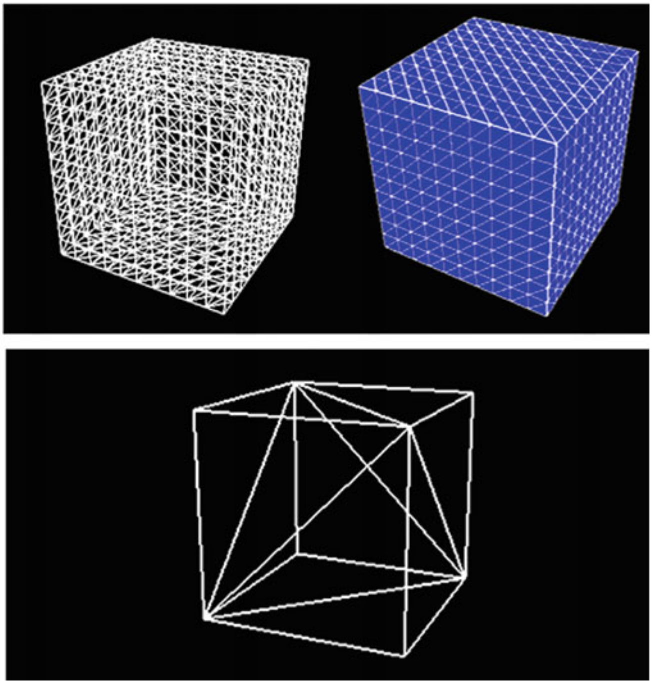

Fig. 3 Image of the MSM model. **a** The MSM model consisting of 1331 nodes, and **b** Image of the spring connections in the form of tetrahedral element where combinations of four tetrahedrons forms a hexahedral structure

3.1 Relationship of the Volume Force and Displacement

In this analysis, four sets of conical spring parameters were used as presented in Table 1. A node located on top surface of the MSM model was subjected to a compression load acting in the normal direction. During the loading process, the volume force acting on the subjected node was recorded with respect to its displacement. It was observed in Fig. 4, all models display the same relationship behaviors where volume forces increased linearly during small displacements and growth nonlinearly

Table 1 Parameters of conical spring used to generate the nonlinear volume force in the MSM model

Parameters	G	D1	D2	d	n	L_0
Set 1	100,000	0.3	1.4	0.1	5	0.5
Set 2	100,000	0.3	1.4	0.1	5	0.6
Set 3	100,000	0.3	1.4	0.1	5	0.8
Set 4	100,000	0.3	1.4	0.1	5	1.0

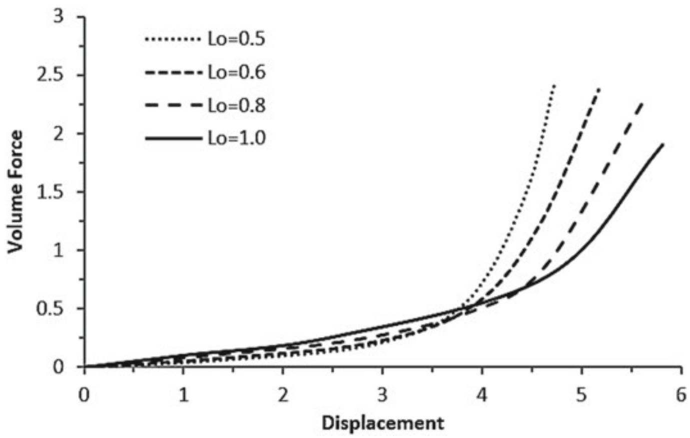

Fig. 4 The relationship between normalize volume force and displacement at the subjected node with different L_0 values

when the node was pushed farther away from its original position. The observations matched the behavior of conical spring where it had linear response at small displacements and changed to nonlinear response at large displacements [3, 18]. Figure 4 suggests that the implementation of the conical spring methodology to produce nonlinear volume force in MSM model has been successful.

In addition, Fig. 4 shows that the nonlinearity of the volume force is getting lighter with longer L_0 values. As described in methodology section, nonlinearity in the conical spring is induced by variation in the spring radius. Longer L_0 allows the active radius to be affected over a longer period of time, thus reducing the stiffness variation leading to a lighter nonlinearity. Further increasing the L_0 value may result in linear relations.

3.2 Relationship of the Applied Load and Displacement

In order to observe the effect of the volume force on the overall model deformation, the relationship between the applied load and the displacement of the subject node was recorded for all the sets listed in Table 1. It can be seen in Fig. 5 nonlinear deformation is plotted which the type of nonlinear deformation shown has a small toe region similar to the Type I soft tissue deformation behavior [20]. The nonlinearity of the deformation is stronger for models with a shorter L_0. The observations suited the relationship in Fig. 4 which suggests that the overall deformation was affected by the volume force. The nonlinearity of the volume force induced a nonlinear deformation in the MSM model.

The load-displacement behavior of the MSM model with and without the force of volume was compared as shown in Fig. 6. It can be seen that both models developed

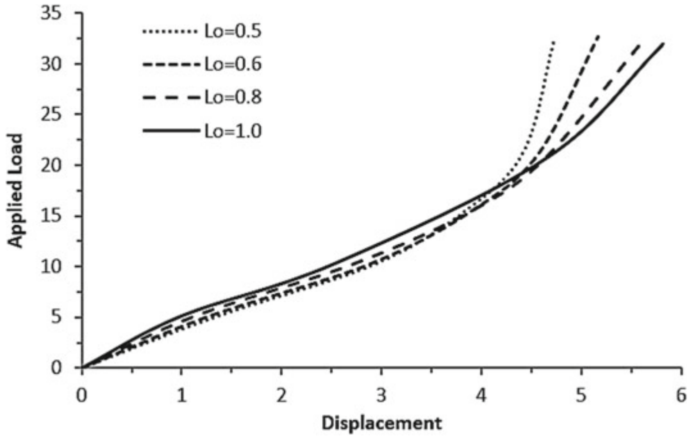

Fig. 5 The relationship between normalize applied load and displacement at the subjected node for models in Table 1

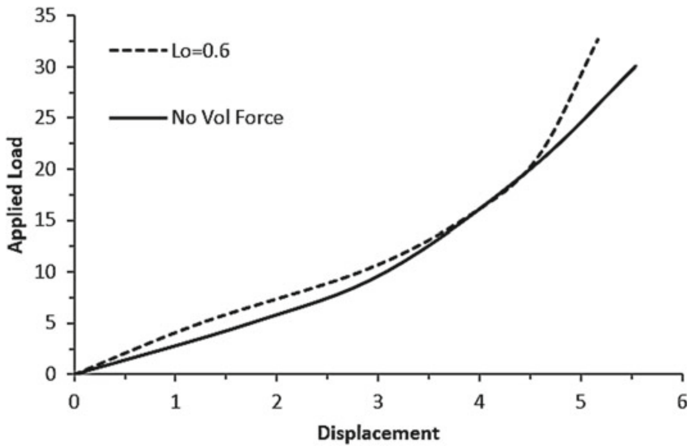

Fig. 6 Load–displacement behavior for the MSM model with and without the nonlinear volume force. The model with volume force is generated using parameters in set 2 (see Table 1). For both models, the spring stiffness $k_s = 5$

similar behavior during the small deformation. At this point, the change in volume is small and not significant, therefore linear deformation is plotted. Nonlinear deformation occurs at a point where volume variations are high enough to become dominant. In Fig. 6, it occurred around 4 units of displacement, which explains the model being stiffer, thus more load is needed to displace the node. It was also observed in Fig. 7, by reducing the spring stiffness, which decreases the resistance force during a small deformation, a smaller resistance force was measured and the volume force becomes dominant at approximately one displacement unit earlier. In addition, as the spring

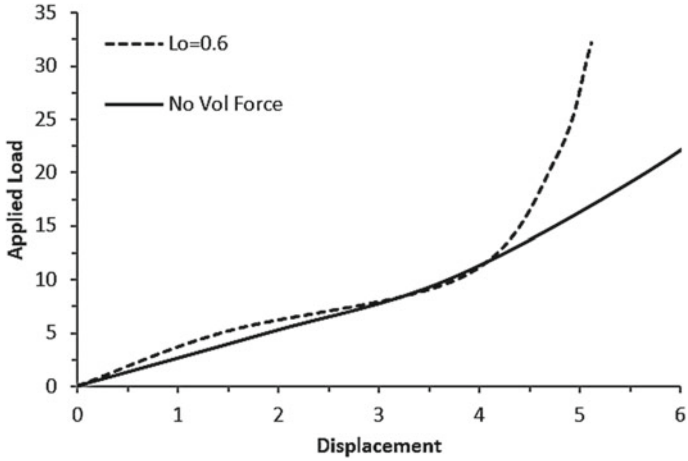

Fig. 7 Load-displacement behavior for the MSM model with and without the nonlinear volume force. The model with volume force is generated using parameters in set 2 (see Table 1). For both models, the spring stiffness $k_s = 2$

stiffness is reduced, the nonlinearity of the MSM model is stronger matching the Type II soft tissue deformation [20].

3.3 Image of the MSM Model During Deformation

Figure 8 compares the images of the MSM model with and without volume force during deformation. The color contour describes the magnitude of the deformation. It is observed, the model with volume force has a smaller deformation. It is due to the additional resistance generated by the volume force.

Moreover, the deformation of the MSM model with volume force is more realistic. It can be seen, around the deformation area, the nodes are displaced upwards, opposite to the direction of the applied load. It creates a bumpy like appearance as illustrated in Fig. 8. The generated behavior matches soft tissue behavior and it is caused by the direction of the volume force which is acted towards the barycenter of the element. However, unrealistic deformation as shown in Fig. 9 can occur if excessive volume force is used. Appropriate selection and optimization of parameters are therefore necessary.

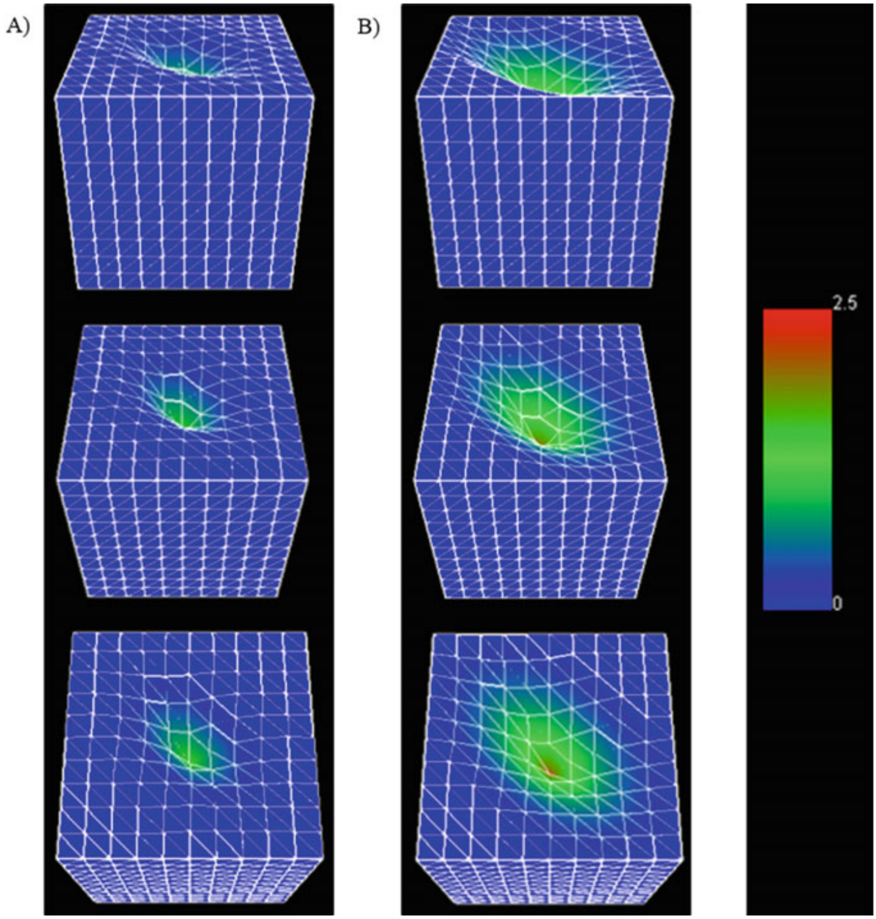

Fig. 8 Images of the MSM model during deformation. **a** The MSM model with the nonlinear volume force and **b** the MSM model without the nonlinear volume force

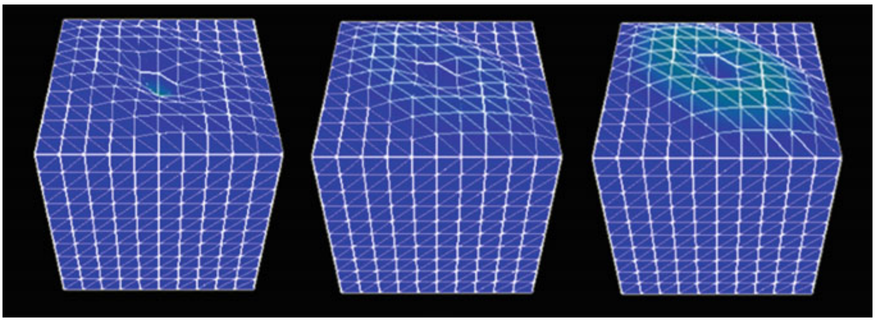

Fig. 9 Images of the MSM model with excessive nonlinear volume force which lead to an unrealistic deformation

3.4 Computational Performance

The computational performance of the proposed model was evaluated in terms of time taken to solve dynamic equations and to update the new position for each node. The simulation was run using Windows 7 based personal computer (Processor: Intel(R) Core (TM) 2 Duo 2.26 GHz, RAM: 3.00 GB, Display Adapter: ATI Mobility Radeon HD 3400 Series) without parallel computation. For a simple cubic model consisting of 1331 nodes, the computational time of the proposed model is approximately 10.6 ms. As seen in the Fig. 10, the computational time is proportional to the number of nodes involved during the deformation.

MSM-based modeling approaches are well-known to be superior in terms of computational performance. One of its disadvantages, however, is the modeling of the two deformation phases. The proposed model capable of generating two phases of deformation and comparing it to the linear volume force model proposed by Huangfu [19], as shown in Table 2, the measurement time difference is less than 2 ms. It demonstrates that the proposed model is capable of generating the two deformation phases without a substantial increase in computational time. Despite that, the computational time can be further improved with more core processors and parallel computations.

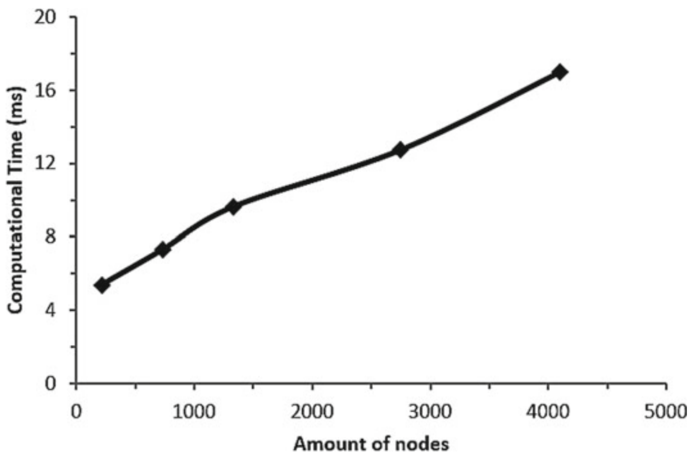

Fig. 10 The computational time of the proposed model at different amount of nodes

Table 2 Comparison of the computational time for the proposed MSM model and the MSM model with linear volume force

MSM model	Number of nodes	Computational time (ms)
With nonlinear volume force	1331	10.1
With linear volume force [19]	1331	8.9

4 Conclusion

This paper proposes a solution for the MSM model to simulate two phases of soft tissue deformation. The two phases of soft tissue deformation consist of a linear behavior during a small deformation and a nonlinear behavior during a large deformation. The proposed model integrates the traditional Hooke's law model with the nonlinear volume force derived from the conical spring methodology. The nonlinear volume force is triggered by changes in the volume of the tetrahedral elements in the MSM model. During a small deformation, where the volume changes are small, the Hooke's law, which derives the spring force, is dominant, leading to a linear response. Meanwhile, when there is a large deformation, volume changes are also large, contributing to a higher volume force. As a consequence, nonlinear deformation occurs. Based on the analyses, it was found that the proposed model was capable of producing the two phases of soft tissue deformation. It was accomplished without a significant increase in computation time. On top of that, a more realistic deformation was also obtained. Future works, such as validation with real soft tissues and parameter optimization, are needed to evaluate the reliability of the proposed model.

References

1. Mozafary V, Payvandy P (2017) A novel method based on loop shape for simulating knitted fabric using mass spring model. Fibers Polym 18:533–541
2. Kot M, Nagahashi H (2017) Mass spring models with adjustable Poisson's ratio. Vis Comput 33:283–291
3. Omar N, Zhong Y, Jazar RN, Subic A, Smith J, Shirinzadeh B (2015) Soft tissue modelling with conical springs. Bio-Med Mater Eng 26(s1):S207–S214
4. Fung YC (2011) Biomechanics: mechanical properties of living tissues. Springer, New York
5. Cooper L, Maddock S (1997) Preventing collapse within mass-spring-damper models of deformable objects. In: 5th international conference, Centre Europe, vol 2, pp 196–204
6. Cui T, Song A, Wu J (2009) Simulation of a mass-spring model for global deformation. Front Electr Electron Eng China 4:78–82
7. Luo Q, Xiao J (2007) Contact and deformation modeling for interactive environments. IEEE Trans Robot 23:416–430
8. Teschner M, Girod S, Girod B (2000) Direct computation of nonlinear soft-tissue deformation. Vis Model Vis 22–24
9. San-Vicente G, Aguinaga I, Celigueta JT (2012) Cubical mass-spring model design based on a tensile deformation test and nonlinear material model. IEEE Trans Visual Comput Graphics 18(2):228–241
10. Golec K, Palierne JF, Zara F, Nicolle S, Damiand G (2019) Hybrid 3D mass-spring system for simulation of isotropic materials with any Poisson's ratio. Vis Comput 36:809–825
11. Shah R, Gupta A (2013) Non-linear cubic spring-mesh model for simulating biological tissues. Bio-Med Eng Sci 51:U–12
12. Cai Y, Chen L, Yu W, Zhou J, Wan F, Suh M, Kay Chow DH (2018) A piecewise mass-spring-damper model of the human breast. J Biomech 67:137–143
13. Basafa E, Farahmand F (2010) Real-time simulation of the nonlinear viscoelastic deformations of soft tissues. Int J Comput Assist Radiol Surg 6(3):297–307
14. García M, Gómez M, Ruiz O, Boulanger P (2007) Spring–particle model for hyperelastic cloth. Modelo Resorte-Particula Para Telas Hiperelasticas. Dyna 74:137–145

15. Keeve E, Girod S, Kikinis R, Girod B (1998) Deformable modeling of facial tissue for craniofacial surgery simulation. Comput Aided Surg 3(5):228–238
16. Meier U, López O, Monserrat C, Juan MC, Alcañiz M (2005) Real-time deformable models for surgery simulation: a survey. Comput Methods Programs Biomed 77(3):183–197
17. Wahl AM (1963) Mechanical springs. McGraw-Hill, New York
18. Rodriguez E, Paredes M, Sartor M (2006) Analytical behavior law for a constant pitch conical compression spring. J Mech Des 128(6):1352–1356
19. Huangfu Z (2013) An improved mass-spring model for simulation of soft tissue deformation. J Inf Comput Sci 10(17):5551–5558
20. Ahmadian MT, Nikooyan AA (2006) Modeling and prediction of soft tissue directional stiffness using in-vitro force. Int J Sci Res 16:385–389

Chaotic Map Initializations with Tiki-Taka Algorithm for Software Remodularization Problem

Kamal Z. Zamli and Md. Abdul Kader

Abstract Software system is often a dynamic entity. During its lifecycle, software system often evolves to reflect the bug fixes and upgrades as well as the addition/removal of features from its users. As the evolution process takes place, the modularization becomes complex and gradually loose its quality. Addressing this issue, this paper evaluates the performance of automated software remodularization using the newly developed Tiki-Taka Algorithm (TTA) and its variants with four chaotic map initializations based on Chebyshev map, Circle map, Logistic Map and Piecewise Map. Remodularization results of 3 selected case studies (i.e., Printer Manager, IOT controller, and Layer Monitor) demonstrate that TTA with Chebyshev map gives the best overall performance over other initializations including the pseudo-random initialization within the original TTA.

Keywords Tiki-Taka algorithm · Software remodularization · Chaotic maps

1 Introduction

Software module clustering involves partitioning the software system into a set of clusters (or packages) in order to achieve high cohesion and low coupling of its implemented modules. Often, software module clustering facilitates software comprehension, evolution, and maintenance [1, 2]. In fact, evidence shows that modularized software could lead to better development and maintenance process [3].

As a subset of software module clustering, software remodularisation involves modifying the existing set of clusters (i.e., its partitions) to accommodate the evolution of the software system of interests. Termed Search-based Software Engineering problem; many researches are undertaken in the literature to adopt suitable metaheuristic algorithms for solving software remodularization problem. For a complete review of the literature, interested readers are referred to the recent survey in [4].

K. Z. Zamli (✉) · Md. Abdul Kader
Faculty of Computing, College of Computing and Applied Sciences, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: kamalz@ump.edu.my

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Mancoridis and Mitchell exploit Hill Climbing (HC) based on a tool called Bunch [5]. In a similar manner, Hill Climbing has also been implemented by Mahdavi et al. [6]. Kumari and Srivinas [7] and Ahmed et al. [8] adopts the hyper-heuristic algorithm for the same purpose. Praditwong et al. [9] has adopted the Pareto optimality concept to established the multi-objective approach for software module clustering. Using the same approach, Huang et al. [10] have introduces a multi-agent evolutionary algorithm. More recently, Zamli et al. [11] exploits Fuzzy Adaptive Teaching Learning based Optimization with adaptive selection of search operators to ensure optimal exploration.

As the software remodularization problem is *NP* hard, the adoption of newly developed meta-heuristic algorithms is most welcomed. In line with the *No Free Lunch theorem* [12], there is no single meta-heuristic algorithm that can outperform all others in different optimization problem (e.g. [13–19]). Supporting this prospect, this paper explores the newly developed Tiki-Taka Algorithm (TTA) and its variants with four chaotic map initializations based on Chebyshev Map, Circle Map, Logistic Map and Piecewise Map for software remodularization problem.

The remaining part of the paper is organized as follows. Section 2 describes the software remodularization problem. Section 3 presents an overview of TTA. Section 4 highlights the TTA algorithm with its chaotic map initialization variants. Section 5 presents our benchmark comparison between different variants of TTA. Finally, Sect. 6 presents the concluding remarks.

2 Software Remodularization Problem

Software remodularization problem relates to the problem of modifying the existing clusters (of partitioned modules) in order to enhance its coupling and cohesion of modules. Here, In general, a software system is defined as a Module Dependency Graph (MDG) [5]. The total weight of external edges (i.e., all leaving or entering a cluster partition termed as *inter-edges*) represents the coupling of a cluster. Meanwhile, the total of the internal edges (i.e., all including the source and target modules termed as *intra-edges*) represents the cohesion. Mitchell and Mancoridis [5] and Praditwong et al. [9] define the Modularization Quality (*MQ*) measure as the total of the ratio of each cluster edges (i.e., intra-edges and inter-edges) by combining coupling and cohesion, called Modularization Factor (MF_k) for cluster *k*. MF_k can be formally defined as in Eq. 1:

$$MF_k = \begin{cases} 0 & if\ \ i = 0 \\ \frac{i}{i+\frac{1}{2}j} & if\ i > 0 \end{cases} \tag{1}$$

where *i* and *j* represent the weight of intra-edges and inter-edges, respectively. The term $\frac{1}{2}j$ is to divide the inter-edges' penalty between the two clusters that are connected by that edge. The *MQ* is the sum of MF_k as in Eq. 2:

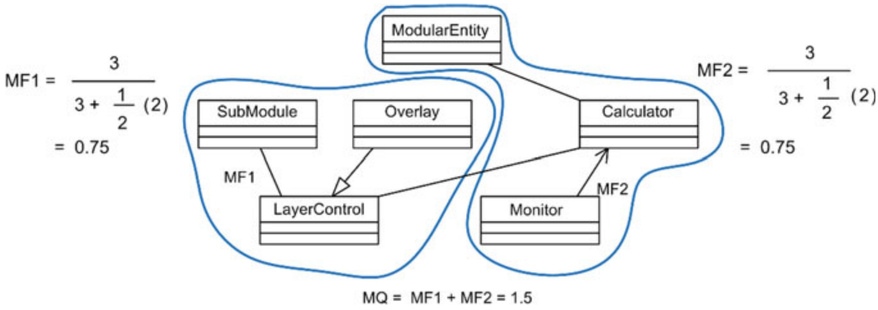

Fig. 1 Sample MQ calculation [11]

$$MQ = \sum_{k=1}^{n} MF_k \tag{2}$$

where n represents the number of clusters.

Figure 1 highlights the modularization quality (MQ) calculation of two cluster modules (i.e., referred to as MF1 and MF2) of a class diagram. In this case, the class relationship is considered bidirectional (i.e., source $\leftrightharpoons$ destination) when no navigation is specified. The class diagram shown in Fig. 1 has a minimum of 1 possible cluster and a maximum of 6 possible clusters. To maximize the MQ, the goal is to find the clusters from 2 to 5.

3 Overview of Tiki-Taka Algorithm

Tiki-Taka Algorithm (TTA) is a sport-inspired metaheuristic algorithm that mimics the playing style of Spanish football game [20]. More precisely, TTA is characterized by short passing and with small movement of players in order to maintain possession. As such, TTA exploits a set of key players to control the ball's possession using tactical superiority and fluidity to defeat the opponents as envisioned by Johan Cruyff and promoted by Pep Guardiola. Following this style, the Spanish national team and Barcelona football club won many trophies from 2008 to 2012.

TTA is divided into three phases: initialization (i.e., the initial position of players and its parameters), update ball, and player position (i.e., positions of key players are updated based on their fitness level).

3.1 Initialization

A football team with n players with their initial positions in d dimensions (bounded) is considered in this phase with the defined lower bound (LB) and upper bound (UB). Concurrently, n_{k} denotes the key players (i.e., 10% of the total players or a minimum of 3 players). The position of the ball and players are stored in the matrix B and P, respectively. The initial position of players is generated randomly based on Eq. 3.

$$p_i = LB + rand()*(UB - LB) \tag{3}$$

A key players (n_{k}) archive h updates the current position of key players in each iteration. Initially, B is equivalent to P. Equations 4 and 5 highlight the respective matrix.

$$B = \begin{bmatrix} b_{1,1} & \cdots & b_{1,d} \\ \vdots & \ddots & \vdots \\ b_{n,1} & \cdots & b_{n,d} \end{bmatrix} \tag{4}$$

$$P = \begin{bmatrix} p_{1,1} & \cdots & p_{1,d} \\ \vdots & \ddots & \vdots \\ p_{n,1} & \cdots & p_{n,d} \end{bmatrix} \tag{5}$$

3.2 Update Ball Position

The short passing concept of the tiki-taka style is used to update the ball position in this phase. Among all passes, 10–30% (i.e., ranges from 0.1 to 0.3) passes are considered the unsuccessful passes represented by a probability parameter, φ. The ball position is updated according to Eq. 6.

$$b_i^{'} = \begin{cases} rand(b_i - b_{i+1}) + b_i, \; r_p > \varphi \\ b_i - (c_1 + rand)(b_i - b_{i+1}), r_p \leq \varphi \end{cases} \tag{6}$$

where, r_p is a uniformly distributed random number. $r_p > \varphi$ signifies the successful pass (i.e., exploitation) and $r_p \leq \varphi$ denotes the unsuccessful pass (i.e., exploration). Coefficient c_1 represents the influence of ball reflection magnitude in the unsuccessful pass that ranges from 0.5 to 1.5. b_i, b_{i+1} and $b_i^{'}$ represent the ith, $(i+1)$th, and updated ith ball position. If $b_{i+1} = b_n$ then $b_{i+1} = b_1$.

3.3 Update Player Position

The positions of the ball and key player are considered in TTA to update the current player position. Equation 7 is used to evaluate the new position of ith player.

$$p_i^{'} = p_i + rand() * c_2 * \left(b_i^{'} - p_i\right) + rand() * c_3 * (h - p_i) \tag{7}$$

where, the coefficients c_2 and c_3 balance the new position of ith player between the ball and the key player, respectively. c_2 ranges from 1.0 to 2.5 and c_3 ranges from 0.5 to 1.5. Simultaneously, the key player position is updated.

4 Tiki-Taka Algorithm Initialization with Chaotic Maps

To date, mathematicians and physicians have found several chaotic maps. As discussed in Sect. 1, four chaotic maps are adopted for the current work. Specifically, these maps are being used as to initialize the initial populations for the TTA.

4.1 Chebyshev Map

Chebyshev map [21] is represented by the following iterative function:

$$\mathcal{X}_{n+1} = \cos\left(n \cos^{-1}(\mathcal{X}_n)\right) \tag{8}$$

where n denotes the iteration number.

4.2 Circle Map

The Circle map [22] can be represented as an iterative function as follows:

$$\mathcal{X}_{n+1} = \mathcal{X}_n + b - (a - 2\pi)\sin(2\pi\mathcal{X}_n) mod(1) \tag{9}$$

where, a chaotic time series $\mathcal{X}_n \in [0,\ 1]$ are generated using a = 0.5 and b = 0.2.

4.3 Logistic Map

The following iterative function defines the logistic map [23]:

$$\mathcal{X}_{n+1} = r\mathcal{X}_n(1 - \mathcal{X}_n) \tag{10}$$

where, $\mathcal{X}_n \in [0,\ 1]$ and r is a parameter. Iterated Logistic map with $r = 4$ signifies that the time series $\mathcal{X}_n \in [0,\ 1]$ are chaotic.

4.4 Piecewise Map

Piecewise map [24] consists of four linear pieces that are determined by the following iterated function:

$$\mathcal{X}_{n+1} = \begin{cases} \frac{\mathcal{X}_n}{d}, & 0 \le \mathcal{X}_n < d \\ \frac{\mathcal{X}_n - d}{0.5 - d}, & d \le \mathcal{X}_n < 0.5 \\ \frac{1 - d - \mathcal{X}_n}{0.5 - d}, & 0.5 \le \mathcal{X}_n < 1 - d \\ \frac{1 - \mathcal{X}_n}{d}, & 1 - d \le \mathcal{X}_n < 1 \end{cases} \tag{11}$$

where, $d \in [0,\ 0,\ 5]$ and $\mathcal{X}_n \in [0,\ 1]$.

Given the defined chaotic maps, four variants of TTA algorithms are generated. The main differences between the variants are the random initialization of the population. Instead of just using pseudo random values, the random generator *rand*() in Eq. 3 is replaced with the respective chaotic map generators ($\mathcal{X}_{n+1}$) from Chebyshev Map, Circle Map, Logistic Map and Piecewise Map as shown in Eq. 11.

$$p_i = LB + \mathcal{X}_{n+1} * (UB - LB) \tag{12}$$

The complete flow chart of TTA is shown in Fig. 2.

5 Benchmarking Case Studies and Evaluation

Our benchmarking experiments focus on characterizing the performances of TTA against its four other variants namely TTA with Chebyshev Map (TTA-ChM), TTA with Circle Map (TTA-CM), TTA with Logistic Map (TTA-LM) and TTA with Piecewise Map (TTA-PM). Based on the suggested values by the original author [20], we have adopted the parameter values of $c_1 = 1.5, c_2 = 2.5, c_3 = 1.0, \varphi = 0.2$, with population size = 30, and maximum iteration = 5,000. In this experiment, a PC is used that configured with Windows 10, CPU 2.9 GHz Intel Core i5, 16 GB 1867 MHz DDR3 RAM and a 512 MB of flash HDD. To ensure statistical significance, we have executed all the TTA variants 20 times in all the experiments. The best and mean MQ for each experiment are listed side-by-side. The best mean values are marked in bold font.

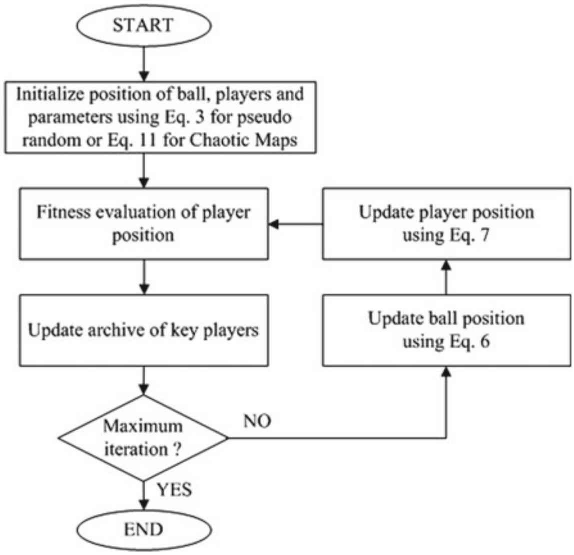

Fig. 2 Flowchart of Tiki-Taka algorithm and its variants

We opt to select 3 remodularization case studies form our earlier work in [11]. Case study 1 studies the printer manager software originally with 9 modules. In this case, the printer manager software is updated with 2 new modules (i.e., Database and Security). Case study 2 relates to IOT controller also originally with 9 modules. Here, the IOT controller software is updated with 1 new module (i.e., Timer). Finally, Case study 3 deals with layer monitor originally with 6 modules. The layer monitor is updated with 3 new modules (i.e., Interface, MainSet, and DB). These case studies along with their evolution are summarized in Fig. 3 while the MQ results and their means from each variant are summarized in Table 1.

Referring to Fig. 3, we can conclude that any addition of new modules can affect the modularity of the whole software system. The whole remodularization process do help to achieve better modularization quality (MQ). In fact, not all cluster changes as some clusters (or software packages) can still remain intact (see Case Study 2 involving IOT controller).

Concerning Table 1, a number of subtle observations can be discussed further. Firstly, all TTA variants are able to achieve the best MQ at least once. Secondly, all the TTA implementations with chaotic map outperformed the original TTA. As TTA is a population-based algorithm, each individual population agent represents a unique starting point in the search space allowing an improved the general exploration of the algorithm. Finally, in terms of individual ranking, TTA-ChM with Chebyshev Map initialization has outperformed all other TTA variants. The best mean values are marked in bold font in Table 1. Putting TTA-ChM aside, TTA-CM with Circle Map initialization and TTA-LM with Logistic Map initialization are the runner up sharing one best mean each. TTA-PM with Piecewise Map initialization comes in the third whilst the original TTA in the last position.

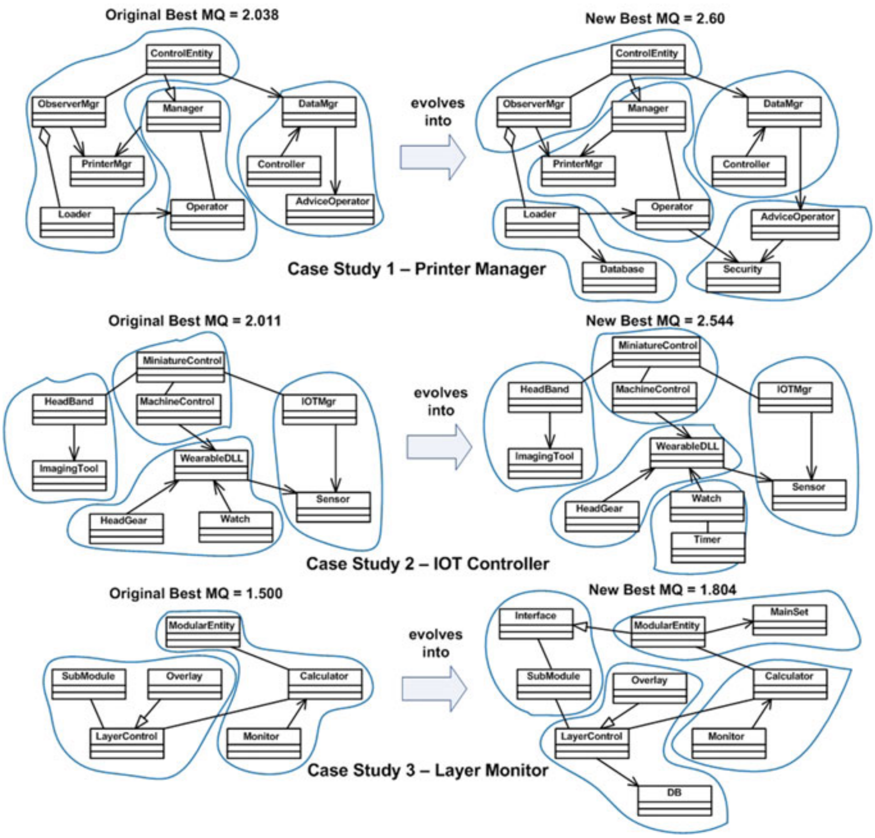

Fig. 3 Software systems case studies and their evolution

Table 1 Comparative MQ performance of between variants of TTA

	Printer manager		IOT controller		Layer monitor	
TTA variants	Best	Mean	Best	Mean	Best	Mean
TTA	2.60	2.293	2.544	2.412	1.804	**1.804**
TTA-ChM	2.60	**2.471**	2.544	**2.478**	1.804	**1.804**
TTA-CM	2.60	2.432	2.544	2.389	1.804	**1.804**
TTA-LM	2.60	2.371	2.544	2.460	1.804	**1.804**
TTA-PM	2.60	2.301	2.544	2.460	1.804	**1.804**

6 Conclusion

The effectiveness of adopting chaotic as part of population initialization for TTA algorithm has demonstrated in this paper. As the scope of future work, we are investigating the adoption of TTA with chaotic map initializations for other optimization problems particularly on software product line test suite generation and wireless sensor network localization.

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References

1. Lucca GAD, Fasolino AR, Pace F, Tramontana P, Carlini UD (2002) Comprehending web applications by a clustering-based approach. In: 10th international workshop on program comprehension, Paris, France. IEEE, pp 261–270 (2002)
2. Jahnke JH (2004) Reverse engineering software architecture using rough clusters. In: IEEE annual meeting of the fuzzy information processing, Alberta, Canada, 27–30 June 2004, pp 4–9
3. Sommerville I (2015) Software engineering, 10th edn. Pearson, Harlow, England (2015)
4. Alsarhan Q, Ahmed BS, Bures M, Zamli KZ (2020) Software module clustering: An in-depth literature analysis. IEEE Trans Softw Eng, 1–33 (2020). https://doi.org/10.1109/TSE.2020.3042553
5. Mitchell BS, Mancoridis S (2006) On the automatic modularization of software systems using the bunch tool. IEEE Trans Software Eng 32(3):193–208. https://doi.org/10.1109/TSE.2006.31
6. Mahdavi K, Harman M, Hierons RM (2003) A multiple hill climbing approach to software module clustering. In: International conference on software maintenance, Amsterdam, The Netherlands, 22–26 Sept 2003, pp 315–324
7. Kumari AC, Srinivas K (2016) Hyper-heuristic approach for multi-objective software module clustering. J Syst Softw. https://doi.org/10.1016/j.jss.2016.04.007
8. Ahmed BS, Enoiu E, Afzal W, Zamli KZ (2020) An evaluation of monte carlo-based hyper-heuristic for interaction testing of industrial embedded software applications. Soft Comput 24(18):13929–13954. https://doi.org/10.1007/s00500-020-04769-z
9. Praditwong K, Harman M, Yao X (2011) Software module clustering as a multi-objective search problem. IEEE Trans Software Eng 37(2):264–282. https://doi.org/10.1109/TSE.2010.26
10. Huang J, Liu J, Yao X (2017) A multi-agent evolutionary algorithm for software module clustering problems. Soft Comput 21(12):3415–3428. https://doi.org/10.1007/s00500-015-2018-5
11. Zamli KZ, Din F, Ramli N, Ahmed BS (2019) Software module clustering based on the fuzzy adaptive teaching learning based optimization algorithm. In: Intelligent and Interactive Computing. Springer, pp 167–177 (2019)
12. Wolpert DH, Macready WG (1997) No free lunch theorems for optimization. IEEE Trans Evol Comput 1(1):67–82. https://doi.org/10.1109/4235.585893
13. Alsewari ARA, Zamli KZ (2012) A harmony search based pairwise sampling strategy for combinatorial testing. Int J Phys Sci 7(7):1062–1072. https://doi.org/10.5897/IJPS11.1633

14. Nasser AB, Zamli KZ, Alsewari ARA, Ahmed BS (2018) Hybrid flower pollination algorithm strategies for t-way test suite generation. PLoS ONE 13(5):1–24. https://doi.org/10.1371/journal.pone.0195187
15. Othman RR, Zamli KZ (2011) ITTDG: integrated t-way test data generation strategy for interaction testing. Sci Res Essays 6(17):3638–3648. https://doi.org/10.5897/SRE10.1196
16. Younis MI, Zamli KZ, Isa NAM (2008) MIPOG-modification of the IPOG strategy for t-way software testing. In: distributed frameworks and applications, Penang, Malaysia, pp 1–6. IEEE (2008)
17. Younis MI, Zamli KZ, Isa NAM (2008) Algebraic strategy to generate pairwise test set for prime number parameters and variables. In: International symposium on information technology, Kuala Lumpur, Malaysia 26–28 Aug 2008. IEEE, pp 1–4 (2008)
18. Zamli KZ, Din F, Kendall G, Ahmed BS (2017) An experimental study of hyper-heuristic selection and acceptance mechanism for combinatorial t-way test suite generation. Inf Sci 399:121–153. https://doi.org/10.1016/j.ins.2017.03.007
19. Zamli KZ, Din F, Ahmed BS, Bures M (2018) A hybrid Q-learning sine-cosine-based strategy for addressing the combinatorial test suite minimization problem. PLoS ONE 13(5):1–29. https://doi.org/10.1371/journal.pone.0195675
20. Ab. Rashid MFF (2020) Tiki-taka algorithm: A novel metaheuristic inspired by football playing style. Eng Comput, 1–31 (2020). https://doi.org/10.1108/ec-03-2020-0137
21. Tavazoei MS, Haeri M (2007) Comparison of different one-dimensional maps as chaotic search pattern in chaos optimization algorithms. Appl Math Comput 187(2):1076–1085. https://doi.org/10.1016/j.amc.2006.09.087
22. Hilborn RC (2000) Chaos and nonlinear dynamics: an introduction for scientists and engineers. Oxford University Press on Demand
23. Feldman DP (2012) Chaos and fractals: an elementary introduction. Oxford University Press
24. Tomida AG (2008) Matlab toolbox and GUI for analyzing one-dimensional chaotic maps. In: 2008 International conference on computational sciences and its applications, 30 June–3 July 2008, pp 321–330

Development of Real-Time Emotion Recognition System Based on Machine Learning Algorithm

Mohd Amzar Azizan, Muhammad Ismail Al Fatih, Alya Nabila, Nurhakimah Norhashim, and Mohd Nadzeri Omar

Abstract Human behavior and emotion are two important elements that correlate with each other. Data from road safety research showed that driving impairment caused by unstable emotion may lead to road accidents and cause injury. This research aims to investigate the driver's emotion while driving and relates with the driving comfort and safety. Therefore, a device called Emotion Recognition Action Savvy (ERAS) has been invented. By measuring the eyes aspect ratio and developing the algorithm for face recognition, this smart device can detect human emotion while driving. The system is connected to the car Global Positioning System (GPS) and detects the face for every 20-min. The system also provides a connection to interactive mediums such as music apps and navigation. A front camera is installed at the driver seat to monitor the face changes and provide variable suggestion solutions on a screen. Drivers are free to choose the solutions based on their emotion at that particular time. The smart system aims to improve the interaction between cars and humans, reduce accidents risk to emotion driving, save lives and enhance road safety.

Keywords Emotion · Machine learning · Recognition

M. A. Azizan (✉) · M. I. Al Fatih · A. Nabila · N. Norhashim
Aero-Ergonomics Research Cluster, Universiti Kuala Lumpur—Malaysian Institute of Aviation Technology, Sepang, Selangor, Malaysia
e-mail: mohdamzar@unikl.edu.my

M. I. Al Fatih
e-mail: ismail.fuad@s.unikl.edu.my

A. Nabila
e-mail: alya.hisham22@s.unikl.edu.my

N. Norhashim
e-mail: nurhakimah@unikl.edu.my

M. N. Omar
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: nadzeri@ump.edu.my

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1 Introduction

Recently, there has been a growing interest in developing human-car interaction. Previous studies have shown that emotion has a high influence on human awareness and safety. Emotions are the intense feelings that control the atmosphere and play an important role in daily life for decision-making, thinking, concentration, inspiration, understanding, awareness, preparation, comprehension and reasoning which contributes to the identification of emotions for areas of study. Emotion recognition can be translated by text, auditory, visual, and facial expressions [1]. Another researcher defines emotions as states of consciousness characterized by strong cerebral action and a solid strength of enjoyment or disapproval. Humans channel their emotional state across several lines: facial expression, voice and body gestures [2]. The awareness of drunk driving has always been raised but not for the emotion. Driving while experiencing strong emotions can increase the risk of car accidents. According to new studies by the Transportation Institutes of Virginia Tech, emotional driving—activity of a car while clearly sad, frustrated, or irritated—raises the accident risk almost tenfold.

The study suggests that impaired driving can increase the chances of a car crashing by doubling, as well as emotional driving. However, the study reveals that drivers participating in behaviors can distract focus about half the time [3]. Emotional considerations are important when driving a car to improve protection and comfort and a car also needs to recognize the driver's emotion. The goal is to help the driver with primary, secondary, and tertiary driving tasks (activities) in car emotion remembered. The primary driving tasks include turning, accelerating, braking, and selection of the correct lane, direction, route, and distance for other cars. The secondary driving tasks are related to protection tasks such as dimming, running windscreen wiper systems, entering, changing gears and blinking, while tertiary driving tasks related to air conditioning, seat heating and so on [4].

In 2019, based on the statistics, up to 94% of car crashes in the US were caused by driver negligence, weakened fatigue and distracted drivers. The driving safety experts have gathered crash collection data from more than 3,500 vehicles over a three-year period to help better explain the causes of these kinds of crashes. Researchers have recorded over 1,600 incidents of seriousness ranging from mild accidents—such as touching a curb to serious legal enforcement accidents. Out of 1,600 accidents, 905 were reported for serious enough to lead an accident or collateral harm and about 90% were clearly classified by the researchers as driver error, disability, fatigue, and distraction [5].

Another factor could be from the view of human factors that contribute to road accidents. Human factors can be physical drivers, cognitive, and emotional characteristics that can contribute to driving patterns. Characteristics can be classified as fatigue, motivation, attitude, traits, and emotional state need to emphasize the reason a driver needs to have a good mood or emotion while driving as it can lead to possible accidents and that can harm people [6]. Bad emotions can have a significant effect on driving ability and can result in crashes or traffic fatalities. Emotional state can be anger, aggressive, fatigue, drowsiness, stress, nervous, confused, lack focused and sad. All these emotions can affect driving behavior, influence the driver's mind and probably cause accidents. According to previous research, driver confusion may also decrease decision making ability [7].

2 Methodology

2.1 *Development of Facial Recognition System*

In order to identify human emotion, a facial recognition algorithm has been developed that is able to detect sad, happy and angry emotion as shown in Fig. 1. Facial features are one of the best solutions for identification of human emotion. However, during the early stage of processing, the prior solution is only to crop the area of both eyes but, the motion recognition accuracy decreases [8].

Meanwhile, Haar-Cascades is added to improve the accuracy of identification by adding variables to be calculated in the detection for mouth features. Object detection with the Haar-Cascade-based Functions is an efficient object detection approach. It is a system based on machine learning that trains a cascade function from several positive and negative images. The objects in other images are then identified [9]. Detecting faces is the first stage of detecting human emotion based on facial expression. Then, the system must be able to detect the emotion of the detected faces. Different algorithm is used which is Facial Action Coding System (FACS) to evaluate facial expressions. More sophisticated approaches have been proposed in recent years with the aid of computers, and features are seen in Fig. 2 [10].

For data collection, variable methods are available and in this research, 200 JPEG formatted images files are used. Basically, there is no limitation for sizes of the

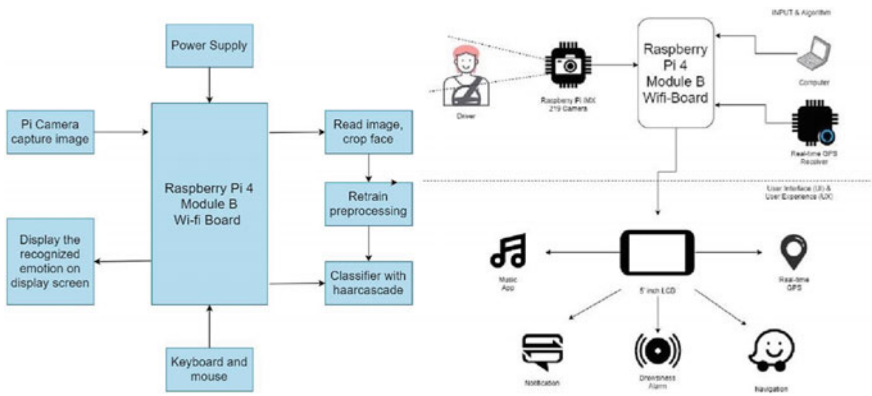


Fig. 1 Block diagram of the project component and integration system between driver and car

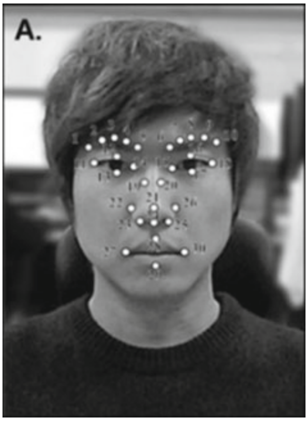


Fig. 2 Facial analysis point used for determining emotion through facial expression

image to be used but indirectly affect the accuracy of the recognition. The number of stored images will affect the accuracy of the face emotion recognition. Before the data samples can be used as a dataset to machine learning, several steps need to be performed. For this method, grayscale methods are used to increase the accuracy of recognition. It is not compulsory to invert and crop the original image to grayscale as it only enhances the accuracy of the pre-training model of machine learning. For instance, a black and white picture with RGB pixel values can be interpreted, but is easier to recognise grayscale pictures (3 × fewer integers used). Instead, a colored image cannot be represented using grayscale pixels because it cannot capture a single hue of the pixels as seen in Figs. 3a, b.

Data teaching algorithms build partnerships, knowledge, make decisions and determine the loyalty from the collection of training data. The amount of training data, determines the efficiency of the model. Indeed, the consistency and quantity of training data related to the data project performance as with algorithms. The algorithm for angry (Fig. 4) happy (Fig. 5) and sad (Fig. 6) were developed as shown in the figure.

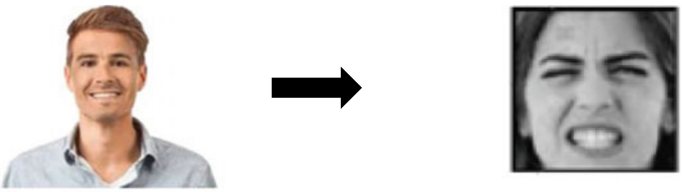


Fig. 3 **a** Original data uncropped. **b** Inverted and cropped to greyscale

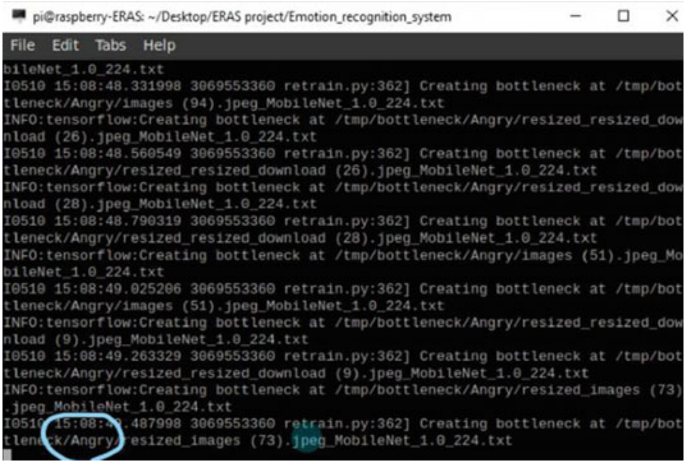


Fig. 4 Training process as AI learning for angry data

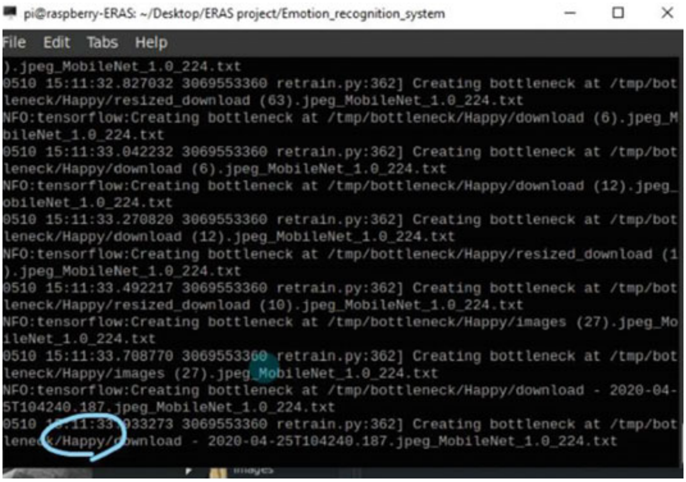


Fig. 5 Training process as AI learning for happy data

2.2 Functionality Test

A group of university students around twenty headcounts with mean age 23.0 ± 1.3 years participated as a volunteer. The range of the height is between 168.2 ± 4.0 cm and weighed around 64.2 ± 12.2 kg. All the volunteer's hearing and vision are normal. All the volunteers must meet all the pre-screening criteria including no medical or history of back pain condition or neck injury, and not using any

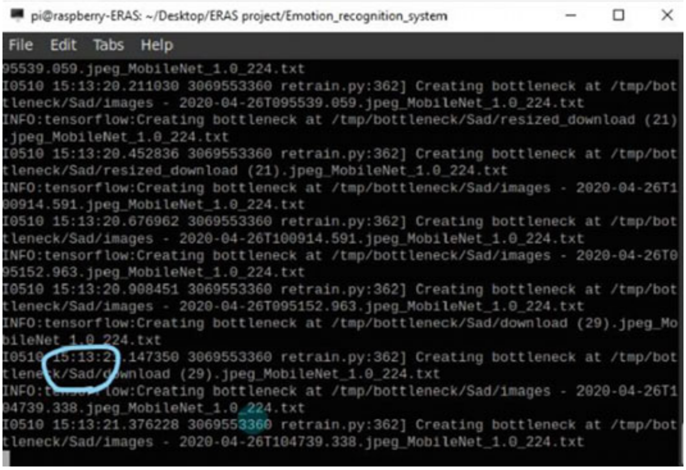


Fig. 6 Training process as AI learning for sad data

medications or drugs. The participants are refrained from taking any medicine or caffeine and required to have sufficient sleep (8 h) before the experiment.

2.3 *Ethical Consideration*

The volunteers were provided with verbal and written explanations about the purpose of the experiment. All the participants have the right to refuse participation in the experiment, and the results of the experiment are confidential. The written consent form was obtained from all the volunteers after the procedure of the experiment was explained.

2.4 *Image Processing and Validation*

Python 3.8 platform with OpenCV 4.5 library was chosen to perform the image processing. The OpenCV 4.5 has a variable function, thus transferring the image is easier and faster. The computer vision process can be solved by importing the OpenCV library. The OpenCV library method is used specifically to detect articulated data and object tracking. The accuracy of the original dataset compared to the proposed method can be calculated using 200 data samples as machine learning pre-train model dataset. Original dataset is fed directly to machine learning while the proposed method clean and filter the dataset before transfer to machine learning. The dataset in the proposed method will only crop the faces and then convert to grayscale pictures to easily receive a clear reading for Facial Action Coding System (FACS).

3 Result

3.1 Human Emotion Detection

Table 1 shows the output of the emotion recognition system for 20 of the university student's volunteers. The age information does not affect the system because the recognition is based on a dataset. The dataset that feeds to the machine learning of AI contains enormous data including difference age, race, and gender.

From Table 1, a method called confusion matrix can be evaluated to calculate the average accuracy of each emotion recognition: happy, sad, and angry. The confusion method is the most suitable method to calculate the image accuracy that compared the actual reading and predicted reading of the system. The actual reading is the system reader that is supposed to read while the predicted reading is what the system read literally. Thus, the precision or the error made by the system will be calculated in order to have the value accuracy and efficiency of the image processing system.

3.2 Confusion Matrix

See Tables 2 and 3.

3.3 Accuracy

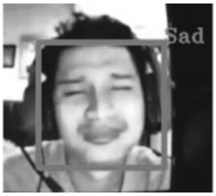
Tables 2 and 3 show the results for the current solution and the proposed method, identifying the differences in accuracy and efficiency. This test involved two groups of data, with each group of data used in three different expressions (happy, sad, angry). There are in total of 200 images data were used.

Tables 4 and 5 show that the result from two sets of data from different outputs. The output is divided by the number of each data set for each expression which is 200. The result shows the ratio of predicted and actual reading of each data set for each expression in percentage. The accuracy between these two data sets can be referred in Fig. 7.

4 Conclusion

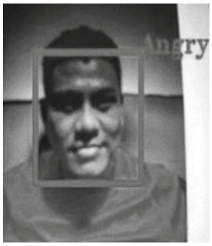
An algorithm for real-time emotion recognition using virtual markers through an optical flow algorithm has been developed to create a real-time emotion recognition system with less computational complexity (execution time, memory) using facial expressions. This algorithm works successfully in uneven lighting and human head

Table 1 Human emotion detection for 20 volunteers. It clearly indicated that, the emotion of happy, sad, and angry can be detected using our self-developed algorithm

Volunteer 1			
Volunteer 2			
Volunteer 3			
Volunteer 4			
Volunteer 5			

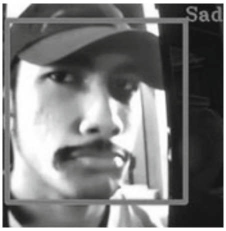
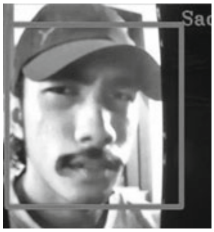
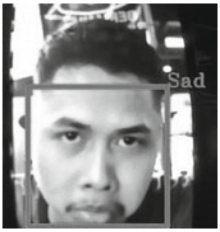
(continued)

Table 1 (continued)

Volunteer 6			
Volunteer 7			
Volunteer 8			
Volunteer 9			
Volunteer 10			

(continued)

Table 1 (continued)

Volunteer 11			
Volunteer 12			
Volunteer 13			
Volunteer 14			
Volunteer 15			

(continued)

Table 1 (continued)

Volunteer 16			
Volunteer 17			
Volunteer 18			
Volunteer 19			
Volunteer 20			

Table 2 Confusion matrix data calculation for the original dataset

		Predicted			
		Happy	Sad	Angry	Total
Actual	Happy	166	24	10	200
	Sad	13	158	29	200
	Angry	7	17	176	200
	Total	186	199	215	600

Table 3 Confusion matrix data calculation for proposed method

		Predicted			
		Happy	Sad	Angry	Total
Actual	Happy	176	15	9	200
	Sad	12	170	18	200
	Angry	5	9	186	200
	Total	193	194	213	600

Table 4 The accuracy for original dataset obtains from confusion matrix

Emotion	Accuracy (%)
Happy	83
Sad	79
Angry	88

Table 5 The accuracy for the proposed method dataset obtains from the confusion matrix

Emotion	Accuracy (%)
Happy	88
Sad	85
Angry	93

rotation (up to 45°), different backgrounds, and various skin tones. The system aims to reduce car accidents due to emotional driving that has been reported repeatedly. In addition, the interaction between human and machine can be enhanced rather than having a monotonous and one-way communication between car and the driver. The driver will be more enthusiastic and energetic throughout the driving experience, the system can recognize three major emotions in real time for facial landmarks and instruct a variety of solutions to the driver depending on the desired solution and it is a user-friendly device. The user just needs to install the plug and play the system with LCD. The results show that the system can recognize different emotions with an average accuracy of 88% for happy faces, 85% for sad faces and 93% for angry faces. The surrounding area was performed with different lighting, situation, times, and places.

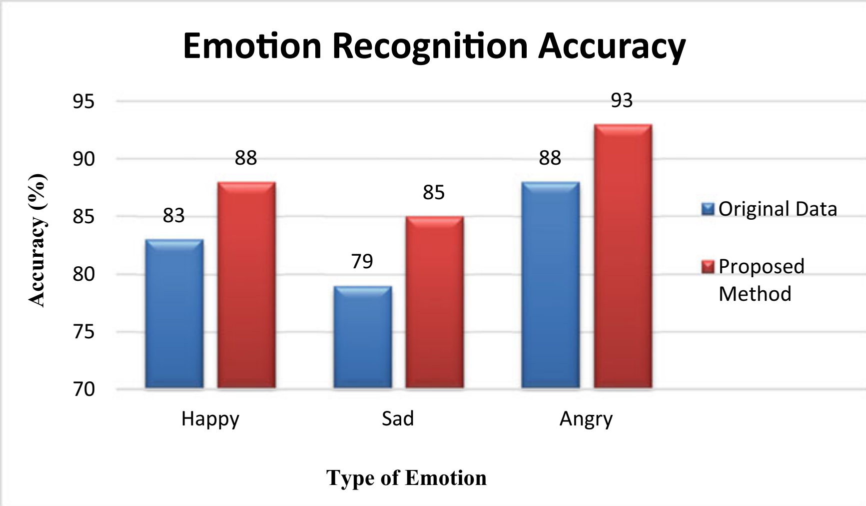


Fig. 7 Accuracy of emotion recognition based on confusion matrix data

For future work, the system's precision and accuracy can be improved by increasing the data collection. Additionally, different techniques can be used to extract more features from FACS. The current research only focuses on three major emotions: happy, sad and angry, so for future works, more emotion can be added such as: anxiety, stress, fear and so on. In addition, the system techniques can be improved by placing the subjects in real situations to express the exact feelings to enhance the system's accuracy for the Emotion Recognition Action Savvy (ERAS).

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References

1. Suchitra PS, Tripathi S (2016) Real-time emotion recognition from facial images using Raspberry Pi II. In: 3rd International Conference on Signal Processing and Integrated Networks, SPIN 2016, pp. 666–670 (2016). https://doi.org/10.1109/SPIN.2016.7566780
2. Keshari T, Palaniswamy S (2019) Emotion recognition using feature-level fusion of facial expressions and body gestures. In: Proceedings of the 4th International Conference on Communication and Electronics Systems, ICCES 2019, no Icces, pp 1184–1189 (2019). https://doi.org/10.1109/ICCES45898.2019.9002175
3. Dooley E (2016) Emotional driving increases crash risk nearly tenfold, study says. ABC News, Feb 24, 2016. https://abcnews.go.com/US/emotional-driving-increases-crash-risk-tenfold-study/story?id=37133840. Accessed 28 Dec 2020

4. Eyben F et al (2010) Emotion on the road—necessity, acceptance, and feasibility of affective computing in the car. Adv Human-Comput Interaction 2010 (2010). https://doi.org/10.1155/2010/263593
5. McGartland (2019) Dangers of driving while emotional—McGartland Law Firm. McGartland Law Firm (2019). https://www.mcgartland.com/library/dangers-of-driving-while-emotional/. Accessed 28 Dec 2020
6. Pêcher C, Lemercier C, Cellier JM (2015) The influence of emotions on driving behavior. Traffic Psychol Int Perspect June 2015:145–158 (2011)
7. Weber M (2018) Automotive emotions: a human-centred approach towards the measurement and understanding of drivers' emotions and their triggers (2018)
8. Yang D, Alsadoon A, Prasad PWC, Singh AK, Elchouemi A (2018) An emotion recognition model based on facial recognition in virtual learning environment. Procedia Comput. Sci. 125:2–10. https://doi.org/10.1016/j.procs.2017.12.003
9. Mordvintsev A (2020) Face Detection using Haar Cascades—OpenCV-Python Tutorials 1 documentation. OpenCV-Python (2013). https://opencv-python-tutroals.readthedocs.io/en/latest/py_tutorials/py_objdetect/py_face_detection/py_face_detection.html. Accessed 27 Dec 2020
10. Wang W, Xu K, Niu H, Miao X (2020) Emotion recognition of students based on facial expressions in online education based on the perspective of computer simulation. Complexity 2020 (2020). https://doi.org/10.1155/2020/4065207

Development of Sign Language Translator for Speech Impairment Person

Mohd Amzar Azizan, Iman Zulkiflee, and Nurhakimah Norhashim

Abstract Although many assistive technologies have been developed to help disabled people, however, in Malaysia the technology for the speech impairment person is still left behind and currently researchers are exploring the technologies. Assistive technology is defined as assistive, adaptive, and rehabilitative devices for Person with Disabilities (PWD) and for the elderly generation. This research focuses on the development of a sign language translator device specialty for a speech impairment person. By capturing a real-time sign language and gesture movement using a high-resolution camera, the system will process the signal and translate the data into visual information. The device is programmed to recognize different alphabets and digits based on the Malaysian Sign Language (MSL) standard. The accuracy of the system obtained was 65.3% for alphabets and 90.6% for digits. It is aimed that this intelligent device invention will bridge the communication barrier and help disabled people to experience a more healthy lifestyle and feel appreciated among the society. The engagement with society will be much easier with the translator device.

Keywords Sign language · Person with disabilities (PWD) · Speech impairment · Assistive technology · Real-time · Gesture movement

1 Introduction

In this 21st century, there are nearly around one million people that have the inability to speak due to deaf or experience speech disorder. These groups of speech disorders

M. A. Azizan (✉) · I. Zulkiflee · N. Norhashim
Aero-Ergonomics Research Cluster, Universiti Kuala Lumpur—Malaysian Institute of Aviation Technology, Sepang, Malaysia
e-mail: mohdamzar@unikl.edu.my

I. Zulkiflee
e-mail: miman.zulkiflee@s.unikl.edu.my

N. Norhashim
e-mail: nurhakimah@unikl.edu.my

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are known as mute people. Mute people experience difficulties to communicate with other normal people and being accepted by the community. It is called the communication barrier and the most challenge that need to be faced by the mute people as they are not be able to deliver the message directly. In addition, mute people are facing the problem to secure a job opportunity. The employer might not consider the mute people to be accepted by the other workers [1]. In order to overcome this problem, sign language is the only medium that can help mute people to be able to deliver an important message and communicate with other people. The majority of mute people has lack awareness of the technology that can help to solve the communication barrier [2]. Sometimes the mute people have low self-esteem to meet and expose themselves to the community. Sign language is a language that employs signs made with the hands and other movements, including facial expressions and postures of the body. It is a form of non-verbal communication, which is referring to visible body actions to deliver messages [3].

According to the Law of Malaysia Act 685—Person with Disabilities 2008, the person with disabilities shall have the right to access to employment on an equal basis with a person without disabilities. The employer shall, in performing their social obligation and endeavor to promote stable employment for PWDs, evaluate their abilities and provide suitable places of employment. Meanwhile, under Section 501 of the Rehabilitation Act of 1973, the law requires the federal government to practice affirmative action to hire and to promote employees with a disability. By referring to the above Malaysia Law, mute people supposedly have equal opportunities for employment with normal people.

1.1 Challenges and Difficulties Faced by Person with Disabilities (PWD)

Education Barriers

Education is very important as it is a crucial determinant for the level of knowledge and skills of a person. In Malaysia and particularly in some industries, the level of education will determine the figure that we as the employer will earn. The highest education level we achieved, the more income that can be earned. A PWD people, often face the gap to match the education with their ability. The barriers that a PWD need to face are (a) lack of disability accommodation and support. Due to this factor, PWD students will take a longer duration of the study and quit in the middle before completing the course. Accommodation is an important factor that will determine the student's decision to further study. If the government does not provide a good accommodation with disability support the probability of the student to further study will become low [4].

(b) Secondly, the funding for the education system. Based on the report, the authority is more concerned about the number of students that be able to attend the class rather than increasing the funding to provide specialized support for students with special needs. The funding can be used to enhance the teaching support system such as a special whiteboard, special table and chair, and so on.

Accessibility Barriers

Accessibility means a person has direct access to sense or having the privilege to services or environments that surround him or her and they are entitled to get benefits from any system or entity [5]. Thus, the accessibility barriers can be in terms of transportation, information, or even health care. For example, the information center must provide staff that is able to understand signal language.

Attitudinal Barrier

The attitudinal barrier is the most fundamental barrier that can affect life of PWDs [6]. The attitude and behavior of the community contribute Attitudinal barriers on the social life of PWDs. Disabled people are commonly related to the unhealthy and poor quality of education due to the disability. The judgments from the community can affect the job employment as well. The discrimination from the employers who believe that a PWD has low life skill and less contribution compare to normal people [7].

1.2 Laws

Person with Disabilities Act 2008

Person with Disabilities Act 2008 is one of the Acts in Law of Malaysia that govern the registration, protection, rehabilitation, development, and well-being of PWDs [8]. According to the Act in Chapter 2—Habilitation and Rehabilitation, the Council shall provide the availability and usage of assistive devices and technologies designed for a special purpose for PWDs. Assistive technology may be very useful to them such as voice recognition programs and screen readers—to help with mobility and sensory impairments using computers and mobile devices [9]. PWDs are a community that needs the protection of their rights.

American with Disabilities Act 1990

For the West country, the law has been a force since in early 1990. The law made it illegal to discriminate against a disabled person in terms of employment opportunities, access to transportation, public accommodations, communications, and government activities [10]. Title III of Public Accommodations prohibits discrimination against the basis with regards to services, facilities, or equal enjoyment of the goods. Employers must provide reasonable accommodations for their disabled employees to enable them to enjoy equal employment opportunities. A deaf applicant may need a sign language interpreter during the job interview [11] and a blind worker may need personal assistance to help them to read information.

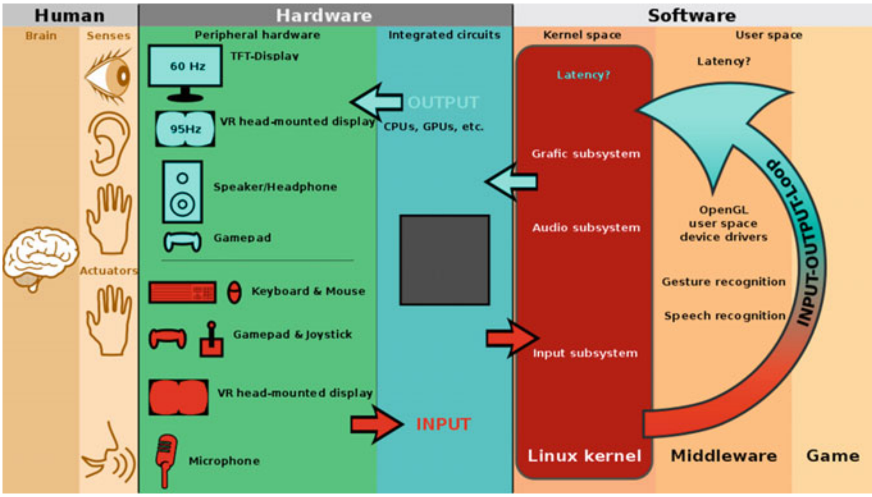

Fig. 1 Process flow of gesture recognition

1.3 Hand Gesture Recognition

Gesture recognition is interpreting human gestures by using mathematical algorithms [12] and eliminate commands based on the gesture [13]. Nowadays, there are many initiatives from the researchers to develop sign language translation systems by using cameras and computer vision where users can simply make gestures without physically having contact with the hardware devices [12]. Figure 1 shows the example of the flow process of gesture recognition. By implementing the fundamental principle of hand gesture and motion, we have developed a real-time sign language translator.

2 Methodology

2.1 Conceptual Design

Figure 2 shows the conceptual design of the project. The purpose of this conceptual design is to show the flows process from the beginning until the end process of displaying the output on the device. The process started with the user making a simple hand gesture in front of the camera. The Pi camera then will detect the hand gestures made by the user and collects the data. After the data is obtained, the data will be transferred to the Raspberry Pi where the code interpretation of data is made. The data will be read according to the algorithm made in Raspberry Pi. If the data match the algorithm that has been set, it will display the output directly on the screen.

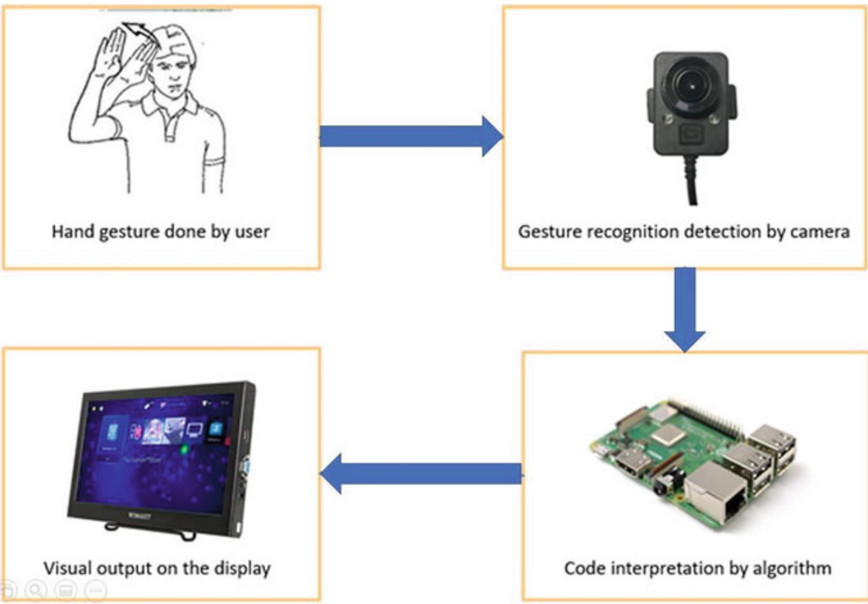

Fig. 2 Conceptual design of sign language translator

2.2 Hardware Implementation

See Fig. 3.

This is the core hardware in this project. The Raspberry Pi is a series of small single-board computers for the usage of advanced computer science projects. This project uses the Raspberry Pi 3B+ version. This version is provided with a Broadcom BCM 2837 SoC equipped with a 1.2GHz 64-bit quad-core ARM Cortex-A53 processor. It also has other useful features such as GPIO pins PoE header, HDMI port, USB 2.0 ports and so on.

Fig. 3 Raspberry Pi 3B+ (single board computer)

2.3 Machine Learning Algorithm

See Fig. 4.

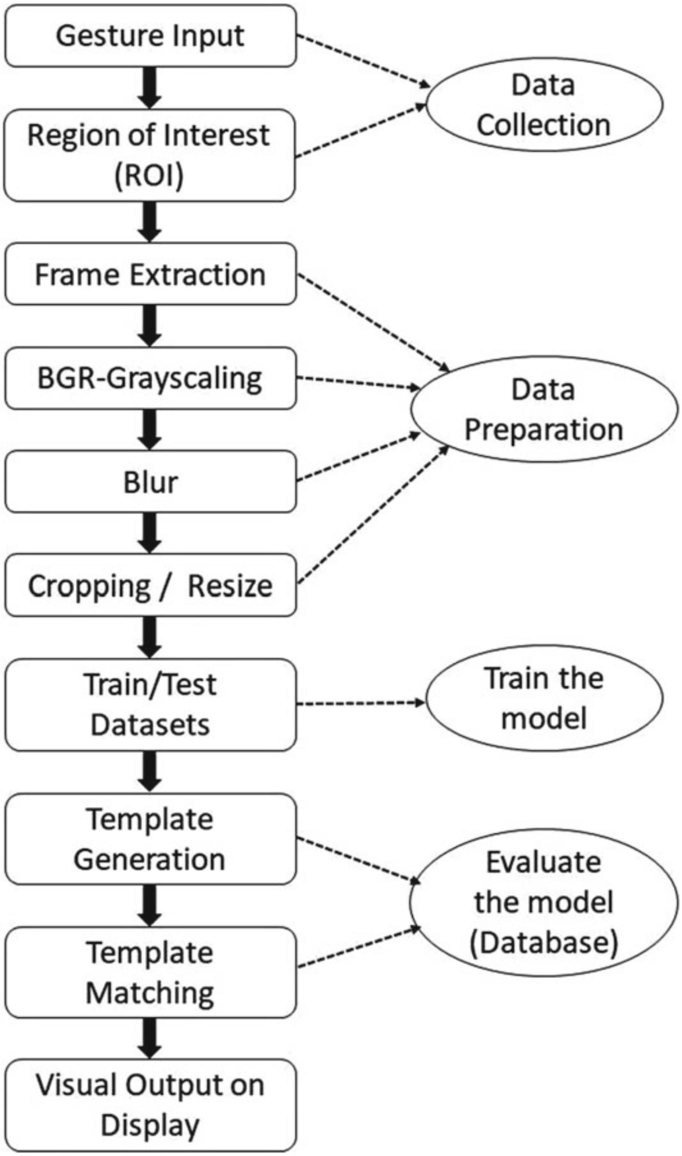

Fig. 4 Detailed flowchart in developing machine learning algorithm

2.4 Data Collection

By referring to Fig. 4, the first step is data collection. Data collection involves collecting images that are suitable to be used as a dataset. A window will appear on the Raspberry Pi containing the green square box called Region of Interest (ROI). ROI is set to 300x300 pixel size. The hand needs to be put in the ROI area to capture the datasets. Only the images in the ROI will be printed.

2.5 Data Preparation

According to Fig. 5, the second step is data preparation. Data preparation is the process where the datasets will retransforming the properties so that the systems can easily read and learn the datasets in the model training process. The captured datasets earlier will change the color of the dataset from Blue Green Red (BGR) to Grayscale as shown in Fig. 6. Then, by using the algorithm, the dataset will be blurred by using

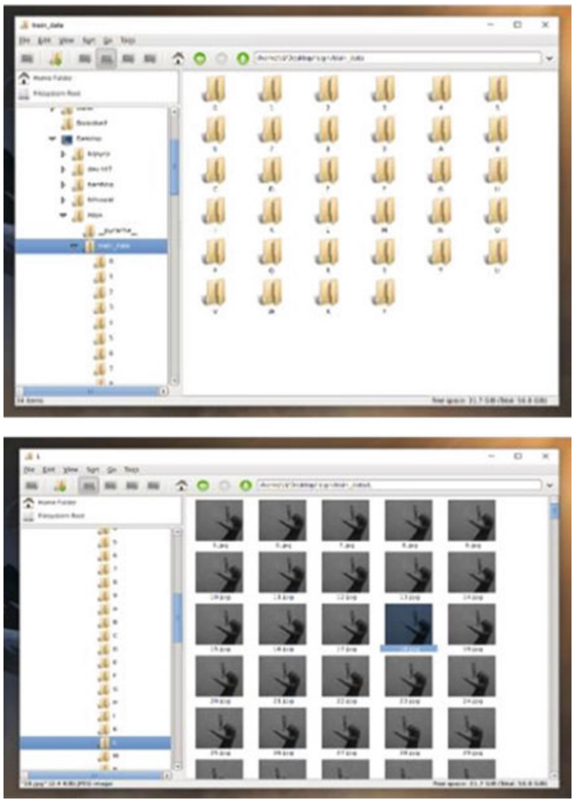

Fig. 5 Example of alphabets datasets that is collected by using OpenCV

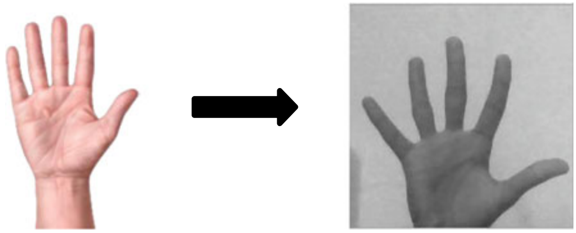

Fig. 6 Transformation of dataset from BGR to grayscale

the Gaussian Blur function. After that, the datasets will be cropped or resized from 300 × 300 pixels (ROI) to 96 × 96 pixels. The total folders are 34 and the total datasets that have been collected and prepared for training are 16,909.

2.6 Model Training

This section explains about the model training that captures the system with new image/memory. For training, the TfLearn tool is used under Tensorflow Framework. At the end of the process, this training session will print out the accuracy and loss produced in its 'brain'. The prepared datasets are divided into each alphabet and digits, with 500 images for every single folder. The total datasets would be around 17,000 images. However, some low-quality images need to be discarded to minimize the noise created by datasets. The actual numbers of datasets are 16,909. Preliminary results obtained from the training model are 78% for alphabets and 97% for digits as shown in Fig. 7.

2.7 Model Evaluation

The evaluation of the classification model can be defined as evaluating the accuracy, precision, and recall. The process involves template generation and template matching. This evaluation can be shown in the confusion matrix. That is used to describe the performance of a classification model.

2.8 Confusion Matrix

2.8.1 Precision

$$\text{Precision} = \frac{\text{Correctly Predicted}}{\text{Total Predicted}}.$$

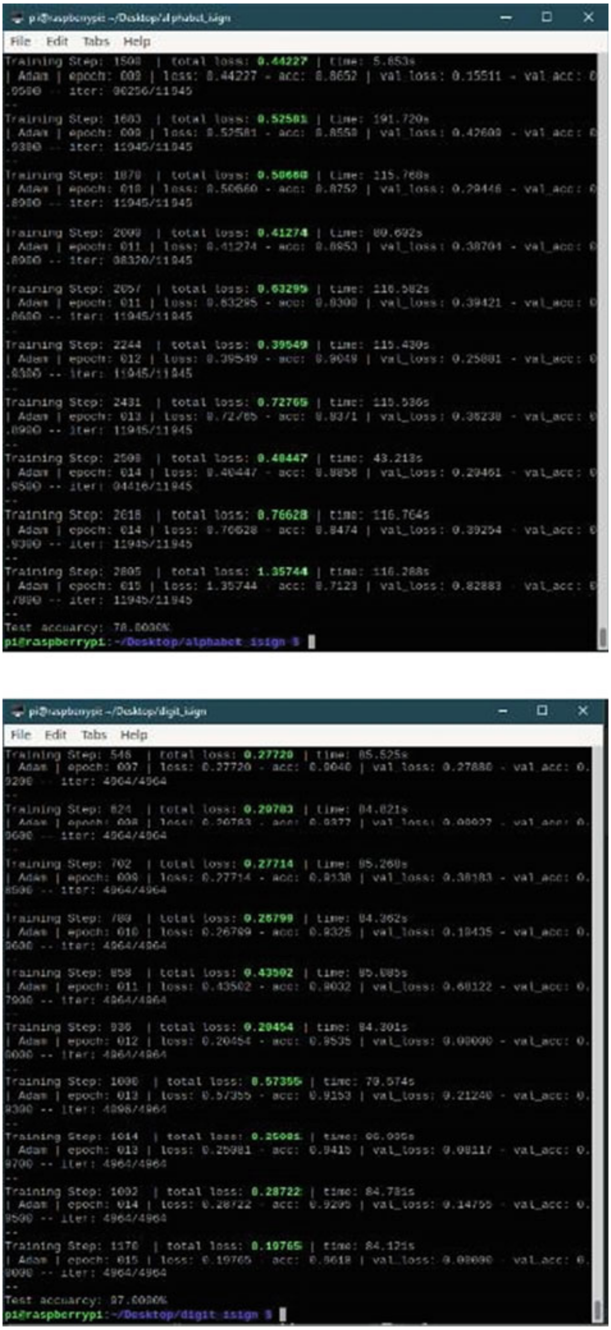

Fig. 7 Result of training alphabets 78% and digits 97%

2.8.2 Recall

$$\text{Recall} = \frac{\text{Correctly Classified}}{\text{Total Actual}}.$$

2.8.3 Accuracy

Calculating the accuracy of datasets or classifier

$$\text{Accuracy} = \frac{\text{Total Correctly Classified}}{\text{Total Actual}}$$

2.8.4 Weighted Average Precisions

$$\begin{gathered}\text{Actual Class A Instances} \times \text{Precision of Class A} \\ + \\ \text{Actual Class B Instances} \times \text{Precision of Class B} \\ + \\ \text{Actual Class C Instances} \times \text{Precision of Class C}\end{gathered}$$

2.8.5 Weighted Average Recall

$$\begin{gathered}\text{Actual Class A Instances} \times \text{Recall of Class A} \\ + \\ \text{Actual Class B Instances} \times \text{Recall of Class B}. \\ + \\ \text{Actual Class C Instances} \times \text{Recall of Class C}\end{gathered}$$

3 Results and Analysis

Figure 8 shows the result of the translation for alphabet A, B and C when the user perform hand gesture in front of the camera. The self-developed algorithm is proven to be able to translate the signs language according to Malaysia Sign Language (MSL) standard as shown in Fig. 9.

Figure 10 shows the result of the translation for different digits for number 1, 2 and 3 when the user performs the hand gesture in front of the camera. The self-developed algorithm is proven to be able to translate the sign language according to Malaysian Sign Language (MSL) standard as shown in Fig. 11.

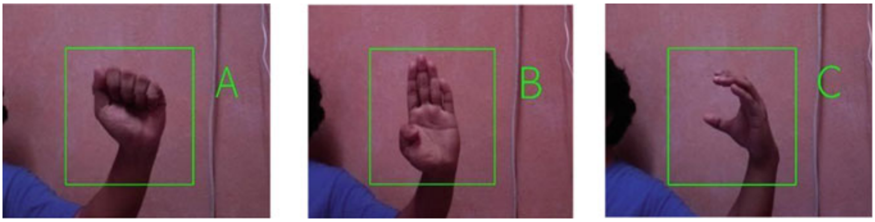

Fig. 8 The example of different hand gesture of A, B, and C being translated into visual display

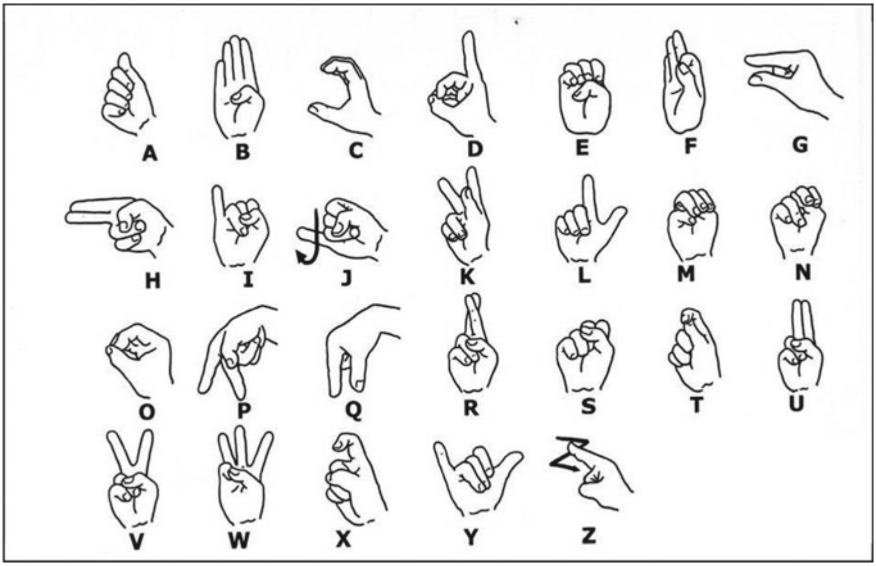

Fig. 9 Malaysian sign language (MSL) for alphabets

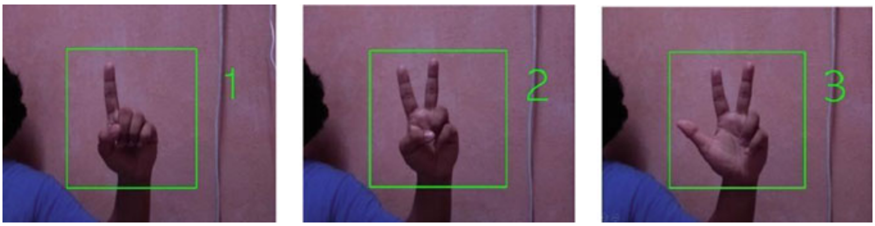

Fig. 10 The example of hand gesture of digits 1, 2 and 3 being translated into the visual display

3.1 Confusion Matrix for Alphabets

See Table 1.

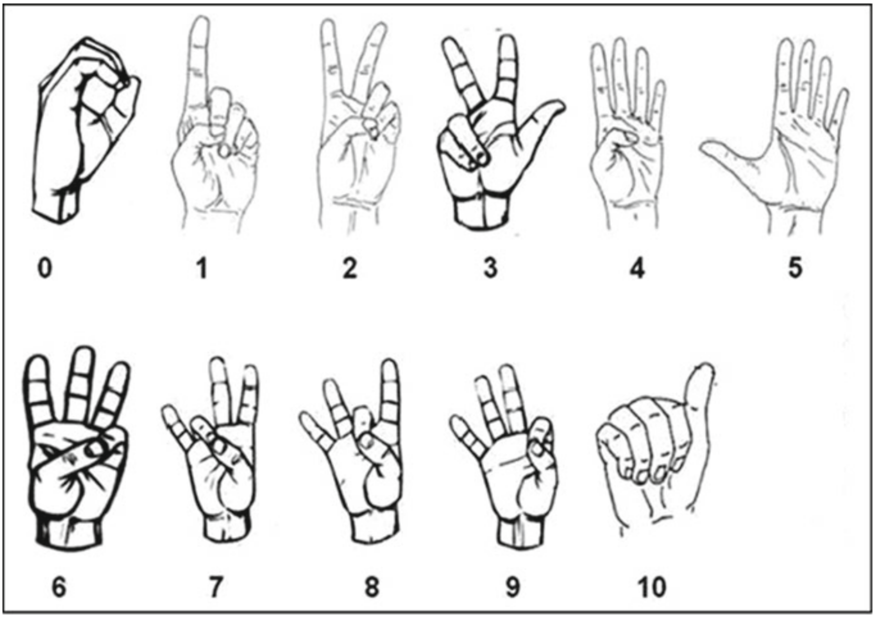

Fig. 11 Malaysian sign language (MSL) for digits

3.2 Confusion Matrix for Digits

See Table 2.

3.3 Accuracy of Alphabets

Table 3 shows the accuracy value of each of the alphabet that have been calculated from the confusion matrix. Alphabet A, H, R, and Y have the highest accuracy value which is 105 out of 150 sample data (70%). This may be due to the machine learning algorithm was able to directly read the datasets as the gestures were very simple. Meanwhile, alphabet D, G, and N have the lowest accuracy value which is 90 out of 150 sample data (60%). This may be due to the machine learning algorithm was only able to read some datasets of those three alphabets since the gesture was a little complicated. For example, the gesture of alphabet G and H is quite similar whilst the gestures of alphabet N are also almost the same with alphabet M.

From these data, it can be concluded that the quality of datasets plays is utmost important role for the algorithm to able to read the image/memory of the brain. If the datasets have noise or damage, the accuracy value will be reduced than the loss value.

Table 1 Confusion matrix table for alphabets

	A	B	C	D	E	F	G	H	I	K	L	M
A	**105**	5	0	0	4	2	1	0	6	1	0	0
B	4	**102**	2	4	2	2	3	0	1	1	2	1
C	1	4	**93**	0	2	3	1	7	3	1	3	4
D	2	5	0	**90**	4	1	0	6	0	2	1	5
E	4	0	2	3	**100**	4	3	2	0	2	4	1
F	8	1	4	2	2	**102**	0	5	0	8	0	0
G	1	0	2	4	0	3	**90**	6	0	6	0	8
H	2	1	0	1	8	5	0	**105**	1	2	0	4
I	6	4	1	2	1	4	0	3	**100**	1	2	0
K	1	7	3	0	0	6	1	0	1	**97**	0	0
L	7	0	7	0	0	6	0	0	1	0	**99**	3
M	1	2	0	1	4	0	0	0	9	3	2	**101**
N	3	0	3	4	0	5	0	2	3	1	5	4
O	2	0	3	2	0	1	0	8	4	0	0	7
P	4	0	2	0	4	1	3	8	2	0	3	0
Q	1	4	0	0	0	2	1	2	1	7	3	2
R	0	2	4	0	5	1	0	6	0	0	3	0
S	9	0	0	5	0	3	0	1	2	0	2	0
T	7	0	0	0	3	0	2	0	5	0	2	0
U	0	2	0	0	4	5	0	1	0	0	3	4
V	8	0	0	0	0	0	8	2	0	7	2	0
W	0	0	1	0	0	1	0	0	6	5	2	1
X	1	2	3	1	0	3	1	4	3	1	3	2
Y	1	3	2	0	3	0	3	1	0	5	2	0
Total	178	144	132	119	146	160	117	169	148	150	143	147

	N	O	P	Q	R	S	T	U	V	W	X	Y	
A	5	1	2	0	8	0	0	3	0	5	2	0	150
B	1	3	1	2	4	2	3	3	4	2	0	1	150
C	1	2	2	1	2	5	2	4	2	2	4	1	150
D	0	2	5	4	1	3	5	3	5	2	3	1	150
E	1	2	1	2	4	2	1	3	1	1	4	3	150
F	5	0	0	0	3	0	0	5	0	0	5	0	150
G	1	6	4	0	7	0	7	3	0	0	0	2	150
H	2	0	5	1	3	0	1	2	0	0	1	6	150
I	1	0	1	2	4	2	4	2	2	1	3	4	150
K	4	7	0	2	7	4	3	0	0	6	0	1	150

(continued)

Table 1 (continued)

	N	O	P	Q	R	S	T	U	V	W	X	Y	
L	1	0	2	0	4	1	0	5	0	0	5	9	150
M	0	4	0	0	2	3	4	0	6	0	3	5	150
N	**90**	4	5	5	3	0	5	4	3	0	0	1	150
O	0	**98**	0	5	0	3	0	0	9	0	0	8	150
P	0	5	**96**	0	0	4	0	8	0	0	8	2	150
Q	3	0	4	**104**	2	5	0	2	4	0	0	3	150
R	2	5	0	0	**105**	0	5	8	1	0	1	2	150
S	0	0	5	0	0	**102**	5	0	0	6	4	6	150
T	4	3	0	2	7	0	**93**	9	0	6	0	7	150
U	0	4	0	8	0	6	4	**95**	0	8	6	0	150
V	5	2	0	6	2	0	6	2	**97**	3	0	0	150
W	0	2	5	8	3	5	0	2	0	**105**	4	0	150
X	1	4	2	4	1	2	2	0	4	2	**100**	4	150
Y	5	1	2	0	6	0	1	4	2	0	4	**105**	150
Total	132	155	142	156	178	149	151	167	140	149	157	171	**3,600**

Table 2 Confusion matrix table for digits

	0	1	2	3	4	5	6	7	8	9	
0	**138**	2	1	1	0	2	1	2	2	1	150
1	2	**135**	2	1	1	1	2	2	1	3	150
2	1	2	**139**	1	1	1	2	1	1	1	150
3	2	2	1	**138**	2	2	1	1	0	1	150
4	0	1	0	2	**137**	3	1	3	2	1	150
5	1	0	2	0	1	**140**	0	1	3	2	150
6	3	2	1	4	0	2	**135**	2	0	1	150
7	1	2	0	1	2	0	3	**136**	4	1	150
8	2	4	0	3	1	1	0	0	**136**	3	150
9	0	1	1	0	2	2	2	1	2	**139**	150
Total	150	151	147	151	147	154	147	149	151	153	**1500**

3.4 Accuracy of Digits

Table 4 shows the digit's accuracy value hat has been calculated from the confusion matrix. Digit 5 has the highest accuracy value which is 141 out of 150 sample data (94%). This may be due to the machine learning algorithm can directly be read the datasets of digit 5 since the gestures are very simple. Meanwhile, digit 1 and 6 have the lowest accuracy value which is 135 out of 150 sample data (90%). This may be

Table 3 Accuracy value for alphabets

Alphabets	Accuracy (%)
A	70
B	68
C	62
D	60
E	66.6
F	68
G	60
H	70
I	66.6
K	64.66
L	66
M	67.3
N	60
O	65.3
P	64
Q	69.3
R	70
S	68
T	62
U	63.3
V	64.66
W	70
X	66.6
Y	70

Table 4 Accuracy value for digits

Digits	Accuracy (%)
0	92
1	90
2	93
3	92
4	91
5	94
6	90
7	90.6
8	90.6
9	93

due to the machine learning algorithm was only able to read some datasets of those two digits. For example, the digit 1 is quite similar to digit 0 and the gestures of the alphabet N are also almost the same as the alphabet M. The accuracy of the data is also depends on the user perform the hand gestures

4 Conclusion

As a conclusion, the research demonstrated good accuracy for the sign language translator with the percentage of 65.3% for alphabets and 90.6% for digits. The sign language translator perhaps will assist the speech impairment person to engage with the society in terms of communication and interaction. The algorithm developed using machine learning technology, indicated a higher confidence level, and can be another important milestone in bridging the communication barrier between the speech impairment community and normal people. It also will assist the speech impairment community in carrying out their daily activities and having more happier lifestyle.

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References

1. Maynard A (2020) The Guardian. https://www.theguardian.com/society/joepublic. Last accessed 21 Dec 2020
2. Glickman NS, Harver MA (1996) Culturally affirmative psychotherapy with deaf persons, 1st edn. Routledge
3. Gugenheimer JKP (2017) The impact of assistive technology on communication quality between deaf and hearing individuals. In: Proceedings of the 2017 ACM conference on computer supported cooperative work and social computing. https://doi.org/10.1145/2998181.2998203
4. Bezyak JL, Sabella SA, Gattis RH (2017) Public transportation: an investigation of barriers for people with disabilities. J Disability Policy Stud 28(1):52–60
5. Rise N' Shine Disability Magazine, http://risenshine.org.za/2018/08/06/some-of-the-challenges-faced-by-disabled-persons/. Last accessed 6 Aug 2018
6. Centers for Disease Control and Prevention. https://www.cdc.gov/ncbddd/disabilityandhealth/disability-barriers.html#ref. Last accessed 16 Sept 2020
7. Coleman N, Wendy S (2013) Barriers to employment and unfair treatment at work: a quantitative analysis of disabled people's experiences. Equality and Human Rights Commission (No. 8)
8. Malaysia, L. o. Person with Disabilities Act 2008 (2008) Malaysia: The Commissioned of Law Revision Malaysia
9. National Institute of Child Health and Human Development. https://www.nichd.nih.gov/health/topics/rehabtech/conditioninfo/device. Last accessed 24 Oct 2018

10. Investopedia, https://www.investopedia.com/terms/a/americans-with-disabilities-act-ada.asp. Last accessed 22 April 2020
11. U.S Equal Employment Opportunity Commission, https://www.eeoc.gov/eeoc/publications/fs-ada.cfm. Last accessed 15 Jan 1997
12. Rouse M (2015) What is. Retrieved from Gesture Recognition: https://whatis.techtarget.com/definition/gesture-recognition. Last accessed 10 Dec 2015
13. Schechter S (2014) https://www.marxentlabs.com/what-is-gesture-recognition-defined/. Last accessed 24 March 2014

Comparative Study of Five Metaheuristic Algorithms for Team Formation Problem

Md. Abdul Kader and Kamal Z. Zamli

Abstract This paper presents a comparative study of five metaheuristic algorithms, namely, salp swarm algorithm (SSA), owl search algorithm (OSA), sooty tern optimization algorithm (STOA), squirrel search algorithm (SqSA), and crow search algorithm (CSA) adopted in the Covid19 team formation (CTF) problem. The performance comparison of these algorithms is conducted by executing each algorithm twenty times to ensure the statistical significance. The study considers the minimum number of experts and the minimum team formation cost in defining the objective function. The CSA was found to be the more effective metaheuristic algorithm for the Covid19 team formation problem from the optimal results in terms of overall solution quality and runtime efficiency.

Keywords Metaheuristic algorithms · Crow search algorithm · Covid19 team formation

1 Introduction

Metaheuristic algorithms can be viewed as a generic framework of algorithm which integrates a collection of search strategies into the basic search process [1]. All metaheuristic algorithms aim to explore the search space more efficiently and effectively to find a sufficiently good solution at a reasonable cost and time for optimization problems [2]. These methods are widely used not only in computer science but also in different fields [3]. The inspirations of the metaheuristic algorithms come from the behavior of natural phenomena. These natural processes are mimicked in metaheuristic algorithms to generalize the artificial procedure for the particular optimization problem. In contrast, the popularity of metaheuristic algorithms is growing

Md. A. Kader · K. Z. Zamli (✉)
Faculty of Computing, College of Computing and Applied Sciences, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: kamalz@ump.edu.my

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because of their simplicity, flexibility, and capability of solving complex optimization problems by avoiding local optimum [4]. Some of the commonly used metaheuristic algorithms include genetic algorithm, particle swarm optimization, salp swarm algorithm, owl search algorithm, sooty tern optimization algorithm, squirrel search algorithm, and crow search algorithm.

Various metaheuristic algorithms have been adopted for team formation problems (TFO) over the last decade [5–9]. In the TFO problem, the best team is formed for a specific job by selecting suitable experts from diverse regions based on the required skills. The challenges of creating the best team can be minimizing the number of competent team members, job completion time, the wage of experts, resource requirements and maximizing the quality of the completed job.

According to the No-Free-Lunch (NFL) theorem [10], there is no single metaheuristic algorithm that can solve all optimization problems - as some algorithms perform better than others on certain types of optimization problems. The NFL theorem has motivated this study to adopt different metaheuristic algorithms and evaluate their performance for solving the Covid-19 team formation (CTF) problem as the case study. The considered metaheuristic algorithms in this comparative study are the salp swarm algorithm (SSA), owl search algorithm (OSA), sooty tern optimization algorithm (STOA), squirrel search algorithm (SqSA), and crow search algorithm (CSA).

The rest of the paper is organized as follows. Section 2 covers the overview of the metaheuristic algorithms adopted for CTF problem as a case study. The Covid19 team formation problem is outlined in Sect. 3. Section 4 describes the experimental setup. The performance comparison of selected metaheuristic algorithms from the experiment results is described in Sect. 5. Finally, Sect. 6 concludes the paper.

2 Metaheuristic Algorithms Adopted for CTF Problem

This study adopts five metaheuristic algorithms in CTF problem solution to compare their performance. The selected algorithms are salp swarm algorithm (SSA), owl search algorithm (OSA), sooty tern optimization algorithm (STOA), squirrel search algorithm (SqSA), and crow search algorithm (CSA). A brief overview of each algorithm is described as follows.

2.1 Salp Swarm Algorithm (SSA)

Mirjalili et al. [11] introduce a population-based metaheuristic algorithm, salp swarm algorithm (SSA) for the single objective and multi-objective optimization. The social interaction (i.e., when navigation and foraging in oceans) of salp swarm for seeking food is modelled mathematically in SSA. The salp chain comprises a head salp and others are follower salps. The working principle of SSA is highlighted using the following eight steps:

Step-1: Initialize the salp population considering the upper and lower bound.
Step-2: Compute the fitness of each salp.
Step-3: Calculate the best salp.
Step-4: Update coefficient using the Eq. (1).

$$c_1 = 2e^{-\left(\frac{4t}{M_t}\right)^2} \tag{1}$$

Step-5: Relocate the position of leader salp using Eq. (2).

$$X_j^1 = \begin{cases} F_j + c_1\left(\left(ub_j - lb_j\right)c_2 + lb_j\right) & c_3 \geq 0 \\ F_j - c_1\left(\left(ub_j - lb_j\right)c_2 + lb_j\right) & c_3 < 0 \end{cases} \tag{2}$$

Step-6: Relocate the position of follower salps using Eq. (3).

$$X_j^i = \frac{1}{2}\left(X_j^i + X_j^{i-1}\right) \tag{3}$$

Step-7: Amend the salp position based on the upper and lower bound.
Step-8: If the termination criteria are met, return the best salp, otherwise, go to Step-2.

The definition of variables used in Eq. (1–3): X_j^1 represents the leader's location in jth dimension, ub_j, lb_j, and F_j denote the upper bound, lower bound, and food source position in jth dimension, respectively. The parameters, c_2 and c_3, represent random numbers generated within the interval [0,1].

2.2 *Owl Search Algorithm (OSA)*

Jain et al. [12] introduced a population-based meta-heuristic algorithm in 2019 and named it as Owl Search Algorithm (OSA). OSA mimics the predatory behaviour of the owls in the dark. The sound intensity is essential to compute the fitness of owl's position. The working principle of OSA is highlighted using the following steps:

Step-1: Generate the random positions of owls.
Step-2: Compute the fitness of each owl.
Step-3: Set the global best and worst solution in the population.
Step-4: Calculate the intensity of owl using Eq. (4).

$$I_i = \frac{F_i - w}{b - w} \tag{4}$$

Step-5: Calculate the distance information of each owl using Eq. (5).

$$\|R_i = X_i,\ V\|_2 \tag{5}$$

Step-6: Calculate the changed intensity of each owl using Eq. (6).

$$Ic_i = \frac{I_i}{R_i^2} + rand(0,\ 1) \tag{6}$$

Step-7: Compute the new position of each owl based on the probability of prey movement using Eq. (7).

$$X_i(t+1) = \begin{cases} X_i(t) + \beta \times Ic_i \times |\alpha V - X_i(t)| & if\ \ p_{vm} < 0.5 \\ X_i(t) - \beta \times Ic_i \times |\alpha V - X_i(t)| & if\ \ p_{vm} < 0.5 \end{cases} \tag{7}$$

Step-8: Update global best in the population.
Step-9: If the termination criteria are met, return the best owl's location, otherwise, go to Step-2.

The definition of variables used in Eq. (4–7): F_i represents the fitness of ith owl. w and b denotes the minimum and maximum fitness, respectively. V indicates the location of the prey, R_i represents the distance between the pray and the owl X_i. p_{vm} specifies the possibility of vole movement, α denotes the random number between [0, 0.5], and β denotes the linearly decreasing constant from 1.9 to 0. Ic_i specifies the intensity variation for ith owl.

2.3 Sooty Tern Optimization Algorithm (STOA)

Dhiman and Kaur [13] proposed STOA in 2019 which is a population-based bio-inspired meta-heuristic algorithm. The key idea of STOA is to mimic the behaviours (i.e., movement and attacking) of sooty tern to emphasize the exploration and exploitation in a given search space. The process of STOA can be represented as follows:

Step-1: Initialize the parameters.
Step-2: Estimate the fitness of each sooty tern.
Step-3: Set the global best sooty tern.
Step-4: Update the positions of each sooty tern using Eq. (8).

$$X_i(t) = \left(D_i(t) \times \left(x' + y' + z'\right)\right) \times X_{best}(t) \tag{8}$$

Step-5: Update the parameters.
Step-6: Compute the fitness value of each sooty tern.
Step-7: Update best search agent based on the current fitness.

Step-8: If the termination criteria are met, return the best search agent, otherwise, go to Step-4.

The definition of variables used in Eq. (8): $X_{best}(t)$ denotes the best search agent. $D_i(t)$ states the distance between the current and best search agent. x', y', and z' combinedly represent the angle of attack.

2.4 Squirrel Search Algorithm (SqSA)

SqSA is a nature-inspired metaheuristic algorithm proposed in 2019 by Mohit Jain et al. [12]. The main idea behind SqSA is to mimic the dynamic foraging and gliding behaviour of southern flying squirrels. These behaviours are modelled mathematically to emphasize the exploration and exploitation in a given search space. The process of SqSA can be represented as follows:

Step-1: Initialize the population.
Step-2: Evaluate the fitness of each flying squirrel's location.
Step-3: Categorize the population depending upon their fitness value.
Step-4: Relocate all flying squirrels based on the winter updating scheme using the following Equations.

$$X_{ai}^{t+1} = \begin{Bmatrix} X_{ai}^{t} + d_g G_c\left(X_h^t - X_{ai}^t\right) & if\ r_1 \geq P_{dp} \\ Random\ location & Otherwise \end{Bmatrix} \tag{9}$$

$$X_{i}^{t+1} = \begin{Bmatrix} X_{i}^{t} + d_g G_c\left(X_{ai}^t - X_{i}^t\right) & if\ r_2 \geq P_{dp} \\ Random\ location & Otherwise \end{Bmatrix} \tag{10}$$

$$X_{i}^{t+1} = \begin{Bmatrix} X_{i}^{t} + d_g G_c\left(X_h^t - X_{i}^t\right) & if\ r_3 \geq P_{dp} \\ Random\ location & Otherwise \end{Bmatrix} \tag{11}$$

Step-5: Randomly update the position of flying squirrels if the summer season arrived.
Step-6: If the termination criteria are met, return the final optimal solution (i.e., location of the squirrel on hickory nut tree), otherwise, go to Step-2.

The definition of variables used in Eq. (9–11): d_g and G_c represent the random gliding distance and gliding constant. r_1, r_2 and r_3 indicate the random number between [0, 1]. X_{ai}^t, X_h^t, and X_i^t represent the flying squirrel on acorn nut, hickory nut, and normal tree, respectively. P_{dp} indicates the predator presence probability.

2.5 Crow Search Algorithm (CSA)

Alireza Askarzadeh [14] introduces a population-based metaheuristic algorithm, Crow Search Algorithm (CSA) in 2016. CSA is inspired by the cleverness of crows for storing and retrieving foods from hiding places in nature. Crows are very greedy birds, and they intelligently follow each other to steal the foods of others. However, they take precautions to protect their food from potential followers. The working principle of the CSA can be represented as follows:

Step-1: Initialize parameters and population.
Step-2: Randomly generate the position of crows and store them in memory.
Step-3: Evaluate the fitness or objective function.
Step-4: Generate new position of all crows.
Step-5: Check feasibility and update the location of crows using Eq. (12).

$$X_i^{t+1} = X_i^t + r_i \times fl \times \left(m_j^t - X_i^t\right) \tag{12}$$

Step-6: Evaluate the fitness of the current location of crows.
Step-7: Update memory with the best fitness.
Step-8: If the termination condition is met, return the best solution stored in the memory, otherwise, go to Step-4.

The definition of variables used in Eq. (12): fl indicates the flight length. m_j^t represents the jth memory at iteration t. r_i is a random number generated for ith crow. X_i^t is the position vector of ith crow at iteration t.

3 Overview of Covid19 Team Formation Problem

The world is currently suffering from a mortal infectious disease, known as coronavirus 2019 (COVID-19), caused by severe acute respiratory syndrome 2 (SARS-CoV-2). This disease has quickly spread to the residents of Wuhan City, Hubei Province, China, from the beginning of early December 2019 [15]. The first COVID-19 case in Malaysia was registered on 25 January 2020. There is an emergency to deal with the outbreak as the number of infected people increases exponentially worldwide. Among all the arrangements, the government of each country needs to form specialized teams for their country to handle the situation. The team comprises the members that can be related to health anyway or others who are in need in this situation. Based on the required skills or knowledge, the covid-19 teams are formed from the millions of respective people.

4 Experimental Setup

All selected metaheuristic algorithms (SSA, OSA, STOA, SqSA, CSA) were developed in Java, running on windows 10 with CPU 2.20 GHz Intel core i7, and 8 GB RAM. While these algorithms can be evaluated for any number of unique skills exist in the corresponding dataset, they are tested for 5, 10, 15, 20, and 25 skills sets. For each skill set, all selected algorithms run by twenty times for the equal number of search agents (i.e., 10), max iteration (i.e., 1000), and the equal number of fitness function evaluations make the experiment fair. The results for the same skill set are averaged and considered for comparison. Covid19 dataset (formatted and cleaned) [16], is used to evaluate and compare the performance of the selected algorithms in this comparative study. This dataset contains 7493 experts and 3291 unique skills.

5 Experimental Results and Comparative Analysis

This section registers the experimental data and illustrates their comparative analysis in terms of team size (best and mean), team cost (best and mean), and running time of the selected metaheuristic algorithms for different sets of test skills. The experimental results for the CTF case study from each metaheuristic algorithms are summarized in Table 1. The average values of team size (best and mean), team cost (best and mean) for the required skills sets 5, 10, 15, 20, 25 are shown in Fig. 1a–e, respectively. Figure 2 illustrates the average running time of metaheuristic algorithms. Moreover, the metaheuristic algorithms are ranked in terms of team size, team cost, and running time. The average ranking analysis is demonstrated in Fig. 3.

Concerning Figs. 1, 2 and 3, several observations can be discussed further. Firstly, the performance of calculating the best results is almost alike for all the metaheuristic algorithms, but the mean results reflect their actual strength. In Fig. 1a–e, the average mean values of team size and team cost represent that the CSA performs better against the other metaheuristic algorithms for different sets of test skills. In addition, any number of test skills can be taken from the unique skill set for the performance evaluation of the compared algorithms. Secondly, the CSA outperforms the other metaheuristic algorithms and secure rank one (i.e., averaged rank) in terms of individual ranking for team size (best and mean) and team cost (best and mean). The ranking of all compared algorithms is shown in Fig. 3. The ranks are evaluated in terms of the average team size (best and mean), team cost (best and mean), and running time for 20 runs. Finally, in terms of running time, the OSA secured rank one, and the CSA secured rank two. The running time comparison of all compared algorithms are shown in Fig. 2.

Table 1 Experimental results for the selected metaheuristic algorithms

Skill set	Algorithm	Team size		Team cost		Running time (ms)
		Best	Mean	Best	Mean	
5	SSA	4.000	4.710	5.767	8.610	22,025.000
	OSA	4.000	4.860	5.754	9.127	5778.400
	STOA	4.000	4.010	5.715	5.868	16,846.200
	SqSA	4.000	4.000	5.726	5.833	19,913.600
	CSA	4.000	4.050	5.726	6.003	6730.800
10	SSA	8.400	9.300	30.805	38.283	16,676.100
	OSA	8.200	9.210	29.261	37.222	5639.900
	STOA	8.000	8.670	27.626	32.845	16,229.200
	SqSA	8.100	8.740	28.432	33.369	18,109.800
	CSA	8.000	8.720	27.715	33.163	5784.100
15	SSA	12.400	13.700	70.048	86.530	22,315.300
	OSA	11.600	12.990	60.962	77.413	13,156.000
	STOA	12.000	12.660	65.103	73.152	22,459.400
	SqSA	11.900	12.640	64.051	72.850	30,187.300
	CSA	11.500	12.550	59.733	71.917	13,623.500
20	SSA	12.600	14.340	72.577	95.017	23,579.300
	OSA	12.300	13.280	68.823	80.816	13,043.200
	STOA	12.100	13.310	66.493	81.226	19,394.100
	SqSA	12.500	13.230	71.084	80.150	25,186.600
	CSA	12.400	13.060	70.023	78.006	13,899.000
25	SSA	15.600	18.820	113.225	167.483	24,710.800
	OSA	15.100	16.330	105.822	124.554	10,148.400
	STOA	16.700	17.800	130.189	148.522	20,574.800
	SqSA	16.100	17.350	120.628	140.984	22,166.000
	CSA	15.800	16.990	116.061	134.850	10,984.000

6 Conclusion

A comparative study of five recent metaheuristic algorithms (SSA, OSA, STOA, SqSA, and CSA) using the CTF problem as a case study has been presented. In our research, the case study aimed to find the best Covid19 team with minimum team size and team cost. Based on the recorded experimental results and their analysis, it can be concluded that the algorithm which secures the first rank in terms of calculating the team size and team cost is CSA. With the running time comparison, the OSA secure first rank and CSA secure second rank. In future, more recent metaheuristic algorithms can be implemented and compare their performance for the Covid19 team formation problem.

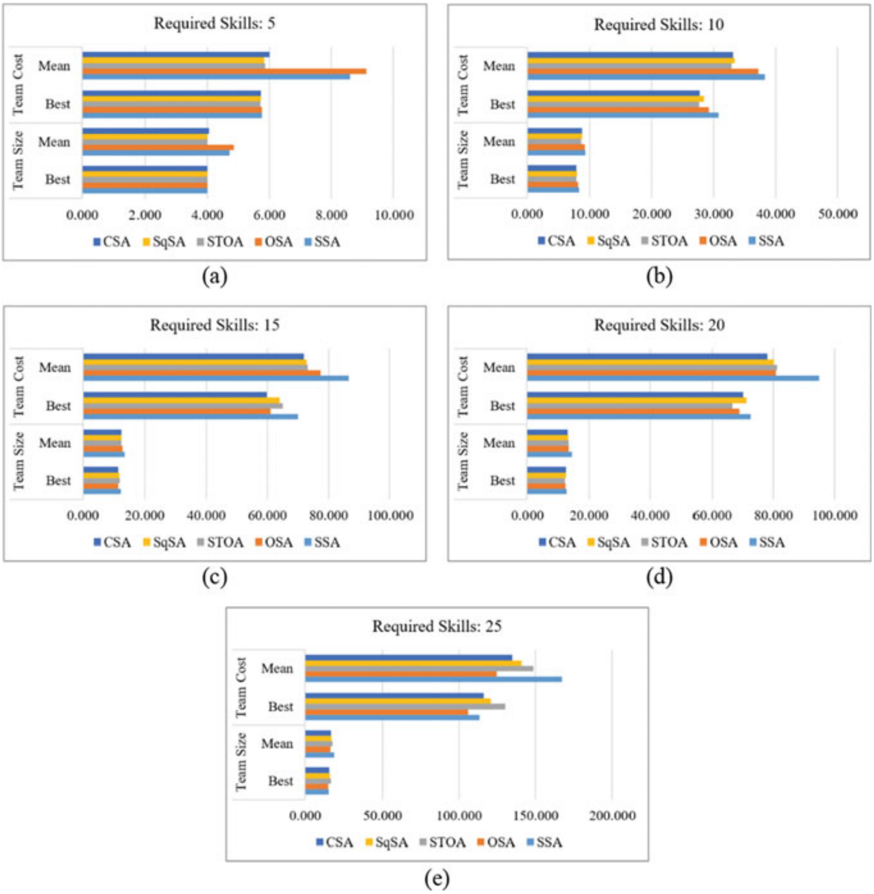

Fig. 1 Average of the best and mean team size and team cost for the 5, 10, 15, 20, 25 required skills shown in figure (**a**), (**b**), (**c**), (**d**), and (**e**), respectively

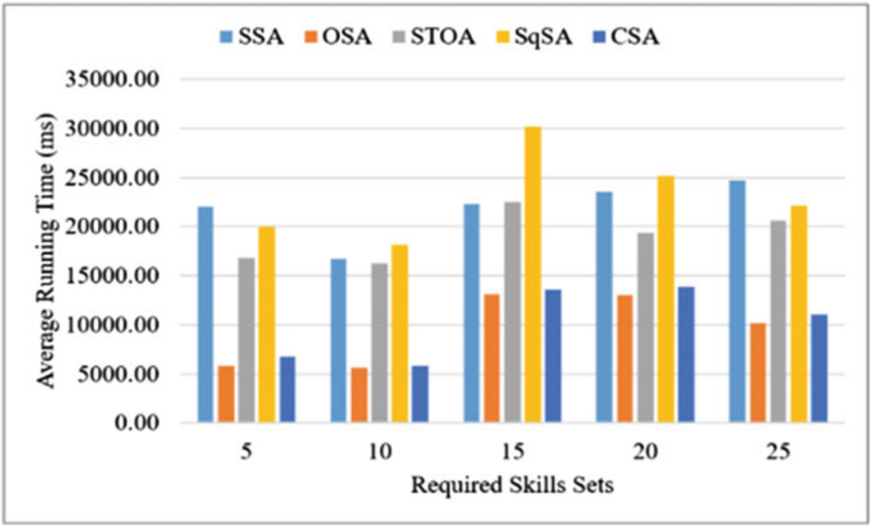

Fig. 2 Average running time (ms) of compared algorithms for the different required skill sets

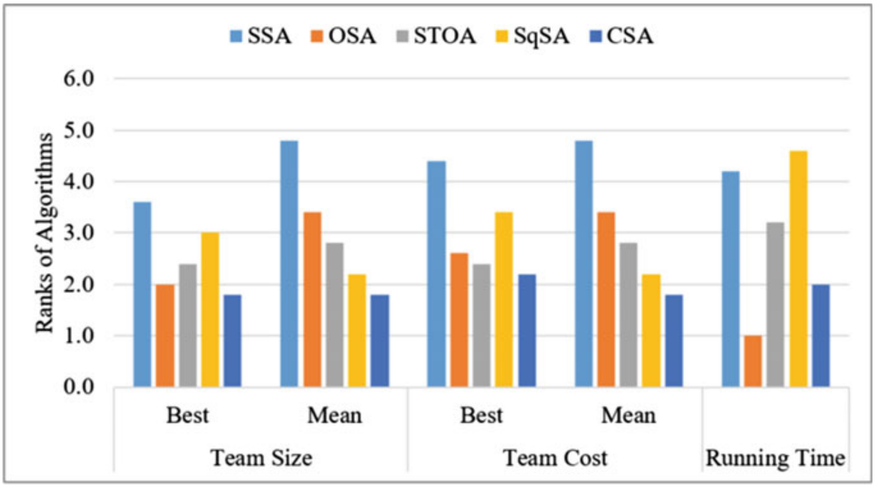

Fig. 3 Average ranking of compared algorithms in terms of team size (best and mean), team cost (best and mean), and running time

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References

1. Alamri HS, Zamli KZ (2019) PMT: Opposition-based learning technique for enhancing metaheuristic performance. IEEE Access 7:97653–97672. https://doi.org/10.1109/ACCESS.2019.2925088
2. Nasser AB, Hujainah F, Al-Sewari AA, Zamli KZ (2020) An improved Jaya algorithm-based strategy for t-way test suite generation. In: International conference of reliable information and communication technology. Emerging Trends in Intelligent Computing and Informatics. Springer International Publishing, Cham, pp 352–361 (2020)
3. Al-Omoush AA, Alsewari AA, Alamri HS, Zamli KZ (2019) Comprehensive review of the development of the harmony search algorithm and its applications. IEEE Access 7:14233–14245. https://doi.org/10.1109/ACCESS.2019.2893662
4. Zamli KZ, Din F, Ahmed BS, Bures M (2018) A hybrid Q-learning sine-cosine-based strategy for addressing the combinatorial test suite minimization problem. PLoS ONE 13(5):1–29. https://doi.org/10.1371/journal.pone.0195675
5. Kader MA, Zamli KZ (2020) Adopting Jaya algorithm for team formation problem. In: Proceedings of the 2020 9th international conference on software and computer applications. Association for Computing Machinery, pp 62–66 (2020)
6. Zhang L, Zhang X (2013) Multi-objective team formation optimization for new product development. Comput Ind Eng 64(3):804–811. https://doi.org/10.1016/j.cie.2012.12.015
7. Fathian M, Saei-Shahi M, Makui A (2017) A new optimization model for reliable team formation problem considering experts' collaboration network. IEEE Trans Eng Manage 64(4):586–593. https://doi.org/10.1109/TEM.2017.2715825
8. Basiri J, Taghiyareh F, Ghorbani A (2017) Collaborative team formation using brain drain optimization: a practical and effective solution. World Wide Web 20(6):1385–1407. https://doi.org/10.1007/s11280-017-0440-6
9. Husseinzadeh Kashan A (2014) League championship algorithm (LCA): an algorithm for global optimization inspired by sport championships. Appl Soft Comput 16:171–200. https://doi.org/10.1016/j.asoc.2013.12.005
10. Wolpert DH, Macready WG (1997) No free lunch theorems for optimization. IEEE Trans Evol Comput 1(1):67–82. https://doi.org/10.1109/4235.585893
11. Mirjalili S, Gandomi A, Mirjalili SZ, Saremi S, Faris H, Mirjalili S (2017) Salp Swarm Algorithm: a bio-inspired optimizer for engineering design problems. Adv Eng Softw. https://doi.org/10.1016/j.advengsoft.2017.07.002
12. Jain M, Singh V, Rani A (2018) A novel nature-inspired algorithm for optimization: squirrel search algorithm. Swarm Evol Comput 44:148–175. https://doi.org/10.1016/j.swevo.2018.02.013
13. Dhiman G, Kaur A (2019) STOA: a bio-inspired based optimization algorithm for industrial engineering problems. Eng Appl Artif Intell 82:148–174. https://doi.org/10.1016/j.engappai.2019.03.021
14. Askarzadeh A (2016) A novel metaheuristic method for solving constrained engineering optimization problems: crow search algorithm. Comput Struct 169:1–12. https://doi.org/10.1016/j.compstruc.2016.03.001
15. Shah AUM, Safri SNA, Thevadas R, Noordin NK, Rahman AA, Sekawi Z, Ideris A, Sultan MTH (2020) COVID-19 outbreak in Malaysia: actions taken by the Malaysian government. Int J Infect Dis 97:108–116. https://doi.org/10.1016/j.ijid.2020.05.093
16. Covid19 dataset. https://github.com/MAK660/Dataset/blob/master/Covid19_DataSet.txt (2020). Accessed 5 Nov 2020

Automatic Identification of Plastic Waste by HSV Colour

Irsyadi Yani, B. Firmansyah, Yulia Resti, Yenni Arnas, Rb. Budi Kartika, Todung Mulia Raja Nasution, W. Hendro, and Ika Endrawijaya

Abstract People don't enjoy living without plastic nowadays. It happens because, in almost every industry, plastic has become a commonly used material. However, at present, it causes the waste of plastic to increase. The process needs to be recycled to reduce the contamination of plastic waste. The manual recycling method has a high possibility of human error, therefore, this automatic system is designed to minimize human error. This research applies Artificial Neural Network (ANN) with three types of plastic to construct an automatic framework to classify and categorized plastic waste. This study also used HSV color space with six input characteristics (RHSV, GHSV, BHSV, mean2, entropy, and variance). The database analysis collected by the training and testing process focused on the implementation of an automatic identification and classification method for plastic bottles, and the rate of the percentage of progress achieved from the training process is 65.3%. The research process's percentage effectiveness is 57%.

Keywords Identification · Classification · Plastic Bottle · PET · HDPE · PP · HSV · Artificial neural networks

1 Introduction

Plastic becomes one of the favorite materials used for producing various items today. Plastic has advantageous bending, easy-to-form, translucent, heat-resistant, and light characteristics. People can discover many things in nearly every section of life that use plastics as the fundamental material. The increased use of plastic bottles begins to pile

I. Yani (✉) · B. Firmansyah
Faculty of Engineering, University of Sriwijaya, Sriwijaya, Indonesia
e-mail: irsyadiyani@ft.unsri.ac.id

Y. Resti
Faculty of Mathematics and Natural Science, University of Sriwijaya, Sriwijaya, Indonesia

Y. Arnas · Rb. B. Kartika · T. M. R. Nasution · W. Hendro · I. Endrawijaya
Indonesia Aviation Polytechnic, Curug, Indonesia

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up waste. Efficient processing is therefore needed. In addition to landfill and incineration [1], a plastic recycling process is an alternative approach toward the disposal of solid waste in the form of plastic. The recycling method was chosen because of the long and stable plastic life cycle. For the sorting process to run securely, cleanly, and effectively, automating the sorting process is a positive step. Nevertheless, the automatic sorting system has some disadvantages in certain processes that make it difficult to develop and also has some image quality and lighting problems [2]. The method of burning and burial is inefficient, can cause environmental contamination, and has an impact on the lives of living beings that are biotic and abiotic. Based on its fundamental compounds, plastic waste is classified into seven types: polyethylene terephthalate (PET), high-density polyethylene or HDPE, polyvinyl chloride (PVC) or vinyl, low-density polyethylene or LDPE, polypropylene or PP, polystyrene (PS), etc. This study uses a color sensor to define and distinguish forms of plastic waste by analyzing digital images of plastic waste to obtain a simple and effective method for its processing.

2 Literature Review

The picture is an object's reflection, resemblance, or imitation, produced from the capture of reflected light. In the kind of video signals such as television images or digital images that can directly be processed on media storage [3], image as the output of an optical data recording device is equivalent. The image is split into three groups, which are; RGB image, grayscale image, and binary image, based on the combined pixel colors. Image value can adjust from its physical properties to a scalar view, including the brightness of the monochromatic image, vectors, and matrices. Two forms, analog and digital divide the picture. For example, television screen images, X-ray images, photos, drawings, CT scans, and images on cassette tapes are a type of image that is continuous.

Digital images are arrays that are spelled out in a particular sequence of bits, containing complex and real values. Next, the analog image is transferred to digital format so that a computer program can be used to process it. The numbers stored are numbers that indicate in pixels the sum of pressure. Computer processing of digital images in the form of numerical data [3], In 2012, Hamed Masoumi carried out a separation of plastic resins based on Near Infrared (NIR) reflectance spectroscopy. With this method, the researchers were able to distinguish the types of plastic resins between polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS). Researchers state that the NIR method is an accurate method of analysis and separation but is not suitable for dark-colored plastics. In 2015, Biswajit Ruj et al. conducted a sorting analysis using a variety of plastic sorting methods. From the results of the analysis and observations of these researchers, it is stated that a good sorting technique is sensitive to small differences in gravity and commercial without high investment.

Image processing is also called an activity that seeks to enhance the quality of an image or image. Besides, it is usually divided into different categories, including image quality improvements, image segmentation, image extraction, and image restoration. Picture segmentation is an aspect of computer vision that separates digital images into segments to facilitate and alter the current image so that it can be analyzed more easily. Picture segmentation, including the use of pixel similarity and pixel discontinuity, can be achieved in two ways. Pixels of similarity are pixels that have the same intensity of the gray level, and pixel discontinuities are boundary pixels that have the community pixels' unequal gray intensity levels. It is easy to group photos using details on borders, colors, and backgrounds [4].

Colour is a set of many values present in a light wave that are spectral. The wavelength of light determines a color's identity. From the object, the capturing effect of the light intensity is mirrored. Each color is shown in a spectrum of critical components in the RGB model that are red, green, and blue. The Cartesian system of coordinates is the basis of this model.

The colors are projected on a cube, the main colors are occupied by three corners of the cube, and the secondary colors are cyan, magenta, and yellow at three more angles. Also, black and white are on the edges. In capturing color, the HSV or Hue, Saturation, Value color space is a reflection of the RGB color space that is adapted to the human sense of sight. Using the HSV color system [5], RGB colors can be translated to HSV colors. In Fig. 1, the HSV color space representation is shown.

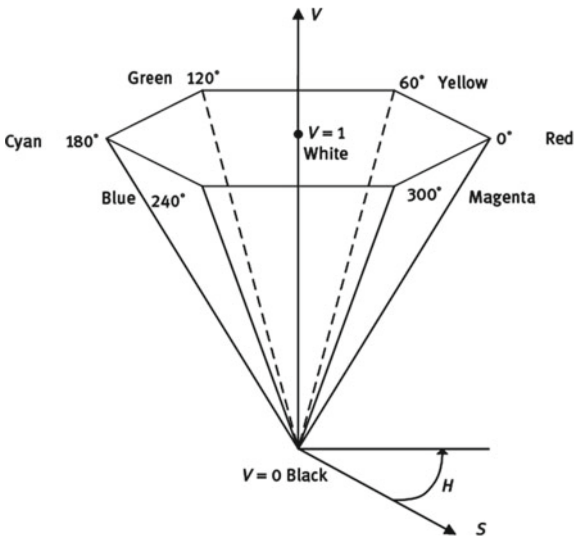


Fig. 1 Representation of HSV color space [3]

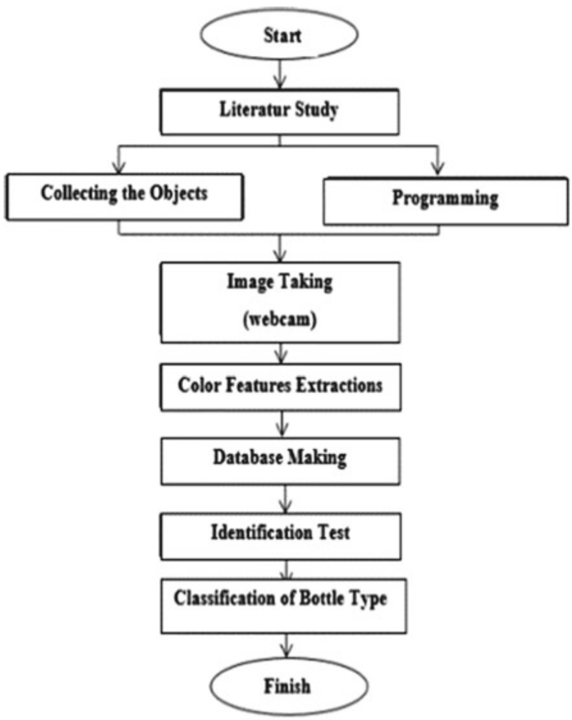
3 Methodology

This research was carried out based on the steps of the flow diagram, as shown in Fig. 2.

This work starts with an attempt to find research that supports, opposes, or similar paper, in order to find any similar studies that have been conducted over the past five years. Afterward that, to support the automatic framework, the items that are needed later should be collected and the software rendered. The three kinds of plastic bottles that need PET (polyethylene terephthalate), HDPE (high-density polyethylene), and PPP are (polypropylene). In this word those samples is chosen because easy to find out everywhere, any products in this world is producting with those plastic. For example is soft drink, many kind of soft drink is producting with PET (polyethylene terephthalate), HDPE (high-density polyethylene), and PP plastic are (polypropylene). This research used transparant bottles because it easier to identifty colored plastics by RGB method.

Taking photographs of things is the next step. This work uses a C270 webcam with a 720p/30fps resolution specification, a 60° view field, and a standard focused lens fixed to take the object's images. Set the image template to a resolution of 640 × 480 pixels and 24-bit colors, then store the image in jpg format. For the best output, high-quality images are necessary. From this process, the system will get a high-quality

Fig. 2 Study flow chart



picture with low noise. The next step is extracting color features after the process of taking pictures. Extraction features needed to obtain the plastic characteristics are used to detail the plastic form. The template is set to 280 180 33 33 cropping so that a 5×5-pixel resolution image is the output of the image cropping. The red variable, green variable, and blue variable color values are the products of this process.

After that, all the pictures have been collected to create the database. In this study, the objective of the database is to collect information based on the extraction of color characteristics. This system uses some new photos in the identification test in the programming process that have been taken randomly from the data test before. At random, but still, on the webcam focal area, the location of objects is put on the table. The data test consists of 90 images of the three types of randomly selected plastics. Finally, plastics will be automatically categorized into each category.

4 Result Dan Discussion

Wearing a webcam, collecting the images of plastic bottles, and then following the recognition and classification method using an automatic computer system. The key components of this study system are the webcam and the automated computer system. The value effects of a webcam capture of a plastic bottle image are in the form of HSV color space.

The first step in the image processing phase is capturing the image of plastic bottles. The image quality previously obtained may affect the quality of the raw data and may also affect the impact of the image results on the functioning of a complete system of identification and classification. The used webcam has an image sensor device that can generate images of high quality but has low noise. For this purpose, in this image processing stage analysis, a webcam has been selected as an image capturing system or can be referred to as an image sensing tool on Table 1.

Table 1 Digital image example of PET type

No	Plastic bottle image	Vertical	Horizontal	Diagonal
1	PET 1			
2	PET 2			
3	PET 3			

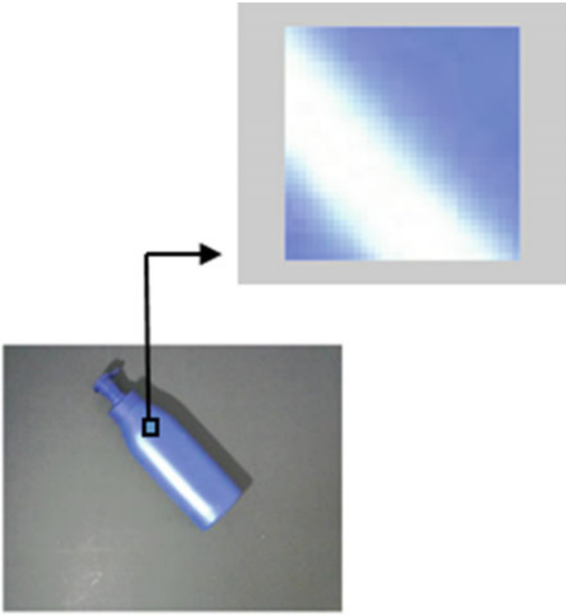


Fig. 3 Image cropping illustration

The image is converted into digital format 'jpg' after capturing the 738 samples, Those photos are collected according to their kinds, PET (polyethylene terephthalate), HDPE (high-density polyethylene), and PPP (polypropylene). To extract image features and find the characteristics of each bottle type, the images collected are needed. Picture capture to obtain the color characteristics of each stored image from each plastic bottle used as a test object. Figure 3. The picture cropping diagram is displayed.

The aim of building a database is to save the results obtained after the process of taking images and extracting image features is carried out. In several levels, digital forms from a database are carried out, such as image processing, image retrieval, identification, and classification. The information that has been compiled is processed and categorized by its sort.

As reference data applied in the identification and classification of plastic bottles, the HSV value of each plastic bottle is stored in the database. Figure 4 shows the RHSV, GHSV, and BHSV values for each type of plastic container. And the average value for RHSV, GHSV, and BHSV is shown in Fig. 5.

The training data total of 738 images; 258 PET images, 243 HDPE images, and 237 PP image samples. In this instruction, detection and classification systems are applied, where the system is attached to a computer system with a webcam as an image sensor interface. Result of the training is indicated to be effective outcomes. Based on the samples from the 738 plastic bottle picture. The results for each method of correct presentation of the plastic bottle identification and classification system are shown in Table 2.

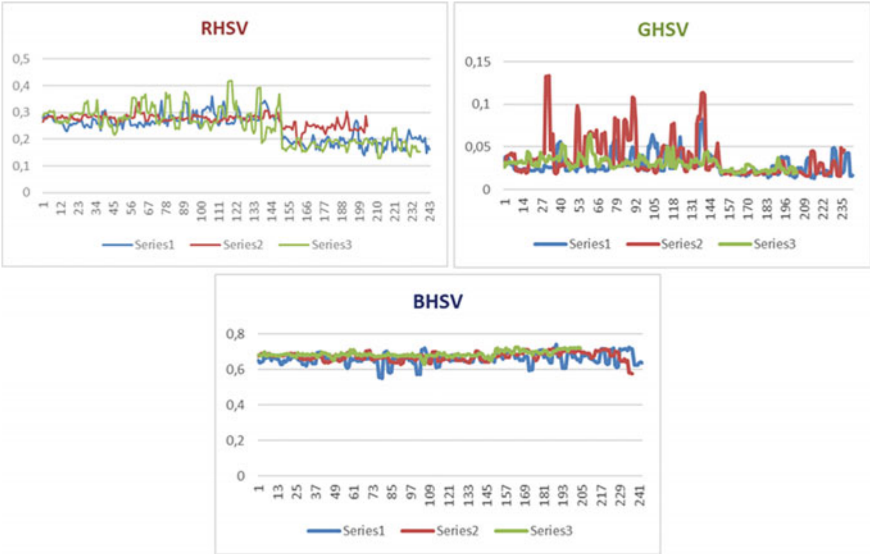


Fig. 4 HSV value of PET type (series 1), PP type (series 2), and PP type (series 3)

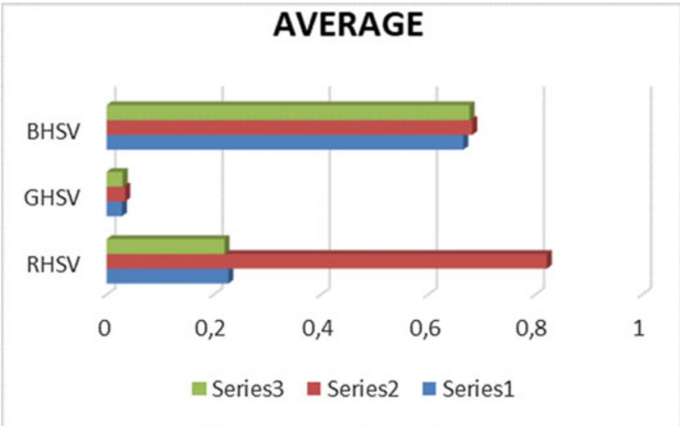


Fig. 5 The average value of RHSV, GHSV and BHSV

Table 2 Accurate presentation of data training

No	Plastic bottle image	Total image	Succeed	Accuracy presentation (%)
1	PET	258	202	78.68
2	HDPE	243	128	52.67
3	PP	237	178	75.10
Total		738	508	68.81

New samples are selected randomly for the testing process. With the central point yet in the image capture range, the bottle position in the image used as test data placed randomly. Test results amounted to 90 samples taken at random from three kinds of plastics. The method from this study is 57.8 percent accurate. 52 were successful in the testing process, 38 were unsuccessful.

The outcome of testing is 8% lower than the training process. Any factor can be triggered, and the bottle location in the picture used in the testing process is not precisely at the focus point of the crop, and the lighting variations between capturing a database image and the image for the testing process.

5 Conclusion

The purpose of this works is: First, a system has been built to simplify the automatic sorting process that can minimize the human error of the manual sorting process. Second, the automatic identification and classification of plastic bottle waste have been developed to facilitate the sorting process. Third, 68.81% of the successful identification and classification system training using HSV color characteristics is accurate. Besides, the accurate percentage of testing for plastic bottle data is 57.8%.

There are the followings suggestion that based on this work: For further it's recommended to use numerous size cropping to get the best template for identification and classification of plastic bottles, increase the number of plastic bottle samples as database as of the accuracy value obtained are getting better, try to use the other color variations of the lamp to maximize the intensity of the color space and it is also recommended to add more features besides R, G, and B in the HSV color space so that the results will be more accurate.

References

1. Chow CF, So WMW, Cheung TY (2016) Study and development of a new waste collection bin to facilitate education in plastic recycling. Appl Environ Educ Commun 15(1):45–57
2. Yani I, Budiman I (2015) Development of identification system of cans and bottle. J Phys Conf Ser 622(1). https://doi.org/10.1088/1742-6596/622/1/012053
3. Iswahyudi C (2010) Jurnal Teknologi Prototype Aplikasi Untuk Mengukur Kematangan Buah Apel Berdasarkan Kemiripan Warna. Institut Sains & Teknologi AKPRIND, Yogyakarta
4. Mitiche A, Ayed IB (2010) Variational and level set methods in image segmentation. Springer, New York
5. Thanki RM, Kothari (2019) Digital image processing using Scilab—exercise, vol 1. Springer, Wadhwan

Validation of Compressive Test of Biodegradable Lumbar Interbody Spinal Cage with Different Porous Structure Using Computed Tomography-Based Finite Element Analysis

Muhammad Hilmi Jalil, M. H. Mazlan, and M. Todo

Abstract Evaluation of spinal cage structures had been done using Computed tomography-based finite element analysis (CT/FEA) with homogenous bone properties. However, it is important to consider the inhomogeneity of bone properties in order to obtain more precise validation. This study compares the experimental and numerical analysis of CT/FEA by establishing relation between the Hounsfield Unit (HU) values, bone density and material properties. 6 cage designs with different pore structure were created and optimized based on the conventional bullet-shaped tip cage design. Specimens were fabricated using a fused deposition method (FDM) 3D printer. Unidirectional compression test machine was done and evaluated using FEA tool. A conventional bilateral mode configuration was applied to simulate standard PLIF procedure in the L4–L5. CT/FEA was done to characterize the stress profile of cage-endplate interface, cage body and failed element distribution. From the results, layers deviation and severe micro crack were seen at ruptured spinal cage specimen's side surface. OPEN SOLID showed highest value of compressive value in the experiment and simulation. Finally, FEM stress profiles indicated that subsidence might have occurred for CLOSE 1 mm, OPEN SOLID, and OPEN 1 mm cage designs at the cage-endplate interface due to the sudden spike at endplate region. Overall, optimally designed PLA spinal cages have sufficient mechanical properties to support lumbar interbody loads. Furthermore, this optimization technique may be utilized to balance the complex requirements of load-transfer, stress shielding, and porosity when using biodegradable material for fusion spinal cages.

M. H. Jalil (✉)
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, Pahang, Malaysia
e-mail: muhammadhilmi@ump.edu.my

M. H. Mazlan
Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia

M. Todo
Research Institute for Applied Mechanics, Kyushu University, Fukuoka, Japan

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Keywords CT-based FEA · Biodegradable · PLA · Lumbar interbody fusion · Spinal cage

1 Introduction

Spinal cage fusion is an alternative treatment for degenerative spinal diseases when conservative treatments fail. In Malaysia, the prevalence of back pain was found to be 6%, and it was rated as the eighth and tenth most common complaint in public and private primary healthcare clinics, respectively, in 2014 [1].

Interbody cages was found to provide instant stability and limit motion at the bone graft site, as well as allow immediate restoration of disk height [2].Conventional cages using metallic or PEEK had been known to give good results especially for fusion rate (>90%) and improved clinical outcomes [3, 4]. However, many studies reported postoperative complications associated with conventional cages, e.g. stress shielding, device-related osteopenia (reduction in protein and mineral content of bone tissue), and subsidence [5, 6]. Mechanical strength superiority of metallic cages was arguably ineffective when considering the failure to transport loads to stimulate bone tissue growth [5, 7].

The application of PLA, a biodegradable polymer has emerged in a wide range of fields, including biomedical engineering [8]. The increasing demand for biodegradable features for fusion spinal cages had driven many researchers to develop ways to optimize the mechanical properties of this material, including by combining it with other material such as chitosan [9]. Another critical aspect that needed to be attended was that the degradation of PLA should be timed with the increase of mechanical stability resulting from bone growth [10, 11]. Despite all these developments, alternative designs and fabrication method were also introduced to address the intrinsic drawbacks of bioresorbable materials. Previous studies had been done on the porous PCL/HA fusion cage design optimization and fabrication using laser sintering method [12]. Another study by C. Lin et.al had reported the using of FEA for analyzing an optimized cage design implanted in a homogenous material properties of spinal bone [13]. Obviously, only until recently, the designing and fabrication of polymer cage using CT-based FEM and 3DP method had not been conducted yet.

In this study, conventional designs such as bullet-shaped tip cages were used for the biodegradable cages. However, mere exchange of permanent based material may not provide sufficient strength for lumbar fusion. The primary advantage of PLA being able to degrade may not be fully optimized. A finite element analysis (FEA) was done using conventional cage design to provide insights on the optimization of new cage designs. In addition, porous structure was able to be introduced in the design using the 3DP method. Porous structure should help the stimulation of bone graft, without compromising the cage stiffness itself.

Thus, the goals of our study are to understand the stress density of implanted biodegradable spinal cage using FEA and to develop s well as fabricate an optimal porous design of spinal cage using 3DP based on the strain energy density distribution of solid cage model with biodegradable material, PLA. Finally, to understand the effect of different designs on the mechanical properties of the specimen and evaluate the experimental result with the simulation.

2 Methods and Materials

2.1 Porous Structure Design and Material

In this study, a spinal cage based on the geometry of TELAMON PEEK™ is used and designed using SOLIDWORKS™. This cage has a bullet-shaped tip, modelled to one lateral region to provide easier insertion during surgical procedure. Sharp teeth–like design on the surface of TELAMON cage was omitted to neglect stress yielding at this region. It could be added later during pre-clinical application to provide primary stability and to prevent possible cage migration. The characteristic of top surface and side surface were defined as Close or Open top, and Solid or Porous side, respectively. Two different unidirectional pore diameter was introduced in this study to understand the subsidence effect at the endplate interface of spinal bone. As shown in Fig. 1, a total of six different designs were created, i.e., CLOSE SOLID, CLOSE 2 mm, CLOSE 1 mm, OPEN SOLID, OPEN 2 mm, and OPEN 1 mm. These pore sizes are the optimum for cell attachment and the capability of the printer [14].

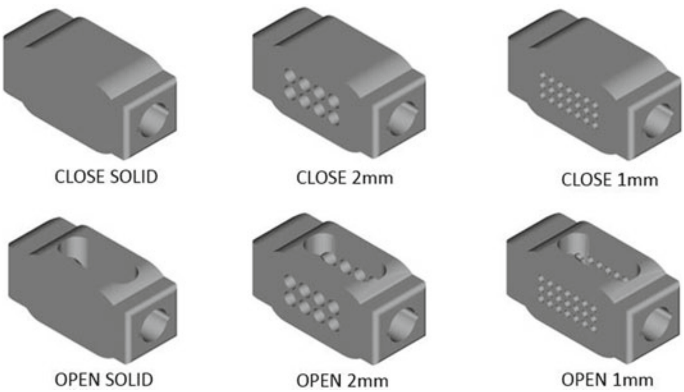

Fig. 1 Six different designs of spinal cage including the base model of CLOSE SOLID and optimized design of CLOSE 2 mm, CLOSE 1 mm, OPEN SOLID, OPEN 2 mm, and OPEN 1 mm

2.2 Experimental Setup

The main material used in this study was a biodegradable thermoplastic polymer, polylactic acid (PLA) filament (Kenbill Co.) with diameter 1.75 mm and natural colored. The melting temperature is around 190–220 °C with density 1.288 g/cm^3. A commercial 3D printer developed based on the FDM technique (Scoovo C170-S, Open Cube Inc.) was used to fabricate spinal cage specimens. The strut layer orientation was set to be perpendicular to the loading, in order to obtain the highest strength [15].

The dimension of finished prototype of the spinal cage was measured using Vernier calliper and any irregularity or defect such as missing or shifting layers, warping, stringing etc. are checked. Then, specimens were cleaned and brought to the compression test. In order to validate the mechanical strength of all 6 spinal cage designs, compression tests ASTM F2267 were conducted on fabricated fusion cages [16]. Compression tests of the specimens were carried out using a Compact Table-Top Universal/Tensile Tester machine Shimadzu EZ-L (Shimadzu Co.) equipped with a 5 kN load cell at a constant crosshead speed of 1 mm min^{-1}. Tests were performed in the direction perpendicular to the printing plane of the cages. The equivalent compressive modulus and the compressive strength were evaluated as the slope of the initial linear region, and the maximum value of stress in the stress–strain curve, respectively.

All tested specimens were selected and fracture morphology were observed using FE-SEM Hitachi S-4100 (Hitachi Co.) to investigate the microcrack phenomenon of each ruptured surface of spinal cage design.

2.3 Computed Tomography Based Finite Element Analysis (CT/FEA)

In order to further validate the load-supporting capacities of the designed cages, two types of FEA were conducted. The first CT/FEA was done using the CT scan images taken from a healthy 29-year old Japanese male (78 kg weight and 176 cm height) with a written informed consent permission received prior to the research. The FE model of L4 and L5 vertebrae was built using the CT images via the bone modelling function in the MECHANICAL FINDER™ software (Research Center of Computational Mechanics Co. Ltd. Japan). The anatomical structure of L4–L5 was obtained by utilizing the functions in the software and by extracting the region of interests (ROI) based on the extracted bone edges. L4 and L5 vertebral bones were defined as cancellous bone core encased by a 0.4 mm thick cortical bone. Next, L4–L5 which consist of the cancellous bone, intervertebral discs, and facet joint cartilage, were configured as solid tetrahedral elements of 1.0 mm in size; while the cortical bone was modelled with 1.0 mm linear shell triangular elements. The model contained approximately 1,286,000 solid elements and 91,000 shell elements [17].

Table 1 Material properties of bone

Young's modulus E(MPa)	Bone density ρ(g/cm^3)
$E = 0.01$	$\rho = 0.0$
$E = 33,900\rho^{2.20}$	$0.0 < \rho \leq 0.27$
$E = 5,307\rho + 46\ 9$	$0.27 < \rho < 0.6$
$E = 10,200\rho^{2.01}$	$0.6 \leq \rho$
Yield stress σ (MPa)	**Bone density** ρ(g/cm$^{\mathbf{3}}$)
$\alpha = 1.0 \times 10^{20}$	$\rho \leq 0.2$
$\alpha = 137\rho^{1.88}$	$0.2 < \rho \leq 0.317$
$\alpha = 114\rho^{1.72}$	$0.317 \leq \rho$
Poisson's ratio	**Bone density** ρ(g/cm$^{\mathbf{3}}$)
0.40	$0.0 \leq \rho$

The mechanical properties of the bone model were calculated using the Hounsfield Unit (HU) values, where the bone density of each tetrahedral element was defined as the average number of HU units inside each of the corresponded elements. The HU values ranged in between 192 and 414 [18]. Utilizing the relationship reported by Keyak [19], the value of Young's modulus, yield stress, and Poisson's ratio were obtained for the heterogeneous bone model as shown in Table 1. Poisson's ratio for the facet joints and intervertebral discs were defined as 0.45 and 0.2 respectively, while the Young's modulus were set at 8.4 MPa and 11 MPa for the facet joint and discs, correspondingly [20]. Figure 2 showed the solid and meshed model of the simulated L4–L5 vertebral bone attached with posterior instrumentation (PI).

The compression loads were 1000 N, flexion 900 N m, extension −1900 N m, lateral bending 4400 N m, and axial rotation 2900 N m, which are generally accepted as human lower back with moderate activity [21]. The loading and boundary condition of the model is shown in Fig. 3. This FEA was conducted to investigate how

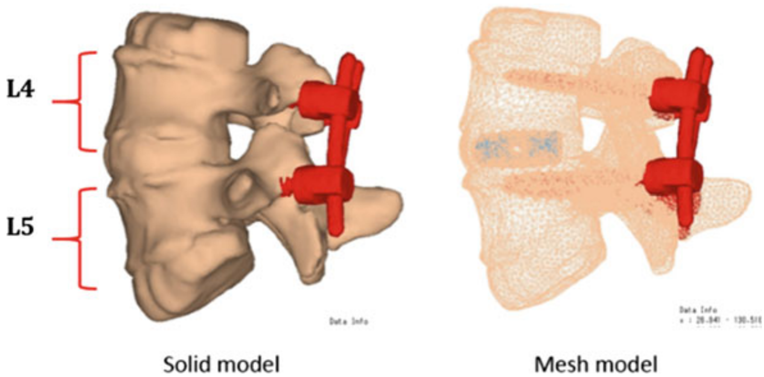

Fig. 2 Simulated L4–L5 bone

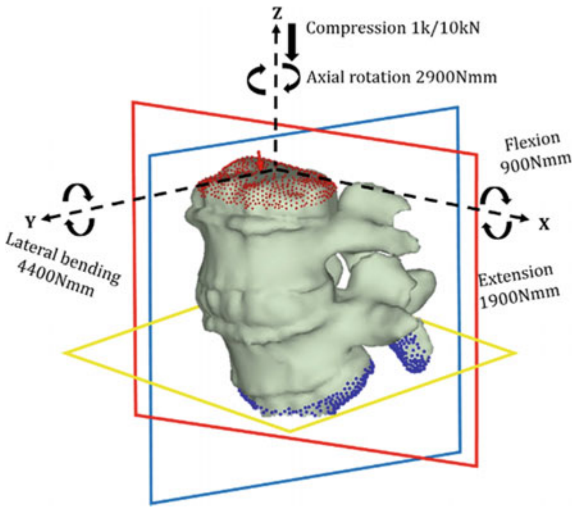

Fig. 3 Loading and boundary condition of FE model

the stress levels changed at the cage's body and inside the vertebral bone following PLIF surgery procedure.

Another FEA analysis was conducted using image-based FE method, where the cage designs were imported to Mechanical Finder software as single implant. Compression of 5000 N was loaded on to the superior surface of the fusion cage. The inferior surface of cage model was constrained at every direction. The loading and boundary condition of the model is shown in Fig. 4. To validate the experimental value of compressive modulus, the compressive modulus of this FE models were calculated and compared.

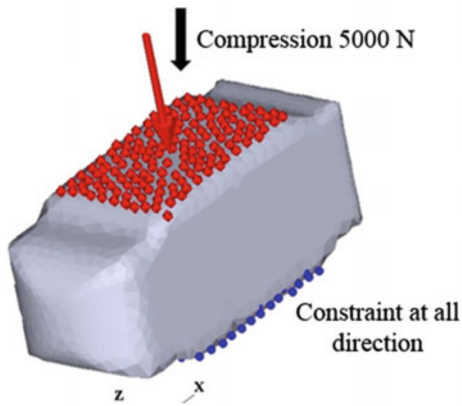

Fig. 4 Loading and boundary conditions of FEA using cage model

3 Results and Discussion

3.1 Porosity

The porosity of optimal design fusion cages was calculated in relative to the CLOSE SOLID cage, which was defined as solid bulk of 0% porosity. The theoretical porosity of volume percentage, $Vol_{porosity,th}$, was calculated for each specimen using the initial deposition geometries based on a unit cube, assuming that the strut diameter and spacing between layers were equal (i.e., no overlap caused by the merging between struts from one layer to another).

$$Vol_{porosity,\,th} = \left(1 - \frac{V_a}{V_{a,bulk}}\right) \times 100\% \tag{1}$$

where V_a is the apparent volume (mm^3) obtained using CAD software for each cage, $V_{a,bulk}$ is the apparent volume of a CLOSE SOLID bulk spinal cage (mm^3). The experimental porosity, $Vol_{porosity,exp}$, was also evaluated by;

$$Vol_{porosity,exp} = \left(1 - \frac{\rho_{exp}}{\rho_{exp,\,bulk}}\right) \times 100\% \tag{2}$$

$$\rho_{exp} = \frac{w_{exp}}{V_t}\ \left(gmm^{-3}\right) \tag{3}$$

$$\rho_{exp,bulk} = \frac{w_{exp,bulk}}{V_{t,bulk}}\ \left(\mathrm{g\,mm^{-3}}\right) \tag{4}$$

$$V_t = \frac{\pi d^2 L_{fil}}{4} \tag{5}$$

$$V_{t,bulk} = \frac{\pi d^2 L_{fil,bulk}}{4} \tag{6}$$

where ρ_{exp}, w_{exp}, $\rho_{exp,bulk}$, and $w_{exp,\,bulk}$ are the experimental density and weight of each spinal cage model, and the density and the weight of bulk specimen, respectively. And V_t, $V_{t,bulk}$, d, L_{fil}, and $L_{fil,bulk}$ refer to the true volume of spinal cage model and bulk model, filament dmeter, length of filament consumed during printing process of spinal cage model and bulk model, respectively.

As shown in Fig. 5, it was obvious that every spinal cage designs had higher porosity in relative to the bulk CLOSE SOLID cage design. Theoretically, the highest porosity was exhibited by OPEN 2 mm model of 15.8%, which had the open mid-surface with through hole and pores with diameter of 2 mm. The lowest theoretical relative porosity was shown by CLOSE 1 mm design with only 5.4%. Obviously, 2 mm porous structures had lesser volume than 1 mm porous structures and increase approximately 8% of SOLID porosity, thus making it as the most porous structure.

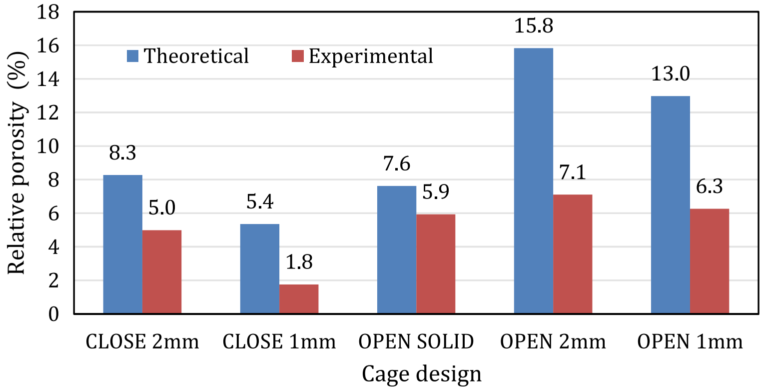

Fig. 5 Porosity of each spinal cage design in relative to bulk CLOSE SOLID model

In spite of this matter, the porosity of fabricated spinal cage of OPEN 2 mm was much lower compared to the theoretical. Experimentally, similar pattern could be seen where CLOSE 1 mm design had the lowest porosity of 1.8%. Unlike theoretical value of which the increase was more than double, OPEN 2 mm design provided 1.2% increase in porosity compared to OPEN SOLID design.

The inconsistency between theoretical and experimental relative porosity might be affected by the fabrication nature of 3DP machine, where each layers of strut will be compressed by the next upper layer and tend to bulge outwardly. Thus, more filaments were required and products of lower porosity were created.

In general, the fabricated spinal cages sustained a good dimensional accuracy and high porosity which is important to conduct fluid flow inside bone graft site. The permeability of spinal cage was directly dependent on its porosity and accuracy of interconnected porous geometry [15, 22].

3.2 Stress–Strain Curve

The stress–strain curves for each optimal cage design including the bulk CLOSE SOLID cage were obtained from the mechanical compression test. The cross sectional was assumed constant during deformation and the stress was calculated using the original cross section of each fusion cage design. As shown in Fig. 6, the SOLID structures with no porous associated reported significantly higher stiffness than the other two groups, i.e. 2 mm and 1 mm, respectively. It is apparent from this figure that the OPEN spinal cage structures design exhibited higher modulus compared to the CLOSE design group.

To assess the compressive modulus of fusion cages, experimental compressive modulus was obtained using the slope of linear region of stress–strain curves in Fig. 6. The experimental modulus and theoretical compressive modulus obtained

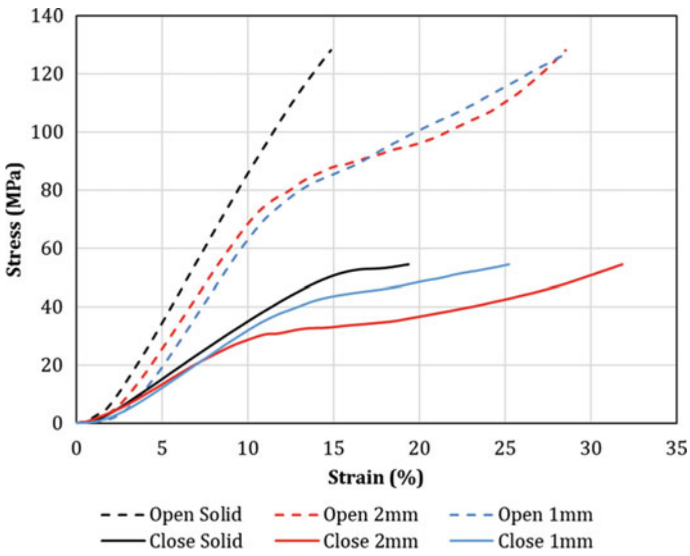

Fig. 6 Stress –strain curve of optimal cage design

using FEA can be compared in Fig. 7. Experimental modulus of CLOSE cage design groups were 399 MPa, 341.4 MPa and 377.5 MPa, for SOLID, 2 mm, and 1 mm, respectively. Experimental modulus of OPEN group of SOLID, 2 mm, and 1 mm, were 951.3 MPa, 868.1 MPa, and 693.4 MPa, respectively. The value of OPEN design group was approximately three times higher than CLOSE group.

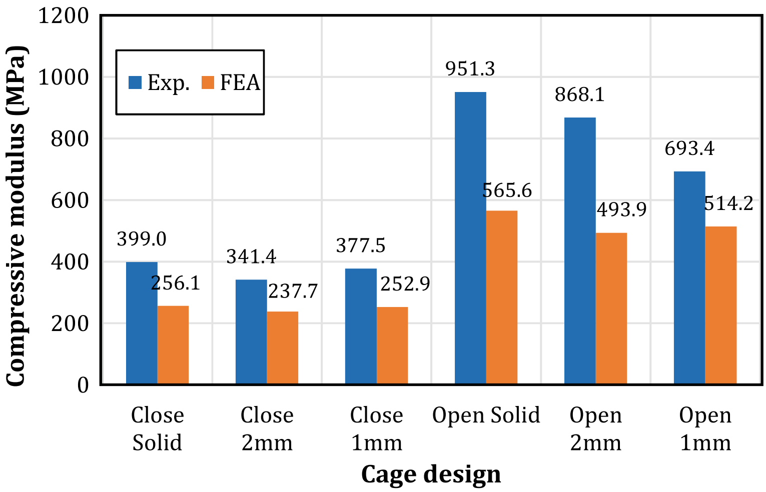

Fig. 7 Compressive modulus of experimental and theoretical fusion cage design

From the simulation result, modulus obtained were on average lower than experimental. The modulus for CLOSE group of SOLID, 2 mm, and 1 mm, were 256.1 MPa, 237.7 MPa, and 252.9 MPa, respectively. Similar to experimental pattern, theoretical modulus value of OPEN group cages was higher with approximately two times the value of CLOSE group cages. Overall, these results indicate that the OPEN group cage design provided a higher compressive modulus for both experimentally and theoretically. The compressive modulus showed by these fusion cages were much higher than average superoinferior vertebral bone compressive modulus, which was 164.7 MPa [23]. In spite of the difference between the predicted modulus and the experimental value, FEA could be used qualitatively to evaluate experimental value [24].

3.3 Morphology

Microscopic observation was conducted to investigate the crack phenomenon which occurred due to the compression test. SEM images of the side surfaces of each cage design followed by rupture by mechanical compression test can be seen in Figs. 8. In Fig. 8 with 300 times magnification, deviation of layers at side apex of tested cages were observed on every design construct. The deviations were obviously initiated from the bulge design at top surface of fusion cages. A dim divergence line could be seen along the deviation going towards the edge of porous region. No other cracks were found along the side of specimens. Some adjacent layers were observed to be isolated at CLOSE 2 mm image.

Additionally, microcracks measuring approximately 10 to 50 μm in length, could be seen to occurr along the deviation route, initiated from the top and proceeded towards porous regions edge. The microcracks were generated at the vertical direction of each strut layer. A possible explanation for these results may be the bending deformation of layers, assuming that opening fracture mode (Mode 1) as the crack propagation was perpendicular to the loading direction. Additionally, it can be assumed that the PLA layers failed under a small-scale yielding. The study by Patterson [25] managed to clarify the failure using the colour changing behaviour of red PLA during plastic deformation. However, due to usage of natural coloured filament in this study, similar images were not possible.

3.4 FEA: Cage-Endplate Interface Stress

Figure 9 represented the maximal Drucker–Prager (DP) stress values distribution of each ROI of L4 and L5. From Fig. 9a, sudden DP stress spikes were observed for CLOSE 1 mm, OPEN SOLID, and OPEN 1 mm cage designs, at cage-endplate interface. However, rest of the designs group showed similar profile of low DP stress through superior L4 to inferior L5. Looking at flexion motion, excluding CLOSE

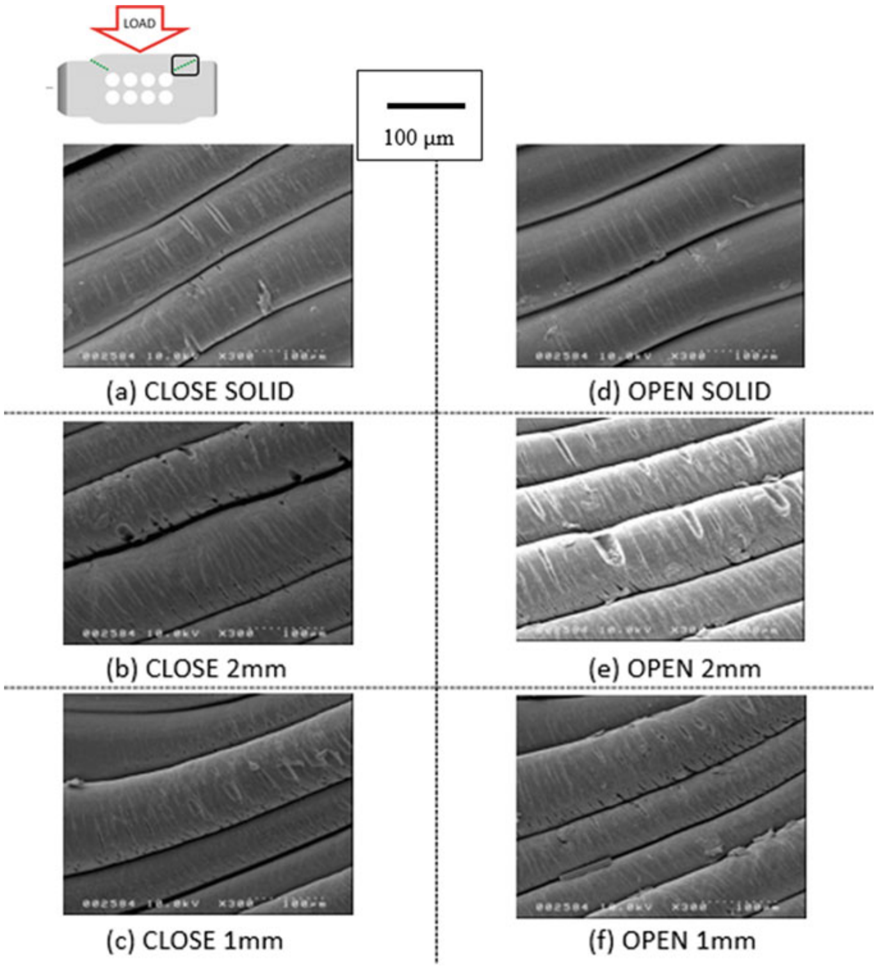

Fig. 8 SEM images at 300 times magnification of tested cages

SOLID design, other cage designs exhibited high DP stress of approximately 8 MPa at L4 superior and the stress decreased gradually towards cage insertion site. Similar pattern was observed for extension, lateral bending, and axial rotation, where CLOSE 2 mm, CLOSE 1 mm, OPEN SOLID, OPEN 2 mm, and OPEN 1 mm, were observed to have high DP stress around the first to third ROI of L4. What is interesting in this data is that the DP stress for CLOSE SOLID cage design remained low through each ROI. That uniform pattern can be seen for flexion, extension, lateral bending, and axial rotation. Slight spikes at cage-endplate interface were exhibited under flexion and extension loading for CLOSE 1 mm, OPEN SOLID, OPEN 2 mm, and OPEN 1 mm cage designs.

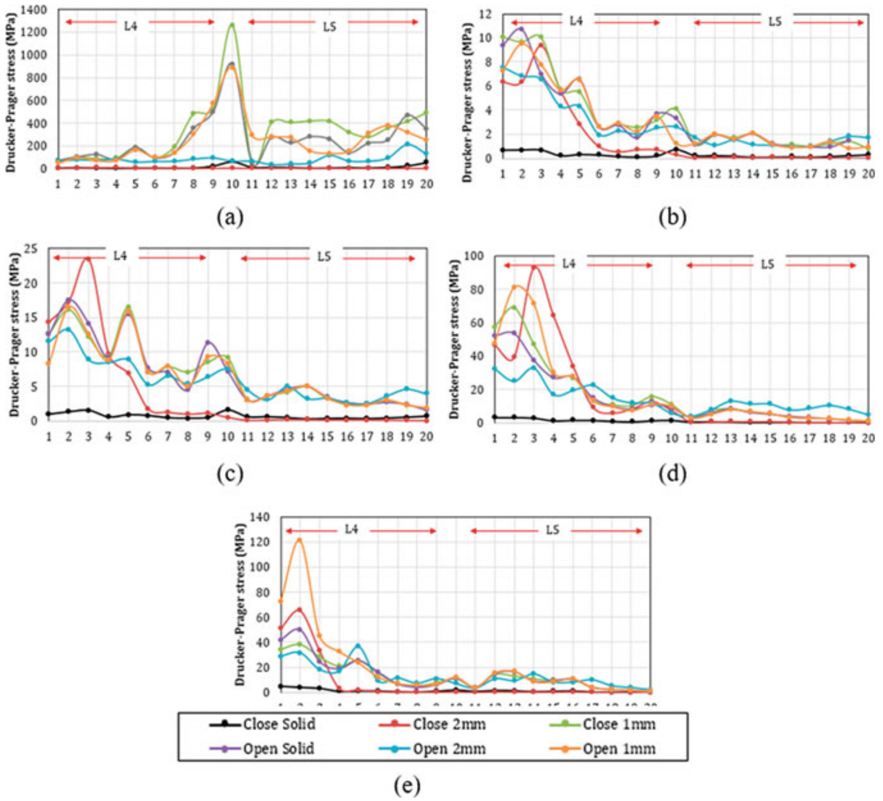

Fig. 9 Maximal **D**rucker–Prager stress distribution of **a** compression 1000 N, **b** flexion, **c** extension, **d** lateral bending, and **e** axial rotation

3.5 Cage Body Stress

Von Mises (VM) stress distribution of cage bodies for every design were observed to get insights on the load transfer mechanism between vertebral endplate and fusion cage bodies. It is also important to compare the load transfer ability of the optimal cage design and the effect of different cage designs. From Fig. 10, under compression, CLOSE 2 mm and OPEN 2 mm showed lower VM stress in relative to other cage designs, which were at 4.9 MPa and 7.1 MPa, respectively. Other designs ranged in between 174 to 231 MPa, which is more than 33 times higher. This result suggested that load was transferred in harmony between cage bodies for porous 2 mm structures. This could be a strong evidence to employ porous structures into fusion cage design. OPEN 2 mm cage design was observed to have lowest VM stress under flexion, extension, lateral bending, and axial rotation. On the other hand, CLOSE 2 mm had the highest stress value under flexion, extension, and lateral bending loading

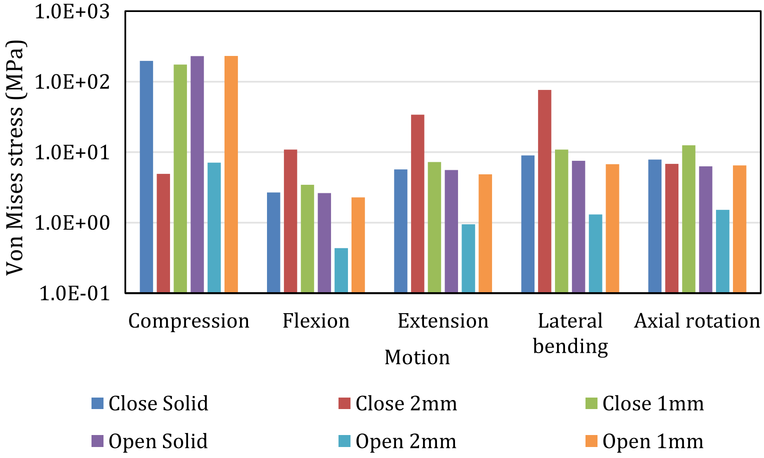

Fig. 10 Maximal Von-Mises stress at cage body

condition. Other cage design groups exhibited similar stress profile with no significant difference.

4 Conclusions

This study presents an optimization of spinal cage design with the help of FEA tool. The optimal designs were tested mechanically and evaluated using FEA. Further investigations on the mechanism of optimal cage design following application in spinal bone were also conducted. The experimental results suggested that porous geometry of 2 mm had the highest relative porosity, thus allowing better nutrients transport which was essential for bone growth. The compressive modulus of OPEN cage design group exhibited higher value, while no significant difference was observed between SOLID, 2 mm, and 1 mm cage structures of the same group.

Microscopic observation showed that layers deviation occurred at cage side and became the propagation site for microcrack at strut layers. Isolation of adjacent layers suggested was also observed, although no open crack was found. Finally, FEM stress profiles indicated that subsidence might have occur for CLOSE 1 mm, OPEN SOLID, and OPEN 1 mm cage designs, at the cage-endplate interface, due to the sudden spike at endplate region. At cage bodies, CLOSE 2 mm, and OPEN 2 mm showed lower VM stress in relative to other cage designs.

Based on experimental and computational verification, optimally designed PLA spinal cages have sufficient mechanical properties to support lumbar interbody loads. This, combined with a dynamic porous structure, may make it viable to control the degradation rate. However, preclinical testing of this hypothesis will be required.

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References

1. Sivasampu S et al (2016) National Medical Care Statistics (NMCS) 2014. National Clinical Research Centre, National Healthcare Statistics Initiative
2. McAfee PC (1999) Interbody fusion cages in reconstructive operations on the spine. J Bone Joint Surg Am 81:859–880
3. Kuslich SD, Ulstrom CL, Griffith SL, Ahern JW, Dowdle JD (1998) The Bagby and Kuslich Method of Lumbar Interbody Fusion: history, techniques, and 2-year follow-up results of a United States prospective, multicenter trial. Spine (Phila. Pa. 1976) 23:1267–78; discussion 1279
4. Whitecloud TS III et al (1998) Degenerative conditions of the lumbar spine treated with intervertebral titanium cages and posterior instrumentation for circumferential fusion. J Spinal Disord 11:479–486
5. Kanayama M et al (2000) In vitro biomechanical investigation of the stability and stress-shielding effect of lumbar interbody fusion devices. J NeurosurgerySpine 93(2):259–265
6. Dalenberg DD, Asher MA, Robinson RG, Jayaraman G (1993) The effect of a stiff spinal implant and its loosening on bone mineral content in canines. Spine (Phila Pa 1976) 18:1862–1866
7. van Dijk M, Smit TH, Sugihara S, Burger EH, Wuisman PI (2002) The effect of cage stiffness on the rate of lumbar interbody fusion: an in vivo model using poly(l-lactic Acid) and titanium cages. Spine (Phila. Pa. 1976) 27:682–688
8. Almeida CR et al (2014) Impact of 3-D printed PLA- and chitosan-based scaffolds on human monocyte/macrophage responses: unraveling the effect of 3-D structures on inflammation. Acta Biomater 10:613–622
9. Suyatma NE, Copinet A, Tighzert L, Coma V (2004) Mechanical and barrier properties of biodegradable films made from chitosan and poly (lactic acid) blends. J Polym Environ 12:1–6
10. Toth JM et al (2002) Evaluation of 70/30 D, L-PLa for use as a resorbable interbody fusion cage. Orthopedics 25:s1131–s1140
11. Lazennec JY, Madi A, Rousseau MA, Roger B, Saillant G (2006) Evaluation of the 96/4 PLDLLA polymer resorbable lumbar interbody cage in a long term animal model. Eur Spine J 15:1545–1553
12. Kang H, Lin CY, Hollister SJ (2010) Topology optimization of three dimensional tissue engineering scaffold architectures for prescribed bulk modulus and diffusivity. Struct Multidiscip Optim 42:633–644
13. Lin C-Y, Hsiao C-C, Chen P-Q, Hollister SJ (2004) Interbody fusion cage design using integrated global layout and local microstructure topology optimization. Spine (Phila. Pa. 1976) 29:1747–54
14. Bose S, Darsell J, Kintner M, Hosick H, Bandyopadhyay A (2003) Pore size and pore volume effects on alumina and TCP ceramic scaffolds. Mater Sci Eng C 23:479–486
15. Farzadi A, Solati-Hashjin M, Asadi-Eydivand M, Osman NAA (2014) Effect of layer thickness and printing orientation on mechanical properties and dimensional accuracy of 3D printed porous samples for bone tissue engineering. PLoS ONE 9:1–14
16. Lim KM, Park TH, Lee SJ, Park SJ (2019) Design and biomechanical verification of additive manufactured composite spinal cage composed of porous titanium cover and PEEK body. Appl Sci 9

17. Jalil MH, Mazlan MH, Todo M (2017) Biomechanical comparison of polymeric spinal cages using Ct based finite element method. Int J Biosci Biochem Bioinforma 7:110–117
18. Vivanco JF et al (2014) Estimating the density of femoral head trabecular bone from hip fracture patients using computed tomography scan data. Proc Inst Mech Eng Part H J Eng Med 228:616–626
19. Keyak JH, Rossi SA, Jones KA, Skinner HB (1998) Prediction of femoral fracture load using automated finite element modeling. J Biomech 31:125–133
20. Mazlan MH, Todo M, Takano H, Yonezawa I (2014) Finite element analysis of osteoporotic vertebrae with first Lumbar (L1) vertebral compression fracture. Int J Appl Phys Math 4:267–274
21. Nachemson A (1966) The load on lumbar disks in different positions of the body. Clin Orthop Relat Res 45:107–122
22. Eshraghi S, Das S (2012) Micromechanical finite-element modeling and experimental characterization of the compressive mechanical properties of polycaprolactone-hydroxyapatite composite scaffolds prepared by selective laser sintering for bone tissue engineering. Acta Biomater 8:3138–3143
23. Nicholson PH et al (1997) Structural and material mechanical properties of human vertebral cancellous bone. Med Eng Phys 19:729–737
24. Miranda P, Pajares A, Guiberteau F (2008) Finite element modeling as a tool for predicting the fracture behavior of robocast scaffolds. Acta Biomater 4:1715–1724
25. Patterson AE (2018) Crack Propagation in 3-D Printed PLA: Finite Element Modeling, Test Bed Design, and Preliminary Experimental Results, pp 1–13

Node-Based Soft Object Deformation Using Stress Estimation Method

Mohd Nadzeri Omar and Yongmin Zhong

Abstract Modeling of soft object deformation was dominated by the Mass Spring Method (MSM) and the Finite Element Method (FEM). Both methods require the discretization of a soft object into interconnected elements. The element-based deformation, however, has several weaknesses, such as it requires high computational costs to mesh the object, difficulty in handling topological changes, and complex mathematical calculations to describe the interconnected elements. This paper presents an initial investigation to address such deficiencies through a node-based approach associated with a stress estimation method. When a soft object is subjected to a load, the induced stresses at each node can be estimated using the Boussinesq equation. The estimated induced stress is then converted into movements based on the principle of energy conservation. The simulation model was developed in the MATLAB software. Simple deformation can be simulated with a high similarity to the FEM model generated by ABAQUS software. In terms of time performance, the proposed method clocked a slightly higher computational time with a difference of 1.0 s compared to the FEM model. Nevertheless, the findings show a promising performance of the proposed method.

Keywords Node-based deformation · Soft object deformation · Stress estimation method · Boussinesq method · Superposition

1 Introduction

In simulating soft object deformation, researchers need to choose between a few factors, accuracy, real-time interaction and computational costs. Accuracy is associated with high computational costs. A lot of resources are needed not only to solve

M. N. Omar (✉)
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: nadzeri@ump.edu.my

Y. Zhong
School of Engineering, RMIT University, Bundoora, VIC 3083, Australia

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complex mathematical formulations, but also to speed up calculations for real-time interaction. On the other hand, for real-time interactions with minimal computational costs, most of the time, assumptions were made to tackle the issue in a very simple way. As a result, the level of accuracy is lower.

Most of the methods used to simulate soft object deformation include the Finite Element Method (FEM) and the Mass Spring Method (MSM). The FEM model is based on continuum mechanics, where a soft object is partitioned into several elements related to each other. The behavior of the elements is governed by certain complex mathematical formulations which are derived from the properties of the material. This method, FEM, is known for its ability to simulate high-precision soft object deformation, thus commonly used in surgical simulators to simulate soft tissue deformation.

General properties of soft tissue, such as nonlinearity, anisotropic and viscoelastic, could be implemented in the FEM model with tiresome mathematical formulations. For the second method, MSM, a soft object is discretized into several mass points that are connected to the springs. MSM is preferred in terms of computational cost and real-time interaction due to its simplicity. Unfortunately, it has limited accuracy [1].

Both FEM and MSM rely heavily on the discretization of the soft object. Usually, element-based discretization is used where a soft object is discretized into a number of nodes that are linked to a specific type of element, such as the hexahedral and tetrahedral elements. In the case of a surgical simulation, where a simulated model is highly irregular, a huge effort is needed in the discretization process to produce a model of good quality and sometimes an experienced analyst is required to complete the job [2]. In addition, provided that a good quality discretized model is available, a further problem with element-based discretization is that it tends to become unstable and erroneous during distortion of large deformations and boundary changes that may occur when simulating neurosurgical procedures such as cutting and tissue removal [3]. Fixing the problems requires sophisticated re-meshing technologies and consumes valuable human time [4].

One of the solutions for simulating soft object deformation with high accuracy and in real time is the use of a numerical method that does not require such a strict element-based discretization. There are several studies that have already ventured into this kind of solution, which has been referred to as a meshless method. For example, Horton et al. [2] improvised the earlier work of Miller et al. [5] using the meshless approach in the Total Lagrangian Explicit Dynamics Method (TLED) to model brain deformation.

The meshless approach is applied in the sense that the deformation is calculated on nodes that are not part of the discretization element. Moreover, using the same TLED concept, Jin et al. [3] apply a meshless approach to simulate the soft tissue cutting process. It was to observe the reliability of the meshless method used to overcome the issue of topological changes. The study found that the meshless method is capable of performing better but only accessible for a two-dimensional model. The meshless approach suggests a new modeling approach that does not require the establishment of a relationship between nodes.

This paper proposes an alternative modeling approach that is not based on an elementary connection. Nodes can be placed almost arbitrarily within an object, not bounded to any elementary structure. When the object is subjected to a load, the stress is induced, leading to deformation. The proposed method estimates the induced stress based on the location of the nodes and converts the stress to displacement using energy conservation. Displacement of the nodes resulting in an object deformation.

2 Methodology

2.1 *The Boussinesq Method*

The load applied to the soft object surface creates stress within the mass of the soft object. For a linear and isotropic object, stress can be estimated at any location within the object. Kelvin, Boussinesq, and Cerruti methods are some of the methods commonly used to estimate stress in a soft object. These methods are widely used for soil mechanics [6]. The Kelvin method calculates stress in the event that a point inside a soft object is subjected to a normal load. The Mindlin method can also be used when tangential is considered [6]. On the other hand, loading on the surface or outside of a soft object is more practical for most of the time. In this case, stress can be estimated using methods such as Boussinesq and Cerruti [7]. The only difference between these two methods is that the Boussinesq method provides a solution for normal loading while the Cerruti method provides a solution for tangential loading. In this study, we will focus on the Boussinesq method, since only normal loading is considered.

The solution for the Boussinesq method is obtained by satisfying the Navier's elasticity equation, which is given as

$$\mu \nabla^2 \boldsymbol{u_i} + (\lambda + G)\frac{\partial e_v}{\partial x_i} + \boldsymbol{F_i} = 0 \tag{1}$$

where the pair of constant λ and μ are called Lame's constants. The term G is referred to as the shear modulus. The terms $\boldsymbol{u_i}$ and $\boldsymbol{F_i}$ are the displacement and body force component respectively. The remaining e_v is the bulk strain and $\boldsymbol{x_i}$ is the Cartesian coordinates. The operation ∇^2 is the Laplace's operator.

According to Saada [8], using the Boussinesq method, stress at any point within a soft object subject to normal load can be determined using the following equations

$$\sigma_r = \frac{\boldsymbol{P}}{2\pi}\left((1-2v)\left[\frac{1}{r^2} - \frac{z}{r^2}\left(r^2+z^2\right)^{-\frac{1}{2}} - 3r^2 z\left(r^2+z^2\right)^{-\frac{5}{2}}\right]\right) \tag{2}$$

$$\sigma_t = \frac{\boldsymbol{P}}{2\pi}(1-2v)\left[-\frac{1}{r^2} + \frac{z}{r^2}\left(r^2+z^2\right)^{-\frac{1}{2}} - z\left(r^2+z^2\right)^{-\frac{3}{2}}\right] \tag{3}$$

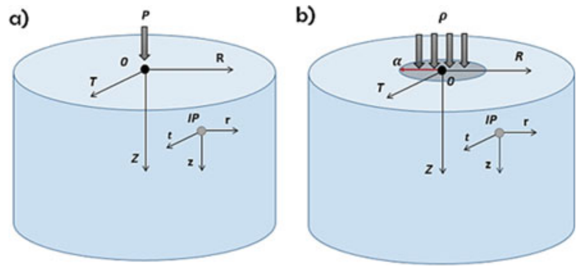

Fig. 1 Setup of the model and coordinate system used to define the Boussinesq method. **a** Point loading and **b** Uniform pressure loading

$$\sigma_z = -\frac{3\boldsymbol{P}}{2\pi} z^3 \left(r^2 + z^2\right)^{-\frac{5}{2}} \tag{4}$$

$$\tau_{rz} = -\frac{3\boldsymbol{P}}{2\pi} rz^2 \left(r^2 + z^2\right)^{-\frac{5}{2}} \tag{5}$$

where (z, r, t) is the coordinate of the Interest Point (IP) in the cylindrical coordinate system ZRT, σ and τ are the normal and shear stresses respectively and v is the Poisson's ratio. Illustration of the coordinate system is presented in Fig. 1a.

2.2 Superposition

The Boussinesq method only provides a point loading solution. In real practice, such a solution is not applicable since all the load applied will be confined to a specific point of contact. Realistically, the load must be applied to an area. In this paper, a soft object is considered to be subject to a uniform normal pressure acting on a circular surface (see Fig. 1b). The stress at any point inside the object can therefore be calculated by applying a superposition approach to the Boussinesq method.

According to McGinnes [9], in order to apply a superposition approach, it is necessary to consider two conditions which are distinguishable on the basis of the location of the point of interest (*IP*). The conditions are as shown in Fig. 2.

The solution for the case of uniform pressure acting over a circular area of radius α is obtained by replacing the concentrated load P by $\boldsymbol{\rho}\, r\, dr d\theta$ where $\boldsymbol{\rho}$ is the uniform pressure and $r\, dr d\theta$ is the differential contact area. It is desired to obtain the stress components along axes Z, R, and T, that are σ_R, σ_T, σ_Z and the shear stress τ_{RZ}. The stress components along the axes can be obtained from the following equations.

$$\sigma_R = \sigma_r \cos^2 \theta + \sigma_t \sin^2 \theta \tag{6}$$

$$\sigma_T = \sigma_r \sin^2 \theta + \sigma_t \cos^2 \theta \tag{7}$$

$$\sigma_Z = \sigma_z \tag{8}$$

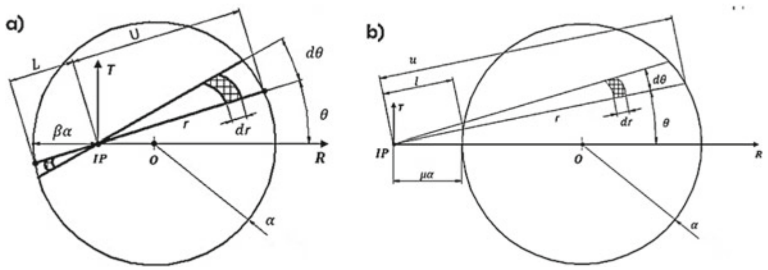

Fig. 2 **a** Illustration of Case 1 where the interest point IP is located within the circular loaded area. **b** Illustration of Case 2 where the interest point IP is located outside the circular loaded area

$$\tau_{RZ} = \tau_{rz} \cos\theta \tag{9}$$

Adding the Boussinesq solutions into Eq. (6)–(9), the solutions of the superposition in integral forms are given as the following

$$\begin{aligned}\frac{\sigma_R}{\rho} = \frac{(1-2v)}{2\pi}\int_{\theta_1}^{\theta_2}\int_{L}^{U} \cos^2\theta\left[\frac{1}{r} - \frac{z}{r\left(r^2+z^2\right)^{\frac{1}{2}}} - \frac{3r^3 z}{(1-v)\left(r^2+z^2\right)^{\frac{5}{2}}}\right] \\ + \sin^2\theta\left[-\frac{1}{r} + \frac{z}{r\left(r^2+z^2\right)^{\frac{1}{2}}} + \frac{rz}{\left(r^2+z^2\right)^{\frac{3}{2}}}\right] dr\, d\theta\end{aligned} \tag{10}$$

$$\begin{aligned}\frac{\sigma_T}{\rho} = \frac{(1-2v)}{2\pi}\int_{\theta_1}^{\theta_2}\int_{L}^{U} \sin^2\theta\left[\frac{1}{r} - \frac{z}{r^2\left(r^2+z^2\right)^{\frac{1}{2}}} - \frac{3r^3 z}{(1-v)\left(r^2+z^2\right)^{\frac{5}{2}}}\right] \\ + \cos^2\theta\left[-\frac{1}{r} + \frac{z}{r\left(r^2+z^2\right)^{\frac{1}{2}}} + \frac{rz}{\left(r^2+z^2\right)^{\frac{3}{2}}}\right] dr\, d\theta\end{aligned} \tag{11}$$

$$\frac{\sigma_Z}{\rho} = -\frac{3}{2\pi}\int_{\theta_1}^{\theta_2}\int_{L}^{U} \frac{rz^3}{\left(r^2+z^2\right)^{\frac{5}{2}}}\, dr\, d\theta \tag{12}$$

$$\frac{\tau_{RZ}}{\rho} = -\frac{3}{2\pi}\int_{\theta_1}^{\theta_2}\int_{L}^{U} (\cos\theta)\frac{r^2 z^2}{\left(r^2+z^2\right)^{\frac{5}{2}}}\, dr\, d\theta \tag{13}$$

In case 1, the interest point IP is located at a distance $\beta\alpha$ (where α is the radius of the circular region) from the boundary of the circle and a distance γa below the surface. Referring to Fig. 2a, the distance U can be calculated using

$$U = \alpha\left[(1-\beta) + \sqrt{(1+\beta)^2 + \frac{\beta(2-\beta)}{\cos^2\ \theta}}\ \right]\cos\ \theta \tag{14}$$

meanwhile, the distance L can be determined using

$$L = -\alpha\left[(1-\beta) - \sqrt{(1+\beta)^2 + \frac{\beta(2-\beta)}{\cos^2\ \theta}}\ \right]\cos\ \theta \tag{15}$$

where in both distances, only the positive root of the square root is used.

The integrals in Eq. (10)–(13), must be evaluated for two sets of limits and summed, namely between U and zero, and between L and zero. Then, the limits of θ are between $\frac{\pi}{2}$ and zero. The solutions for both U and L distance limits over the [0, $\frac{\pi}{2}$] angle, are then multiplied by two for the entire circular region.

In case 2, the interest point IP is located at a distance $\mu\alpha$ from the boundary of the circle and a distance $\gamma\alpha$ below the surface. The limits, upper and lower, of the bracketed terms in Eq. (10)–(13), can be represented by Eq. (16) and Eq. (17) respectively while the limits of θ are between $arc\ \tan\sqrt{\frac{1}{\mu(\mu+2)}}$ and zero. Again, superposition for the entire circular area can be found by multiplied the solutions by two.

$$u = \alpha\left[(1+\mu) + \sqrt{(1+\mu)^2 - \frac{\mu(\mu+2)}{\cos^2\ \theta}}\right]\cos\theta \tag{16}$$

$$l = \alpha\left[(1+\mu) - \sqrt{(1+\mu)^2 + \frac{\mu(\mu+2)}{\cos^2\ \theta}}\right]\cos\ \theta \tag{17}$$

The final form of the superposition solutions for both cases are given in the Appendix.

2.3 Model Dynamics

Stress that occurs at a point as a result of the load being distributed generates potential energy at that point. In order to balance the total energy, the potential energy must be transformed into another form of energy. Supposing that the problem is adiabatic, total energy can simply be balanced by converting potential energy into kinetic energy. Kinetic energy gives the point some movements that can be measured in terms of displacements or strains.

The potential energy at a point can be measured in the form of the energy density of the strain. The energy density of the strain is a measure of the energy of the strain stored in a small volume element in the material. Assuming that the volume is unity, according to Hooke's law, the total energy density of the strain SE at point i can be calculated using stress components as

$$SE_i = \frac{1}{2E}\left(\sigma_r^2 + \sigma_\theta^2 + \sigma_z^2\right) - \frac{v}{E}\left(\sigma_r\sigma_\theta + \sigma_\theta\sigma_z + \sigma_z\sigma_r\right) + \frac{1}{2G}\left(\tau_{r\theta}^2 + \tau_{\theta z}^2 + \tau_{rz}^2\right) \tag{18}$$

where E and G are the elastic and shear modulus respectively.

The force on node i can be determined from derivative of the strain energy at the point position $\boldsymbol{x}$, in any desired direction as given in Eq. (19).

$$\boldsymbol{F}_i = -\frac{\partial SE}{\partial \boldsymbol{x}_i} \tag{19}$$

The proposed method can then be proceeded dynamically using the explicit forwarding scheme of the first order. At each time step Δt, the new position of the node i can be determined using

$$\mathbf{x}_\mathbf{i}^{t+\Delta t} \leftarrow \mathbf{x}_\mathbf{i}^t + \Delta t\left(\mathbf{v}_\mathbf{i}^t + \Delta t\frac{\boldsymbol{F}_i^t}{m_i}\right) \tag{20}$$

where $\mathbf{x}_\mathbf{i}^{t+\Delta t}$ and $\mathbf{x}_\mathbf{i}^t$ are the positions of node i at time $t + \Delta t$ and t, respectively; $\mathbf{v}_\mathbf{i}^t$ is the velocity of node i at time t, $\boldsymbol{F}_i^t$ is the force acting on the node i at time t, and m_i is the mass of node i.

The new velocity $\mathbf{v}_\mathbf{i}^{t+\Delta t}$ of node i at time $t + \Delta t$ is calculated by

$$\mathbf{v}_\mathbf{i}^{t+\Delta t} \leftarrow \frac{\mathbf{x}_\mathbf{i}^{t+\Delta t} - \mathbf{x}_\mathbf{i}^t}{\Delta t} \tag{21}$$

3 Results and Discussion

3.1 Stress Distribution

A cylindrical model representing a soft object is designed with a radius and a height of 0.08 m and 0.2 m respectively. The cylinder is subjected to a uniform compression pressure of 10 kPa in the normal direction on a circular area with a radius of 0.01 m at the top of the cylinder. The location of the applied pressure is at the center of the cylinder, which is also the location of the origin (see Fig. 1b). In terms of material properties, the elastic modulus and the Poisson ratio of the cylinder are respectively 50 GPa and 0.3.

First, an analysis was carried out to compare the distribution of stress within a soft object between the proposed method and the FEM model. The proposed method

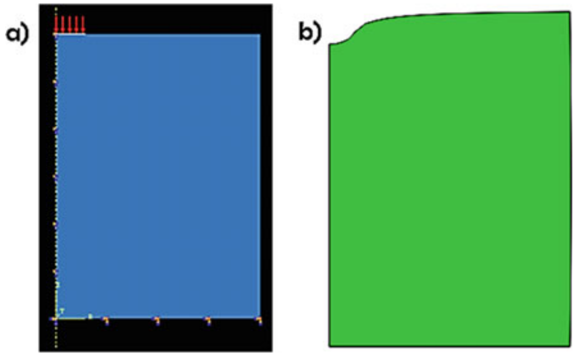

Fig. 3 **a** The setup of the FEM simulation model. **b** The FEM model during deformation

has been developed in MATLAB software while the FEM model has been generated using ABAQUS software. The setup of the FEM model is shown in Fig. 3a where the axisymmetric cylinder was used and the nodes were meshed at 0.002 m apart. The resulting stress distributions for the proposed model are shown in Fig. 4 while the FEM model is in Fig. 5.

Based on Figs. 4 and 5, the stress distribution for both models is similar for all the stress components. The similarity indicates the applicability of the Boussinesq method and the superposition approach. Besides, as indicated by Omar et al. [12], for the uniaxial compression test, the dominant component is the vertical stress which is parallel to the compression direction. The fact is true for both models (see Figs. 4c and 5c).

3.2 Simulation Model

The same cylindrical model as shown in Fig. 1b is used with the material properties in terms of the elastic modulus and the Poisson ratio is 30 GPa and 0.3 respectively. Nodes are placed arbitrarily (0.002 m between nodes) along the volume of the cylinder. The model is subjected to a uniform compression pressure of 10 kPa and the image of the model during deformation is shown in Fig. 6. The result shows that significant deformation occurs around the loading area. Nodes located in the center of the contact region are the most displaced.

Furthermore, a comparison was also made by plotting the resulting vertical displacement of the point of origin under different compression pressures. Both the proposed and FEM models are 20 kPa and 0.4 for the elastic modulus and the Poisson ratio respectively. It can be seen in the Fig. 7 that the results plotted for both models have similar behavior where the displacement is proportional to the pressure. Plus, it is noted that both findings are consistent at lower pressures, but vary during higher pressures. At a point where the normal pressure is equal to 60 kPa, the relative difference between the two results is approximately 10%.

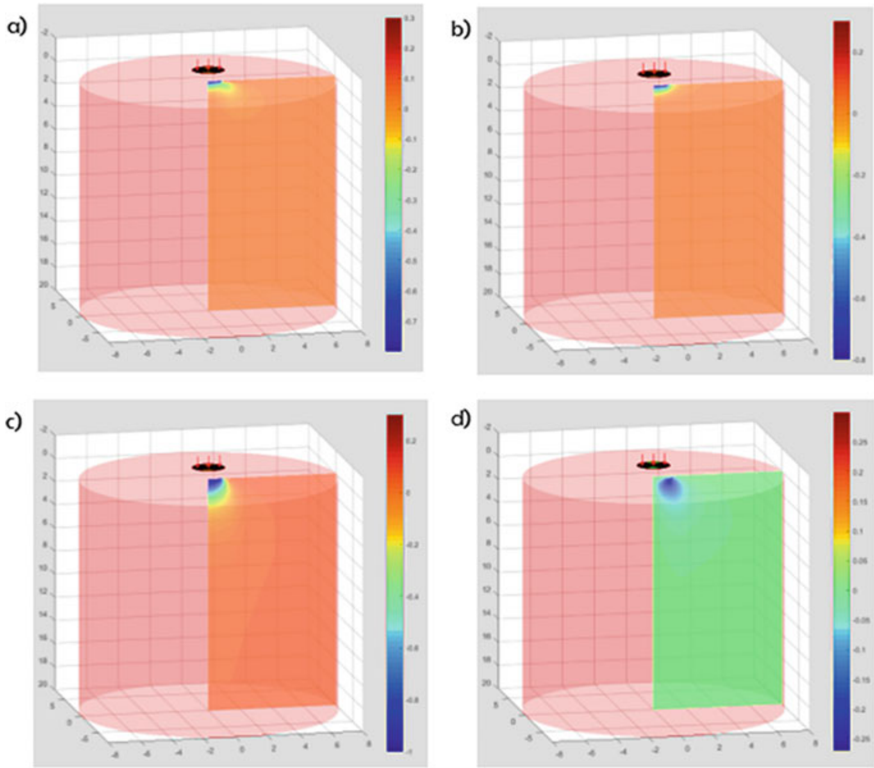

Fig. 4 Stress distribution for the proposed method. **a** Analytical result of horizontal stress (σ_R) distribution. **b** Analytical result of horizontal stress (σ_T) distribution. **c** Analytical result of vertical stress (σ_z) distribution. **d** Analytical result of shear stress (τ_{rz}) distribution

3.3 Computational Efficiency

A further analysis was conducted to assess the computational efficiency of the system. It was measured in terms of computational time which the time is recorded using an embedded timer. Computational time is recorded for both the proposed model (measured in MATLAB) and the FEM model (measured in ABAQUS). Both measurements were run on a Windows 10 desktop with Intel Core i7 processor, 16 GB RAM and NVDIA GT710 2 GB graphics memory. It should be noted here that the comparison used may not be accurate since it has been carried out on different platforms. However, the recorded time can still be used to observe the overall performance of the system. The time recorded measures the time taken to complete the numerical parts only. As shown in Table 1, it can be seen that the proposed method was slightly higher than the FEM model. The difference is about 1.0 s.

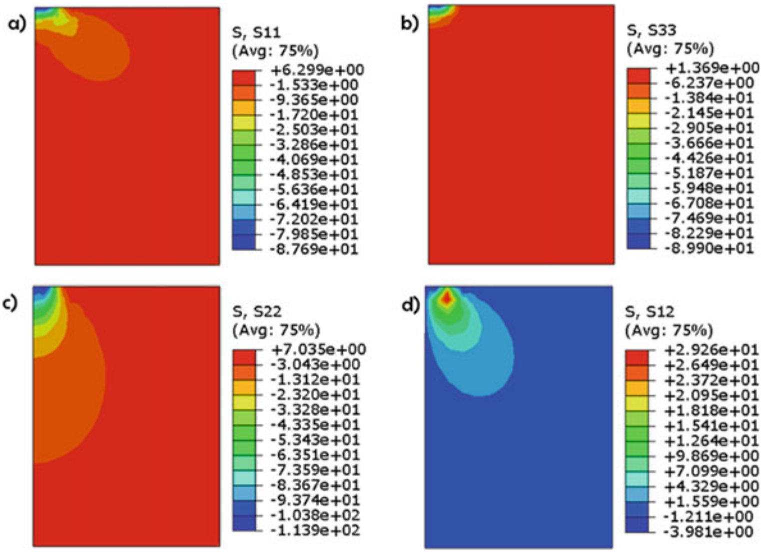

Fig. 5 Stress distribution of the FEM model generated using ABAQUS software. **a** FEM result of horizontal stress (σ_R) distribution. **b** FEM result of horizontal stress (σ_T) distribution. **c** FEM result of vertical stress (σ_z) distribution. **d** FEM result of shear stress (τ_{rz}) distribution

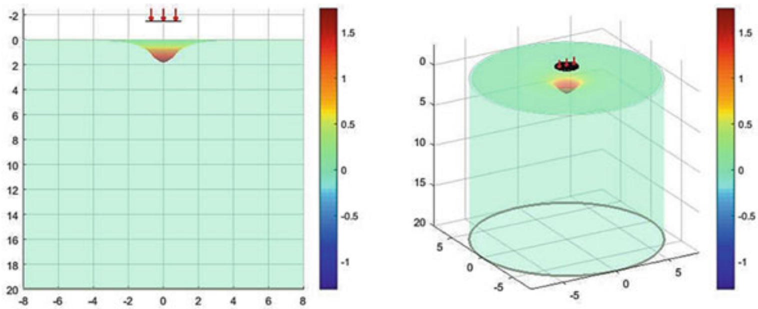

Fig. 6 Image of the proposed cylindrical model during deformation

4 Conclusion

A new approach to modeling soft object deformation was proposed and analyzed in this paper. The approach is developed with regard to linear elastic theory. By using the Boussinesq method and the superposition approach, stress can be determined at any point in a soft object under uniform compression pressure. The estimated stress is then used to define the deformation and dynamics of the soft object model.

Moreover, the comparisons made with the FEM model show a promising behavior of the proposed method. The proposed method is capable of producing similar stress

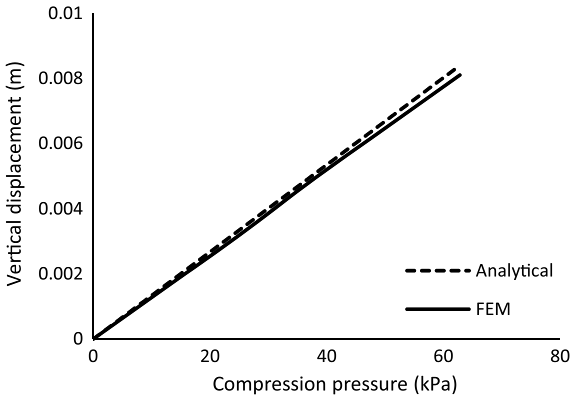

Fig. 7 The resulting vertical displacement of the point of origin when subjected to different compression pressures for the analytical (proposed) and FEM models

Table 1 Computational time for the FEM and proposed model

Model	Computational time (s)
FEM Model	1.94
Proposed Model	3.13

distributions and deformation behavior. Although the computational time of the proposed method is higher than that of the FEM, it was expected since the proposed method was compared to a commercial software that had been installed for certain optimizations. On top of that, the FEM model was an axisymmetric model that simplifies the calculation. However, future work can be done to improve the calculation structures, in particular the integration of the components in the superposition method.

Calculation of stress and subsequent deformation took place independently on the individual node. Node arrangement is not critical, but higher accuracy may be recorded if more nodes are located near the contact region. Although the proposed method is capable of simulating deformation, only uniaxial loading is considered. Further analysis should be carried out in order to observe the behavior of the model under different loading conditions.

Future work can be done using different stress estimation methods. The Boussinesq method is a classical approach, limited to linear and isotropic materials. There are a number of current studies that extend the Boussinesq method to nonlinear and anisotropic materials, for example, the studies conducted by Prioul et al. [10] and Tekinsoy et al. [11]. These studies can be used to improve the application of the proposed method.

Appendix

Calculation for Case 1 [9]

$$\frac{\sigma_{R1}}{p} = \frac{(1-2v)}{\pi} \int_0^{\pi/2} \left(os\ 2\theta \left[\log \frac{\left(\gamma + \sqrt{U^2+\gamma^2}\right)\left(\gamma + \sqrt{L^2+\gamma^2}\right)}{4\gamma^2} \right] + \frac{\cos^2\ \theta}{(1-2v)} \left[\frac{3\gamma\left(U^2 + \frac{2}{3}\gamma^2\right)}{\left(U^2+\gamma^2\right)^{\frac{3}{2}}} + \frac{3\gamma\left(L^2 + \frac{2}{3}\gamma^2\right)}{\left(L^2+\gamma^2\right)^{\frac{3}{2}}} - 4 \right] - \sin^2\ \theta \left[\frac{\gamma}{\left(U^2+\gamma^2\right)^{\frac{1}{2}}} + \frac{\gamma}{\left(L^2+\gamma^2\right)^{\frac{1}{2}}} - 2 \right] \right) d\theta \tag{22}$$

$$\frac{\sigma_{T1}}{p} = \frac{(1-2v)}{\pi} \int_0^{\pi/2} \left(\cos\ 2\theta \left[\log \frac{\left(\gamma + \sqrt{U^2+\gamma^2}\right)\left(\gamma + \sqrt{L^2+\gamma^2}\right)}{4\gamma^2} \right] + \frac{\sin^2\ \theta}{(1-2v)} \left[\frac{3\gamma\left(U^2 + \frac{2}{3}\gamma^2\right)}{\left(U^2+\gamma^2\right)^{\frac{3}{2}}} + \frac{3\gamma\left(L^2 + \frac{2}{3}\gamma^2\right)}{\left(L^2+\gamma^2\right)^{\frac{3}{2}}} - 4 \right] - \cos^2\ \theta \left[\frac{\gamma}{\left(U^2+\gamma^2\right)^{\frac{1}{2}}} + \frac{\gamma}{\left(L^2+\gamma^2\right)^{\frac{1}{2}}} - 2 \right] \right) d\theta \tag{23}$$

$$\frac{\sigma_{Z1}}{\boldsymbol{p}} = \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \left[\gamma^3 \left(\frac{1}{\left(U^2+\gamma^2\right)^{\frac{3}{2}}} + \frac{1}{\left(L^2+\gamma^2\right)^{\frac{3}{2}}} \right) - 2 \right] d\theta \tag{24}$$

$$\frac{\tau_{RZ1}}{\boldsymbol{p}} = -\frac{1}{\pi} \int_0^{\pi/2} (cos\ \theta) \left[\frac{U^3}{\left(U^2+\gamma^2\right)^{\frac{3}{2}}} - \frac{L^3}{\left(L^2+\gamma^2\right)^{\frac{3}{2}}} \right] d\theta \tag{25}$$

where

$$U = \left[(1-\beta) + \sqrt{(1+\beta)^2 + \frac{\beta(2-\beta)}{cos^2\ \theta}} \right] \cos\theta \tag{26}$$

$$L = -\left[(1-\beta) - \sqrt{(1+\beta)^2 + \frac{\beta(2-\beta)}{\cos^2\ \theta}} \right] \cos\theta \tag{27}$$

Calculation for Case 2 [9]

$$\frac{\sigma_{R2}}{\boldsymbol{p}} = \frac{(1-2v)}{2\pi} \int_0^{\Phi} \Bigg(\cos\ 2\theta \left[\log \frac{\left(\gamma + \sqrt{u^2+\gamma^2}\right)}{\left(\gamma + \sqrt{l^2+\gamma^2}\right)} \right] + \frac{\left(\cos^2\ \theta\right)(3\gamma)}{(1-2v)} \left[\frac{\left(u^2 + \frac{2}{3}\gamma^2\right)}{\left(u^2+\gamma^2\right)^{\frac{3}{2}}} - \frac{\left(l^2 + \frac{2}{3}\gamma^2\right)}{\left(l^2+\gamma^2\right)^{\frac{3}{2}}} \right] - \left(\ \sin^2\ \theta\right)(\gamma) \left[\frac{1}{\left(u^2+\gamma^2\right)^{\frac{1}{2}}} - \frac{1}{\left(l^2+\gamma^2\right)^{\frac{1}{2}}} \right] \Bigg) d\theta \tag{28}$$

$$\frac{\sigma_{T2}}{\boldsymbol{p}} = \frac{(1-2v)}{2\pi} \int_0^{\Phi} \Bigg(-\cos\ 2\theta \left[\log \frac{\left(\gamma + \sqrt{u^2+\gamma^2}\right)}{\left(\gamma + \sqrt{l^2+\gamma^2}\right)} \right] d\theta + \frac{\left(\sin^2\ \theta\right)(3\gamma)}{(1-2v)} \left[\frac{\left(u^2 + \frac{2}{3}\gamma^2\right)}{\left(u^2+\gamma^2\right)^{\frac{3}{2}}} - \frac{\left(l^2 + \frac{2}{3}\gamma^2\right)}{\left(l^2+\gamma^2\right)^{\frac{3}{2}}} \right] - \left(\ \cos^2\ \theta\right)(\gamma) \left[\frac{1}{\left(u^2+\gamma^2\right)^{\frac{1}{2}}} - \frac{1}{\left(l^2+\gamma^2\right)^{\frac{1}{2}}} \right] \Bigg) \tag{29}$$

$$\frac{\sigma_{Z2}}{\boldsymbol{p}} = \frac{\gamma^3}{\pi} \int_0^{\Phi} \left(\frac{1}{\left(u^2+\gamma^2\right)^{\frac{3}{2}}} - \frac{1}{\left(l^2+\gamma^2\right)^{\frac{3}{2}}} \right) d\theta \tag{30}$$

$$\frac{\tau_{RZ2}}{\boldsymbol{p}} = -\frac{1}{\pi} \int_0^{\Phi} (\cos\ \theta) \left[\frac{u^3}{\left(u^2+\gamma^2\right)^{\frac{3}{2}}} - \frac{l^3}{\left(l^2+\gamma^2\right)^{\frac{3}{2}}} \right] d\theta \tag{31}$$

where

$$u = \left[(1+\mu) + \sqrt{(1+\mu)^2 - \frac{\mu(\mu+2)}{cos^2\ \theta}} \right] \cos\theta \tag{32}$$

$$l = \left[(1+\mu) - \sqrt{(1+\mu)^2 - \frac{\mu(\mu+2)}{\cos^2\ \theta}} \right] \cos\theta \tag{33}$$

$$\Phi = \arctan\sqrt{\frac{1}{\mu(\mu+2)}} \tag{34}$$

References

1. Omar N, Zhong Y, Jazar RN, Subic A, Smith J, Shirinzadeh B (2015) Soft tissue modelling with conical springs. Bio-Med Mater Eng 26(s1):S207–S214
2. Horton A, Wittek A, Joldes GR, Miller K (2010) A meshless Total Lagrangian explicit dynamics algorithm for surgical simulation. Int J Numer Methods Biomed Eng 26(8):977–998
3. Jin X, Joldes GR, Miller K, Yang KH, Wittek A (2012) Meshless algorithm for soft tissue cutting in surgical simulation. Comput Methods Biomech Biomed Eng 17(7):800–811
4. Nguyen VP, Rabczuk T, Bordas S, Duflot M (2008) Meshless methods: a review and computer implementation aspects. Math Comput Simul 79(3):763–813
5. Miller K, Joldes G, Lance D, Wittek A (2006) Total Lagrangian explicit dynamics finite element algorithm for computing soft tissue deformation. Commun Numer Methods Eng 23(2):121–134
6. Okumura IA (1995) On the generalization of cerruti's problem in an elastic half-space. Doboku Gakkai Ronbunshu 519:1–10
7. Talybly LK (2010) Boussinesq's viscoelastic problem on normal concentrated force on a half-space surface. Mechanics of Time-Dependent Materials 14(3):253–259
8. Saada AS (2009) Elasticity: theory and applications. J. Ross, Boca Raton, FL
9. McGinness H (1980) Stress distribution in a semi-infinite body symmetrically loaded over a circular area
10. Prioul R, Bakulin A, Bakulin V (2004) Nonlinear rock physics model for estimation of 3D subsurface stress in anisotropic formations: theory and laboratory verification. Geophysics 69(2):415–425
11. Tekinsoy MA, Taşkıran T, Kayadelen C, Baran T (2009) An approximation to the stress distribution analysis for anisotropic clayey soil. Sci Res Essays 4(2):078–087
12. Omar N, Zhong Y, Smith J, Gu C (2016) Local deformation for soft tissue simulation. Bioengineered 7(5):291–297

Effect of Airway Stent on Stenosed Trachea

Mohd Norhakem Hamid, Kahar Osman, Zuliazura Mohd Salleh, Rima Efriani Rusli, Mohamad Ikhwan Kori, and Ahmad Zahran Md Khudzari

Abstract Tracheal stenosis is a windpipe obstruction that can cause breathing problems. Besides, complications from past surgery or external injuries are several other common causes of tracheal stenosis. Besides, some other common causes of tracheal stenosis are complications from previous surgery or external injuries. Computational fluid dynamics (CFD) technique is allowed to understanding to flow characteristic inside stenosed trachea. This study uses patient computed tomography (CT) images to investigate the relationship of pressure distribution and air flow rate in the tracheal airway. In order based on CT-scans of a patient for all breathing condition. We assessed flow patterns and pressure drops over tracheal stenosis artificially inserted into a actual three-dimensional upper airway model. The actual airway model is extremely irregular and the presence of stenosis adds to its geometrical complexity, resulting in very complex flow patterns with flow separations. In this analysis, the findings show air flow velocity and pressure with trachea stenosis and stenting.

Keywords Patient specific model · Computational fluid dynamics · Trachea stent

1 Introduction

An irregular narrowing of the trachea is tracheal stenosis. Tracheal stenosis is usually caused by trachea injuries, often caused by intubation. External injuries, cancers, bacterial infections and complications after surgery are other causes of tracheal

M. N. Hamid · M. I. Kori
School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

K. Osman (✉) · R. E. Rusli · A. Z. Md Khudzari
School of Biomedical Engineering and Health Sciences, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
e-mail: kaharosman@utm.my

Z. Mohd Salleh
Jabatan Teknologi Kejuruteraan Mekanikal, Fakulti Teknologi Kejuruteraan, Universiti Tun Hussein Onn Kampus Pagoh, Jalan Panchor, 84600 Panchor, Johor, Malaysia

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stenosis [1]. Breathing difficulty or weakness due to obstruction is found in patients affected by tracheal stenosis. As part of the treatment for stenosis, invasive surgical repairs are performed. For less invasive treatment, stent implantation is implemented and carried out in the stenosis area of the trachea.

Stent is a tubular mesh or graft used to extend the area of vessels stenosed trachea. Airway stents come with either metallic or silicone stents [2]. The stent works as a scaffold to preserve the trachea's patency after dilation. Airway stent implantation has shown good promise in terms of its efficacy. Previous clinical trials have shown that, compared to surgical procedures, stent implantation increases tracheal air flow with minor complications [3]. Tracheal stenosis stent implantation can be an effective way of restoring and improving the flow of air to the lungs without further surgical reconstruction.

Further understanding of the effects of stent implantation is required to enhance patients' breathing performance. Thus, in this study, the efficacy of stent implantation in trachea airflow activity during exercise, normal and sleep breathing conditions is investigated and analyzed. The characteristics of flow within the trachea and the effect of stent implantation on the patient's breathing severity are analyzed and compared. This can be achieved by using computational fluid dynamics (CFD) analysis.

2 Methodology

2.1 Geometry Modeling

In this analysis, two human trachea models were used. The first model is based on the real geometry of the human stenosis trachea. This model was developed using images of the female patient's stenosis problem using CT scanner data. As shown in Fig. 1, the model is then simplified and drawn using CAD software. The length of trachea

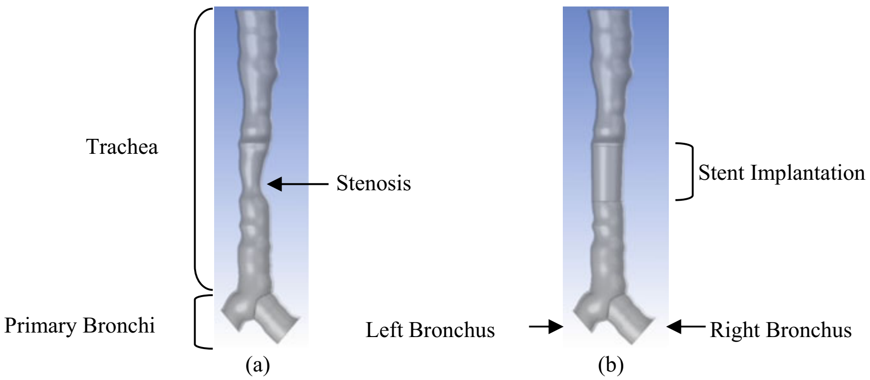

Fig. 1 Three-dimensional model **a** stenosed trachea; **b** stented trachea

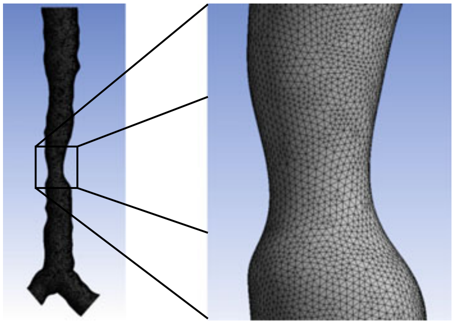

Fig. 2 Trachea model after meshing

is 10.7 cm; continue with 1.05 cm left bronchus and 0.7 cm right bronchus. The inlet of trachea was 0.16 cm in diameter. The second model is stented trachea, which is some modification from the first model in the stenosis area. Using the lofted method in CAD software, the stenosis from the first model was removed and redrawn. After all the models were done, the fluid region was filled with the ANSYS software inside the trachea. The fluid area of the model of the trachea was then meshed, as shown in Fig. 2.

2.2 Boundary Condition

Boundary conditions are another aspect besides the model geometry that needs to be looked at when studying airflow. With the exception of very narrow airways deep into the lung at rest, laminar flow does not occur in human lung airways. Even at a low local Reynolds number, airflow from the larynx to the third generation is transitional-to-turbulent.

Due to flow instabilities caused by the broad geometric transition at the carina ridges, the turbulence can be induced again at the central region, which can complicate flow structures have shown that the turbulent affected the deposition of particles. For modeling the air flow in a human trachea, the choice of boundary conditions is important.

The condition of the outlet boundary was set at a constant pressure of zero [4]. This was achieved in order to use the difference in pressure between the inlet and the outlet to measure the decrease in pressure, which is the driving force that moves the air from the inlet to the outlet. The pressure was set to zero at the outlet.

Clearly, to identify the airway resistance from the inlet to the outlet, the average pressure can be used. Based on daily physical activity, three different flow rates were selected. Steady state flows denote sleep, natural, and exercises breathing in this analysis, based on previous researchers, were used as the inlet boundary conditions. All information was tabulated in Table 1 as a description of the boundary conditions used in the fluid domain analysis.

Table 1 Summary of boundary condition

Parameter	Sleeping [5]	Normal [6]	Exercise [7]
Reynolds number, Re	1201 (15 l/min)	3012 (60 l/min)	4660 (100 l/min)
Inlet velocity, U (m/s)	1.2400	4.9736	8.2894
Air density, ρ (kg/m^3)	1.19		
Air viscosity, μ (kg/ms^{-1})	1.82×10^{-5}		

3 Results and Discussions

3.1 Flow Behaviors

The overall velocity streamline from Fig. 3 shows the differences between stenosis and stented trachea in the flow behavior within the trachea from the inlet to the left bronchus and right bronchus. The direction of flow from the inlet to the stenosis area was usual for all breathing conditions in Fig. 3a. But the flows became non-uniform velocity fields after the stenosis area, and so were not consistent with the normal direction of flow. On the right side of the tracheal wall, the swirl-flow of air was observed. This is because, due to the small size of the cross-sectional area, velocity variations occur in the stenosis region. However, in Fig. 3b after stent implantation in the stenosis region, for all breathing conditions, the air flow was in the normal direction from the inlet to the carina before splitting in the bifurcation region. This has shown that the stent is capable of preserving the air flow patency along the trachea [8]. So, indirectly, the stent will enhance the patient's breathing performance.

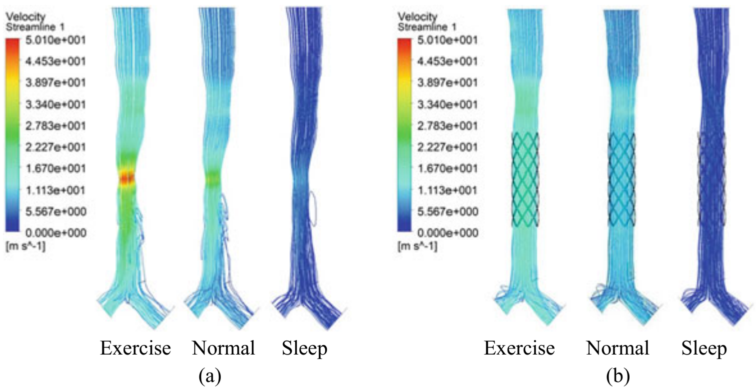

Fig. 3 All velocity streamline **a** stenosed trachea; **b** stented trachea

3.2 Velocity Distributions

The significant velocity difference in the stenosis area can be seen from Figs. 4, 5 and 6. The distribution of velocity for all breathing conditions shows a similar trend in stenosis and stented trachea. Figures 4a, 5a and Fig. 6a show that the velocity in the area of stenosis has been increased. The maximum velocity magnitude for exercise breathing condition was increased up to 50.1 m/s. For the normal breathing condition, the maximum velocity magnitude of air was increased up to 30.11 m/s and lastly for sleep breathing condition, the maximum velocity magnitude was increased up to 7.69 m/s. This leads to an increased risk of breathing difficulties especially during exercise. For all breathing conditions, when compared with stented trachea in

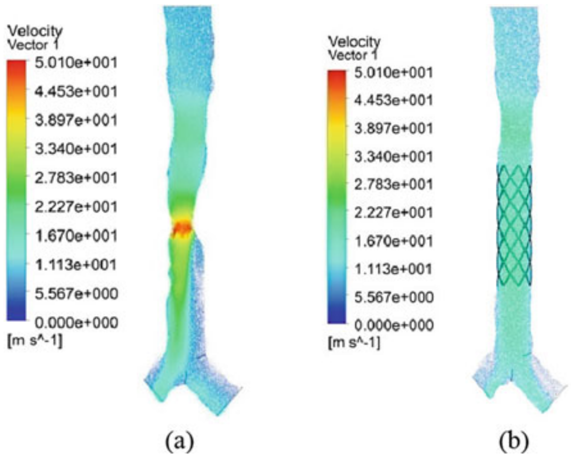

Fig. 4 Velocity distributions for exercise condition **a** stenosed trachea; **b** stented trachea

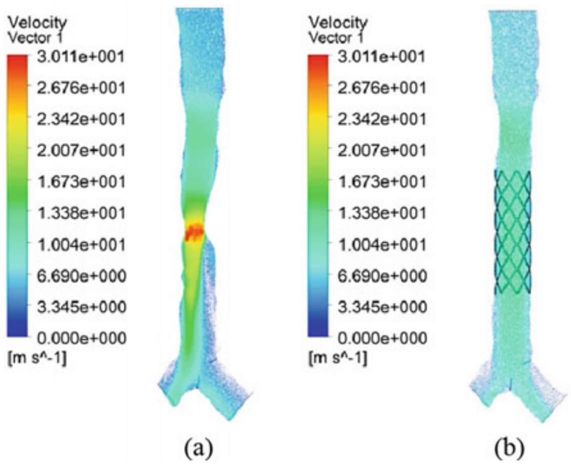

Fig. 5 Velocity distributions for normal condition **a** stenosed trachea; **b** stented trachea

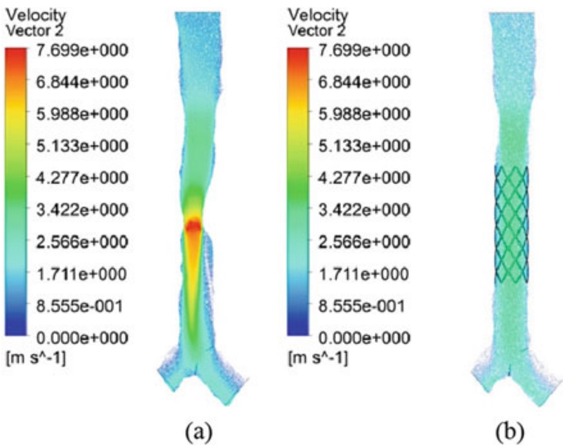

Fig. 6 Velocity distributions for sleep condition **a** stenosed trachea; **b** stented trachea

Figs. 4b, 5b and 6b, the velocity can be reduced by almost 50% in the stenosis area. The stent will also have a direct impact on the air velocity within the trachea.

In healthy trachea, as the size of the right lung is greater compared to the left lung, the right bronchus requires more air supply from the trachea. Flow rate distributions were then measured and the cases were compared together to see the effect of the stent on the airway. The difference in the flow rate distribution for stenosis and stented trachea is shown in Table 2. For all breathing conditions, especially for normal conditions, the distribution of flow rate to the right bronchus was increased by stent implantation, with 11.43% increases and 11.34% increases in exercise conditions. However, the flow rate distribution to the right bronchus in sleep breathing condition, does not differ significantly, only increases by 0.97%. This means that the airway stent will play an important role in adjusting more to the right bronchus than to the left bronchus in the direction of air flow. Next, this will enhance patient breathing quality. The same findings were obtained by Shen Yu et al. for a normal trachea [9].

Table 2 The differences of flow rate distribution to right bronchus between stenosed trachea and stented trachea

Breathing condition	Main trachea inlet flow rate (m^3/s)	Right bronchus inlet average flow rate (m^3/s)	Percentage distribution to right bronchus (%)	Right bronchus inlet average flow rate (m^3/s)	Percentage distribution to right bronchus (%)
		Stenosed trachea	Stented trachea	Stenosed trachea	Stented trachea
Exercise	0.001303	0.0005793	0.0007271	44.46	55.80
Normal	0.000782	0.0003536	0.0004430	45.22	56.65
Sleep	0.000195	0.0001118	0.0001137	57.34	58.31

3.3 Pressure Distributions

Figures 7, 8 and 9 show a comparison of the pressure distribution between the stenosis and stent trachea models. This study found that the pressure difference between stenosis and stented trachea occurs only from the inlet to the stenosis area. The highest pressure in the upper part of the main trachea was observed and the lowest pressure in the stenosis area was observed for almost all stenosis trachea breathing conditions. It occurs because the velocity in the area of stenosis has increased. So, it will cause the patient some discomfort in the upper part of the main trachea when breathing.

Table 3 shows that the pressure in the upper part of the main trachea of the stented trachea was reduced compared to stenosed trachea for all breathing conditions. It demonstrates that the trachea stent can play an important role in reducing stenosis

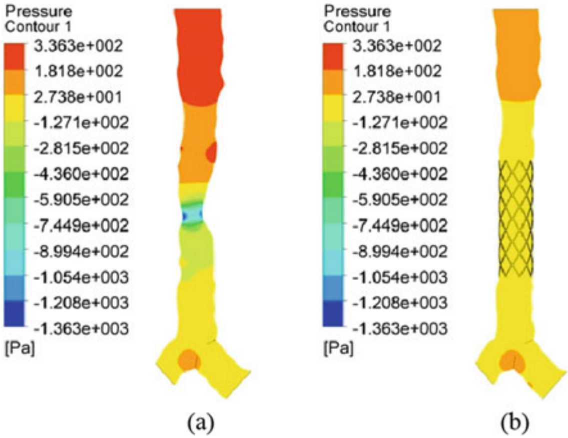

Fig. 7 Pressure distributions for exercise condition **a** stenosed trachea; **b** stented trachea

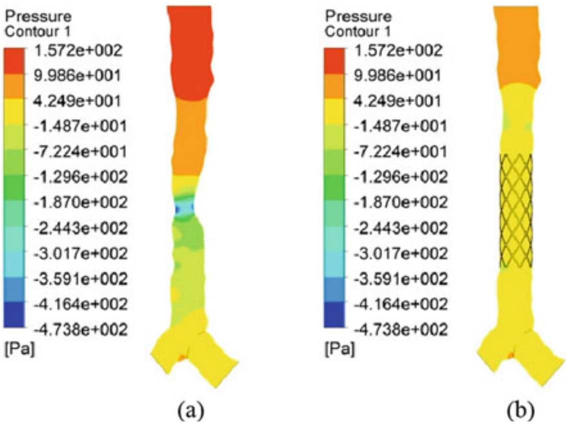

Fig. 8 Pressure distributions for normal condition **a** stenosed trachea; **b** stented trachea

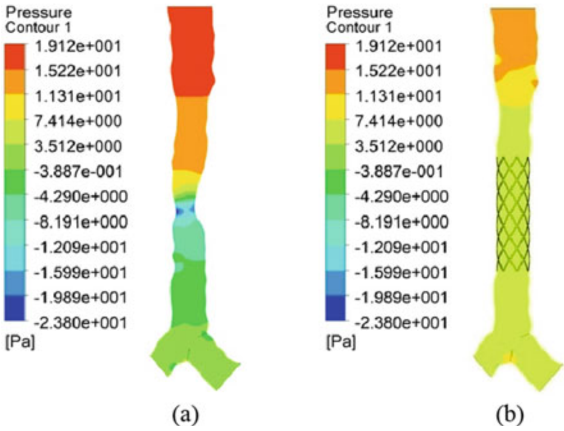

Fig. 9 Pressure distributions for sleep condition **a** stenosed trachea; **b** stented trachea

Table 3 Maximum pressure at upper part of main trachea for all breathing conditions

Breathing condition	Maximum pressure at upper part of main trachea (Pa)	
	Stenosed trachea	Stented trachea
Exercise	336.3	181.8
Normal	157.2	99.86
Sleep	19.12	15.22

pain. However, there is no difference in pressure distribution between stenosis and stented trachea in the lower part of the main trachea and primary bronchi.

4 Conclusion

In this paper, studies to understand the flow characteristic using CFD technique by ANSYS software had the effect of trachea stent. Trachea stent can play an important role from the findings in changing the flow behavior within the stenosis trachea. The high pressure decrease in the upper part of the main trachea of the stenosis trachea may also be caused by the trachea stent. Therefore, due to the good results obtained, the airway stent can treat trachea stenosis.

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References

1. Mostafa BE, Chaouch-Mberek C, El-Halafawi A (2012) The effects of brief mindfulness intervention on pain experience: an examination of individual difference. J Tracheal Stenosis Diagn Treat 1:1–70
2. Ratnovsky A, Regev N, Wald S, Kramer M, Naftali S (2015) Mechanical properties of different airway stents. J Med Eng Physics 37:408–415
3. Puma F, Ragusa M, Avenia N, Urbani M, Droghetti A, Daddi N, Daddi G (2000) The role of silicone stents in the treatment of cicatricial tracheal stenoses. J Thorac Cardiovasc Surg 120:1064–1069
4. Liu Y, So RMC, Zhang CH (2002) Modeling the bifurcation flow in a human lung airway. J Biomech 35:465–473
5. Douglas NJ, White DP, Pickett CK, Well JV, Zwillich CW (1982) Respiration during sleep in normal man. Thorax 37:840–844
6. Luo XY, Hinton JS, Liew TT, Tan KK (2004) LES Modelling of flow in a simple airway model. J Med Eng Phys 26:403–413
7. Calay RK, Kurujareon J, Holdø AE (2002) Numerical simulation of respiratory flow patterns within human lung. Respir Physiol Neurobiol 130:201–221
8. Huang S, Xu J, An Z, Yuan P, Xu H, Lv W, Hu J (2018) Clinical assessment of airway stent placement in patients with malignant airway lesions. J Thorac Dis 10:3277–3288
9. Yu S, Wang J, Sun X, Liu Y (2016) Numerical study of the effects of bronchial structural abnormalities on respiratory flow distribution. Biomed Eng Online 15:164

An Improved Momentum Rate in Artificial Neural Networks for Estimating Product Cycle Time at Semi-automatic Production

Ahmad Afif Ahmarofi

Abstract Among all the prediction techniques, the Artificial Neural Networks (ANN) shows excellent performance. The ANN technique has a momentum rate to slow down the ANN learning process. However, the value of the momentum rate has no restriction since it is commonly based on the experiment with different values as presented in the previous studies. In this regard, the objective of this study is to formulate a momentum rate to achieve a better prediction result. The proposed momentum rate equation was tested on three ANN models. Subsequently, the 3-2-1 network emerged as the best network based on the smallest mean square error. To evaluate the proposed momentum rate, a problem based on a real company situation in producing audio products was considered. Cycle time of the new audio products at its semi-automatic production line was predicted based on several factors, which were manpower shortage, material preparation time and machine breakdowns through the 3-2-1 network. As a result, the best cycle time to complete new audio products can be estimated accurately. In conclusion, the proposed momentum rate can improve the convergence of the ANN learning process for a better prediction result. Consequently, audio products delivery is smooth and fulfil customer's demands.

Keywords Momentum rate · Artificial neural networks · Cycle time · Semi-automatic · Production

1 Introduction

Cycle time is defined as the length of time needed to process a product with specific tasks at the production line [1, 2]. The uncertainty of cycle time could affect the efficiency of production operation [3–5]. Hence, the cycle time of a specific task must coordinate efficiently to ensure the smoothness of production operation.

The uncertain cycle time which resulted from related factors, namely, manpower shortage, material preparation time, and machine breakdown becomes a big problem

A. A. Ahmarofi (✉)
Department of Computer Science, Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, 08400 Merbok, Kedah, Malaysia

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for the management [5] and more critical in a semi-automatic production [6, 7]. A semiautomatic production is a product layout with a combination of an almost equal percentage of manpower and machines to perform the production operations [8]. Due to its structure that is still manpower-dependent, predicting cycle time is an essential issue in semi-automatic production. Moreover, the semi-automatic line is the choice for many manufacturers in Malaysia and other developing countries due to the high initial cost to set up a fully automatic line [9]. As such, predicting cycle time is deemed crucial to be foreseen.

In previous studies, it is found that various techniques have been utilised to predict cycle time of a production operation such as regression analysis [10, 11], decision tree [12, 13] and artificial neural networks (ANN) [14, 15]. Among these techniques, ANN which is a brain metaphor model of historical data processing shows high accuracy in prediction due to its ability to capture the relationship of various variables toward output through multiple stages in the learning processes [9].

Moreover, the ANN technique has a momentum rate to slow down the ANN learning process [16]. However, the momentum rate for the ANN learning process was randomly determined in the previous studies such as in [15] and [17]. The selection of a suitable parameter for the momentum rate has no restriction as it is commonly based on the experiment with different values.

In this regard, this study is deemed essential to fill the gaps. Thus, the objective of this study is to formulate a momentum rate for a better-predicted cycle time at a semi-automatic production line. The methodology of the study, related results, and the conclusion are presented in the following sections.

2 Research Methodology

To formulate the proposed momentum rate for ANN learning processes, a problem based on a real company situation was considered. The company is a global business manufacturer for audio products in the automotive sector for both the local and international markets.

However, the company is facing an issue with an uncertain cycle time of the new audio products at its semi-automatic production line based on several factors, which were manpower shortage, material preparation time, and machine breakdowns. Therefore, secondary data on the number of manpower, material preparation time, and machine breakdowns rate of existing audio products were collected from the production department and considered as the input variables. On the other hand, actual cycle time was recorded as the output variable to predict cycle time. Table 1 shows a list of secondary data.

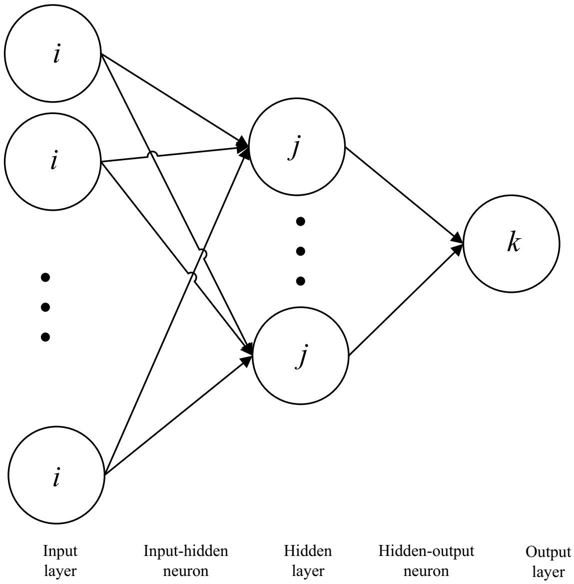
In this study, a feed-forward multilayer perceptron (MLP) network was established for the ANN learning process to predict cycle time based on the input variables. Figure 1 illustrates the network of MLP to predict cycle time.

The MLP network is developed based on the number of input node-the number of hidden node-the number of output node, *i-j-k*. In this study, three types of the

Table 1 Secondary data for estimating product cycle time at a semi-automatic production

Secondary data	Unit
The number of manpower	Person
Waiting time for material	Hours
Machine breakdown rate	1 per piece
Cycle time of a specific task	Seconds
Completion time of existing audio product	Hours

Fig. 1 The network of feed-forward multilayer perceptron

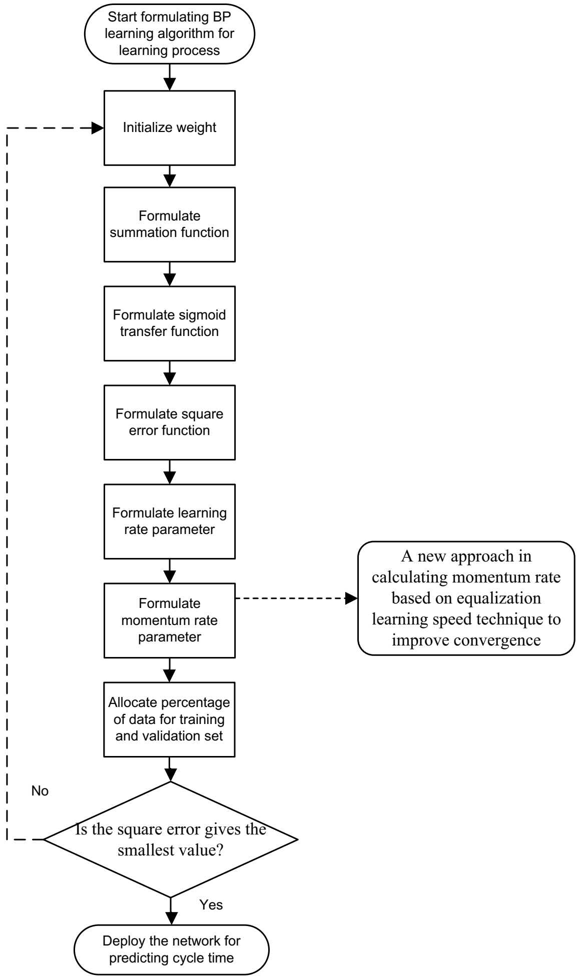


MLP network were established with the number of hidden nodes, j, varied from one node until three nodes to find the best-so-far network in predicting cycle time. One the other hand, the number of input node, i, and an output node, k, is constant as there were only three input variables (*manpower, material, and machine*) and one output variable (*cycle*), respectively. Therefore, three types of MLP networks were established which are 3-1-1, 3-2-1, and 3-3-1 to predict the cycle time.

Subsequently, a backpropagation (BP) learning algorithm was developed as a learning process for the three MLP networks to predict cycle time. The learning process of a BP learning algorithm was generated by the initialization of connection weight, w. Then, summation function, sigmoid transfer function, square error function, learning rate parameter, and momentum rate parameter were formulated to adjust the connection weight as described in Fig. 2.

The connection weights for the ith input node to the jth hidden node, w_{ij}, and the jth hidden node to the kth output node, w_{jk}, were initialized with random values since the determination of weight had no restriction in a learning process. Besides,

Fig. 2 The flowchart of the backpropagation learning algorithm



the value of learning rate, ε, was set randomly as long as the value is in the range of 0.1–1.0. In this study, the value of the learning rate was set randomly to 0.2.

To train and validate the learning process for the BP algorithm, the related data, i.e., *manpower*, *material*, *machine*, and *cycle* are allocated separately for the training set and validation set. By allocating a higher percentage for training in the ANN learning process, the performance of the network in predicting cycle time is better. Thus, 80% of data were allocated for the training process while 20% were allocated for the validation process. Finally, the smallest value of mean square error, E_r, between the value of network output and actual cycle time was selected for predicting cycle time.

The adjustment of connection weight is then adjusted by momentum rate. In this stage, momentum rate is formulated for slowing down the speed of the learning process. Furthermore, the selection of suitable value for the momentum parameter in the MLP network has no restriction as it is commonly based on experiments with different values.

Moreover, the value of momentum is normally within the range of $0 \leq |\mu| < 1$ [18]. Therefore, in this research, a new approach in determining momentum value is proposed. The approach taken in calculating the momentum rate is motivated by the equalization learning speeds concept [19] such that for a given neuron, the process of learning should be inversely proportional to the square root of connections to the neuron between the input node and hidden node. However, generally, this concept is only suggested for a learning process. As such, a similar formulation suitable for the momentum rate in the learning process is introduced in this research. Hence, the convergence of the learning process in the MLP network is controllable.

The motivation of formulating this method for momentum rate is to observe its potential with other methods from previous literature, thus fulfilling the objective of this research. Hence, the formulation of a proposed equation for determining momentum rate value for this research is formulated as follows.

$$\mu = \frac{1}{\sqrt{f_{ij}}} \tag{1}$$

where,

μ momentum rate.
f_{ij} the number of neuron between the ith input node and jth hidden node.

On the other hand, the new increment of connection weight for oth iteration is formulated as follows:

$$\Delta \boldsymbol{w_o} = \boldsymbol{\mu} \Delta \boldsymbol{w}_{0-1} - (1 - \boldsymbol{\mu}) \boldsymbol{\varepsilon} \boldsymbol{d_o} \tag{2}$$

where,

Δw_o the increment for a connection weight of oth iteration.
μ momentum rate.
Δw_{o-1} the increment of previous connection weight of oth iteration.
ε learning rate.
d_o the gradient value of the oth iteration.

By substituting Eqs. (2) into (1), the equation for adjusting the increment of connection weight is formulated as follows:

$$\Delta w_o = \left(\frac{1}{\sqrt{f_{ij}}}\right) \Delta w_{o-1} - \left(1 - \left(\frac{1}{\sqrt{f_{ij}}}\right)\right) \varepsilon d_o \tag{3}$$

Subsequently, the increment of the connection weight until the network has a minimum value of mean square error. Each type of developed 3-1-1, 3-2-1, and 3-3-1 MLP networks was experimented with using the developed BP learning algorithm.

Subsequently, consequently, each of the developed 3-1-1, 3-2-1, and 3-3-1 MLP networks have experimented with two experiments through BP learning algorithm. The value for momentum rate, μ, was set to random for the first experiment for each of the MLP network while the proposed formulated momentum rate based on Eq. (3) was used for the second experiment. The results of this research are discussed in the following section.

3 Results and Discussion

The value of final square error, Er_o for the 3-1-1 network based on the random value for momentum rate, μ, are presented in Table 2.

The value of final square error, Er_o for the 3-2-1 network based on the random value for momentum rate, μ, is presented in Table 3 as follows.

The value of final square error, Er_o for the 3-3-1 network based on the random value for momentum rate, μ, is presented in Table 4 as follows.

Table 2 The final square error, Er_o of the 3-3-1 network with random momentum rate, μ

Connection weight		Momentum rate	Iteration	Final square error
w_{ij}	w_{jk}	μ	o	Er_o
0.1	0.1	0.5	58	0.0164
0.3	0.3		60	0.0373
0.5	0.5		61	0.0671
0.7	0.7		59	0.0934
0.9	0.9		63	0.1898
1	1		67	0.0676
1.5	1.5		74	0.0786

Table 3 The final square error, Er_o of the 3-2-1 network with random momentum rate, μ

Connection weight		Momentum rate	Iteration	Final square error
w_{ij}	w_{jk}	μ	o	Er_o
0.1	0.1	0.5	65	0.0367
0.3	0.3		65	0.0354
0.5	0.5		66	0.0589
0.7	0.7		78	0.0743
0.9	0.9		56	0.0945
1	1		45	0.0234
1.5	1.5		78	0.0156

Table 4 The final square error, Er_o of the 3-3-1 network with random momentum rate, μ

Connection weight		Momentum rate	Iteration	Final square error
w_{ij}	w_{jk}	μ	o	Er_o
0.1	0.1	0.5	49	0.0290
0.3	0.3		58	0.0458
0.5	0.5		66	0.0786
0.7	0.7		74	0.0456
0.9	0.9		50	0.0234
1	1		48	0.0453
1.5	1.5		84	0.0734

For the second experiment, the proposed formulated momentum rate, μ, based on Eq. (3) for the 3-1-1 MLP network is calculated as follows.

$$\begin{aligned}\mu &= \frac{1}{\sqrt{f_{ij}}}\\ &= \frac{1}{\sqrt{3}}\\ &= 0.577\end{aligned}$$

Hence, with the proposed formulated momentum rate ($\mu = 0.577$), the value of final, Er_o for the 3-1-1 network are presented in Table 5 as follows.

Next, the value of final square error, Er_o for the 3-2-1 network based on the proposed formulated momentum rate, μ, i.e., Eq. (3) are presented in Table 6 as follows.

$$\mu = \frac{1}{\sqrt{f_{ij}}}$$

Table 5 The final square error, Er_o of the 3-1-1 network with formulated momentum rate, μ

Connection weight		Momentum rate	Iteration	Final square error
w_{ij}	w_{jk}	μ	o	Er_o
0.1	0.1	0.577	56	0.0153
0.3	0.3		61	0.0360
0.5	0.5		59	0.0609
0.7	0.7		60	0.0905
0.9	0.9		61	0.1898
1	1		62	0.0677
1.5	1.5		74	0.0785

Table 6 The final square error, Er_o of the 3-2-1 network with formulated momentum rate, μ

Connection weight		Momentum rate	Iteration	Final square error
w_{ij}	w_{jk}	μ	o	Er_o
0.1	0.1	0.408	53	0.0154
0.3	0.3		60	0.0357
0.5	0.5		59	0.0612
0.7	0.7		60	0.0102
0.9	0.9		62	0.1878
1	1		61	0.0608
1.5	1.5		72	0.0753

$$= \frac{1}{\sqrt{6}}$$
$$= 0.408$$

Next, the value of final square error, Er_o for the 3-3-1 network based on the proposed formulated momentum rate are presented in Table 7 as follows.

$$\mu = \frac{1}{\sqrt{f_{ij}}}$$
$$= \frac{1}{\sqrt{9}}$$
$$= 0.333$$

Based on the results of Tables 2, 3, 4, 5, 6, and 7, the smallest value of Er_o is 0.0102 as obtained from the 3-2-1 network with formulated momentum rate, $\mu = 0.408$, while $w_{ij} = 0.7$, $w_{jk} = 0.7$ and learning rate, $\varepsilon = 0.2$ during iteration, $o = 60$ as described in Table 6. Thus, the result of the smallest Er_o, i.e., 0.0102 shows that the proposed formulated momentum rate is slightly better for predicting cycle time

Table 7 The final square error, Er_o of the 3-3-1 network with formulated momentum rate, μ

Connection weight		Momentum rate	Iteration	Final square error
w_{ij}	w_{jk}	μ	o	Er_o
0.1	0.1	0.333	34	0.0271
0.3	0.3		45	0.0462
0.5	0.5		56	0.0371
0.7	0.7		50	0.0482
0.9	0.9		56	0.0945
1	1		63	0.0627
1.5	1.5		68	0.0418

Table 8 The best-predicted cycle time based on the 3-2-1 network

Variables	Parameters	The predicted cycle time
$manpower_{121}$	30 persons	5 s
$material_{121}$	1 h	
$machine_{121}$	0.0013	

compared to the random momentum rate. Consequently, the 3-2-1 MLP network with the proposed formulated momentum rate is selected for predicting the cycle time of the new audio product at the semi-automatic production line as presented in Table 8.

According to Table 8, if the company would like to predict the cycle time of the new audio products for the next production lot, let say n = 121 with the available number of manpower, manpower121 = 30 persons, waiting time of material, material121 = 1 h and machine breakdown rate, machine121 = 0.0013, the best-predicted cycle time of the new audio products during the 121st production lot is 5 s.

4 Conclusion

The result of the smallest square error value shows that the proposed formulated momentum rate is slightly better for predicting the cycle time compared to the random momentum rate as obtained in Table 6. To the best of our knowledge, none of the approaches from previous studies can be considered to be the best practice in determining the momentum rate since it is based on the results of one's own personal heuristics approach. Thus, the 3-2-1 MLP network with formulated momentum rate is another alternative predictive model to predict the cycle time based on the smallest square error as compared to the 3-1-1 and 3-3-1 networks. Hence, the proposed formulated momentum rate can provide a better prediction result instead of being randomly determined. Consequently, the proposed formulated momentum rate assists production planner in predicting cycle time from historical data of existing product and evaluating completion time for producing new audio speaker products. As a result, it can reduce the occurrence of tardiness efficiently and fulfil customer delivery on-time.

References

1. Russell RS, Taylor BW (2011) Operations management. Wiley, Alaska
2. Seth D, Seth N, Dhariwal P (2017) Application of value stream mapping (VSM) for lean and cycle time reduction in complex production environments: a case study. Prod Plan Control 28(5):398–419
3. Hariga M, Ben-Daya M (1999) Some stochastic inventory models with deterministic variable lead time. Eur J Oper Res 113(1):42–51

4. Lee A (2008) A continuing lean journey: an electronic manufacturer's adoption of Kanban. Assem Autom 28(2):103–112
5. Bülbül K, Şen H (2017) An exact extended formulation for the unrelated parallel machine total weighted completion time problem. J Sched 20(4):373–389
6. Ahmarofi AA, Abidin NZ, Ramli R (2017) Effect of manpower factor on semiautomatic production line completion time: a system dynamics approach. J Mech Eng Sci 11(2):2567–2580
7. Ahmarofi AA, Ramli R, Zainal Abidin N (2017) Predicting completion time for production line in a supply chain system through artificial neural networks. Int J Supply Chain Manag 6(3):82–90
8. Hager T, Wafik H, Faouzi M (2017) Manufacturing system design based on axiomatic design: case of assembly line. J Indus Eng Manag 10(1):111–139
9. Ahmarofi AA, Ramli R, Abidin NZ, Jamil JM, Shaharanee IN (2020) Variations on the number of hidden nodes through multilayer perceptron networks to predict the cycle time. J Inf Commun Technol 19(1):1–19
10. Adembo SO, Mcisn M, Toyin A (2012) Firm's competitiveness through supply chain responsiveness and management practices in Nigeria. Br J Arts Soc Sci 10(1):42–52
11. Ismail Y, Mir SA, Nazir N (2018) Utilization of parametric and nonparametric regression models for production, productivity and area trends of apple (*Malus domestica*) in Jammu and Kashmir, India. Int J Curr Microbiol App Sci 7(4):267–276
12. Su CT, Shiue YR (2010) Intelligent scheduling controller for shop floor control system: a hybrid genetic algorithm and decision tree learning approach. Int J Prod Res 41(12):2619–2641
13. Robert M, Thomas A, Sekhar M, Badiger S, Ruiz L, Raynal H, Bergez JE (2017) Adaptive and dynamic decision-making processes: a conceptual model of production systems on Indian farms. Agric Syst 157:279–291
14. Mehrjerdi YZ, Aliheidary T (2014) System dynamics and artificial neural networks integration: a tool to evaluate the level of job satisfaction in services. Int J Indus Eng Prod Res 25(1):13–26
15. Wang C, Jiang P (2017) Deep neural networks based order completion time prediction by using real-time job shop RFID data. J Intell Manuf 1–16
16. Turban E, Sharda R, Delen D (2011) Decision support and business intelligence system. Pearson Education Inc., New Jersey
17. Ghosh G, Mandal P, Mondal SC (2019) Modelling and optimization of surface roughness in keyway milling using ANN, genetic algorithm, and particle swarm optimization. Int J Adv Manuf Technol 100(5–8):1223–1242
18. Kumar S (2013) Neural networks: a classroom approach. McGraw Hill, New Delhi
19. Haykin S (2009) Neural networks and learning machines. Prentice Hall, New Jersey

A Review of Mass Spring Method Improvements for Modeling Soft Tissue Deformation

Mohd Nadzeri Omar and Yongmin Zhong

Abstract Significant research efforts have been dedicated to the creation of virtual reality simulators that empower medical students to learn anatomy and surgery in a virtual environment and allow surgeons to practice surgical operations. The degree of realism is determined by the simulation's accuracy and the processing efficiency of its underlying models. Deformable models should ideally be able to precisely recreate soft tissue deformation simultaneously providing real-time visual and force feedback. One of the most well-known approaches is the Finite Element Method (FEM). It has been demonstrated that the FEM can effectively replicate soft tissue deformation, but it requires a significant processing cost to enable real-time interaction. In this context, the Mass Spring Method (MSM) has been suggested as an alternative. The standard MSM model mimics soft tissue deformation with excellent computational performance but is constrained to linear behavior because it is based on simple Hooke's law theory. This paper provides recent studies on the enhancement of the standard MSM model to examine the viability of the MSM model to simulate soft tissue deformation for surgical simulation.

Keywords Mass spring method (MSM) · Nonlinear soft tissue deformation · MSM optimization · Real-time interaction · Soft tissue simulation

1 Introduction

There are two types of deformable models: non-physics and physics-based. Non-physics approaches defined a deformable model solely on geometrical characteristics. The splines model is one of the ways. In this method, a curve or surface is represented by a set of control points. When control points are changed to various positions, added

M. N. Omar (✉)
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia, Pahang 26600, Pekan, Pahang, Malaysia
e-mail: nadzeri@ump.edu.my

Y. Zhong
School of Engineering, RMIT University, Bundoora, VIC 3083, Australia

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or deleted, or their weights are altered, the contour of the respective curve, surface, or volume changes [1]. The large number of parameters involved allows for extensive control over the morphology and geometrical features of the mesh. The parameters, on the other hand, are difficult to discern empirically. Another modeling tool used in the non-physics approach is free form deformation (FFD). The FFD approach provides a higher and more efficient degree of control than the splines approach. The FFD changes the shape of an item by deforming the space in which it dwells. This approach may be used to build a wide range of graphical representations, including lines, polygons, curved surfaces, and parametric patches [2]. However, in order to handle it, experience and perseverance are required due to its randomness.

Meanwhile, the physics-based approach outperforms the non-physics-based method in many ways, particularly in terms of precision. The physics-based formulations can explain experimentally the deformations that occur as well as the material characteristics involved. In most circumstances, this approach may be further classified into two groups: methods based on discrete mechanics and methods based on continuum mechanics.

1.1 Discrete Mechanics

The Mass Spring Method (MSM) is typical in discrete mechanics. The MSM is commonly used to simulate deformable objects because of its conceptual simplicity and computational speed. Since the early work of Terzopoulos et al. [3, 4], MSM has been a common approach for modeling deformable bodies in surgical simulations. MSM necessitates the discretization of an object into mass points connected by elastic linkages (see Fig. 1). Discretization might occur on the object's surface or in its volume. The linear spring, which is derived from Hooke's law, is a popular

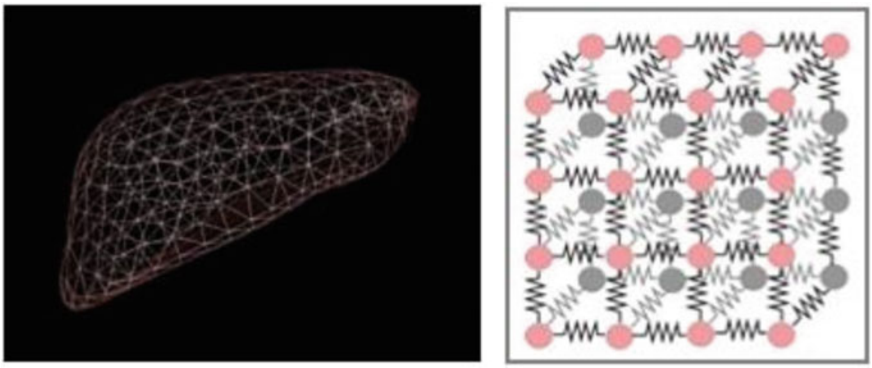

Fig. 1 An example of a structure for MSM models

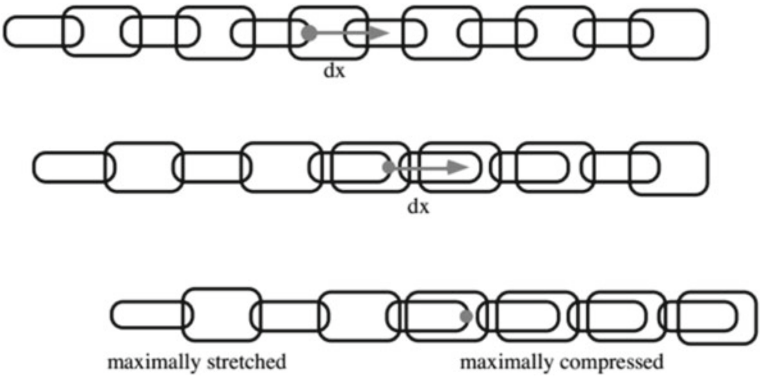

Fig. 2 A one-dimensional chainmail structure undergoing deformation [5]

choice for the elastic link. The action of global deformation is calculated by solving differential equations, which are frequently derived from Newton's law of motion.

Another method is the Chainmail concept. As seen in Fig. 2 [5] it is a collection of interconnected units that resembles a chain. The motion of a single mesh node is absorbed by the interface of the link between surrounding nodes. Displacements are moved to surrounding nodes whenever the link between two nodes is extended or squeezed beyond established bounds. As a result, slight displacements inside a single node's relaxed medium cause local deformation, but displacements inside a completely stressed medium cause global deformation. This approach is computationally efficient and can manage small changes in a mesh topology. However, there is some doubt about the simulation's accuracy.

1.2 Continuum Mechanics

The Finite Element Method (FEM) is included in this approach group. In FEM, a body is discretized into several elements that are characterized by continuum mechanics (see Fig. 3) [6–8]. The displacements and locations in an element are interpolated

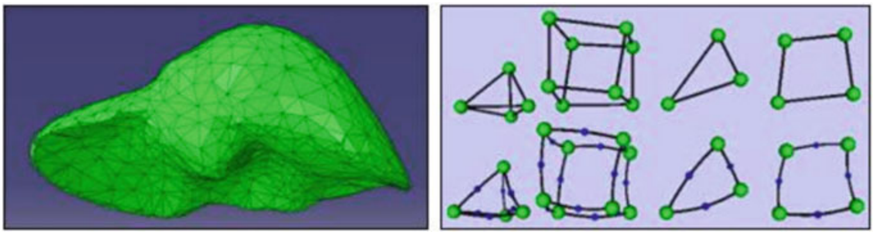

Fig. 3 An example of a structure of a FEM model and types of element

from discrete nodal values. The partial differential equations regulating a node's motion are defined separately for each element, resulting in a discrete system of differential equations. The primary advantages of FEM over node-based discretization approaches include more flexible node location and a large reduction in the total number of degrees of freedom necessary to attain the desired accuracy of the solution.

The Boundary Element Method (BEM) is another continuum mechanics-based method. Unlike FEM, the underlying partial differential equations were expressed in boundary integral form [9], which further simplified the FEM formulation and improved computing performance. Meanwhile, the method's disadvantage is that it is based on linear elasticity and so does not tolerate large displacements of soft tissues. Furthermore, it is frequently limited to homogenous and isotropic materials, which may not be true for soft tissues in general.

The advancement of the meshless approach has resulted in significant improvements to the FEM model. The meshless method utilizes continuum mechanics theories as well, but an object is modeled by a group of points with no explicit connectivity [10]. It eliminates the need to modify meshing steps. As a result, it has a significant benefit when modeling a topologically modified instance, such as cutting and insertion. It does, however, demand a large number of computer resources and requires specialized optimization methods.

Moreover, there is a technique that combines the advantages of discrete and continuous techniques. It is discovered in the Tensor Mass Method (TMM). The reaction forces are computed in this manner using an energy-based continuum formulation and transmitted to the vertices of the meshed components, which then give motion by solving Newton's second law of motion [11].

2 Improvement in MSM Model

There is various research in the literature that focuses on the enhancement of the MSM model. The research usually focuses on the modeling of nonlinear deformation, the optimization of parameters, and the increase of computing efficiency.

2.1 Nonlinear Deformation

A review of current research on nonlinear MSM models has been conducted. It was revealed that several current models had substantial similarities. As a consequence, models with similar features have been categorized in order to have a better awareness of the models that are present.

Quadratic stiffness and displacement function. Cooper and Maddock [12] proposed one of the first nonlinear MSM models. The displacement solution was calculated using a quadratic function. The model's main drawbacks were that it was only applicable to two-dimensional objects and that no validation data was supplied. Teschner et al. [13] defined spring stiffness using a quadratic function rather than a quadratic function on the displacement equation. They have proposed three distinct stiffness equations for the user to choose between linear, small nonlinear, and large nonlinear ranges. However, their methodology is only applicable to stiffness equations that converge to linearity at modest deformations. This restriction indicates that more study is required to obtain a suitable stiffness equation. Furthermore, the deformation behavior of this approach is restricted to only those three functions. Another series of works [14–16] employed a quadratic function to represent total deformation. According to Duysak et al. [16], neural networks and an adaptive learning rate formula were used to identify the optimal quadratic function to represent nonlinear deformation. The paper claimed that the approach could achieve adequate accuracy, however, no nonlinear behavior characteristics were supplied, and the approach also required a large number of iterations before the results converged.

Duffing's equation. This approach employs Duffing's equation, a second-order nonlinear differential equation. Duffing's equation is commonly used to define a third-order polynomial oscillator system. This technique was first proposed by Luo and Xiao [17]. Although their study was successful in mimicking nonlinearity, no validation result was presented. The identical methodology is used by Cui et al. [18] and Sulaiman et al. [19]. Furthermore, Chen et al. [20] presented research that provided more insights into Duffing's equation. The research shows that by varying the parameters in Duffing's equation, several types of spring behavior may be generated. However, the outcome was not confirmed, therefore the method's accuracy is unknown.

Spring configurations. The following method was described by San-Vicente et al. [21]. A combination of linear springs in a cubical arrangement produced a nonlinear response in the analysis (see Fig. 4). Edge, diagonal, and internal diagonal springs

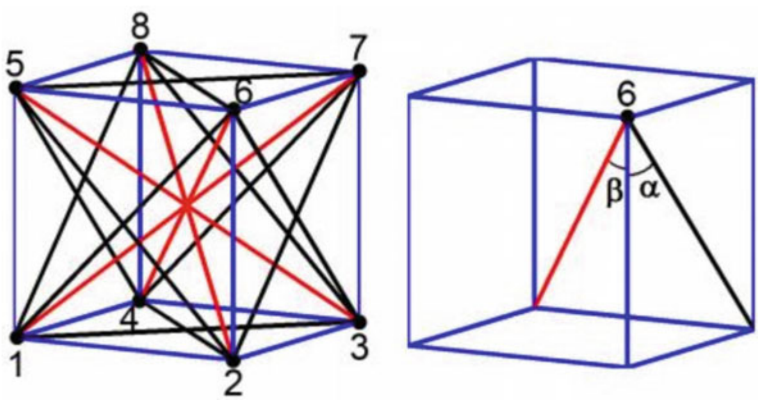

Fig. 4 The nonlinear MSM using spring configuration given by San-Vicente et al. [21]

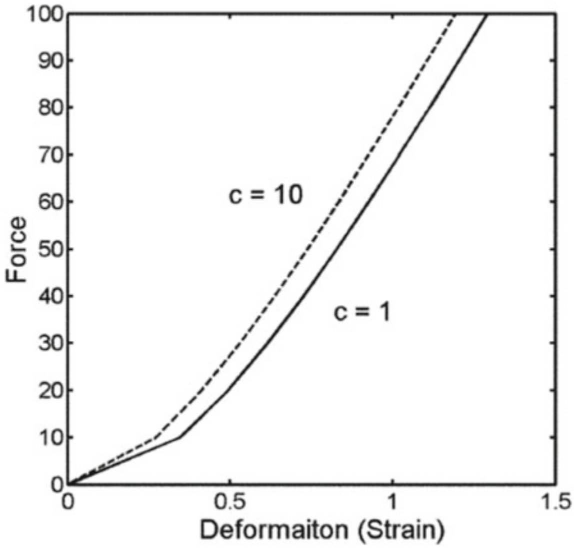

Fig. 5 The nonlinear deformation behavior, as taken from Choi et al. [25]

were employed in three different combinations. All of the springs have a certain stiffness constant and are used to control the model's nonlinearity. Following that, Shah et al. [22] improved on the earlier work by incorporating a cubical spring constant to keep the model stable. While approaches in this technique have been successful in simulating nonlinearity, the optimization process remains critical. A similar strategy may also be found in Garg et al. [23].

Force propagation. Another MSM approach that can create a nonlinear response is the force propagation approach. This approach may well be found in several studies [24–28]. The applied force was propagated layer by layer to the surrounding nodes using this approach. The number of nodes involved increased as depth progressed. As a result, a greater resistance force was measured, yielding a nonlinear reaction. Although the approaches can mimic nonlinearity, the models' nonlinearity is rarely clear and is typically a mixture of two linear functions (see Fig. 5).

2.1.1 Piecewise function

The piecewise technique divides the deformation behavior, which is commonly in the form of a load–displacement curve, into sections, each with its mathematical function. A linear or nonlinear function is employed to characterize the behavior of that section based on its behavior. Basafa et al. [29], for example, split the deformation's pattern into two sections. The first section is linear and is controlled by a linear function, but the second portion, which corresponds to a nonlinear deformation, is controlled by a nonlinear function. Nikolaev [30] followed a similar strategy. On the other hand, other researchers define nonlinearity using a mix of linear functions. A smoother nonlinear response, however, necessitates the use of more than two linear functions. It is possible to observe this by contrasting the work of Keeve et al. [31] and Garcia et al. [32]. Garcia et al. employed more than two linear functions, whereas Keeve et al. utilized two linear functions. The results reveal that more linear functions result in improved accuracy, although at a little higher computing cost. Despite the fact that nonlinearity can be replicated, this method demands a time-consuming effort to determine the transition points [33].

Hybrid approach. Researchers utilized continuum mechanics and the MSM concept in this method. Delingette et al. [34] and Picinbono et al. [35] might be considered the founders of this strategy. Xiaoping et al. [36] reported the usage of this strategy in a recent review. The internal forces of the model were retrieved using nonlinear continuum dynamics in the study, whereas the displacement was explicitly solved using the MSM concept. While implementing a nonlinear response is possible, the cost of computing will rise owing to the employment of extensive mathematical equations.

Other approach. Aside from the methods already discussed, the following MSM models can also be used to simulate nonlinear deformation. First, Castillo et al. [37] employed a method that associates a nonlinear deformation with elongation resistance. They modified the conventional MSM model by adjusting spring stiffness in elongation increments. This was accomplished by modeling the spring stiffness coefficient as an exponential function of elongation. Ahmadian et al. [38] provide another method, using an empiric approach to characterize internal resistance. They proposed two empirical equations for two different forms of nonlinear soft tissue. The suggested method correctly simulates nonlinear deformation but requires a significant amount of resources before establishing the suitable empirical formulation, which must be repeated for different objects. Wang and Guo [39] and Duan et al. [40] use similar empirical methodologies too.

2.2 Parameter Optimization

One of the main disadvantages of MSM is that its parameters have no direct relationship to soft tissue properties. As a result, an optimization technique is required to determine the ideal parameters for modeling a certain type of deformation. Plenty of optimization strategies have been published in the literature, which can be categorized into two groups in general. The optimization approach of the first group is based on the direct relationship between the reference object and the MSM parameters, whereas the optimization approach of the second group is based on the convergence of the MSM parameters for the objective function. The first optimization group can be further divided into two methods.

The first method makes use of actual soft tissue as a reference [41–44]. Zerbato et al. [45], for example, calibrated their MSM model with an arbitrary topology utilizing computer-assisted tomography (CAT) pictures and load–displacement data.

Meanwhile, in the second method, the MSM parameters are optimized for continuum mechanics. In this approach, FEM was employed as a reference by the majority of researchers [21, 25, 46, 47]. As an example, by linearizing the MSM equations, Gelder [48] sought to find an MSM comparable to a triangular linear FEM model. The work sparked numerous more attempts to achieve equivalency between MSM and FEM, such as those described by Lloyd et al. [49] and Delingette [50].

The second optimization group employs an objective function to accurately alter the MSM parameters to fit the features of the reference model. Simulated annealing, a probabilistic approach for finding a global minimum optimization problem, is a regularly used approach. This method was utilized to extract system parameters for MSM models, as demonstrated by Choi et al. [24], who directly retrieved MSM parameters by benchmarking the MSM model against FEM-produced models. The simulated annealing optimization is also available here [44, 51]. Furthermore, the genetic algorithm technique offers another widely used probabilistic strategy. The method starts with a collection of solutions known as the population, and the optimization process is continued until certain requirements are fulfilled. This methodology is introduced by Louchet et al. [52] in their MSM model, which was employed for fabric simulation. The genetic algorithm methodology has also been used in several other investigations [53–55]. The evolutionary technique [52, 56] and the least square technique [39] are two more famous probabilistic approaches.

2.3 Computational Performance

Improving the traditional MSM, specifically by including non-linear behavior, has had an impact on computing time. This section discusses various existing strategies for reducing MSM computational time.

2.3.1 Localization

One of the most effective strategies for minimizing computational effort is localization. Instead of analyzing the whole model, localization specifies and executes the analysis just in the targeted area [20]. Several studies have been published on the use of localization to improve computing performance. For example, Qiao et al. [57] utilized the Nearest Neighbor Particle (NNP) method to limit the number of nodes involved during deformation. Moreover, to establish localization, Zhu et al. [58] introduced the term influence area. The influence area was created using a triangular mesh and is defined by the position of the probe. Another example of localization can be found in Choi et al. [25, 26]. In their Force Propagation Method (FPM), deformation was localized based on the penetration depth regulated by user. Despite faster processing times, the main drawbacks of present approaches are that they have no relevance to material properties and that the size of the area is fixed during simulations.

2.3.2 Parallel computation

Furthermore, evidence shows that parallel computing, which incorporates another computational component known as the General Processing Unit (GPU), might enhance computational time. The concept is to separate all of the mathematical work and utilize GPU to complete the computations concurrently rather than sequentially. With the MSM nature that is parallelizable, parallel computing suits well with it. Georgii and Westermann [59] utilized the GPU to compute the internal resistance of the MSM and to get information on the locations of the mass spots. This data was then utilized to update the deformations. Similarly, Leon et al. [60] employed the GPU to compute internal force and update the location of recorded mass locations. Meanwhile, Vassilev et al. [61], Rasmusson et al. [62], and Etheredge [63] used the recent CUDA parallel computing framework to conduct parallel processing.

2.3.3 Numerical integration

Another frequent option is to enhance the numerical integration method for solving the model dynamic equation [57]. Several studies comparing the computing performance of common numerical integration algorithms have been published. The results show that the selection is not only based on computational time. The stability of the integration must also be considered throughout the evaluation process. In general, an explicit technique, such as the central difference technique, is favored due to its good processing speed. However, at a shorter time step, the method's stability may be a concern. The implicit technique, on the other hand, gives more stability but necessitates more computing work. As a result, determining the best numerical integration method remains an essential topic to investigate.

3 Discussion

Despite improvements to the nonlinear deformation of traditional MSM models, only a small number of investigations corroborated the findings with actual soft tissue deformation. The difficulty in characterizing soft tissue deformations may account for the lack of a validation procedure. Soft tissue deformation exhibits a mixture of linear and nonlinear responses, according to Fung [64]. At small deformations, the linear response occurs, followed by a nonlinear response at larger deformations. Holzapfel [65] supports it, though with more differentiation during the big deformation period. According to Holzapfel, soft tissue deformation at large deformation begins with a nonlinear response but subsequently recovers to linear before rupture. Thus, soft tissues exhibit a three-phase response for a whole deformation process: linear, nonlinear, and linear deformation. Future updates to MSM models should take this multiple-phase response into account in order to replicate detailed soft tissue deformation. Nonlinear soft tissue deformation is also more complicated than polynomial or exponential functions. While some nonlinear deformations may be simulated, they are confined to a certain kind of soft tissue, resulting in the model's inability to replicate diverse forms of soft tissue deformation. To correctly replicate the nonlinearity, a different methodology is necessary. The piecewise technique may be a suitable answer to the problem since it allows for the use of several functions during modeling.

The missing relationship between MSM parameters and soft tissue properties, on the other hand, is a big concern. At the moment, the optimization procedure can only partially fix the problem. An ideal solution should include a direct equivalence between MSM parameters and soft tissue properties. While some studies, such as Lloyd [49] and Delingete [50], have found a solution, yet it is confined to a certain type of MSM structure. Furthermore, as a prerequisite for the optimization process, experimental data are usually required. The findings are often presented as a load–displacement relationship. This procedure is time-consuming. Future optimization can be constructed so that the derivation process occurs in real-time interaction. Estimation techniques with real-time capacity, like the Kalman filter, can be utilized to get MSM parameters simultaneously throughout the soft tissue experiment.

4 Conclusion

Several findings can be derived from the study on the enhancement of the MSM model in this paper. First, the existing nonlinear MSM models do not account for the multiple stages of soft tissue deformation which simplification or generalization are commonly used as the solution. Second, only a few nonlinear MSM models are validated using either experimental data or continuum mechanics. Furthermore, no approach exists that links MSM parameters to soft tissue properties directly. Therefore, MSM models rely significantly on the precision of the optimization process to attain accuracy in simulating soft tissue deformations.

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References

1. Hsu WM, Hughes JF, Kaufman H (1992) Direct manipulation of free-form deformations. ACM SIGGRAPH Comput Graph 26:177–184
2. MacCracken R, Joy KI (1996) Free-form deformations with lattices of arbitrary topology. In: Proceedings of the 23rd annual conference on computer graphics and interactive techniques—SIGGRAPH '96, pp 181–188
3. Terzopoulos D, Platt J, Barr A, Fleischer K (1987) Elastically deformable models. ACM SIGGRAPH Comput Graph 21:205–214

4. Ishikawa T, Sera H, Morishima S, Terzopoulos D (1998) Facial image reconstruction by estimated muscle parameter. In: Proceedings third IEEE international conference on automatic face and gesture recognition, pp 342–347
5. Gibson SF (1997) 3D chainmail. In: Proceedings of the 1997 symposium on interactive 3D graphics—SI3D ’97, pp 149–154
6. Klaus-Jürgen B (2014) Finite element procedures. Prentice-Hall, Englewood Cliffs, N.J
7. Bro-Nielsen M, Cotin S (1996) Real-time volumetric deformable models for surgery simulation using finite elements and condensation. Comput Graph Forum 15:57–66
8. Taylor ZA, Cheng M, Ourselin S (2008) High-speed nonlinear finite element analysis for surgical simulation using graphics processing units. IEEE Trans Med Imaging 27:650–663
9. Brebbia CA (1982) boundary element methods in engineering. Springer, Berlin (U.A.)
10. Belytschko T, Krongauz Y, Organ D, Fleming M, Krysl P (1996) Meshless methods: an overview and recent developments. Comput Methods Appl Mech Eng 139:3–47
11. Xu S, Liu XP, Zhang H, Hu L (2011) A nonlinear viscoelastic tensor—mass visual model for surgery simulation. IEEE Trans Instrum Meas 60:14–20
12. Cooper L, Maddock S (1997) Preventing collapse within mass-spring-damper models of deformable objects. In: 5th international conference centre Europe, computer graphic visual, vol 2, no 1, pp 196–204
13. Teschner M, Girod S, Girod B (2000) Direct computation of nonlinear soft-tissue deformation. Vis Model Vis 22–24
14. Mohammadi H (2009) A numerical method to enhance the accuracy of mass-spring systems for modeling soft tissue deformations. J Appl Biomech 25:271–278
15. Pourhosseini M, Azimirad V, Kazemi M (2014) A new fast nonlinear modeling of soft tissue for surgical simulation. J Robot Surg 8:141–148
16. Duysak A, Zhang JJ, Ilankovan V (2003) Efficient modelling and simulation of soft tissue deformation using mass-spring systems. Int Congr Ser 1256:337–342
17. Luo Qi, Xiao J (2007) Contact and deformation modeling for interactive environments. IEEE Trans Rob 23:416–430
18. Cui T, Song A, Wu J (2008) Simulation of a mass-spring model for global deformation. Front Electr Electron Eng China 4:78–82
19. Sulaiman S, Sing Yee T, Bade A (2014) Effect of time complexities and variation of mass spring model parameters on surgical simulation. Malays J Fundam Appl Sci 9:171–179
20. Chen F, Gu L, Huang P, Zhang J, Xu J (2007) Soft tissue modeling using nonlinear mass spring and simplified medial representation. In: 2007 29th annual international conference of the IEEE engineering in medicine and biology society, pp 5083–5086
21. San-Vicente G, Aguinaga I, Celigueta JT (2012) Cubical mass-spring model design based on a tensile deformation test and nonlinear material model. IEEE Trans Visual Comput Graph 18:228–241
22. Shah R, Gupta A (2013) Non-linear cubic spring-mesh model for simulating biological tissues. Bio-Med Eng Sci 51(Supplement):U-12
23. Garg A, Sreeni KG (2013) Haptic rendering of thin and soft objects. ICTACT J Image Video Process 3(3):539–550
24. Choi K-S, Sun H, Heng P-A (2004) An efficient and scalable deformable model for virtual reality-based medical applications. Artif Intell Med 32:51–69
25. Choi K-S, Sun H, Heng P-A (2003) Interactive deformation of soft tissues with haptic feedback for medical learning. IEEE Trans Inf Technol Biomed 7:358–363
26. Choi K-S, Sun H, Heng P-A, Zou J (2004) Deformable simulation using force propagation model with finite element optimization. Comput Graph 28:559–568
27. Mun P, Zhong Y, Shirinzadeh B, Smith J, Gu C (2011) An improved mass-spring model for soft tissue deformation with haptic feedback. ICMT 2011:1–6
28. Chang Y-H, Chen Y-T, Chang C-W, Lin C-L (2010) Development scheme of haptic-based system for interactive deformable simulation. Comput Aided Des 42:414–424
29. Basafa E, Farahmand F, Vossoughi G (2008) A non-linear mass-spring model for more realistic and efficient simulation of soft tissues surgery. Stud Health Technol Inf 132(1):23–25

30. Nikolaev S (2013) Non-linear mass-spring system for large soft tissue deformations modeling. Sci Tech J Inf Technol Mech Opt 5(87):88–94
31. Keeve E, Girod S, Kikinis R, Girod B (1998) Deformable modeling of facial tissue for craniofacial surgery simulation. Comput Aided Surg 3:228–238
32. García M, Gómez M, Ruíz Ó, Boulanger P (2005) Spring–particle model for hyperelastic cloth. In: Canadian Congress of Applied Mechanics, CANCAM
33. Hammer PE, del Nido PJ, Howe RD (2011) Anisotropic mass-spring method accurately simulates mitral valve closure from image-based models. Funct Imaging Model Heart 233–240
34. Delingette H, Cotin S, Ayache N (1999) A hybrid elastic model allowing real-time cutting, deformations and force-feedback for surgery training and simulation. Proc Comput Animation 1999:70–81
35. Picinbono G, Delingette H, Ayache N (2003) Non-linear anisotropic elasticity for real-time surgery simulation. Graph Models 65:305–321
36. Liu XP, Xu S, Zhang H, Hu L (2011) A new hybrid soft tissue model for Visio-haptic simulation. IEEE Trans Instrum Meas 60:3570–3581
37. del-Castillo E, Basañez L, Gil E (2013) Modeling non-linear viscoelastic behavior under large deformations. Int J Non-Linear Mech 57:154–162
38. Ahmadian MT, Nikooyan AA (2006) Modeling and prediction of soft tissue directional stiffness using in-vitro force-displacement data. Int J Sci Res 16:385–389
39. Wang Y, Guo S (2014) Elasticity analysis of mass-spring model-based virtual reality vascular simulator. In: 2014 IEEE international conference on mechatronics and automation, pp 292–297
40. Duan Y, Huang W, Chang H, Chen W, Zhou J, Teo SK, Su Y, Chui CK, Chang S (2016) Volume preserved mass-spring model with novel constraints for soft tissue deformation. IEEE J Biomed Health Inform 20:268–280
41. Maciel A, Boulic R, Thalmann D (2003) Deformable tissue parameterized by properties of real biological tissue. Surg Simul Soft Tissue Model 74–87
42. Jansson J, Vergeest JSM (2002) A discrete mechanics model for deformable bodies. Comput Aided Des 34:913–928
43. Nogami R, Noborio H, Ujibe F, Fujii H (2004) Precise deformation of rheologic object under MSD models with many voxels and calibrating parameters. In: IEEE international conference on robotics and automation, 2004. Proceedings. ICRA ’04, pp 1919–1926
44. Morris D, Salisbury K (2008) Automatic preparation, calibration, and simulation of deformable objects. Comput Methods Biomech Biomed Eng 11:263–279
45. Zerbato D, Galvan S, Fiorini P (2007) Calibration of mass spring models for organ simulations. In: 2007 IEEE/RSJ international conference on intelligent robots and systems, pp 370–375
46. Sala A, Turini G, Ferrari M, Mosca F, Ferrari V (2011) Integration of biomechanical parameters in tetrahedral mass-spring models for virtual surgery simulation. In: 2011 annual international conference of the IEEE engineering in medicine and biology society, pp 4550–4554
47. Baudet V, Beuve M, Jaillet F, Shariat B, Zara F (2009) Integrating tensile parameters in hexahedral mass-spring system for simulation. In: Proceeding of 29th international conference on computer graphics, visualization, and computer vision (WSCG ’09), pp 145–152
48. Gelder AV (1998) Approximate simulation of elastic membranes by triangulated spring meshes. J Graph Tools 3:21–41
49. Lloyd B, Szekely G, Harders M (2007) Identification of spring parameters for deformable object simulation. IEEE Trans Visual Comput Graph 13:1081–1094
50. Delingette H (2008) Triangular springs for modeling nonlinear membranes. IEEE Trans Visual Comput Graph 14:329–341
51. Deussen O, Kobbelt L, Tücke P (1995) Using simulated annealing to obtain good nodal approximations of deformable bodies. Eurographics 30–43
52. Louchet J, Provot X, Crochemore D (1995) Evolutionary identification of cloth animation models. Eurographics 44–54
53. Joukhadar A, Garat F, Laugier C (1997) Parameter identification for dynamic simulation. Proc Int Conf Robot Autom 1928–1933

54. Etzmuss O, Gross J, Strasser W (2003) Deriving a particle system from continuum mechanics for the animation of deformable objects. IEEE Trans Visual Comput Graph 9:538–550
55. Bianchi G, Solenthaler B, Székely G, Harders M (2004) Simultaneous topology and stiffness identification for mass-spring models based on FEM reference deformations. Med Image Comput Comput-Assist Interv MICCAI 2004, pp 293–301
56. Mosegaard J (2003) Parameter optimisation for the behaviour of elastic models over time. Stud Health Technol Inform 98:253–255
57. Qiao B, Chen G, Ye X (2009) The research of soft tissue deformation based on mass-spring model. In: 2009 international conference on mechatronics and automation, pp 4655–4660
58. Zhu L, Ye X, Ji'er X, Gu Y, Guo S (2010) A real-time deformation modeling scheme of soft tissue for virtual surgical. In: 2010 ieee international conference on information and automation, pp 771–775
59. Georgii J, Westermann R (2005) Mass-spring systems on the GPU. Simul Model Pract Theor 13:693–702
60. Leon CA, Eliuk S, Gomez HT (2010) Simulating soft tissues using a GPU approach of the mass-spring model. 2010 IEEE Virtual Reality Conf (VR) 261–262
61. Vassilev T, Rousev R (2008) Algorithm and data structures for implementing a mass-spring deformable model on GPU. Res Lab Univ Ruse, pp 102–109
62. Rasmusson A, Mosegaard J, SØrensen TS. Exploring parallel algorithms for volumetric mass-spring-damper models in CUDA. Biomed Simul 49–58
63. Etheredge CE (2011) A parallel mass-spring model for soft tissue simulation with haptic rendering in CUDA. In: 15th Twente student conference on IT
64. Fung YC (2011) Biomechanics: mechanical properties of living tissues. Springer, New York
65. Holzapfel GA (2001) Biomechanics of soft tissue. Handbook Mater Behav Models 3:1049–1063

Biomechanics, Safety and Sports

Injury Pattern Among Drivers Involved in Single Frontal Crash Based on the Police Reported Accident Data in Malaysia

M. N. Noordin, H. Osman, Hanida Abdul Aziz, N. Rosli, M. Widia, E. H. Sukadarin, Nur Syafiqah Fauzan, H. R. Zadry, Ahmad Azad Ab. Rashid, and Zulhaidi Mohd Jawi

Abstract More than 8.2 million police reported motor vehicles crashed, resulting in 67,882 fatalities and over 140,000 injured victims from 2009 to 2018 recorded by Ministry of Transport, Malaysia. Single-vehicle crash can cause more fatalities than multi vehicle crashes as reported in previous study. Therefore, a better understanding of real frontal crashes is needed to support the decision making for future frontal test program. One of the important part to discover is the injury pattern of occupants based on real accidents. Furthermore, different frontal crash configurations may result in different level of injury severity. The objective of this study is to analyse the injury severity category and body part injury of drivers based on police reported single frontal crashes in Malaysia. Reported accident cases from 2015 to 2018 were gathered from Bukit Aman Traffic Investigation and Enforcement (JSPT), Royal Malaysia Police. The single-vehicle crashes categorized under full-width and offset and sideswipe configurations were selected. 757 cases were meeting selection criteria. 81.9% of the cases involved in the full-width and offset type of crashes configuration, while the sideswipe crash configuration contributes to 19.1% of the cases. Most of the drivers were reported with no injury (64%), fatal (17.6%), slight injury (11.8%) and severe injury (6.6%) of categories in both crash configurations.

M. N. Noordin · H. Osman · H. Abdul Aziz (✉) · M. Widia · E. H. Sukadarin · N. S. Fauzan
Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang Pahang, Malaysia
e-mail: hanidaaziz@ump.edu.my

M. N. Noordin
e-mail: miminabilamn@ump.edu.my

N. Rosli
Centre for Mathematical Sciences, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang Pahang, Malaysia

H. R. Zadry
Department of Industrial Engineering, Faculty of Engineering, Universitas Andalas, Kampus Limau Manis, Kode Pos 25163, Padang—Sumatera Barat, Indonesia

A. A. Ab. Rashid · Z. Mohd Jawi
Malaysian Institute of Road Safety Research (MIROS) , 43000 Kajang Selangor, Malaysia

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The most frequent injury sustained by fatal drivers were head injury for full-width and offset configuration, and multiple body parts injury for sideswipe configuration. The chi-square test was used to study the association between the crashes configuration and injury severity category. The p-values are less than 0.05, hence there is a significant effect between frontal crash configuration and injury severity category. Based on calculated odd ratio, full-width and offset configuration is 6.88 more likely to be fatal than sideswipe.

Keywords Real frontal crashes · Driver injury · Police reported accidents · Full-width and offset · Sideswipe

1 Introduction

Road traffic crashes now represent the eighth leading cause of death globally, affected more than 1.35 million lives each year and cause up to 50 million injuries [1]. Investigation and statistical analysis in Malaysia from 2009 to 2018 indicates that more than 8.2 million police reported motor vehicles crashed, resulting in 67,882 fatalities and over 140,000 injured victims [2]. Car accidents are the most frequently occurred every year (Fig. 1). Most of ASEAN countries also have high in percentage (%) of traffic accident fatalities which involving drivers as well as passengers of four (4) wheeled vehicles. In fact, the trend is worse when encountered worldwide cases [3].

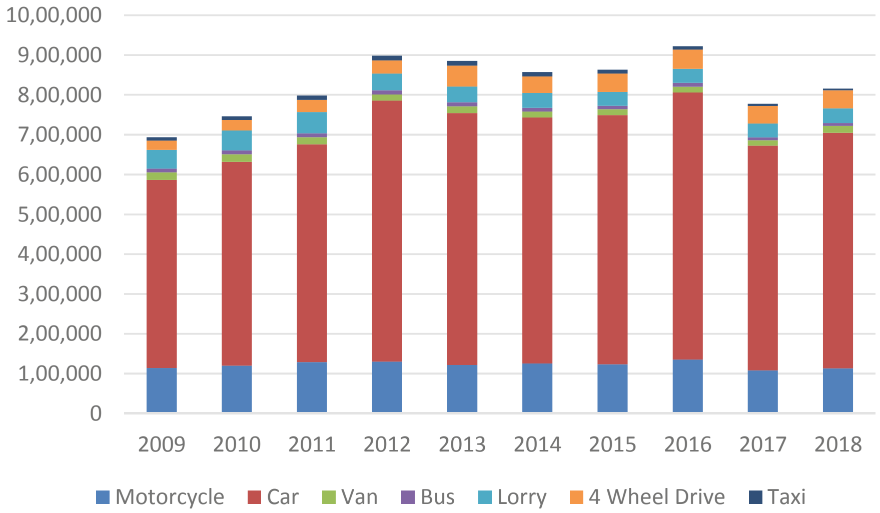

Fig. 1 Motor vehicles involved in road accidents by type of vehicle in Malaysia, 2009–2018 (MOT 2018)

Single-vehicle accidents are defined as "those only involve driver of one vehicle without any involvement of any other road users" [4]. Single-vehicle crashes are also found to have more fatalities than multi-vehicle crashes, as was proved by the fact that single-vehicle crashes contribute 28.9% of all crashes, but it accounted 58.1% of all fatal crashes in the US in 2015 [5]. Furthermore, Insurance Institute for Highway Safety (IIHS) also revealed that 56% of the car occupants' death involved in frontal single-vehicle crashes in 2018. It contributes the highest percentage (%) of the car occupant death from the frontal crash compared to the side, rear and other (mostly rollover) point of initial impact [6]. Therefore, as a preparation to face the challenging road traffic accidents nowadays, the New Car Assessment Programme for Southeast Asian Countries (ASEAN NCAP) has announced a New Road Map 2021–2025 with more inclusive assessment protocol whereby frontal crash impact test remains the largest point under Adult Occupant Protection (AOP) pillar [7].

Injury severity and fatality based on the vehicle type had been investigated among driver victims with different age and sex that involved in single vehicle crashes. Based on this study, male and older driver victims were at a greater risk of case-fatality and the type of vehicles involved were car and truck. They generally associated with lower injury rates but higher in fatality rates [8].

Hu et al. [9] studied the prediction of the injury trends for US adult population based on age, sex, stature, and body mass index (BMI) by using parametric Finite Element (FE) human models in frontal crash simulation. Based on their study, chest injury risk was strongly affected by age and sex, with older female occupants having the highest risk. Other than that, a strong correlation was also observed between BMI and knee–thigh–hip injury risk, but there were none occupant parameters meaningfully affected neck injury risks. Based on discussion of experts from multiple related fields in Malaysia, the current situation showed that the head, neck, and chest remain the most affected (severe) body region's if the frontal crash happened [10]. Further study needs to be done in order to consolidate those findings.

Therefore, in this study, the patterns of injury among drivers involved in frontal crashes were analysed in terms of injury severity and body part injury based on police reported accident data from year 2015 to 2018. The main objective of the present study is to determine the injury patterns related to full-width and offset and sideswipe frontal crashes configurations involving single passenger vehicle.

2 Methodology

2.1 Source of Data

The police reported accident data for year 2015–2018 were gathered from Bukit Aman Traffic Investigation and Enforcement (JSPT), Malaysian Royal Police, Malaysia. Only passenger vehicles involved in full-width and offset and sideswipe crash configuration were selected in this study. Nevertheless, full-width and offset have been recorded under the same configuration (front crash) and the frequency of offset also not stated in JSPT accident data.

Data for injury severity category and body part injury also obtained directly as recorded in JSPT accident database. The injury severity category was categorized into fatal, severe injury, slight injury and no injury. Meanwhile body part injury that affected by the frontal crash were head, neck, chest, back, pelvis, hand, lower leg, multiple injury and no injury.

2.2 Statistical Analysis

The police reported accident data is analysed in terms of frequency and percentage for the passenger vehicles type, injury severity category and body part injury in frontal crash configurations of full-width and offset and sideswipe. Chi square test is used to investigate the significant effect between frontal crash configurations and level of injury severity. Odd ratio test is performed to identify the frontal crashes type of configuration that contribute to the fatality based on the police reported accident data. Result analysis was performed in MINITAB 18 Statistical Software.

3 Results and Discussion

3.1 Single Frontal Crashes Accident in Malaysia Between 2015 and 2018

Table 1 shows the total number of single frontal crashes accident in Malaysia based on the full-width and offset and sideswipe type of crash configurations. The total of 757 cases were reported between 2015 and 2018. From the total case, 189 accidents happen in 2015, 231 accidents were reported in 2016, 239 cases occur in 2017 and 98 accidents were reported in 2018.

Table 1 Total number of single frontal crash accident cases depend on type of configurations

Year	Crash configuration		Total
	Full-width and offset	Sideswipe	
2015	146	43	189
2016	186	45	231
2017	197	42	239
2018	91	7	98
Grand total	620	137	757

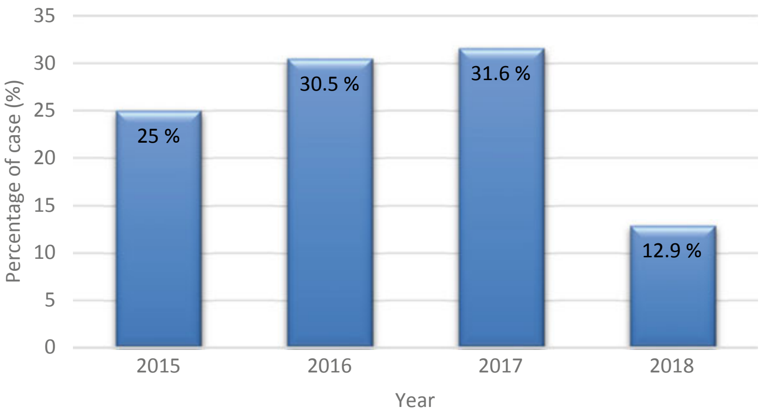

Fig. 2 The percentage of the single frontal crash accident cases between 2015 and 2018

Fig. 3 Percentage of single frontal crash configurations

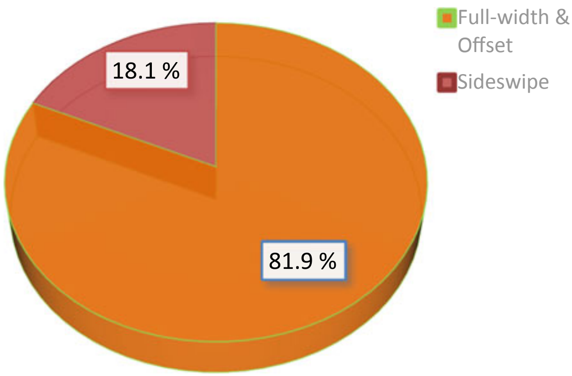

Figure 2 depicts the distribution of the accident cases between 2015 and 2018. The distribution is slightly increase from 2015 to 2017. However, in 2018 the number of accident cases shows decreasing trend with only 12.9% cases was reported.

Figure 3 shows the percentage of the single frontal crash configurations for cases involving the total of 757 vehicles. 81.9% of the cases involve in the full-width and offset type of crashes configuration, while the sideswipe crash configuration contributes to 18.1% of the cases.

3.2 *Distribution of Vehicles*

Figure 4 shows the frequency of the vehicles involve in single frontal crash accidents based on the type of configuration. The total number of vehicles involve is 757

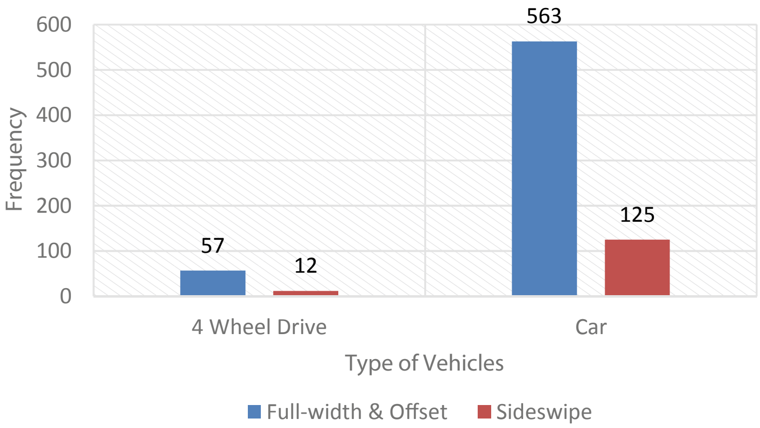

Fig. 4 Frequency of passenger vehicles based on single frontal crash configuration

which were reported that car contribute the highest cases with the total of 563 in full-width and offset configuration and 125 cases in sideswipe configuration. Meanwhile, another type of vehicles which was 4 Wheel Drive was reported 57 cases under category of full-width and offset configuration and only 12 cases were reported involved in sideswipe configuration.

3.3 Distribution of Injury Category

Based on the Fig. 5, fatality is more likely to occur in full-width and offset with the total of 128 cases. Meanwhile, 5 fatality occur in sideswipe type of configuration. Severe injury was contributed by full-width and offset configuration with the total of 44 cases and 6 cases occur in sideswipe configuration crash.

Police record shows that 21% of the fatality occur in full-width and offset crashes and 4% of the fatal was reported in sideswipe crash configuration as can be seen in Figs. 6 and 7 respectively. Severe injury is more likely to occur in full-width and offset crashes compare than sideswipe as the reported cases is 7% in full-width and offset crashes. Only 4% of severe injury was reported in sideswipe crash configuration. No injury is more likely to happen in sideswipe crash configuration as it contributed to 83% compare than in full-width and offset crashes with the reported cases of 60%.

3.4 Distribution of Body Part Injury

Table 2 shows the frequency of the body part injury of drivers under each injury severity category. In both types of configurations, the highest frequency was recorded

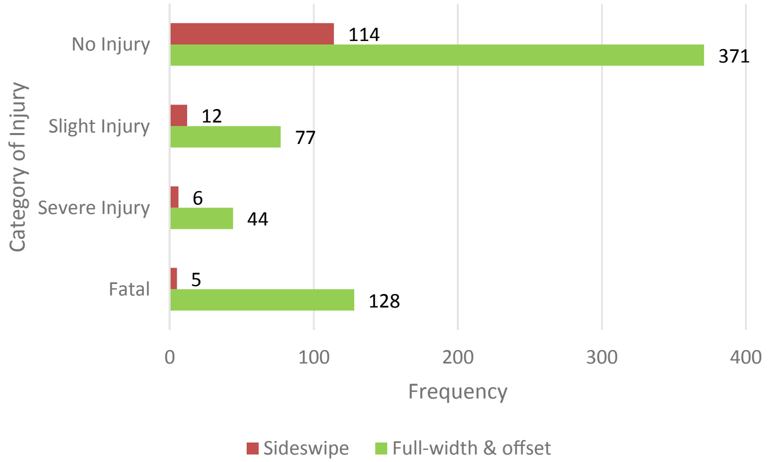

Fig. 5 Frequency of the driver injury based on frontal crash configuration

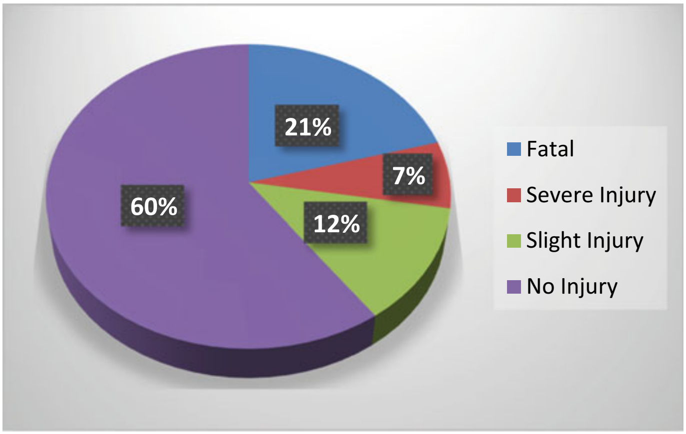

Fig. 6 Percentage of the driver injury based on full-width and offset crash configuration

for no injury with the 370 cases in full width and offset and 114 cases in sideswipe crash configuration. The head (6 cases) and multiple injury (3 cases) were reported contributing to the fatality in full-width and offset crashes configuration. While multiple injury (1 case) was reported contributing to the fatality in sideswipe crash configuration. Severe injury was contributed by the multiple body part injury (11 cases) in full-width and offset crashes configuration and hand, head and lower leg body part injury with 2 cases respectively in sideswipe crash configuration. The findings are in agreement with expert discussion which stated that head, neck, and chest remain the most affected (severe) body region's if the frontal crash happened in Malaysia [10].

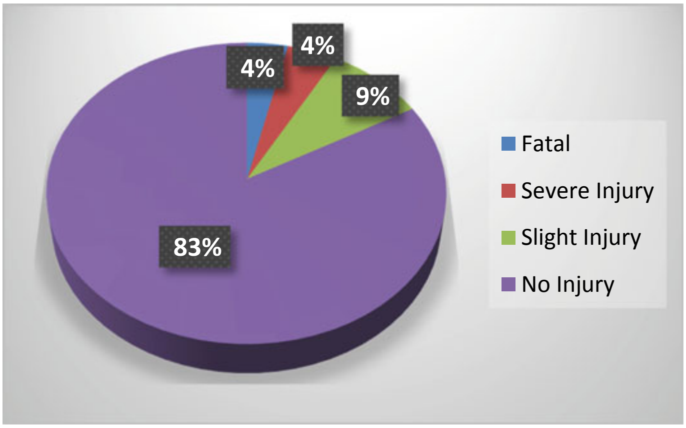

Fig. 7 Percentage of the driver injury based on sideswipe crash configuration

Based on the threat-to-life hierarchy and the body region, lower leg injury (including injuries to femur and pelvis) was at the number three after spinal cord injury and brain injury [11]. Other analysis of the UK in-depth accident data revealed that the older car occupants that involved in frontal impacts were significantly more prone to serious chest injury than their younger counterparts [12]. Other work revealed that head injury was more common in those who had crashes in four-wheel-drive vehicles (45.6%) than those who had crashes in small cars (37.3%) according to his study about the pattern of injuries caused by the road traffic crashes involving four wheel drives (4WD) vehicles and passenger cars in the United Arab Emirates (UAE) [13].

According to the police-reported accident data within the year 2015–2018, it is noticeable that very extreme missing information of body region injury for fatality with the frequency of 119 in full-width and offset and 4 were reported in sideswipe crash configurations. Huge missing data and underreporting case can cause underestimation of the overall burden of road crash injuries. Therefore, the analysis should be referred to hospital databases and not only through police crash database according to the recommendation from the studies on comparison of Malaysian road accident statistics with Sweden [14, 15].

3.5 Crash Configuration and Category of Injury Severity Association

Chi square test is used to investigate the significant effect between frontal crashes configuration and level of injury severity. Odd ratio is calculated to identify the frontal crash configuration that contribute to the fatality. The hypothesis is as follows:

Table 2 Distribution of injury severity category based on body part injury

	Body part injury	Injury severity category				
		Fatal	Severe injury	Slight injury	No injury	Total
Full-width and Offset	Back	0	1	2	0	3
	Chest	0	4	6	0	10
	Hand	0	2	7	0	9
	Head	6	9	12	0	27
	Lower leg	0	10	19	0	29
	Multiple	3	11	10	1	25
	Neck	0	0	1	0	1
	Pelvis	0	1	0	0	1
	No Injury	0	0	0	370	370
	Underreporting	119	6	20	0	145
	Total	128	44	77	371	620
Sideswipe	Back	0	0	0	0	0
	Chest	0	0	1	0	1
	Hand	0	2	1	0	3
	Head	0	2	0	0	2
	Lower leg	0	2	1	0	3
	Multiple	1	0	1	0	2
	Neck	0	0	0	0	0
	Pelvis	0	0	0	0	0
	No injury	0	0	0	114	114
	Under reporting	4	0	8	0	12
	Total	5	6	12	114	137
	Grand total	133	50	89	485	757

H_0 There is no significant effect between frontal crash configuration and level of injury severity in the single crashes.

H_1 There is a significant effect between frontal crash configuration and level of injury severity in the single crashes.

The result for the chi-square test analysis is summarized in Table 3.

The *p*-values are less than 0.05, hence we can conclude that there is a significant effect between frontal crash configuration and level of injury severity in the single crashes. Based on the odd-ratio value between frontal crash configuration and level

Table 3 Chi-square test of the effect between frontal crashes configuration and injury severity category

	Chi-square	DF	*P*-Value
Pearson	30.548	3	0.00
Likelihood ratio	37.275	3	0.00

of injury severity, we can conclude that full-width and offset is 6.88 more likely to fatal than sideswipes in the single crash incidents.

4 Conclusions

A total of 757 accident cases were reported under full-width and offset and sideswipe crashes configuration. 81.9% of the cases involve in the full-width and offset type of crashes configuration, while the sideswipe crash contributes to 19.1% of the cases. Most of the drivers were reported with no injury (64%), fatal (17.6%), slight injury (11.8%) and severe injury (6.6%) of categories in both crash configurations. Body regions injury that contribute to the fatality in full-width and offset crashes configuration were head and multiple injury for both crash configurations. The chi-square test was used to study the association between the crashes configuration and injury severity category. The *p*-values are less than 0.05, hence there is a significant effect between frontal crash configurations and injury severity category. Based on calculated odd ratio full-width and off-set configuration is 6.88 more likely to fatal than sideswipe. Due to very extreme of underreporting of body part injury for fatality, it is highly recommended that analysis should be referred to other sources such as hospital databases. A bigger database will likely increase the accuracy and show the real trends of road traffic accidents in Malaysia.

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References

1. World Health Organization (WHO) (2018) Global status report on road safety. https://www.rtmc.co.za/images/rtmc/docs/publications/Global%20Status%20Report%202018.pdf, 26 Dec 2020
2. Ministry of Transport (2018) Statistik Pengangkutan Malaysia. https://www.mot.gov.my/my/Statistik%20Tahunan%20Pengangkutan/Statistik%20Pengangkutan%20Malaysia%202018.pdf, 26 Dec 2020
3. World Health Organization (WHO) (2015) Global status report on road safety. https://www.who.int/violence_injury_prevention/road_safety_status/2015/en/, 26 Dec 2020
4. af Wåhlberg A (2009) Driver behaviour and accident research methodology: unresolved problems. Ashgate, Farnham, Surrey
5. Li Z, Ci Y, Chen C, Zhang G, Wu Q, Qian Z, Ma DT (2019) Investigation of driver injury severities in rural single-vehicle crashes under rain conditions using mixed logit and latent class models. Accid Anal Prev 124:219–229. https://doi.org/10.1016/j.aap.2018.12.020
6. Insurance Institute for Highway Safety (IIHS) (2020) Fatality facts 2018, Passenger Vehicle Occupants. https://www.iihs.org/topics/fatality-statistics/detail/passenger-vehicle-occupants, 25 Dec 2020

7. ASEAN NCAP (2018) ASEAN NCAP Roadmap 2021–2025. New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP), http://www.aseancap.org/v2/wp-content/uploads/2019/01/ASEAN-NCAP-ROADMAP-2021-2025.pdf, 24 Dec 2020
8. Chang Y-H, Li C-Y, Lu T-H, Artanti KD, Hou W-H (2020) Risk of injury and mortality among driver victims involved in single-vehicle crashes in Taiwan: comparisons between vehicle types. Int J Environ Res Public Health 17(13):4687. https://doi.org/10.3390/ijerph17134687
9. Hu J, Zhang K, Reed MP, Wang J-T, Neal M, Lin C-H (2019) Frontal crash simulations using parametric human models representing a diverse population. Traffic Inj Prev 20(sup1):S97–S105. https://doi.org/10.1080/15389588.2019.1581926
10. Sukadarin E, Aziz H, Suhaimi N, Osman H, Noordin M, Shafiee I (2020) Evaluation of ASEAN NCAP's adult occupant protection on body region using analytical hierarchy process. SAE J Automot Eng 4:82–91
11. Martin PG, Crandall JR, Pilkey WD (2000) Injury trends of passenger car drivers in frontal crashes in the USA. Accid Anal Prev 32(4):541–557. https://doi.org/10.1016/S0001-4575(99)00076-7
12. Welsh R, Morris A, Hassan A, Charlton J (2006) Crash characteristics and injury outcomes for older passenger car occupants. Transport Res F: Traffic Psychol Behav 9(5):322–334. https://doi.org/10.1016/j.trf.2006.03.007
13. Bener A, Ghaffar A, Azab A, Sankaran-Kutty M, Toth F, Lovasz G (2006) The impact of four-wheel drives on traffic disability and deaths compared to passenger cars. J Coll Physicians Surg Pak 16(4):257–260
14. Kamaluddin NA, Abd Rahman MF, Várhelyi A (2019) Matching of police and hospital road crash casualty records—a data-linkage study in Malaysia. Int J Inj Contr Saf Promot 26(1):52–59. https://doi.org/10.1080/17457300.2018.1476385
15. Manan M, Varhelyi A (2012) Motorcycle fatalities in Malaysia. IATSS Res 36:30–39. https://doi.org/10.1016/j.iatssr.2012.02.005

Traffic Accident in Indonesia and Blind Spot Detection Technology—An Overview

Hilma Raimona Zadry, Hanida Abdul Aziz, Mirta Widia, Ezrin Hani Sukadarin, Hairunnisa Osman, Zulhaidi Mohd Jawi, and Muhammad Afif Rahman

Abstract The development of the number of motorized vehicles in Indonesia has increased every year. The increasing number of vehicles affects the number of developments in traffic accidents. It has a direct effect on the increase in the number of victims and losses due to accidents. This paper provides an overview of traffic accidents in Indonesia and the importance of efforts to prevent them. An accident, especially road traffic, results from a cumulative number of factors causing accidents, such as human factors, facility factors, infrastructure factors, and environmental factors. By knowing the leading causes of road traffic accidents, mitigation measures and recommendations can be determined to reduce the number of accidents. Traffic accidents can be reduced with a road safety management program that can be interpreted as an effort to deal with accidents that occur on the road crashes and improve vehicle technology that can minimize the impact and losses caused by accidents. Blindspot is one of the causes of accidents from the side. Blind-spot detection and blind-spot visualization (BSD/BSV) would help provide early detection/image to avoid collision with the motorcycle. It is expected that 37% of collisions can be avoided if all cars are equipped with such technology.

Keywords Traffic accident · Blind spot detection · Road safety · Transportation

H. R. Zadry (✉) · M. A. Rahman
Department of Industrial Engineering, Faculty of Engineering, Universitas Andalas, Padang 25163, West Sumatra, Indonesia
e-mail: hilma@eng.unand.ac.id

H. Abdul Aziz · M. Widia · E. H. Sukadarin · H. Osman
Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang, 26300 Gambang Pahang, Malaysia

Z. Mohd Jawi
Vehicle Safety and Biomechanics Research Centre, Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang Selangor, Malaysia

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1 Introduction

The transportation system is designed to facilitate the movement of people and goods. In the service of transportation safety, both people and goods are always attached to it; therefore, people who travel must obtain a guarantee of safety even if possible obtain comfort, while the goods transported must remain intact and not diminished in quality. Transport services that are equipped with a guarantee of safety will provide a sense of certainty and comfort for travelers so that they will be able to support the socio-economic activities of the community [1]. Safety guarantees protect the public from the impacts of transportation operations in unexpected costs due to poor safety.

Transportation as the basis for economic development, the development of society, and industrialization are needed to support the mobility of people, goods, and services. A good and regular transportation system can guarantee the mobility and movement of goods, people, and services so that, in the end, it can spur regional economic growth. Transportation has a vital role in supporting economic growth improvement; transportation is based on the large transportation needs to support mobility and efficient use of transportation. The transportation system is designed to facilitate the movement of people and goods [2].

Road transportation safety is now a global problem, which is not merely a transportation problem but has become a social problem. The rapid growth of motor vehicle ownership in Indonesia in recent years, combined with the population at a relatively young age and the diversity of vehicles, has resulted in worsening road safety problems. This condition will continue to deteriorate with an increase in the average number of vehicles of around 10% per year and an increase in population if not followed by improvements in safety management in terms of infrastructure, vehicles, and human resources [3]. In recent years, the rapid growth of vehicle ownership has put considerable pressure on the road network and traffic control devices.

Road transportation accidents worldwide, based on WHO reports, have reached 1.5 million deaths and more than 35 million injuries/disabilities due to traffic accidents per year (2739 people and 63,013 people injured per day). As many as 85% of the victims who died due to accidents occurred in developing countries where the number of vehicles is only 32% of the world's total number. Road transportation accident rates in the Asia–Pacific region contribute 44% of the world's total accidents, including Indonesia [4].

Socio-economic costs due to traffic accidents based on estimates made by WHO reached US$ 520 billion, or an average of 2% of GDP. How about Indonesia? Based on UGM and UI studies, the estimated economic losses due to traffic accidents in 2002 are at least 2.9% of Indonesia's GDP. This is a loss that occurs every year and is likely to continue and will even increase in the years to come if no appropriate steps are taken to overcome this problem [3]. Thus, this study provides an overview of traffic accidents in Indonesia as a preliminary step to determine the appropriate steps and techniques used to reduce traffic accidents.

2 Traffic Accidents in Indonesia

A traffic accident, a traffic collision or crash occurs when a vehicle collides with another vehicle, pedestrian, animal, road barriers, or any stationary obstruction such as a tree or a utility pole [5]. Reasons can explain most accidents, and even if they are said to be accidental, the opposite may be true, even if not directly. Allowing driving with conditions not roadworthy or forcing to drive while sleepy is an act of intent that leads to an accident.

Kadiyali [6] classifies accidents based on some criteria. Based on accident victims consisting of fatal injuries/fatalities, serious injuries, and minor injuries. The accident's location consists of straight roads, road bends, road intersections climbs, derivatives, plains or the mountains, outside the city, or inside the city. Based on the time of the accident incident consists of the type of workday and time. The accident's position consists of front-front collisions, front-back side collisions, front-side collisions, corner collisions, loss of control, backward collisions, collisions when overtaking, and collisions with pedestrians. The number of vehicles involved consists of a single accident, multiple accidents, and streak accidents.

The development of the number of motorized vehicles in Indonesia has increased every year. The Indonesian Central Transportation Statistics Agency noted that the number of vehicles per year from 2014 to 2018 had increased by 6.49%. The increase in the number of vehicles occurred in all types of vehicles. A reasonably high increase in the number of motorized vehicles occurred in passenger cars by 6.88% per year, followed by motorbikes, freight cars, and buses, respectively by 6.61%, 5.68% 1.42% per year [7].

The increasing number of vehicles affects the number of developments in traffic accidents. The Indonesian National Police Traffic Corps noted that the number of accident cases in Indonesia during the 2014–2019 period had an average increase of 3.30% per year. The increase in the number of accidents directly affects the increase in the number of victims and losses due to accidents. In 2018, according to data from the Central Bureau of Statistics, the number of motorized vehicles reached 35,854,932 units of vehicles. For details on annual vehicle growth data on several major islands in Indonesia, according to data from the Indonesian Central Statistics Agency, it can be seen in Table 1.

Table 1 Number of accidents, victims and material losses [7]

Details	2014	2015	2016	2017	2018	Growth per year (%)
Number of accidents	95,906	96,233	106,644	104,327	109,215	3.30
Death victim (person)	28,297	24,275	31,262	30,694	29,472	1.02
Serious injury (Person)	26,840	22,454	20,075	14,559	13,315	−16.08
Minor injury (person)	109,741	107,743	120,532	121,575	130,571	4.44
Material loss (Million Rp,)	250,021	215,892	229,137	217,031	213,866	−3.83

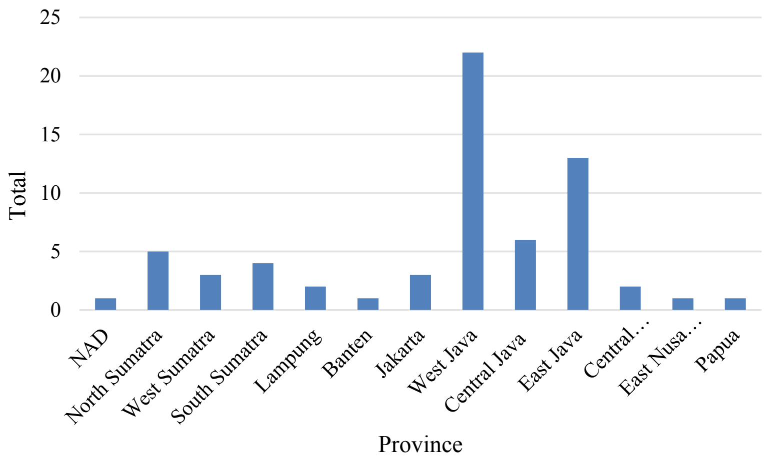

Fig. 1 Location of road traffic accidents investigated by KNKT in 2007–2016 [8]

Based on Table 1, the highest number of traffic accidents that occurred between 2014 and 2018 was in 2018, namely 109,215 cases. This number increased from data recorded in 2014 of 95,906 cases. Due to traffic accidents, the number of victims has increased by 1.02% per year for victims who died and by 4.44% per year for minor injuries. Meanwhile, serious injuries decreased by 16.08% per year. The highest number of victims died in 2016, with a total of 31,262 victims [7].

In 10 years (2007–2016), the National Committee for Transportation Safety (KNKT) has carried out investigations and research on 64 cases of road traffic accidents that occurred in Indonesia. The investigation results found that the number of road traffic accidents on Java Island occupies the highest number of accidents compared to other islands in Indonesia (Fig. 1). West Java Province, with geographical conditions consisting mostly of hilly and mountainous areas with geometric climbs, slopes, and bends, is likely to cause the number of road accidents in this province to rank highest compared to those occurring in other provinces both on the island of Java and provinces outside Java, as many as 22 cases of accidents. Whereas for the island of Sumatra, the highest road traffic accident was found in North Sumatra Province with five accident cases.

3 Road Traffic Accident Data Analysis

In general, it can be said that an accident, predominantly road traffic, is the result of a cumulative number of factors causing accidents. These causes include, among others, human factors, facility factors, infrastructure factors, and environmental factors [9–11]. Besides, certain factors can indirectly contribute to the occurrence of accidents. Accidents can arise if one of these elements does not play a role as it should. The

Table 2 Factors causing road traffic accidents (2007–2016) based on 64 investigated cases [8]

No	Year	No. of accidents	Main causative factor				
			Man	Means	Infrastructure	Environment	Others
1	2007	8	5	2	–	–	1
2	2008	6	3	1	–	–	2
3	2009	9	8	1	–	–	–
4	2010	3	2	1	–	–	–
5	2011	7	6	–	1	–	–
6	2012	8	6	2	–	–	–
7	2013	8	6	2	–	–	–
8	2014	5	1	–	2	–	2
9	2015	5	2	1	–	–	2
10	2016	5	–	1	–	–	4
Total		64	39	11	3	–	11

factors that cause road traffic accidents are interrelated or support the occurrence of accidents [12]. However, by knowing the leading causes of road traffic accidents, mitigation measures and recommendations can be determined to reduce the number of accidents. Factors causing road traffic accidents investigated by the National Transportation Safety Committee of Indonesia from 2007 to 2016 are presented in Table 2.

The factors that cause the accident are as follows:

1. Human Factors. The human factor is the most dominant in road traffic accidents because humans as road users are the main traffic movement elements. Human factors or human resources that affect accidents on this highway can be identified due to the following matters: (a) Lack of competence of officers in the field; (b) The lack of driver discipline in traffic; (c) Lack of training for drivers by vehicle owners; (d) Lack of officer assertiveness in the field of drivers who commit violations; (e) Lack of attention to working hours for drivers.
2. Facility. Means of transportation as the primary tool for moving goods and people, in this case, are vehicles. The vehicle is a device that can move on the road, consisting of motorized and non-motorized vehicles. Motorized vehicles can be grouped into several types, namely: motorcycles, passenger cars, bus cars, freight cars, and select vehicles. Motorized vehicles resulting from factory production have been designed with a safety factor value to ensure safety for the rider. Still, the vehicle will be vulnerable to triggering an accident when the preparation/maintenance procedures, as stipulated, are not followed. Deviations from the procedure include the following matters: (a) Lack of technical vehicle maintenance by drivers and vehicle owners; (b) Technical conditions of vehicles that are not roadworthy; (c) Lack of safety facilities in vehicles; (d) Lack of supervision regarding vehicle worthiness and permission to operate in the field;

(e) There is no standardization for vehicle spare parts by the regulator; (f) Use of vehicles that are not following the provisions (vehicles are overloaded).

3. Infrastructure. Infrastructure as a supporting factor for the implementation of road transportation should be built and maintained to meet safety standards. Some findings of the condition of transportation infrastructure that triggered an accident are: (a) Areas that are prone to accidents have not been handled well by the regulator; (b) Imperfect road construction and geometric; (c) Poor condition of the bridge; (d) Access that is not controlled or controlled; (e) Lack of traffic signs, road lighting equipment, road markings, and traffic signal devices, as well as control and safety devices for road users.
4. Environmental. This factor cannot be separated from all events/processes of people and goods movement because these factors provide space for the procedure.
5. Special Causes. Specific factors for road traffic accidents are the presence of inappropriate regulations/policies. The tolerance of overload is associated with levies (for example, a fine of Rupiah/kilogram overloaded).

4 Traffic Accident Management

Traffic accidents can be reduced with a road safety management program that can be interpreted as an effort to deal with accidents that occur on the highway (road crashes) and improve vehicle technology that can minimize the impact and losses caused by accidents. With the increasing needs of the community for land transportation in supporting economic growth, as well as the amount of loss and problems that accompany it, then with the support of the development of science and technology, design and production of motor vehicles will always be demanded to be able to answer the developing environmental issues, namely: (1) energy saving; (2) environment-friendly; (3) safe; (4) comfortable; (5) easy to operate by anyone. Thus a challenge for vehicle designers to present means of transportation by these demands so that several motor vehicle technologies emerge.

Various improvements in vehicle design, passenger protection, and vehicle maintenance have contributed significantly to reducing accident rates in industrialized countries. In developing countries, vehicle safety design lags in developed countries, especially in local vehicle assembly. Likewise, the condition of the vehicle becomes dangerous if the spare parts are difficult to obtain. The number of vehicles that exceed the load limit, both goods and passengers, is another factor that generally contributes to the high number of traffic casualties. Therefore, vehicle safety equipment's completeness is one of the essential things that need to be present in every vehicle to reduce the number of accidents. Here is some integrity of vehicle safety equipment.

- Anti Lock Brake System (ABS)

Anti-lock Brake System (ABS), referred to as antiskid, is an additional brakes system to anticipate vehicle slippage when braking. The use of Anti-lock has been known for a long time. In 1980 began to be introduced with an additional system that is the use of microprocessors/microcontrollers instead of units that use analog.

- Cruise Control System

The cruise control system is one of the comfort facilities in driving, which has the primary function of regulating the vehicle's speed to replace the driver's duties under what the driver expected. Although the primary function as a device to maintain the vehicle's speed, to meet the desired speed changes, the driver has been accommodated through the functions of the Cruise system.

- Intelligent Transport System (ITS)

One model of this tool is the Ford's Blind Spot Information System (BLIS), a cross-traffic alert (CTA) developed by Ford that provides information to the driver about the dangers during driving, especially when backing up. This system is equipped with a radar module to censor vehicle movements of less than five mph (8 km/h) between 45 ft (14 m).

- Active Park Assist

Lexus is one of the companies that first applied this smart parking technology. Finally, the Ford Motor Company (FMC) introduces Active Park Assist, which will be applied to the Lincoln MKS sedan and MKT crossover. This technology uses an ultrasonic sensor system and electric power-assisted steering (EPAS) to automatically position the vehicle by calculating and optimizing the steering wheel angle when parallel parking.

- Automatic Braking and Pre-Crash

Volvo presents a safety technology called Collision Warning with Full Auto Brake (CWAB). This new feature will detect the position of the vehicle in front of the radar and camera sensors. It will trigger the braking system automatically if the driver is not aware of any potential accidents.

- Vehicle Dynamics Integrated Management (VDIM)

VIDM is a control and software control system for vehicles developed by Toyota. This includes a combination of traction control systems, Electronic Stability Control, electronic steering, and other systems, which are useful for increasing vehicle response rates, performance, and safety.

- Vehicle Stability Assist (VSA)

Vehicle Stability Assist (VSA) is a safety technology specifically designed to stabilize vehicle maneuvering even if the steering wheel is turned suddenly. For complete control, VSA works in harmony with ABS (Anti-lock Braking System) and TCS (Traction Control System). In Indonesia, VSA technology has been applied to the New Honda Accord VTi-L and New Honda Civic 2.0 L.

- Distance Control

Advanced technology in automotive is also intended to secure passengers in the event of a collision. Mercedes Benz and Toyota have installed a distance control system. Thus the driver can determine what the desired distance from the car in front of him is. The computer will manage to reduce speed to near the desired distance limit. This equipment has also been installed for parking purposes.

- Electronic Stability

Daimler Chrysler, General Motor, and BMW have used an electronic stability system, which keeps the car stable even if the steering wheel slams left or right to avoid people crossing or animals that pass suddenly. The sensor system on the wheels and steering wheel will send a signal to the computer, and the computer will adjust the brakes so that the wheel rotation does not slip, and the driver can still control the vehicle.

- Smart Tires

In addition to mechanical and mechanical fields, other car components are also progressing. Some time ago, Michelin tire factory introduced a tire that can still be operated as far as 200 km even without wind. These tire models have been used in Mercedes and Lexus luxury cars. With tires like this, the driver does not need to worry if suddenly the tire is flat. He can find a safe place to replace it.

- Automatic Vehicle Location (AVL)

Now automotive manufacturers are developing AVL (automatic vehicle location) that uses Global Positioning System (GPS) facilities. AVL technology has been widely used in cars in Europe, Japan, and America. It is beneficial to find a home address or turn the car to look for alternative ways to avoid congestion. A telematics system that is connected to satellites will allow someone to find a location on land. In using this technology, the car must be equipped with a signal receiver and a standard map displayed on the computer monitor screen.

- Theft Different System

Theft Different System is commonly called the Engine Immobilizer System. This feature prevents the engine from starting if the key ID code does not match that contained in the ECU. This system uses a Transponder Chip on each key. Where the coil is installed on each key house, the amplifier and transponder key ECU will refuse to start the engine if the ID code that is found does not match the ID code contained in the key.

- Electronic Gas Pedals

The gas pedal system (Electronics Throttle Control System ETCS-i) makes this generation equipped with a gas pedal sensor that can convert any magnetic motion into an electrical signal to be sent to the ECU. The ECU will calculate each throttle valve opening through the driving motor located in the throttle body so optimal for each road condition.

- Shock Absorber Control

The suspension system's function on the vehicle is to add comfort and stability in driving the vehicle. An essential requirement in a suspension system is to accommodate the development of comfort and stability in driving even though the vehicle is moving on uneven or poor road conditions.

- Electronic Control Unit (ECU)

Electronic Control Module/ECM, which is also often called the ECU (Electronic Control Unit), functions to calculate and evaluate the sensor's input data during the engine work. It is applied to control the engine's operation by setting actuator or drive devices such as injectors, ignition coil, idle air control valve.

5 Blind Spot Detection

Concerning crash configurations, crash data from the Royal Malaysian Traffic Police (RMP) showed the largest group of motorcycle fatalities occurred from 'Angular or Side followed by 'Out of Control' and Head-on' type of collisions. The majority of motorcycle fatalities occur on arterial or primary roads [13]. Moreover, investigation data revealed that nearly 90% involved cars as crash partners in motorcycle crashes. A study conducted in the USA by the National Highway Traffic Safety Administration (NHTSA) also found that cars' passenger was highly involved in collisions with motorcycles, which was similar to the Malaysian scenario [14]. Unlike car drivers, motorcyclists are directly exposed to the environment. Compared to other types of road motor vehicles, the motorcycle is designed with low safety protection and inferior structural integrity [15, 16].

However, this data is different from the data in Indonesia. A survey conducted by Lokadata found that the most severe accident in Indonesia between 2016 and 2017 was caused by a single accident, followed by a collision of rounds of opposite directions and a collision from the front while the directional collision is in fourth place [17]. A survey of accidents from the side in Indonesia has not been carried out intensively. A preliminary survey has been conducted in Padang City, West Sumatra,

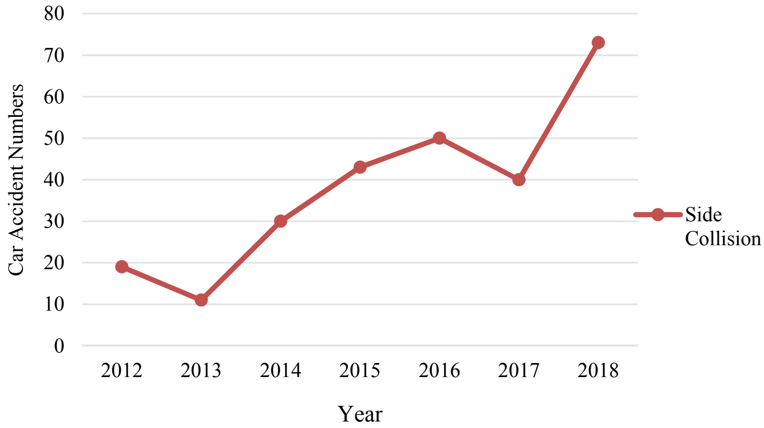

Fig. 2 Car accidents from the side (2012–2018)

Indonesia. Data obtained from 2012 to 2018 can be seen in the following table. These data indicate an increase in the number of motor vehicle (car) accidents from 2012 to 2018 with various causes (Fig. 2).

Blindspot is where the driver cannot see an area well. The term blind spot is often referred to as a no-zone area that applies to car drivers only. Motorcycle riders can also experience this blind spot because they are not visible or apparent in vision. Blindspot is one of the causes of accidents from the side.

Because of this situation, the New Car Assessment Programme for Southeast Asian Countries (ASEAN NCAP) remains committed to ensuring motorcyclists' safety in the ASEAN region. ASEAN NCAP has announced a New Road Map 2021–2015 with a more inclusive assessment protocol whereby the motorcyclist safety pillar has been added. Items of the pillar, including blind-spot detection and blind-spot visualization (BSD/BSV), advanced rear mirror, auto high beam, pedestrian protection, advanced motorcyclist safety technology. Among these criteria, BSD contributes the most significant point under the pillar. Both BSD and BSV would help in providing early detection/image to avoid collision with the motorcycle. It is expected that 37% of collisions can be avoided if all cars are equipped with such technology [18].

In the aspect of safe driving, blind spots are very crucial, considering that this factor is not only a relationship between vehicles but also humans. Because this factor is one of the leading causes of traffic accidents, especially when overtaking other vehicles—Blindspot where motorists cannot see well an area. The term blind spot is often referred to as a no-zone area that applies to car drivers only. Motorcycle riders can also experience this blind spot because they are not visible or apparent in vision. Indirectly, the blind spot is very influential in driving safely on the road, especially in very crowded road conditions. Therefore, special abilities are needed that are very good in order to avoid it.

In general, a blind spot is a condition when we cannot see objects around us. Various possibilities can occur while driving, including the danger of traffic accidents. Some causes of blind spots include the vehicle itself, internal factors, environmental factors such as when a vehicle is at an intersection, a hilly road, dusty conditions, rain, or heavy traffic. These factors need to be considered in order to create safe driving on the road. A collision study in 10 states to determine the effectiveness of various safety systems found that lane change technology at blind spots reduced collisions by 26% [19].

To provide more protection related to blind spots, several of Toyota's latest products, such as C-HR and Camry, have been equipped with blind-spot monitoring sensors. This feature will notify the driver through the sonar and car logo indicators on the end of the rear view mirror when objects or other vehicles are approaching from the right or left side of the car [20].

6 Conclusion

This overview shows that the level of traffic accidents in Indonesia is still high. Various things cause a high number of accidents. One of them is a type of side accident caused by a blind spot. Multiple kinds of newest vehicles have applied blind spot detection technology. However, this technology still needs proof of its success. Therefore, further research is necessary to estimate BSD technology's effectiveness on lane-change crashes based on crash rate and collision claim in Indonesia and further in the ASEAN context. Emphasizing this crash avoidance technology' impact in terms of crash rate and economic losses would increase industry player's and users' awareness of BSD capability.

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References

1. Silondae S, Muthalib AA (2016) Ernawati: Keterkaitan Jalur Transportasi dan Interaksi Ekonomi Kabupaten Konawe Utara dengan Kabupaten/Kota Sekitarnya. Jurnal Progres Ekonomi Pembangunan 1(1)
2. Salvendy G (2001) Handbook of industrial engineering: technology and operations management. Wiley
3. Arifin Z (2012) Perkembangan Teknologi Kendaraan Bermotor. Yogyakarta
4. WHO. Global Status Report on Safety 2018, https://www.who.int/publications/i/item/9789241565684. Last accessed 27 Dec 2020
5. Mohammed AA, Ambak K, Mosa AM, Syamsunur D (2019) A review of traffic accidents and related practices worldwide. Open Transp J 13:65–83

6. Kadiyali LR (2011) Traffic engineering and transportation planning. Khanna Publisher, New Delhi
7. BPS (2018) Statistik Indonesia, Statistical Yearbook of Indonesia. BPS-Statistics Indonesia. Jakarta
8. Saputra AD (2018) Studi Tingkat Kecelakaan Lalu Lintas Jalan di Indonesia Berdasarkan Data KNKT (Komite Nasional Keselamatan Transportasi) dari Tahun 2007–2016. Warta Penelitian Perhubungan 29(2):179–190
9. Gicquel L, Ordonneau P, Blot E, Toillon C, Ingrand P, Romo L (2017) Description of various factors contributing to traffic accidents in youth and measures proposed to alleviate recurrence. Front Psych 8:94
10. Touahmia M (2018) Identification of risk factors influencing road traffic accidents. Eng Technol Appl Sci Res 8(1):2417–2421
11. Santosa SP, Mahyuddin AI, Sunoto FG (2017) Anatomy of injury severity and fatality in Indonesian traffic accidents. J Eng Technol Sci 49(3):412–422
12. Mohammed AA, Ambak K, Mosa AM, Syamsunur D (2019) A review of traffic accidents and related practices worldwide. Open Transp J 13(1)
13. Manan MMA, Varhelyi A (2012) Motorcycle fatalities in Malaysia. IATSS Res 36(1):30–39
14. Abidin ANSZ, Jalil NAA, Wong SV, Tan CY (2018) Evaluating risk factors in motorcycle-passenger car crashes through real-world investigation. J Soc Automot Eng 2(1):92–105
15. Walker GH, Stanton NA, Salmon PM (2011) Cognitive compatibility of motorcyclists and car drivers. Accid Anal Prev 43(3):878–888
16. Aziz HA, Sukadarin EH, Widia M, Osman H, Khaidzir MH, Maamor MM, Jawi ZM (2020) An analysis of accident claims for cars with blind spot detection (BSD) technology in Malaysia. J Soc Automot Eng Malaysia 4(3)
17. Lokadata. Jumlah kecelakaan lalu lintas darat berdasarkan jenis kecelakaan. https://lokadata.beritagar.id/chart/preview/jumlah-kecelakaan-lalu-lintas-darat-berdasarkan-jenis-kecelakaan-1503468880. Last accessed 12 Jan 2020
18. NCAP (2018) A. ASEAN NCAP Roadmap 2021–2025. New car assessment program for Southeast Asian Countries (ASEAN NCAP), Malaysia
19. Manggalani RRU, Nainggolan MJ. Sistem Pengereman Otomatis Ternyata Mampu Tekan Angka Kecelakaan. https://www.suara.com/otomotif/2019/09/12/110000/sistem-pengereman-otomatis-ternyata-mampu-tekan-angka-kecelakaan. Last accessed 01 Mar 2020
20. Toyota: Apa yang Dimaksud dengan Blind Spot pada Kendaraan? https://www.toyota.astra.co.id/corporate-information/news-promo/read/apa-yang-dimaksud-dengan-blind-spot-pada-kendaraan. Last accessed 27 Dec 2020

Contributing Factors Towards Human Errors on Road Transport Safety Among Commercial Vehicle Drivers

J. Syarah Adibah and Y. Mohd Najib

Abstract Human errors have consistently been implicated in a high percentage of road transport accident. In this study, there are three factors that have been considered as contributing factors to the human error which are social factor, driving behaviour and also individual factors. The aims of this research were to study the level and to compare the contributing factors to the human error among commercial vehicle drivers at Pahang and Terengganu. The relationship between factors that contribute to human error and road transport accident also determined. Data were collected from 80 respondents. Plus, observational technique was conducted at two roads chosen in Pahang and Terengganu. The questionnaire results concluded that there had association between factors that contribute to human error and road transport accident. Observational technique results indicate that drivers had highest percentage in not wearing seatbelts. Therefore, this research concludes that the factors that contribute to human error have the tendency to road transport accident.

Keywords Road transport safety · Road transport accidents · Human errors · Commercial vehicle drivers

1 Introduction

Road Transport Safety (RTS) is the one of the main topic that concerned by many countries around the world. RTS refer to the prevention of road users from being killed or seriously injured. Based on [10], many accidents related to RTS were caused by various factors that related to human errors. Human errors was contributed high percentage toward vehicle crashes or road accidents rather than environmental factors and vehicle failure literally. Every year, there are more than one million of deaths worldwide reported due to road transport accident (RTA) and caused serious injuries to drivers (World Health Organization 2004).

J. Syarah Adibah · Y. Mohd Najib (✉)
Faculty of Science and Technology Industry, Universiti Malaysia Pahang, 26300 Kuantan, Pahang, Malaysia
e-mail: mohdnajibyacob@ump.edu.my

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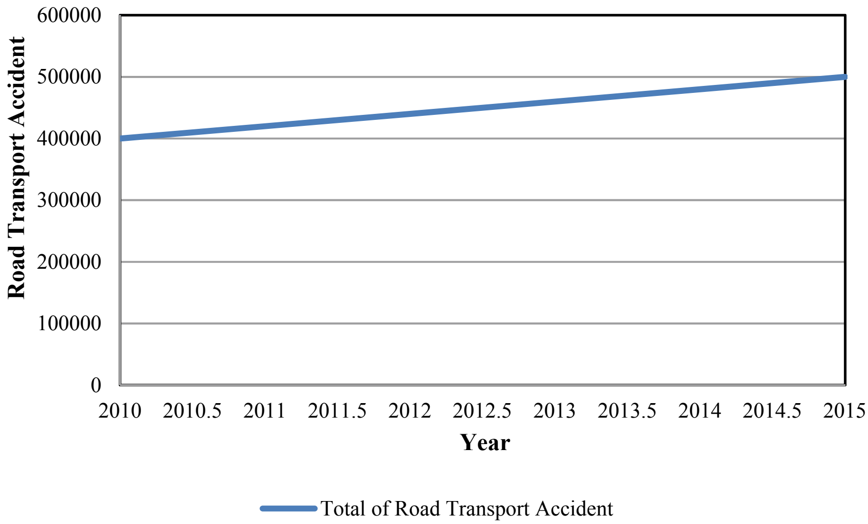


Fig. 1 Total of road transport accident in Malaysia. *Source* Official Portal of Road Transport Department of Malaysia (2017)

Based on previous research, RTS most often related to human errors which cause at approximately 75% of roadway crashes (Salmon et al. 2005). Driver's fault and carelessness was identified as one of the factors that contributed to human error and consequently contributed to the occurrence of traffic accidents or injuries among drivers, passengers and person nearby. According to [6], the study found that the most of RTA cases happened mainly depending on the conditions of the drivers and also how the drivers react or respond towards the situation. Figure 1 shows the total number of RTA cases reported specifically in Malaysia from year 2010 to 2015.

In this study, there are three factors related to human errors which are social factors, driving behaviours and individual factors has been assessed thoroughly. Social factors refers as the factor that affected performance of daily lifestyle of person including exercise, smoking and entertainment [9]. Most of drivers like to smoke while driving as daily habits especially in long distance journey. Furthermore, smoking habit lead to distraction and decrease the driving performance of the driver. In fact, the driver tends to react slowly compared in normal conditions especially during the emergency situations. In addition, entertainment like listening to music and watching television while driving is also another factor that possibly cause the distraction of driver performance [7].

Next, misuse of mobile phone, not wearing seatbelts and high speed driving has been identified as driving behaviours factor in order to assess the causes of RTA. Using mobile phone while driving lead to the RTA happened because the drivers are not really stay focused to finishing the journey. Drivers are routinely like to use mobile phone not in hands-free mode, and not even if it's in a device cradle. In fact, nowadays there are many new applications available and consequently gives a self-satisfaction towards driver especially the younger generation [3]. Furthermore, many drivers tend to not wearing seat belts while driving and this behaviour could give serious injuries if the vehicle crash or collide in the accident. According to [2] stated that other factor like not wearing seatbelts and high speed speeding also leads to the road fatality and injuries.

Meanwhile, individual factors which referred to lack in driving skill, serious health problem and lower driving attitude also affected to the RTS. Lack in driving skill contributes to RTA because drivers might get difficulties to manoeuvre the vehicle when facing the dangerous situations. Based on study done by [12], lacking of driving skill and experience among younger drivers is the most causes of RTS. In other hands, health problem is referring to physical and mental conditions of drivers while driving. Various health problem conditions were associated with an increasing number of RTA risks [5]. These are the factors that contributed to the human errors of the drivers in the occurrence of RTS.

Therefore, the driver's issues should be highlighted in order to reduce the occurrence of RTS. Physical health or disease such as diabetes, high blood pressure and injuries make the driver's reaction became slower than normal. Moreover, mental health problem also creates cognitive impairment against the driving task in normal conditions. This problem can effect on how the driver's feel, think and act rigorously. Attitude problem is another elements of individual factors because many of road users lack of self-discipline and tend to jeopardize the rules. These bad attitudes has been derived from personal or family problems which arise at the workplace or at home.

2 Methodology

All method involved in this study were carried out as shown in Fig. 2. This study was conducted to determine human factors which effect the driving performance among the commercial vehicle drivers.

A. *Document Review*

The documents analysis used to identify the human errors and accident statistics among commercial vehicle drivers. All related documents from MIROS, Royal Malaysian Police report and Department Transport of Malaysia has been reviewed in order to acquire the statistical data regarding to RTA records.

B. *Observational Technique*

The first method used in this study was observation at the selected two roads for two different locations around Pahang and Terengganu. This method able to give a clear evidence to support the results obtained from the questionnaire. Observational technique was conducted via video recording the misuse of cell phone, not wearing seatbelts and smoking habit among vehicle commercial drivers who drove along

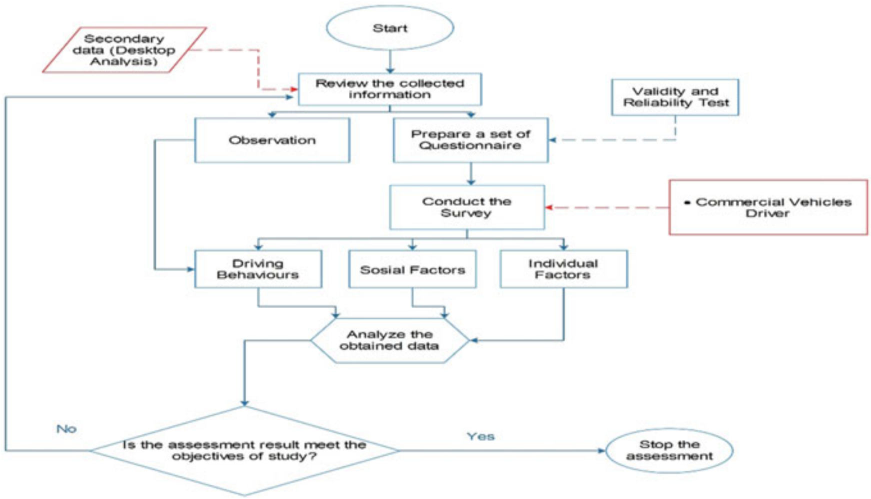


Fig. 2 Research flow

the respective roads. These video(s) were recorded by the research who monitor the driver behaviors near the traffic light.

In order to compare factors that contribute to human errors among commercial vehicles drivers, the data obtained from three periods of time which identified as a peak hour along the respective roads. The first period was recorded from 07:00 to 09:00 as a beginning of work or starting to deliver the passengers or packages in a day. Then, the second period was from 12:00 to 14:00 as lunch break hour where the increasing numbers of commercial driver re-route to restock the packages or taking their passengers. Lastly, the time selected was starting from 1600 to 1800 as the time of many commercial vehicle drivers were travelled back to home from work. These three periods were chosen as peak hours traffic as the number of commercial vehicle are considered high.

C. *Questionnaire*

A new set of questionnaire consist of 60 closed-ended questions were divided into three different parts. In Part A, the questions related to the demographic information. Meanwhile, Part B for RTS related the past accidents scenario and incidents experienced by drivers. Lastly, Part C covered for questions on the social factor, driving behaviours and individual factors that contributed to human errors. All these questions has been assigned with score value.

Therefore, Eqs. 1 and 2 were applied to calculate the average value and importance index respectively. The first step was calculating the average value for each parameter which has 5 items or questions in questionnaires. Then, followed by calculating the importance index.

Table 1 Range of score

Range of score (%)	Level of importance
< 50	Low
50–74	Medium
75–100	High

$$\text{Average Value} = \frac{(v1 \times 1) + (v2 \times 2) + (v3 \times 3) + (v4 \times 4) + (v5 \times 5)}{(\text{Total number of respondents})} \quad (1)$$

where,

V1 = number of response for never significant value
V2 = number of response for rarely significant value
V3 = number of response for sometimes significant value
V4 = number of response for often significant value
V5 = number of response for very often significant value.

$$\text{Importance Index} = \frac{\text{Average Value}}{(\mathbf{z})} \times 100\% \quad (2)$$

where,

z = Highest value on a scoring scale.

Level of importance factors that contributed to human errors were referred the Green–Yellow–Red list (Yacob, 2017) as shown in Table 1.

3 Results and Discussion

i. Validity and Reliability Test Result

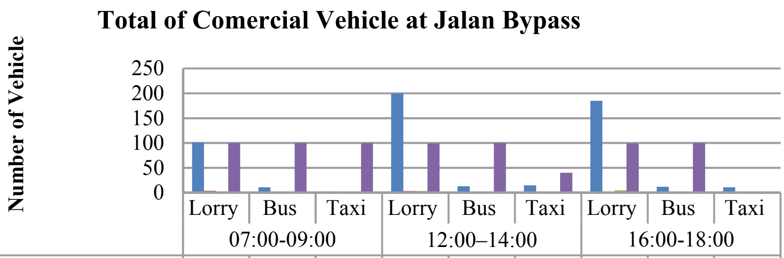
Pilot study referred as a pre-test for a particular research instrument before use for collecting data. It helps to identify suitable questions for respondent and problems that may lead to the biased answers. It also helps to identify which languages that must be used for main data collection. In this study, 10 respondents participated in the pilot study in order to improve the validity of questionnaires. The result as shown in Table 2.

ii. Observational Results

Figures 3, 4, 5 and 6 show the data collection of total commercial vehicle drivers and percentage of factors that contribute to human error on RTS among commercial

Table 2 The Cronbach's alpha result for the pilot study

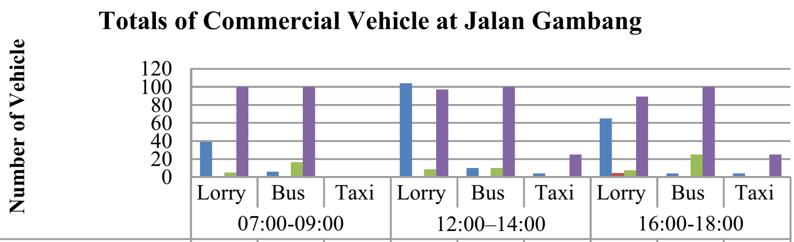
Cronbach's alpha (α)	Cronbach's alpha based on standardized items	No. of items
0.932	0.934	60



	Lorry	Bus	Taxi	Lorry	Bus	Taxi	Lorry	Bus	Taxi
	07:00-09:00			12:00–14:00			16:00-18:00		
Total (n)	101	11	3	200	13	15	185	12	11
Percentage of smoking (%)	3.96	0	0	3.5	0	0	0.54	0	0
Percentage of using mobile phone (%)	2.97	0	0	3.5	0	0	4.86	0	0
Percentage of not wearing seatbelts (%)	100	100	100	99.5	100	40	99.46	100	0

Time

Fig. 3 Totals of commercial vehicle at Jalan Bypass, Pahang

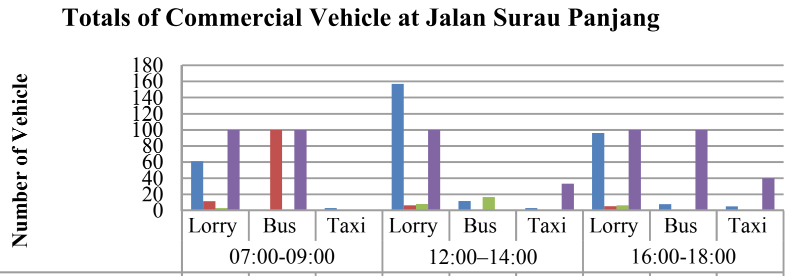


	Lorry	Bus	Taxi	Lorry	Bus	Taxi	Lorry	Bus	Taxi
	07:00-09:00			12:00–14:00			16:00-18:00		
Total (n)	39	6	1	104	10	4	65	4	4
Percentage of smoking (%)	0	0	0	0	0	0	4.62	0	0
Percentage of using mobile phone (%)	5.13	16.67	0	8.65	10	0	7.69	25	0
Percentage of not wearing seatbelts (%)	100	100	0	97.12	100	25	89.23	100	25

Time

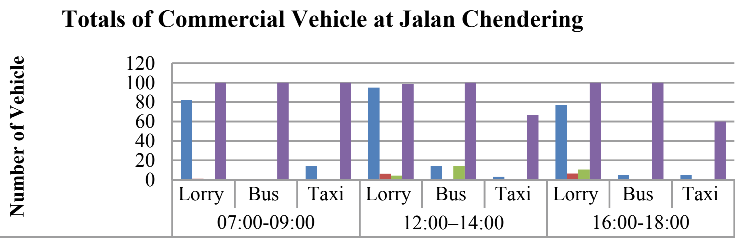
Fig. 4 Totals of commercial vehicle at Jalan Gambang, Pahang

vehicle drivers at Jalan Bypass, Jalan Gambang, Jalan Surau Panjang and Jalan Chendering respectively. From the figures, most lorry drivers had all elements of factors that contribute to human error compare to bus and taxi drivers as there were high in total of lorries. The overall results indicated that many drivers had high



	Lorry (07:00-09:00)	Bus (07:00-09:00)	Taxi (07:00-09:00)	Lorry (12:00–14:00)	Bus (12:00–14:00)	Taxi (12:00–14:00)	Lorry (16:00-18:00)	Bus (16:00-18:00)	Taxi (16:00-18:00)
Total (n)	61	1	3	157	12	3	96	8	5
Percentage of smoking (%)	11.48	100	0	6.37	0	0	5.21	0	0
Percentage of using mobile phone (%)	3.28	0	0	8.28	16.67	0	6.25	0	0
Percentage of not wearing seatbelts (%)	100	100	0	100	0	33.33	100	100	40

Fig. 5 Totals of commercial vehicle at Jalan Surau Panjang, Terengganu



	Lorry (07:00-09:00)	Bus (07:00-09:00)	Taxi (07:00-09:00)	Lorry (12:00–14:00)	Bus (12:00–14:00)	Taxi (12:00–14:00)	Lorry (16:00-18:00)	Bus (16:00-18:00)	Taxi (16:00-18:00)
Total (n)	82	1	14	95	14	3	77	5	5
Percentage of smoking (%)	1.22	0	0	6.32	0	0	6.49	0	0
Percentage of using mobile phone (%)	0	0	0	4.21	14.29	0	10.39	0	0
Percentage of not wearing seatbelts (%)	100	100	100	98.95	100	66.67	100	100	60

Fig. 6 Totals of commercial vehicle at Jalan Chendering, Terengganu

percentage on not wearing seatbelts. Based on [8], previous study also found that most of commercial vehicle drivers were not wearing seatbelts while driving.

iii. Scoring Results

Table 3 shows the results of the identified factors based on the average value and importance index. Exercise factor was the highest level in factors that contribute to human error with 47.75%, followed by not wearing seatbelts, smoking, entertainment, high speed driving, serious health problem, using mobile phone, lack of

Table 3 Scoring value of the identified factors

Parameter	Average value	Importance index (%)	Level of importance
Social factor			
Exercise	2.3875	47.75	Low
Smoking	1.6725	33.45	Low
Entertainment	1.6575	33.15	Low
Driving behaviours			
Using mobile phone	1.435	28.7	Low
Not wearing seatbelt	1.7375	34.75	Low
High speed driving	1.51	30.2	Low
Individual factor			
Lack of driving skill	1.3475	26.95	Low
Serious health problem	1.4775	29.55	Low
Attitude problem	1.33	26.6	Low

skill driving and attitude problem with 34.75%, 33.45%, 33.15%, 30.2%, 29.55%, 28.7%, 26.95% and 26.6% respectively. However the level of importance of exercise factor still in low score value. Most of the commercial vehicle drivers were answered 'never' for the answer option given in the questionnaire.

According to [1], only two out of three drivers exercise regularly prior the long journey. Therefore, the exercise factor in other research was high percentage compare to other factors but least impact to contribute the human errors on RTS. Meanwhile, other research stated that commercial vehicle drivers had high percentage of body fatigue after the long journey [4]. Therefore, the exercise factor needs to be considered in contributing to the human error which indirectly lead to RTA.

iv. Inferential Analysis

Table 4 shows Mann–Whitney test for the identified factor that contributed to human errors among the commercial vehicle drivers at the selected roads in Pahang and

Table 4 Mann–Whitney test on the identified factors

	Social factor	Driving behaviour	Individual factor
Mann–Whitney U*	732.0	754.0	742.5
Z-score	− 655	− 444	− 556
P-value	0.512	0.657	0.578

*Mann–Whitney U is significant at the value ($p < 0.05$)

Table 5 Relationship between Factors that Contribute to Human Error and Road Transport Accident

		Social factor	Driving behaviour	Individual factor
Road transport accident	Correlation coefficient (r)	0.363	0.539	0.708
	p-value	0.001**	0.000**	0.000**

**Correlation is significant at the p value < 0.05 (2-tailed level)

Terengganu. The result indicated that Z-score and *P*-value for social factor, driving behaviour and individual factor were not significant differences between the commercial vehicle drivers in Pahang and Terengganu, $Z = -6.55$, $Z = -444$, $Z = -556$ and $p > 0.05$. This is because both of these states has similar culture in driving behaviour and lifestyles.

Table 5 shows the relationship between the identified factors that contribute to human errors among commercial vehicle drivers at the selected roads in Pahang and Terengganu. From this table, there was a very strong relationship between individual factor and RTA, $r(80) = 0.708$, p-value < 0.05 followed by the relationship between driving behaviour and RTA was strong with $r(80) = 0.539$, p-value < 0.05. Lastly, the relationship between social factor and RTA was medium with $r(80) = 0.363$, p-value < 0.05. Based on previous research results, there was significant relationship between factors that contributed to human errors and the number of road accidents [11].

4 Conclusion

As the conclusion, the highest level of the identified factors that contributed to human errors among commercial vehicle drivers was exercise factor with 47.75% and the lowest level was attitude problems with 26.6%. The ranking level of the identified factors in ascending order which are exercise, not wearing seatbelts, smoking, entertainment, high speed driving, serious health problem, using mobile phone, lack of driving skill and attitude problem. The attitude problem shows the lowest level in human errors because most of the commercial vehicle drivers were successfully passed the comprehensive training provided by the company.

Based on the comparison result between commercial vehicles driver form Pahang and Terengganu, it shown that there was no significant different between them due to the similar culture in driving styles. Lastly, from the observational techniques, the results showed that lorry drivers habits like smoking and not wearing seatbelts is lower compared to other group of drivers. Most of lorry drivers were not wearing seatbelts which major contributor to high percentage of RTA happened.

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References

1. Al-hemoud AM, Simmons RJ, Al-asfoor MM (2010) Behavior and lifestyle characteristics of male Kuwaiti drivers. J Saf Res 41(4):307–313
2. Alonso F, Esteban C, Calatayud C, Sanmartín J (2013) Speed and road accidents: behaviors, motives, and assessment of the effectiveness of penalties for speeding. Am J Appl Psychol 1(3):58–64
3. Carter PM, Bingham CR, Zakrajsek JS, Shope JT, Sayer TB (2014) Social norms and risk perception: predictors of distracted driving behavior among novice adolescent drivers. J Adolesc Health 54(5 Suppl.):S32–S41
4. Christensen A, Petersen F, Soret S, Spencer-hwang R (2013) The association between low back pain and fatigue among commercial drivers. Occup Med Health Aff 1:1–4
5. Dischinger PC, Ho SM, Kufera JA (2000) Medical conditions and car crashes. Annu Proc Assoc Adv Automot Med 44(Cvd):335–346
6. Olmus H (2012) Analysis of traffic accidents caused by drivers by using log-linear models. Promet-Traffic Transp 24(6):495–504
7. Johnson R, State S (2016) State of Michigan
8. Mooren L, Williamson A (2013) Literature review of heavy vehicle driver seatbelt use Final report
9. Myers DG (2009) Behaviour and attitudes. Soc Psychol 109–140
10. Pakgohar A, Sigari R, Khalili M, Esmaeili A (2011) The role of human factor in incidence and severity of road crashes based on the CART and LR regression: a data mining approach. Procedia Comput Sci 3:764–769
11. Rajabi H (2014) Assessment of human errors in driving accidents; analysis of the causes based on aberrant behaviors
12. Sigurdardottir SB (2009) Exploring the lifestyle factors influencing young males driving style comparative study of Danish and Icelandic sample

Sprint Performance in Rugby Players: A Systematic Review

Sharul Nizam Turiman, Zulkifli Ahmad, and Nasrul Hadi Johari

Abstract The purpose of this review is to summarize the recent research that has examined the sprint performance and training of rugby players at different playing standards. Research articles published between 2010 and 2020 in PubMed, Science Direct and OATD were searched using key terms related to rugby player and sprint movement. Twenty related articles investigating sprint performance in both men and women players were included. Sprinting training were differently assessed using GPS device, timing gate, high speed camera, stopwatch and performance profiler database (PPD). Back rugby players were recorded sprint faster than forward players with the average of 1.69 s $\pm$ 0.06 s for 10 m sprint. On top of that, professional back rugby players logged longer sprint distance in 15 side rugby game for male (353.0 $\pm$ 147.0 m) and 7 side rugby game both male (168.0 $\pm$ 88.2 m) and female (133.0 m) player. Comparative analysis in terms of sprint performance between professional and amateur players were also presented. The sprint performance recorded in this review will be useful as the benchmark and guide for rugby training strategy at different playing standards. Future studies should investigate the factors likely to influence the player sprinting performance, especially on the technique and skills.

Keywords Rugby · Sprinting · Back and forward players

1 Introduction

Sprinting is running over a short distance at the top-most speed of the body in a limited period of time. It is used in many sports that incorporate running, in rugby game sprinting typically as a way of quickly reaching a target or goal or avoiding or catching an opponent. Sprinting isn't exactly just a sped-up version of our regular running form during an easy run, It's similar but different, the movement patterns of running and sprinting are similar in that you still need to put one foot in front of

S. N. Turiman · Z. Ahmad · N. H. Johari (✉)
Human Engineering Group (HEG), Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: nhadi@ump.edu.my

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the other, but different in that sprinting is a much more dynamic version of running but more explosive, to be precise. Having enough traction for fast start and stop movements or for performing quick changes of direction is therefore a key component for the successful participation in modern sports [1]. Quickness on the field with rapid accelerations and decelerations as well during cutting movements has become increasingly important in the modern game of soccer, therefore footwear plays an important role in assisting the player to perform fast movements on the field while providing comfort and protecting the foot [2]. For rugby sport, the game speed is faster on harder pitch playing surfaces [3]. The physical contact associated with tackles and rucks induces a unique physiological response compared to other team sports. Speed in rugby was moderately correlated to line breaks, tackle breaks and tries scored which have been shown to be related to successful phase and team outcomes. A decreased ability to perform repeated sprints may reduce the involvement of the player in multiple rucks and open play, thus decreasing the number of activities completed. In contrast, greater repeated sprint ability may increase the player's involvement in more rucks, emphasized by the loose forwards small correlation between fatigue and first three on attack and defense, increasing the chance to receive the ball and the subsequent involvement in more tasks [4].

The aim of this review is to provide a summary of the recent advances of sprinting movement training of rugby players in different clubs. The recorded sprinting timing according to different players' criteria will be discussed alongside with the sprint equipment technology and validity of the sprint assessment. The spring patterns recorded in this study could be useful as the benchmark for future improvement in player's sprint ability.

2 Methods

This systematic review was conducted in accordance with the guidelines of Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA). The databases searched were PubMed, OATD (Open Access Theses Dissertation) and Science Direct, that were completed in end of November 2020. Searches were limited to publication between 2010 and 2020, to ensure the latest advancements of rugby players' sprint movement training. The search term set "Rugby Sprint" was used in all searches. All titles and abstracts were screened for inclusion based on the criteria of interest, as stated in Fig. 1. Journal articles, theses, dissertations, and conference abstracts were all included. Whenever the content of a thesis or dissertation was found to duplicate corresponding to journal articles, the thesis or dissertation was excluded. Similarly, conference abstracts were excluded if they duplicated the content of a published journal article. The full text articles of all remaining studies were retrieved and screened to ensure they reported about sprinting. Bibliographies of both review articles identified at any time during the search and the full text articles retrieved were read to identify any further articles that may need to be included.

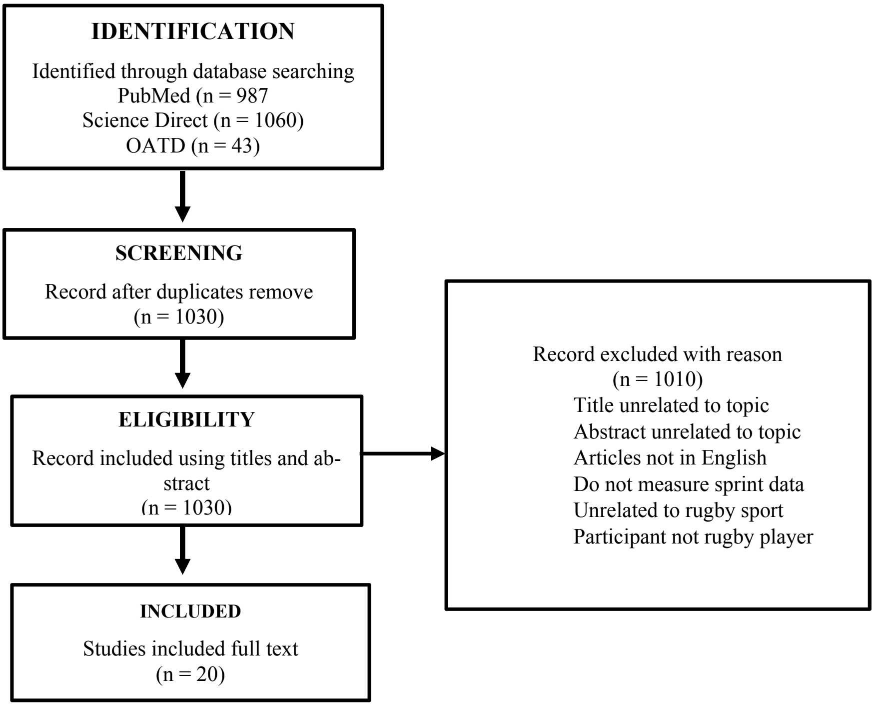

Fig. 1 Flow diagram depicting the literature search (n = number of studies)

During this process, 1010 articles were excluded in the eligibility screening where most of the articles do not record proper rugby sprint data.

3 Results and Discussion

3.1 Participant Characteristics

A total of twenty (20) studies were included in this review (Table 1) combining 1613 male players and 116 female players. Seven studies from Australia and New Zealand, five from Spain, four from United Kingdom, two from USA and each for Ireland and Brazil. Sixteen studies were on male rugby player only, three were on female and only one study on both male and female.

Eleven studies accessed players in rugby seven (7) side competition style, three studies on fifteen (15) side competition style, whilst seven studies did not specify. Six studies observed junior players whilst the rest were seniors. From the 20 studies, eleven studies involved professional player's levels, two at university level and a study involved state players.

Table 1 Participant and equipment characteristic

Study	Participants	Gender	Age (years)	Mass (kg)	Height (cm)	Playing level	Registered league	Nation	Competition	Equipment
Kempton et al. [12]	29	Male	25.5 ± 3.7	97.7 ± 11.1	183.0 ± 6.0	Professional	National Rugby League (NRL)	Australia & New Zealand	15 side	GPS device
Suarez-Arrones et al. [13]	7	Male	27.4 ± 1.6	87.9 ± 11.0	180.4 ± 7.8	Professional	Spanish Rugby Federation	Spain	7 side	GPS device
Suarez-Arrones et al. [14]	12	Female	27.8 ± 4.0	63.4 ± 4.8	165.5 ± 6.2	Professional	Spanish Rugby Federation	Spain	7 side	GPS device
McLellan and Lovell [15]	12	Male	24.5 ± 7.1	94.6 ± 27.1	188.0 ± 17.1	Professional	National Rugby League (NRL)	Australia & New Zealand	15 Side	GPS device
	12	Male	23.0 ± 7.4	92.8 ± 25.9	186.0 ± 9.6	Semi-Professional	Queensland Cup			
	12	Male	19.0 ± 1.0	88.6 ± 30.5	183.0 ± 20.4	Elite Junior	National Youth Competition			
Smart et al. [7]	1161	Male	NA	NA	NA	Amateur	–	New Zealand	Not specified	Performance Profiler Database
Suarez-Arrones et al. [16]	10	Male	27.4 ± 1.6	87.9 ± 11.0	180.4 ± 7.8	Professional	Spanish Rugby Federation	Spain	7 side	GPS device
Portillo et al. [17]	10	Female	26.27 ± 4.0	65.39 ± 5.01	166.7 ± 6.7	Professional	Spanish Rugby Federation	Spain	7 side	GPS device

(continued)

Table 1 (continued)

Study	Participants	Gender	Age (years)	Mass (kg)	Height (cm)	Playing level	Registered league	Nation	Competition	Equipment
	10	Female	32.12 ± 6.4	66.48 ± 5.38	167.4 ± 3.0	Amateur				
Darrall-Jones et al. [8]	28	Male	16–18	85.9 ± 9.4	180.9 ± 6.4	Elite Junior	English Super League	United Kingdom	Not specified	Timing gates
Ross et al. [9]	65	Male	21–24	95.7 ± 7.06	186.0 ± 5.74	Professional and Amateur	National Rugby League (NRL)	New Zealand	7 side	Timing gates
Seitz et al. [18]	24	Male	19.15 ± 1.0	78.0 ± 11.25	178.5 ± 9.5	Elite Junior	National Rugby League (NRL)	Australia	Not specified	Timing gates
Till et al. [19]	65	Male	16–20	68–100	171–187	Elite Junior	English Super League	United Kingdom	Not specified	Timing gates
Higham et al. [20]	42	Male	20–22	91.0 ± 6.15	183.0 ± 5.5	Professional	Australian Rugby Union	Australia	7 side	GPS device
Darrall-Jones et al. [21]	68	Male	15–20	70–107	172–193	Elite Junior	English Super League	United Kingdom	Not specified	Timing gates
Suarez-Arrones et al. [22]	12	Male	26.7 ± 2.1	85.7 ± 9.0	181.6 ± 6.9	Professional	Spanish Rugby Federation	Spain	7 side	GPS device
Wang et al. [11]	15	Male	20.6 ± 1.23	86.51 ± 14.18	178.0 ± 6.0	Professional	USA Rugby	USA	Not specified	High speed camera
La Monica et al. [23]	25	Male	20.2 ± 1.6	82.4 ± 13.2	180.0 ± 1.0	Professional	USA Rugby	USA	Not specified	Stopwatch
Clarke et al. [24]	22	Male	< 18	81.9 ± 7.1	182.0 ± 8.0	Elite Junior	National Rugby League (NRL)	Australia	7 side	GPS device
	18	Male	> 18	88.5 ± 10.2	181.0 ± 5.0	Amateur				

(continued)

Table 1 (continued)

Study	Participants	Gender	Age (years)	Mass (kg)	Height (cm)	Playing level	Registered league	Nation	Competition	Equipment
	13	Male	> 18	92.0 ± 6.9	184.0 ± 7.0	Professional				
	24	Female	< 18	63.6 ± 11.8	164.0 ± 7.0	Elite Junior				
	22	Female	> 18	70.4 ± 9.3	170.0 ± 7.0	Amateur				
	11	Female	> 18	68.6 ± 4.4	169.0 ± 2.0	Professional				
Read et al. [25]	65	Male	< 18	–	–	Junior	England Rugby	England	15 side	GPS device
	31	Male	20–23	–	–	Amateur				
Pereira et al. [26]	10	Male	25.2 ± 3.6	88.7 ± 7.1	182.2 ± 6.3	Professional	Brazilian Rugby Confederation	Brazil	7 side	GPS device
Malone et al. [27]	27	Female	24.4 ± 2.1	67.9 ± 4.3	168.0 ± 7.1	Professional	Irish Rugby Football Union	Ireland	7 side	GPS device

3.2 Sprint Monitoring Equipment

Majority of the studies used global positional system (GPS) device to tract sprinting profile of the rugby players. The GPS device frequency are set between 5 and 15 Hz. Other than that, five studies used timing gate and the rest used Performance Profiler Database (PPD), high speed camera and stopwatch. The GPS unit usually fitted at the upper back of rugby player (Fig. 2) to detect signals that are emitted by at least 3 Earth-orbiting satellites to give an accurate reading. The device determines the player's position at a given time to allow calculation of movement speeds and distance travelled. Despite a possible underestimation of high-intensity running distance with the time resolution of 10–15 Hz frequency, a good accuracy and reliability have been reported for the assessment of peak sprinting speed for this GPS device compared with that of an infrared timing system. Recent advancement of GPS tracking system using global navigation satellite system (GNSS) can calculate specifically the player position in terms of longitude, latitude and altitude [5]. Velocity is measured using Doppler shift that is based on frequency changing due to movement of the receiver [5]. However, prior to recording, the devices often need to be at the open area to avoid interruption throughout the session.

Performance Profiler Database (PPD) contains data of players' performance tests measured from various strength and conditioning assessment. Smart et al. [7] used PPD to monitor professional and amateur rugby players in New Zealand. Data were collected from the stipulated New Zealand Rugby Union testing procedures and entered into a database. The data may help rugby coaches and management to develop strategies to improve a player's performance in the long period of time, based on the recorded playing profiles in multiple levels. The procedure aims to provide standardize assessments protocols, however, the interpretation of the protocols may be differed between individuals, especially in terms of nutrition intake, hydration and the assessment timing. Nonetheless, players were typically tested by

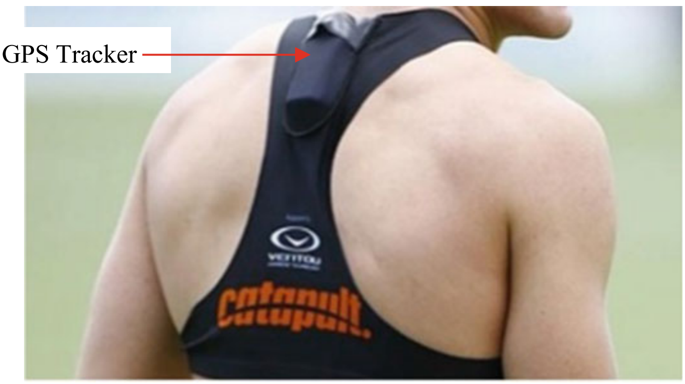

Fig. 2 Photo of Catapult OptimeyeS5 that contain GPS device attached to the vest of a rugby player [6]

the same individual strength and conditioning coach, thus minimizing the variation associated with multiple testers, no familiarization trials were performed as players were familiar with testing protocols and had tested on numerous occasions before the period of this study.

Sprints were also assessed using timing gates, either single beam [8] or dual-beam electronic [9] timing gates. The electronic timing beam also referred electronic photocells are commonly used in measuring sprint speed, agility and running pace. Timing gates system can be considered as the gold standard because it is accurate and eliminates human error. Nonetheless, the electronic photocells also prone to errors. Single beam timing systems have been reported to increase the likelihood of false signals, where infrared beam was broken by limbs rather than the torso [10]. The five studies that used timing gate in Table 1 assessed players' sprint performance at 5, 10, 20, 30, and 40 m. Players started sprint from a 2-point start, slightly behind the first timing gate, and set off their maximal run through 40-m timing gate [8]. The best recorded time from each split and cycles will be used as players' current sprint performance. Figure 3 show the example of sprint assessment. High-Speed Camera or slow-motion camera also used in measuring sprint performance. The camera works by capturing video at a higher rate frame per second (fps), allowing slow motion footage with high resolution or at least, less blur. Similar with other sprint assessment method, players were instructed to run for more than 40 m from the starting point and the speed was recorded at the poles of 5, 10, 20 and 40 m. Wang et al. [11] used Casio EX-FH20 that is capable to capture high speed video at 1000 fps (224 $\times$ 56 pixels) in their study to measure correlation of speed and agility of junior players with isometric mid-thigh pull. Another study used stopwatch to measure 40 m sprint. All recorded time were manually hand-held control upon the players' movement. The faster of the two 40 m sprints was recorded.

3.3 Sprint Movement

Rugby training intervention aims to develop a good foundation anaerobic fitness among rugby players. Sprint is among the fundamental component of the training. The reviewed articles in Table 2 reported sprint data of rugby players in rugby 7- and rugby 15-side tournament. Particularly, five studies [13, 16, 20, 24, 26] investigated male rugby players in 7-side competition whilst another three studies [12, 15, 25] examined the distance covered by the player when making the sprint movement in the game are acquired from actual competitive rugby tournament in different playing level. The study differently recorded the sprint movement speed between 5.0 and 6.4 m s^{-1}. The minimum distance covered by sprint movement in 14-min rugby 7-side game was 89.6 m $\pm$ 71.4 m recorded by forward players [20] whilst the maximum sprint distance was 168.0 m $\pm$ 88.2 m by back players [16]. For the rugby 15-side game, the minimum distance covered by sprint movement in 80-min game was 64.0 m $\pm$ 65.0 by forward players [25] and the maximum distance was 413.0 m $\pm$ 60.0 by professional player in Mclellan and Lovel [15] study. Only Read et al. [25]

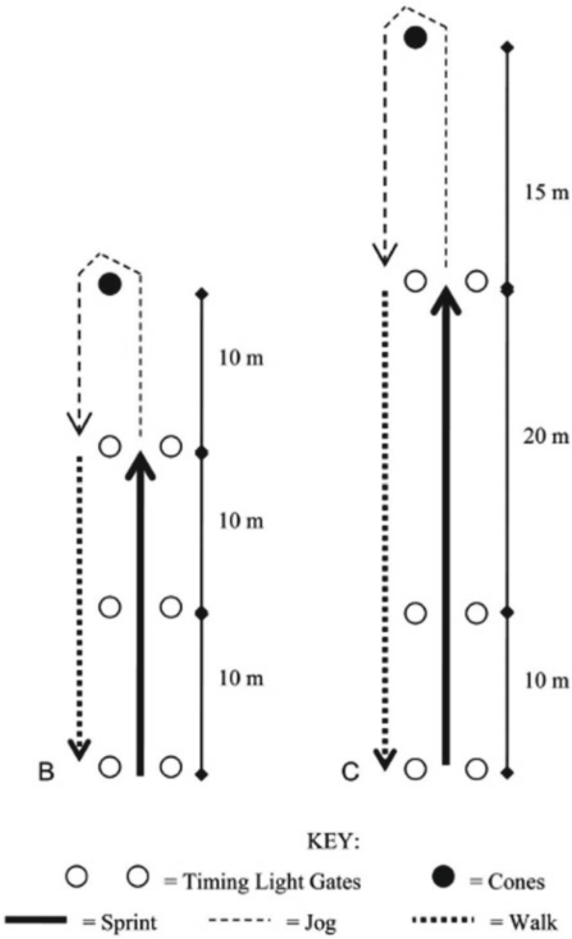

Fig. 3 Sprint assessment of the rugby repeated speed in Smart et al. [7] using timing gates

analyzed the sprint distance by player position for rugby 15-side in which the back players sprint maximum distance covered was 353.0 m ± 147.0 m and the forward was only 94.0 m ± 93.0 m. Most research generally confirms that male back player sprinting more distance than the male forward player in both rugby 7- and rugby 15-side game.

Only three studies recorded the average number of sprints in a rugby game, 2 studies from Suarez-Arrones et al. [13, 16] on the 7-side games and Mclellan and Lovel [15] on the 15-side competition. The maximum number of sprints recorded in 7- and 15-side International playing level was 4.5 ± 2.0 and 24.0 ± 6.0, respectively. The different number of sprints between 7- and 15-side games is due to the play time in rugby 15 side are 80 min and it gave more time for player to sprint in the game.

Table 2 Male player sprint distance covered in rugby 7 and 15 side tournament

Study	Competition type	Playing level	Position	Sprint distance (m)	Sprint movement speed (m s^{-1})	No. of sprint (n)
Suarez-Arrones et al. [13]	7 side	National	–	137.0 ± 84.9	> 5.5	4.5 ± 2.0
Suarez-Arrones et al. [16]	7 side	National	Back	168.0 ± 88.2	> 5.5	4.3 ± 1.5
			Forward	133.0 ± 44.8		3.2 ± 1.6
Higham et al. [20]	7 side	National	Back	137.2 ± 92.4	> 6.0	–
			Forward	89.6 ± 71.4		
Clarke et al. [24]	7 side	Junior	–	93.8 ± 47.4	> 5.0	–
		Senior	–	126.9 ± 42.9		
		Elite	–	148.639.1		
Pereira et al. [26]	7 side	National	–	146.6 ± 62.0	> 5.5	–
Kempton et al. [12]	15 side	Professional	–	121.0	> 6.4	–
McLellan and Lovell [15]	15 side	Professional	–	413.0 ± 60.0	> 6.1	24.0 ± 6.0
		S-Professional	–	298.0 ± 52.0		15.0 ± 7.0
		Elite Junior	–	237.0 ± 48.0		12.0 ± 7.0
Read et al. [25]	15 side	Junior	Back	165.0 ± 101.0	> 5.84	–
			Forward	87.0 ± 86.0		
		Junior	Back	319.0 ± 176.0		
			Forward	94.0 ± 93.0		
		University	Back	353.0 ± 147.0		
			Forward	64.0 ± 65.0		

Table 3 Female player sprint distance covered in rugby 7 side tournament

Study	Playing level	Position	Sprint distance (m)	Sprint movement speed (m s^{-1})
Suarez-Arrones et al. [14]	National	–	181.0 ± 64.0	> 5.5
Portillo et al. [17]	National	–	47.0 ± 38.8	
	International	–	118.8 ± 61.4	> 5.5
Clarke et al. [24]	Junior	–	93.8 ± 47.4	
	Senior	–	126.9 ± 42.9	> 5.0
	Elite	–	148.6 ± 39.1	
Malone et al. [27]	International	Back	133.0	> 5.5
		Forward	102.0	

For female players, there are 4 recent studies [14, 17, 24, 27] examined female players' sprinting in 7-side (Table 3). Majority of the study recorded the sprint movement speed at > 5.5 ms^{-1}, only Clarke et al. [24] recorded the sprint movement speed at > 5.0 ms^{-1}. The minimum distance covered by sprint movement in 14-min rugby game by female player was 47.0 m ± 38.8 [17] and the maximum distance was 181.0 m ± 64.0 [14]. Malone et al. [27] summarize the sprint distance by player position in which the study shows back player sprint distance covered were 133.0 m and the forward player sprint distance covered only 102.0 m.

Sprint and acceleration are important components in field sports where the ability to cover ground quickly from varying starting speeds is critical to success. Table 4 shows 8 studies that have reported and acquired the data of rugby players sprinting from repeated 5 to 40 m sprint assessment in controlled environment. In terms of player playing level, the international back rugby player was faster with record of 1.69 s ± 0.06 s in 10 m sprint assessment and record of 5.09 s ± 0.16 s in 40 m sprint assessment. For the junior playing level, the fastest time record by back junior player are 1.76 s ± 0.12 s in 10 m sprint assessment and 5.32 s ± 0.22 s in 40 m sprint assessment. It can be summarized that back rugby player is faster than forward rugby player in any competition level.

4 Conclusion

Sprint capability is fundamental in rugby. It is usually a major determinants of elite rugby teams that signify them from beginner and amateur teams. The reviewed articles comparing different population group of playing level and nation from different rugby league. This study present table of distance covered in 7 and 15 side rugby game for sprint movement and sprint assessment value for both male and female rugby players. Studies comparing the rugby player for position of back and forward found that the back player covered more distant in rugby game and the fastest sprinter in 40 m sprint assessment. Also, when comparing between playing level, seem like the international rugby player are more capable than any player in different playing level based on the comparing result acquired. More studies are required with larger number of female rugby player from different playing level. The study of sprint assessment for the Asian player should be include in the future research to differentiate the sprint movement ability between continents. The result from this research can be used as a benchmark for rugby coach to select capable and qualified rugby player for different playing level.

Table 4 Summary of sprint assessment of rugby player

Study	*N*	Playing level	Position	Assessment (s)				
				5 m	10 m	20 m	30 m	40 m
Smart et al. [7]	442	Amateur	Back	–	1.70 ± 2.00	2.93 ± 3.80	4.12 ± 4.00	–
	556	Amateur	Forward	–	1.80 ± 4.50	3.13 ± 4.20	–	–
Darrall-Jones et al. [8]	28	Junior	–	–	1.80 ± 0.06	3.11 ± 0.09	4.34 ± 0.14	5.57 ± 0.18
Ross et al. [9]	12	International	Back	1.00 ± 0.04	1.69 ± 0.06	–	–	5.09 ± 0.16
	10	International	Forward	1.04 ± 0.07	1.75 ± 0.08	–	–	5.22 ± 0.22
Seitz et al. [18]	24	Elite Junior	–	–	1.80 ± 0.09	3.16 ± 0.10	–	5.39 ± 0.23
Till et al. [19]	35 (U16)	Junior	–	–	1.81 ± 0.07	3.12 ± 0.11	–	–
	35 (U17)	Junior	–	–	1.81 ± 0.06	3.12 ± 0.10	–	–
	34 (U18)	Junior	–	–	1.80 ± 0.06	3.09 ± 0.11	–	–
	34 (U19)	Junior	–	–	1.80 ± 0.07	3.09 ± 0.13	–	–
Darrall-Jones et al. [21]	14 (U16)	Junior	Back	1.01 ± 0.05	1.77 ± 0.08	2.99 ± 0.15	–	5.45 ± 0.41
	15 (U16)		For ward	1.09 ± 0.11	1.88 ± 0.12	3.21 ± 0.18	–	5.87 ± 0.30
	12 (U18)	Junior	Back	1.05 ± 0.04	1.79 ± 0.06	3.02 ± 0.10	–	5.34 ± 0.17
	12 (U18)		Forward	1.07 ± 0.05	1.84 ± 0.06	3.14 ± 0.10	–	5.63 ± 0.21
	6 (U21)	Junior	Back	1.05 ± 0.07	1.76 ± 0.12	3.02 ± 0.15	–	5.32 ± 0.22
	9 (U21)		Forward	1.09 ± 0.07	1.82 ± 0.10	3.12 ± 0.11	–	5.52 ± 0.17
Wang et al. [11]	15	National	–	1.24 ± 0.10	1.90 ± 0.11	3.06 ± 0.14	4.15 ± 0.18	5.22 ± 0.22
La Monica et al. [23]	25	University	–	–	–	–	–	5.57 ± 0.38

References

1. Grund T, Senner V (2010) Traction behavior of soccer shoe stud designs under different game-relevant loading conditions. Procedia Eng 2(2):2783–2788. https://doi.org/10.1016/j.proeng.2010.04.066
2. Hennig EM, Sterzing T (2010) The influence of soccer shoe design on playing performance: a series of biomechanical studies. Footwear Sci 2(1):3–11. https://doi.org/10.1080/19424281003691999
3. Caple M (2011) Mechanical behaviour of natural turf sports surfaces. Cranfield University
4. Smart DJ (2011) Physical profiling of rugby union players: implications for talent development. Eur J Sport Sci 14(Suppl 1):1–182
5. Scott MTU, Scott TJ, Kelly VG (2016) The validity and reliability of global positioning systems in team sport: a brief review. J Strength Cond Res 30(5):1470–1490
6. Theodoropoulos JS, Bettle J, Kosy JD (2020) The use of GPS and inertial devices for player monitoring in team sports: a review of current and future applications. Orthop Rev 12(1):1–7. https://doi.org/10.4081/or.2020.7863
7. Smart DJ, Hopkins WG, Gill ND (2013) Differences and changes in the physical characteristics of professional and amateur rugby union players. J Strength Cond Res 27(11):3033–3044
8. Darrall-Jones JD, Jones B, Roe G, Till K (2016) Reliability and usefulness of linear sprint testing in adolescent rugby union and league players. J Strength Cond Res 30(5):1359–1364
9. Ross A, Gill ND, Cronin JB (2015) Comparison of the anthropometric and physical characteristics of international and provincial rugby sevens players. Int J Sports Physiol Perform 10(6):780–785. https://doi.org/10.1123/ijspp.2014-0331
10. Newton RU, Earp JE (2012) Advances in electronic timing systems: considerations for selecting an appropriate timing system. J Strength Cond Res 26(5):1245–1248
11. Wang R, Hoffman JR, Tanigawa S et al (2016) Isometric mid-thigh pull correlates with strength, sprint, and agility performance in collegiate rugby union players. J Strength Cond Res 30(11):3051–3056. https://doi.org/10.1519/JSC.0000000000001416
12. Kempton T, Sirotic AC, Coutts AJ (2017) A comparison of physical and technical performance profiles between successful and less-successful professional rugby league teams. Int J Sports Physiol Perform 12(4):520–526
13. Suarez-Arrones LJ, Nunez FJ, Portillo J, Mendez-Villanueva A (2012) Running demands and heart rate responses in men rugby sevens. J Strength Cond Res 26(11):3155–3159. https://doi.org/10.1519/JSC.0b013e318243fff7
14. Suarez-Arrones L, Nunez FJ, Portillo J, Mendez-Villanueva A (2012) Match running performance and exercise intensity in elite female rugby sevens. J Strength Cond Res 26(7):1858–1862
15. McLellan CP, Lovell DI (2013) Performance analysis of professional, semiprofessional, and junior elite rugby league match-play using global positioning systems. J Strength Cond Res 27(12):3266–3274
16. Suarez-Arrones L, Arenas C, López G, Requena B, Terrill O, Mendez-Villanueva A (2014) Positional differences in match running performance and physical collisions in men rugby sevens. Int J Sports Physiol Perform 9(2):316–323. https://doi.org/10.1123/IJSPP.2013-0069
17. Portillo J, Gonzalez-Rave JM, Juarez D, Garcia JM, Suarez-Arrones L, Newton RU (2014) Comparison of running characteristics and heart rate response of international and national female rugby sevens players during competitive matches. J Strength Cond Res 28(8):2281–2289
18. Seitz LB, Barr M, Haff GG (2015) Effects of sprint training with or without ball carry in elite rugby players. Int J Sports Physiol Perform 10(6):761–766. https://doi.org/10.1123/ijspp.2014-0193
19. Till K, Jones B, Darrall-Jones J, Emmonds S, Cooke C (2015) Longitudinal development of anthropometric and physical characteristics within academy rugby league players. J Strength Cond Res 29(6):1713–1722

20. Higham DG, Pyne DB, Anson JM, Hopkins WG, Eddy A (2016) Comparison of activity profiles and physiological demands between international rugby sevens matches and training. J Strength Cond Res 30(5):1287–1294
21. Darrall-Jones JD, Jones B, Till K (2016) Anthropometric, sprint, and high-intensity running profiles of English academy rugby union players by position. J Strength Cond Res 30(5):1348–1358
22. Suarez-Arrones L, Núñez J, De Villareal ES, Gálvez J, Suarez-Sanchez G, Munguía-Izquierdo D (2016) Repeated-high-intensity-running activity and internal training load of elite rugby sevens players during international matches: a comparison between halves. Int J Sports Physiol Perform 11(4):495–499. https://doi.org/10.1123/ijspp.2014-0523
23. La Monica MB, Fukuda DH, Miramonti AA et al (2016) Physical differences between forwards and backs in American collegiate rugby players
24. Clarke AC, Anson JM, Pyne DB (2017) Game movement demands and physical profiles of junior, senior and elite male and female rugby sevens players. J Sports Sci 35(8):727–733. https://doi.org/10.1080/02640414.2016.1186281
25. Read D, Weaving D, Phibbs P et al (2017) Movement and physical demands of school and university rugby union match-play in England. BMJ Open Sport Exerc Med 2(1):1–7. https://doi.org/10.1136/bmjsem-2016-000147
26. Pereira LA, Nakamura FY, Moraes JE, Kitamura K, Ramos SP, Loturco I (2018) Movement patterns and muscle damage during simulated rugby sevens matches in national team players. J Strength Cond Res 32(12):3456–3465. https://doi.org/10.1519/jsc.0000000000001866
27. Malone S, Earls M, Shovlin A, Eddy A, Winkelman N (2018) Match-play running performance and exercise intensity in elite international women's rugby sevens. J Strength Cond Res 34(6):1741–1749. https://doi.org/10.1519/JSC.0000000000002547

Brief Review on Recent Technology in Particle Image Velocimetry Studies on Hemodynamics in Carotid Artery

A. Fahmi Huwaidi M. Noor and Nasrul Hadi Johari

Abstract Cardiovascular disease is number one causes of morbidity and mortality in global. In-vitro studies are widely applied in the investigation of blood hemodynamics under pathological conditions to diagnose atherosclerosis in carotid artery. This article presents a brief review on the latest published articles was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses on the particle image velocimetry (PIV) studies of blood flow in carotid artery geometries. Fourteen (14) recent articles from 2016 to 2020 in main databases i.e. Scopus, PubMed and ScienceDirect were included. The data of the published articles were focused on the technical aspects of PIV flow measurement and were organized in two categories i.e. carotid phantom geometries constructions and the blood mimicking flow circuits. This systematic review paper summarises the updated methodology in the PIV and identify potential areas to elucidate the accuracy and limitations of each method.

Keywords PIV · Carotid artery phantom · Blood flow

1 Introduction

Atherosclerosis is one of the underlying problems to the cardiovascular disease that causes the hardening and thickening of arterial wall due to the formation of plaque. In 2016 alone, cardiovascular disease (CVD) killed 15.2 million people, contributing almost half of the global deaths in the year [1]. The atherosclerosis occurs in the tunica intima, the innermost layer of arteries which direct contact with blood. It is characterized by inflammatory process which triggered on blood contained high level low of density lipoprotein (LDL) as well as abnormal wall shear stress [2, 3]. The LDL accumulate in the intima layer which LDL undergo chemical modifications in the inner layer of vessel wall called as plaque. The plaque include of dead foam

A. F. H. M. Noor · N. H. Johari (✉)
Human Engineering Group, Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: nhadi@ump.edu.my

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cells, macrophages, smooth muscle cells and extracellular matrix [4]. The plaque will cause lumen of blood body become narrow and stiff, hence reduces the arterial compliance [5]. In carotid artery, the blood supply to part of the brain may cut off if the blockage is left untreated. Moreover, if the plaque is unstable, it can rupture and causing thromboembolism, where small pieces of the plaque are carried to the cerebral network, blocking channels and causing ischemic stroke.

The CVD patient need invasive treatment i.e. surgery to restore and improve blood flow such as carotid endarterectomy, carotid angioplasty and stent placement and arterial bypass graft surgery. Stent implantation is less invasive technique for treating the narrowed artery and can restore blood to the brain [7] whilst endarterectomy is an open surgery procedure to open narrowed or blocked blood vessels that supply blood to the heart.

Hemodynamic analysis has been studied through in-vitro techniques by using a physical representation measurement of blood flow in arterial system. There have been many in-vitro studies for qualitative and quantitative flow visualization. Particle Image Velocimetry (PIV) has been most selected techniques in understanding the key parameter to capture hemodynamic system. The PIV measurement may determine 3D flow phantom model's internal and external flow characteristics and provide parametric data such as velocity and wall shear stress data [5]. To date, the most common method of flow phantom construction includes the core or mold making, casting using silicone and extraction [6]. As the process is laborious and time consuming, recent advances of 3D printing technology has enables the flow phantoms to be constructed using transparent resin. The 3D printing techniques could print optically clear wall resolution, typically using PolyJet and Stereolithography (SLA) [7]. This is an alternative low-cost option to study an internal flow in complex geometries, however, requires special attention to meet the suitable refractive index as compared to conventional cast silicone.

The objective of this review article is to summarize the recent studies (from 2016 to 2020) of flow measurement used in blood vessel phantoms using PIV. The methodology used in phantom construction including rapid prototyping of rigid and compliant phantoms, blood mimicking flow circuit and experimental analysis are also reviewed.

2 Methods

The methodology used in the search and review of the literature follows the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which can develop to help authors to report a wide array of systematic reviews.

2.1 Search Strategy

A systematic search of the literature was carried out until 10 October 2020, with the use of the keywords "PIV", "Carotid" and "Atherosclerosis", and the Boolean operators AND, OR and NOT in the Scopus, PubMed, ScienceDirect and Microsoft academic databases.

2.2 Study Selection

The selected articles are from the searchers like PubMed, ScienceDirect, Scopus and Microsoft academic. The data have organized while remove duplicate article. Then all the abstracts of the articles from selected papers were reviewed while the complete texts selected were separated. The criteria used for searching database (1) conference and thesis article. (2) not carotid artery (3) studies on animal (4) not in English language, and (5) review paper.

3 Results and Discussion

After filtering and removing similarity finding keywords and related, of 286 studies found in the publication database, total of 14 were selected to be included in the final review. Details of exclusion are stated in the Fig. 1.

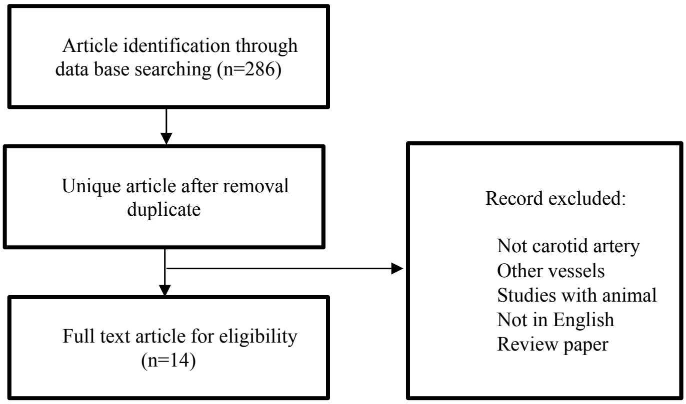

Fig. 1 Flow diagram depicting the literature search (n = number of studies)

3.1 Study Characteristics

A total of 14 recent studies were included in this review where the focus is to explore the methodology used in the construction of the PIV phantoms and the flow profile. Table 1 shows majority of the studies used idealized carotid artery phantoms in their PIV measurements—only one study used patient-specific phantom [8]. In terms of wall characteristics, there are 5 studies used compliant and flexible [6, 9–12] wall whilst the rest are rigid. Details explanation on the phantom geometry construction for both rigid and compliant wall will be described in next sections.

3.2 Phantom Geometry Construction

A realistic patient-specific geometry is perhaps among the key steps in obtaining accurate PIV flow measurement [13]. Previous studies in computational modelling used different medical imaging technique in capturing the flow domains such as magnetic resonance image (MRI), computational tomography (CT) scanning, OCT and IVUS, and others. The acquired medical images were segmented based on thresholding and region growing technique using any available software such as MIMICS, CAD, Segment and others. Blood vessels are not homogeneous in diameter or wall thickness and have surface complexity and irregularity, especially at bifurcation. However, there are only few studies in PIV that used patient-specific geometry phantom.

Majority of previous studies used idealized or simplified model for PIV experiments with the aims to compare different phantom geometry cases such as normal and stenotic. A realistic patient-specific phantom requires special attention to the irregularities of the wall surface and the thickness. [14]. In carotid geometries, bifurcation and curvature are also essential considerations and are difficult to create as a 3D phantom [9].

The only study with patient-specific phantom in Table 1 reconstructed the geometry based on the MRI images using MIMICS software [8]. Other studies used idealized phantom geometries due to the difficulties in the rapid prototyping (RP) of the mold and casting techniques that require advancement of the proses. Particularly during the mold casting, the structure must be bubble free, the wall must be transparent with a proper refractive index, suitable for PIV analysis. Conventional phantom making process involve both mold and core fabrication and casting procedure. Four studies used lost-core casting technique without specific information on the core making process [8, 15–17] whilst three studies constructed the cores using steel or alloyed using CNC [6, 12, 18] before the casting.

The advancement of technology in 3D printing has enables manufacturing of 3D flow phantom in low-cost to be used with mold casting technique. Three studies have involved 3D printer in the printing the phantom core for the mold [6, 12, 18]. Geoghegan [10, 19] are among the earliest community that utilized 3D printing in the

Table 1 Summary of some carotid geometries phantom used in PIV studies

Articles	Geometry	Image source	Software	RP technique	RP material	Wall characteristics	Analysis method
Zhuo et al. [18]	Idealized, stenotic			Alloyed mold	Polyvinyl alcohol (PVA) cryogel	Rigid	Echo PIV
Medero et al. [15]	Idealized, normal			Lost-core casting	Polydimethylsiloxane (PDMS) Silicone	Rigid	Stereo-PIV
Johari et al. [8]	Patient-specific, stenotic	MRI	MIMICS	Lost-core casting	PDMS Sylgard-184 silicone	Rigid	PIV
Sharma et al. [16]	Idealized, stenotic			Lost-core Casting	Acrylic	Rigid	PIV
DiCarlo et al. [17]	Idealized, stenotic	NASCET criteria [20]		Lost-core casting	PDMS, Silicone	Rigid	Stereo-PIV
Yazdi et al. [6]	Idealized (Aortic arch)		SolidWorks	FDM 3D printed, CNC mold, casting	ABS plastic, PVA, Sylgard-184 silicone	Compliant	Stereo-PIV
Hong et al. [21]	Idealized, stenotic			FDM 3D printed and PLA	PDMS	Rigid	PIV
Gates et al. [22]	In-vivo					Rigid	PIV
Wang et al. [23]	Idealized, stenotic				Glass, Silicone	Rigid and Compliant	PIV
Geoghegan et al. [10]	Idealized, normal				Sylgard-184 silicone	Rigid and Compliant	PIV
Bulusu and Plesniak [24]	Idealized, stented				Silicone	Rigid	Stereo-PIV

(continued)

Table 1 (continued)

Articles	Geometry	Image source	Software	RP technique	RP material	Wall characteristics	Analysis method
Akagawa et al. [11]	Idealized, normal	CT			PVA	Compliant	PIV
Novakova et al. [25]	Idealized, stenotic				Acrylic	Rigid	PIV
Geoghegan et al. [12]	Idealized, stenotic		SolidWorks	3D Printed, CNC mold	Sylgard-184 silicone	Compliant	Stereo PIV

core and mold making for the rigid and compliant phantoms. The core for the mold was printed usually using PLA materials. For the rapid prototyping (RP) of phantom materials, PDMS, PVA and Silicone (Sylgard-184) were mostly used. DiCarlo [17] show the PIV-compatible carotid bifurcation phantoms were produced like a box in the square PDMS compartment using lost-core casting. The study varied the stenosis size in the internal carotid artery (ICA) at 30, 50 and 70% according to NASCET to see the post-stenotic flow conditions.

3.3 PIV Setup and Flow Profile

PIV is a laser based optical measurement technique of flow visualization in experiment to capture fluid velocity and related properties (Fig. 2). This technique uses a light source of high intensity to illuminate small tracer particle across plane of interest within phantom. The PIV setup consist of laser source to highlight the plane for the high speed camera to record, 3D phantom geometry, a set of pump for the flow profile generator and a computer interface for the data processing [26]. Successful PIV analysis includes transparent and physiological relevant phantoms because easy to observe blood flow during experiment. PIV measurement of the velocity vector is according to a symmetry plane. Viewing the 3D model from any angle can cause the optical distortion across image. Thus, need a proper calibration step by placing Cartesian grid calibration on target plane during experiment.

Blood is a non-Newtonian liquid where in which the viscosity of blood decreases with increasing of shear rate. The viscosity of the blood varies across gender, age, healthy and shear rate. Blood mimicking fluid is generally used in the PIV experiment

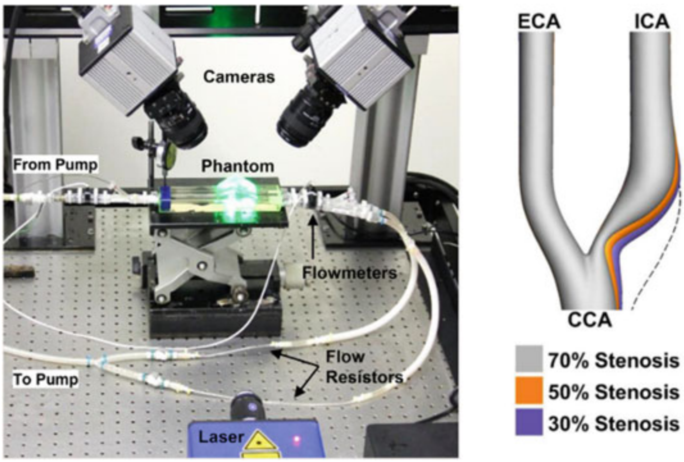

Fig. 2 (Right) PIV experimental setup including the flow circuits and (Left) Carotid bifurcation with different stenosis sizes phantom [17]

Table 2 Example of the content of blood mimicking fluid [27]

Fluid	Ratio	RI	Density (kg m^3)	Dynamic viscosity (mPa s)
Blood @ 20 °C			1060 @ 37 °C	2.9–4.37
Water @ 20 °C		1.333	998.2	1.0016
Glycerine		1.474	1261.08	1.76
Water-glycerol-Nal	47.38–36.94–15.68 wt%	1.414	1244 ± 2	4.31
Water-glycerol	61.39	1.417	1156.6	10.6

to replicate the realistic properties of blood material. Table 2 show example of the content of blood mimicking fluid in the experiment [27]. Another important factor in optical experiment is the refractive index (RI) of blood mimicking fluid. This refraction can cause distortion when capturing images of the internal fluid leading to degradation of the experimental results. Most of researchers used RI to match the refractive index of phantom wall and blood mimicking fluid to mitigate the issue. In all PIV experiments listed in Table 1, the common refractive index used was 1.4.

Flow Profile. The blood pressure waveform in arteries varies as it travels [27]. Arterial compliance, vascular resistance, cardiac output and arterial geometry affect the pressure waveform. As pressure waves travel from the aorta and large arteries to the narrower, less compliant distal arteries, they travel at a greater speed. The wave's rising portion is steeper and the overall systolic pressure continues to increase [26].

Figure 3 show blood pressure and velocity profile at different region of arterial tree. The variant of the curve patterns is depending on the size of the vessel and the location. Two dimensionless numbers are important to consider in the study of pulsatile biological flow to ensure dynamic similarity i.e. Womersley number and Reynold number. The Womersley number (α) represents the ratio of the pulsation frequency to viscosity [28] whilst the Reynolds number (Re) is important to relates inertial to viscous forces. In the previous PIV experiment, the blood mimicking flow profile was drive by several types of pump such as magnetic drive pump [16], computer-controlled positive-displacement pump [17], perfusion pump [15] and piston pump [10].

4 Conclusion

Cardiovascular diseases are a leading cause of morbidity and mortality around the globe. PIV is one of the alternative ways to provide insights of hemodynamics in the blood vessel and could provide foundation to the diagnosis and treatment of CVD. In this article, recent PIV experiments from 2016 to 2020 were reviewed. In particular, the recent methodology in phantom geometric reconstruction i.e. prototyping the 3D phantoms, PIV setup and flow profile were reviewed. The advancement of compliant

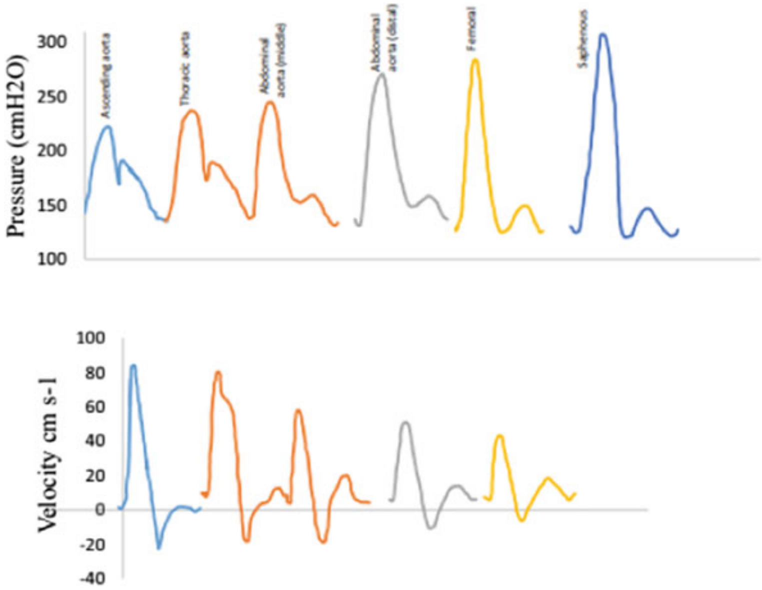

Fig. 3 Pressure and velocity profiles in different sites of vessels [29]

phantoms construction techniques surely could provide advantages in the future PIV flow measurement on details hemodynamics especially at the stenotic site of a vessel. This short review could be extended in the upcoming articles with the relative benefits and costs of each experimental options.

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References

1. WHO (2016) Global health estimates 2016: deaths by cause, age, sex, by country and by region. World Health Organization
2. Sakellarios A, Bourantas CV, Papadopoulou SL et al (2017) Prediction of atherosclerotic disease progression using LDL transportmodelling: a serial computed tomographic coronary angiographic study. Eur Heart J Cardiovasc Imaging 18(1):11–18. https://doi.org/10.1093/ehjci/jew035
3. Tarbell JM (2003) Mass transport in arteries and the localization of atherosclerosis. Annu Rev Biomed Eng 5:79–118. https://doi.org/10.1146/annurev.bioeng.5.040202.121529
4. Sun N, Torii R, Wood NB, Hughes AD, Thom SAM, Xu XY (2009) Computational modeling of LDL and albumin transport in an in vivo CT image-based human right coronary artery. J Biomech Eng 131(2):1–9. https://doi.org/10.1115/1.3005161

5. Hewlin RL, Kizito JP (2018) Development of an experimental and digital cardiovascular arterial model for transient hemodynamic and postural change studies: "a preliminary framework analysis." Cardiovas. Eng. Technol. 9(1). https://doi.org/10.1007/s13239-017-0332-z
6. Yazdi SG, Huetter L, Docherty PD et al (2019) A novel fabrication method for compliant silicone phantoms of arterial geometry for use in particle image velocimetry of haemodynamics. Appl Sci 9(18):1–16. https://doi.org/10.3390/app9183811
7. Ho WH, Tshimanga IJ, Ngoepe MN, Jermy MC, Geoghegan PH (2020) Evaluation of a desktop 3D printed rigid refractive-indexed-matched flow phantom for PIV measurements on cerebral aneurysms. Cardiovasc Eng Technol 11(1):14–23. https://doi.org/10.1007/s13239-019-00444-z
8. Johari NH, Wood NB, Cheng Z et al (2019) Disturbed flow in a stenosed carotid artery bifurcation: comparison of RANS-based transitional model and les with experimental measurements. Int J Appl Mech 11(4):1–21. https://doi.org/10.1142/S1758825119500327
9. Chen Y, Yang X, Iskander AJ, Wang P (2020) On the flow characteristics in different carotid arteries. Phys Fluids 32(10). https://doi.org/10.1063/5.0022092
10. Geoghegan PH, Jermy MC, Nobes DS (2017) A PIV comparison of the flow field and wall shear stress in rigid and compliant models of healthy carotid arteries. J Mech Med Biol 17(3):1–16. https://doi.org/10.1142/S0219519417500415
11. Akagawa O, Fukazu K, Nagaoka R, Saijo Y (2016) Two-dimensional blood flow vector and wall shear stress of carotid artery obtained with dual-angle Doppler method. In: IEEE International ultrasonics symposium, IUS 2016; pp 0–3. https://doi.org/10.1109/ULTSYM.2016.7728523
12. Geoghegan PH, Docherty PD, Sellier M, Jermy MC (2016) Understanding arterial pressure from PIV data. In: 18th international symposium on the application of laser and imaging techniques to fluid mechanics
13. Marshall I, Zhao S, Papathanasopoulou P, Hoskins P, Xu XY (2004) MRI and CFD studies of pulsatile flow in healthy and stenosed carotid bifurcation models. J Biomech 37(5):679–687. https://doi.org/10.1016/j.jbiomech.2003.09.032
14. Johari NH, Hamady M, Xu XY (2020) A Computational study of the effect of stent design on local hemodynamic factors at the carotid artery bifurcation. Artery Res 26(3):161–169. https://doi.org/10.2991/artres.k.200603.001
15. Medero R, Hoffman C, Roldán-Alzate A (2018) Comparison of 4D flow MRI and particle image velocimetry Using an in vitro carotid bifurcation model. Ann Biomed Eng 46(12):2112–2122. https://doi.org/10.1007/s10439-018-02109-9.Comparison
16. Sharma N, Sastry S, Sankovic JM, Kadambi JR, Banerjee RK (2020) Influence of near-wall PIV data on recirculation hemodynamics in a patient-specific moderate stenosis: experimental-numerical comparison. Biorheology 1:1–24. https://doi.org/10.3233/bir-201001
17. DiCarlo AL, Holdsworth DW, Poepping TL (2019) Study of the effect of stenosis severity and non-Newtonian viscosity on multidirectional wall shear stress and flow disturbances in the carotid artery using particle image velocimetry. Med Eng Phys 65(xxxx):8–23. https://doi.org/10.1016/j.medengphy.2018.12.023
18. Zhou H, Meng L, Zhou W et al (2017) Computational and experimental assessment of influences of hemodynamic shear stress on carotid plaque. Biomed Eng Online 16(1):1–11. https://doi.org/10.1186/s12938-017-0386-z
19. Geoghegan PH, Buchmann NA, Spence CJT, Moore S, Jermy M (2012) Fabrication of rigid and flexible refractive-index-matched flow phantoms for flow visualisation and optical flow measurements. Exp Fluids 52:1331–1347. https://doi.org/10.1007/s00348-011-1258-0
20. Barnett (1991) Benefial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. New Engl J Med 325(7):445–453
21. Hong H, Ji HS, Kim HD, Kim KC (2017) Temporal and spatial flow structures in a simulated vessel with stenotic lesion using time-resolved PIV technique. J Visualization 20(4):833–845. https://doi.org/10.1007/s12650-017-0432-8
22. Gates PE, Gurung A, Mazzaro L et al (2018) Measurement of wall shear stress exerted by flowing blood in the human carotid artery: ultrasound Doppler velocimetry and echo particle image velocimetry. Ultrasound Med Biol 44(7):1392–1401. https://doi.org/10.1016/j.ultrasmedbio.2018.02.013.Measurement

23. Wang Y, Joannic D, Patrick J et al (2016) Comparison of flow measurement by 4D flow magnetic resonance imaging and by particles image velocimetry on phantom of abdominal aortic aneurysm to cite this version. SM Vasc Med 1(2):1008. https://hal.archives-ouvertes.fr/hal-01463873/documentAccessed
24. Bulusu KV, Plesniak MW (2016) Experimental investigation of secondary flow structures downstream of a model type IV stent failure in a 180° curved artery test section. J Vis Exp 2016(113):1–18. https://doi.org/10.3791/51288
25. Novakova L, Kolinsky J, Adamec J, Kudlicka J, Malik J (2016) Vascular stenosis asymmetry influences considerably pressure gradient and flow volume. Physiol Res 65(1):63–69. https://doi.org/10.33549/physiolres.932944
26. Yazdi SG, Geoghegan PH, Docherty PD, Jermy M, Khanafer A (2018) A review of arterial phantom fabrication methods for flow measurement using PIV techniques. Ann Biomed Eng 46(11):1697–1721. https://doi.org/10.1007/s10439-018-2085-8
27. Docherty PD, Geoghegan PH, Huetter L, Jermy M, Sellier M (2017) Regressive cross-correlation of pressure signals in the region of stenosis: insights from particle image velocimetry experimentation. Biomed Signal Process Control 32:143–149. https://doi.org/10.1016/j.bspc.2016.09.025
28. Womersley J (1955) Method for calculation of velocity, rate of flow and viscous drag in arteries when the pressure gradient is known. J Physiol 127(3):553–563
29. Caro CG, Pedley TJ, Schroter RC, Seed WA, Parker KH (2011) The mechanics of the circulation. Cambridge University Press, Cambridge

Characterization Porous HA/SiO_2 Composite Prepared Using Natural Space Holder

Amir Arifin, Gunawan, M. Wahyudi Amin, Alim Mardhi, Ganang Trycahyono, and Firmansyah Burlian

Abstract Hydroxyapatite based on bovine bone has been developed in addition to medical needs, adsorbents, catalysts, and other engineering applications. The use of hydroxyapatite-based catalysts in the industry is still very high, one of which is solid catalysts. This study aims to develop a solid porous catalyst from a HA/SiO_2 composite. The porous composite was prepared with SiO_2 as much as 25% of the total weight fraction and utilized sweet potato powder heated at a temperature of 150 °C as a space holder. The manufacturing process begins by mixing hydroxyapatite powder (200 μm), SiO_2 powder (200 μm), and purple sweet potato powder (200 μm), then mixing it using a ball mill with a rotating speed of 225 rpm for 1 h. The mixture was then put into the molding and compacted with a pressure of 69.805 MPa. The green body was then sintered at 1100 and 1200 °C and held for 3 h. Apparent density measurements were carried out using the Archimedes method, and the highest density was 1.4983 g/cm^3 with a porosity of 50.34% in the 30% space holder specimen. The XRD test shows that the dominant phases are hydroxyapatite (HA), β-TCP, and SiO_2. The compressive strength test showed the highest average compressive strength of 33,073 MPa in the 30% space holder specimen. The SEM observations showed pores formed in the samples with varying sizes ranging from 4.510 to 67.32 μm and showed interconnecting porous.

Keywords Porous · Hydroxyapatite · Space holder · Powder metallurgy

A. Arifin · Gunawan (✉) · M. W. Amin · G. Trycahyono · F. Burlian
Department of Mechanical Engineering, Sriwijaya University, Indralaya, Sumatera Selatan 30662, Indonesia
e-mail: gunawan@unsri.ac.id

A. Mardhi
Center for Nuclear Reactor Technology and Safety—BATAN, Nuclear Serpong Area, PUSPIPTEK complex Building 80th, South-Tangerang, Banten, Indonesia

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1 Introduction

The development of science in the health sector has developed very rapidly, including efforts to improve the body to develop in line with the increasing number of accidents. Efforts to repair the body include using biomaterials that are non-toxic, can work following the compatibility of the recipient body (biocompatible), and can quickly form direct bonds with bones (bioactive) [1].

Calcium hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$, commonly referred to as HA, is a synthetic biomaterial similar to the biology of HA, which is a structural component of human bones and teeth. HA widely used for various bone and dental implants due to its excellent biocompatibility and bioactivity. It binds firmly to the bone and supports the Osseointegration of the bone-implant, which is necessary to minimize damage to the surrounding tissue. BCP ceramics, consisting of a mixture of hydroxyapatite and beta-calcium phosphate (β-TCP, $Ca_3(PO_4)_2$) are considered useful in promoting bone formation at the implant site. The bioceramic properties of BCPs can be attributed to the fact that they consist of the more stable HA stage and the highly soluble TCP [2].

Bovine bone heated at 600–1000 °C shows the formation of pure hydroxyapatite and the crystallinity of HA increases with an increase in heating temperature. At a temperature of 1100–1200 °C, it is found that a small portion of B-TCP shows the partial decomposition of hydroxyapatite however, the calcination process at temperatures below 1000 °C is preferred [3].

The application of porous hydroxyapatite in the non-medical field is packaging media, catalysts, gas sensors, and column chromatography [4]. Hydroxyapatite serves as the main catalyst for the preparation of ribose from formalin and glyceraldehyde [5]. The utilization of biowaste as a resource of catalyst for biofuel production increased in the recent report due to its low cost and sustainability [6].

Researchers have developed various methods to make porous hydroxyapatite, one of which is by using a space holder. At the sintering process, a porous structure (sponge) will be formed in the hydroxyapatite composite caused by the burnt space holder during the sintering process [7]. Recently, several types of natural space holders have been developed as alternative space holders, which are abundant, cheap, and easy to process [8, 9]. However, the resulting porous hydroxyapatite still shows low mechanical strength. In this study, the porous HA/SiO_2 composite material used a purple sweet potato space holder then characterized its properties.

2 Materials and Method

The first thing that is done from this research process is to prepare all the tools and materials regarding the system related to the materials to be processed, hydroxyapatite (HA) extracted from bovine femur bones obtained from the local waste restaurant. Hydroxyapatite is produced using a calcination process as previous research [10].

The raw material for reinforced in the form of SiO_2 was obtained from glass waste that crushed using grinding, then continued using mortar, and then sieved into a powder measuring 200 μm. The space holder's raw material, i.e., sweet potato, is collected from the local market and then processed independently. Refer to the TGA result; the space holder was sieved into a 200 μm powder and then heated in an oven at a temperature of 150 °C for 1 h.

The preparation of porous HA/SiO_2 composites was carried out by mixing hydroxyapatite powder, reinforced powder, and space holder powder using a ball mill for 1 h at a speed of 225 rpm. The composition reinforced SiO_2 with 25% of the total weight fraction that then added space holder with variation 20 and 30% of the weight. The powder that has been mixed is then weighed as much as 10 g and put into the molding. The pressing process is then carried out using a compacting device by applying a pressure of 69.805 MPa for 10 min. Furthermore, in the sintering process, the molded specimen is put into an electric furnace heating rate of 10 °C/min. Then at a temperature of 600 °C, it is held for 1 h to give enough time for the space holder to burn completely. Heating then continued with a higher temperature with sintering temperature variations of 1100 and 1200 °C, with holding time for 3 h.

To determine the mechanical, physical and chemical properties of porous HA/SiO_2 composite some characterization process has been performed including Thermo Gravimetric Analyzer (TGA) on TA Instruments TGA Q500, X-Ray Diffraction (XRD) testing on Rigaku MiniFlex 600, Scanning Electron Microscopy (SEM) on Inspect S50 testing by FEI company. Composite density is determined based on Archimedes' theory. The compressive test is carried out on a porous cylindrical specimen; the testing was carried out using a Universal Hydraulic Testing Machine.

3 Results and Discussion

Porosity of samples at various space holder (SH) percentages as depicted in Fig. 1 can be seen that the porosity shows the average percentage value of porous HA/SiO_2 composites with 20% of SH at 1100 °C of 42.01% smaller than at 1200 °C of 44.61%. Meanwhile, HA/SiO_2 composites with 30% of SH at 1100 °C has an average porosity value of 41.24% at 1200 °C temperature of 44.50%. The results show an increasing porosity trend when sintered up to 1200 °C.

The results obtained in this study are in good agreement with previous studies [11], where the average porosity increases with increasing sintering temperature. The

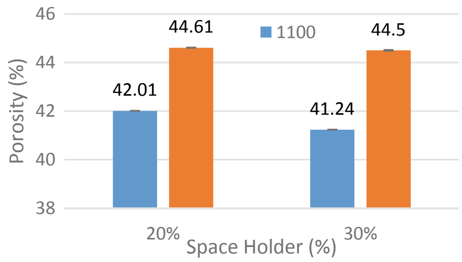

Fig. 1 Porosity of 75% HA/25% SiO_2 composites at 1100 and 1200 °C with various space holder (SH) content

increase in porosity was due to an increase in the lost mass of SiO_2. Based on TGA analysis, when heating at 1200 °C, it loses more weight than 1100 °C. So, because at a temperature of 1200 °C, more SiO_2 mass lost will increase the sample's porosity.

The XRD test for the bovine bone powder that has been calcined at a temperature of 900 °C can be seen in Fig. 2. From the resulting graph, the XRD test graph after calcination at 900 °C has peaks that are almost the same as the ICDD 09-432 standard for hydroxyapatite. It shows 5 highest peaks at the angle of 2θ equal to 32.13, 26.27, 49.82, 47.07, and 40.18°. The SiO_2 XRD test obtained in Fig. 3 has graphical results similar to those of the reference SiO_2 graph [12].

XRD test results of porous HA/SiO_2 composites figured in Fig. 4. For this graph, the peaks that appear are hydroxyapatite, β-TCP, and silica. The one that dominates the peaks in the 1100 °C temperature specimen is hydroxyapatite, which has 14 peaks, then β-TCP with six peaks then silica has a peak number of 2 peaks. The hydroxyapatite peak is marked (HA), while the β-TCP peak is marked with β, and

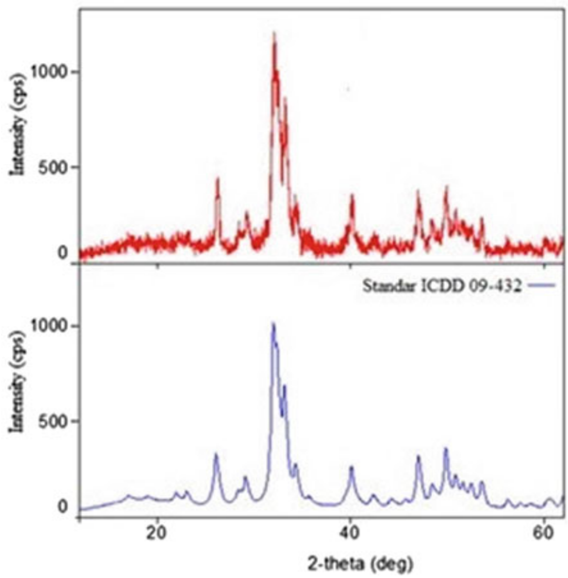

Fig. 2 XRD of Calcined bovine bone at 900 °C

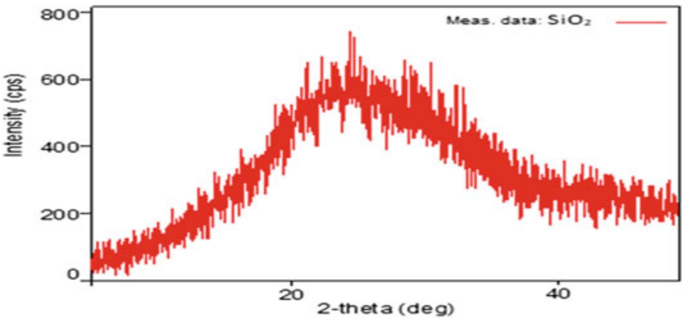

Fig. 3 The spectrum of SiO_2 powder XRD results

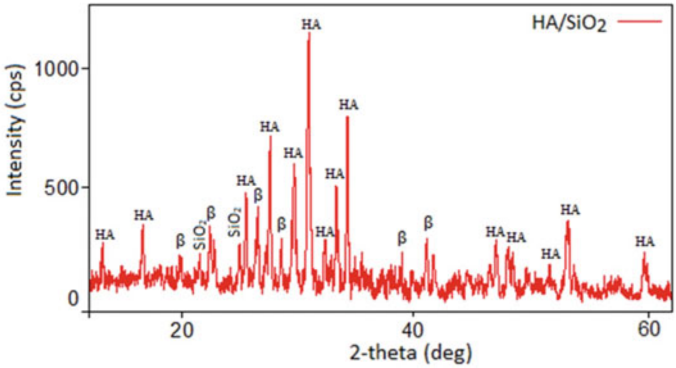

Fig. 4 The spectrum XRD results for porous 75% HA/25% SiO_2 sintered at 1100 °C

the silica peak is marked with SiO_2. The HA has been decomposed to β-TCP at a sintering temperature of 1100 °C.

Figure 5 shows XRD test results of porous HA/SiO_2 composites that have been sintered at a sintering temperature of 1200 °C. It can be seen that the peaks that appear are hydroxyapatite, β-TCP, and silica. The peaks in this temperature specimen, the dominant peak, are still the same at 1100 °C, namely the hydroxyapatite peak with 14 peaks, while for the β-TCP peak, it has a peak of 7 peaks, and then for silica, it has two peaks. The more HA has been decomposed to β-TCP at sintering temperature of 1200 °C than at lower temperatures.

The test (TGA) of the Thermo Gravimetric Analyzer is useful for determining the speed of change in weight to the temperature function of sweet potato powder from room temperature to 600 °C. It can be seen that at the initial temperature (Fig. 6), 49.78 °C, the weight of sweet potato powder is still 100%. The weight reduction of sweet potato powder began to be seen at a temperature of 200.2 °C with a weight of 94.88% until the final temperature is 586 °C; the weight of sweet potato weights 0.99%. The weight reduction does not reach 0% because at a temperature of 600 °C,

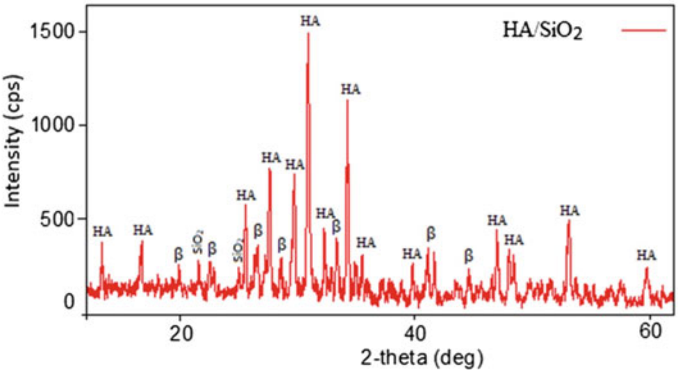

Fig. 5 The spectrum of XRD results for 75% HA / 25% SiO_2 composites with 20% SH sintered at 1200 °C

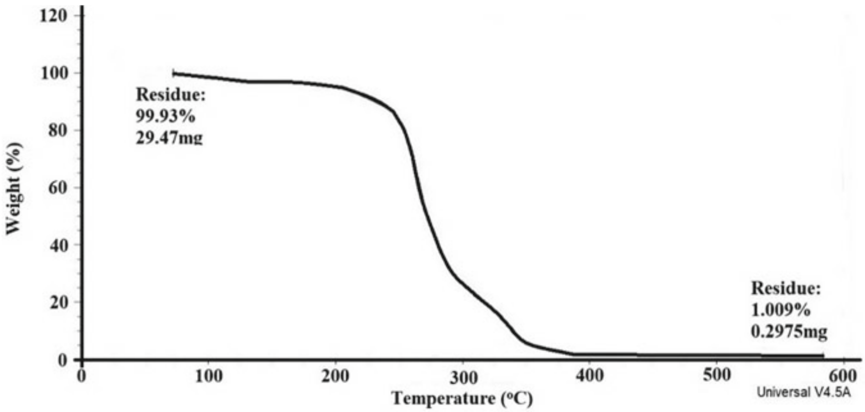

Fig. 6 TGA of sweet potato

the sweet potato powder remains in the form of ash. During the sintering process, the sweet potato powder will become a pore agent on the specimens.

The results of the compressive strength test at Fig. 7 can be seen that it has a graphical form of an increase in the average compressive strength. The porous HA/SiO_2 composite of 20% SH at a temperature of 1100 °C having an average compressive strength of 7735 MPa. However, for a temperature of 1200 °C it has an average compressive strength of 28.008 MPa. The same trend also can be found at HA/SiO_2 composite of 30% SH which has an average compressive strength of 33,073 MPa at the temperature of 1200 °C.

The compressive strength increases with increasing sintering temperature because the composite materials diffuse to one another. In this study, each temperature's average strength is much greater than in previous studies [8] because the composite has reinforced silica and modified on SH processing.

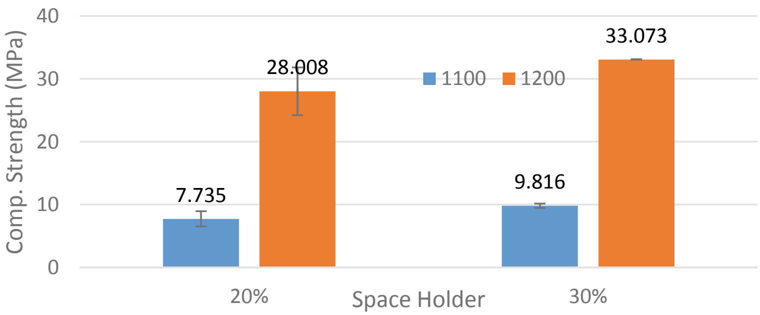

Fig. 7 Compressive strength test for composite 75%HA/25% SiO_2 porous at various sweet potato space holder percentages

During the sintering process, the composite undergoes a more significant decomposition process that the resulting value of porosity is smaller and causes the compressive value to increase as the porosity value decreases in the composite. The decreasing porosity value is due to the variety of space holder powder treatment used in this study. The heat treatment was carried out at a temperature of 150 °C for one hour, while the previous research only reached the powder stage. In previous studies [8], where the same SH is used, the maximum compressive strength at a temperature of 1200 °C was 4.41 MPa. There is a possibility that this might happen because water vapor has been lost when heating at 150 °C; there is no excessive evaporation, which encourages the bonding of particles during sintering, which can reduce the strength of the bonds between particles.

In the observations using SEM, the porous HA/SiO_2 composite at two different magnifications can be seen in Fig. 8. The composite has seen the shape and size of the pores, and the pores appear due to the loss of space holder used in the composite.

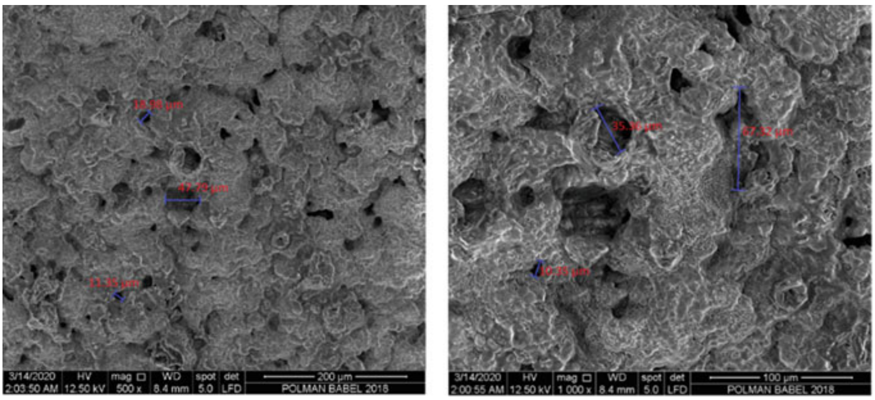

Fig. 8 SEM observations of composites 75% HA/25% SiO_2 with 20% SH 1200 °C at 2 different magnification

It can be seen that the shape and size of the micropores have variations ranging from 10.35 to 67.32 μm. It also can be seen clearly that some pores are interconnected.

4 Conclusion

Porous composite HA/SiO_2 successfully fabricated using sweet potato starch as a space holder. The porosity shows an increasing porosity trend when sintered up to 1200 °C, due to at a temperature of 1200 °C, more SiO_2 mass lost increase. The XRD testing of HA/SiO_2 composites at temperatures of 1100 and 1200 °C depicts 3 phases, namely hydroxyapatite, β-TCP, and silica. The dominant phase is the hydroxyapatite phase, followed by the β-TCP phase and the silica phase. The compressive strength test was found that the HA/SiO_2 porous at the temperature of 1200 °C has an average compressive strength of 33,073 MPa. The Scanning electron microscopy (SEM) clearly shows pore in micro size and interconnected porosity.

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References

1. Dorozhkin SV (2017) Hydroxyapatite and other calcium orthophosphates: general information and history
2. Dorozhkin SV (2014) Acta biomaterialia calcium orthophosphate coatings on magnesium and its biodegradable alloys. Acta Biomater 10(7):2919–2934
3. Ramirez-Gutierrez CF, London SM, Rubio-Rosas E (2016) Study of bovine hydroxyapatite obtained by calcination at low heating rates and cooled in furnace air
4. Ibrahim M, Labaki M, Giraudon J, Lamonier J (2020) Hydroxyapatite, a multifunctional material for air, water and soil pollution control: a review. J Hazard Mater 383:121139
5. Usami K, Okamoto A (2017) Hydroxyapatite: catalyst for a one-pot pentose formation. Org Biomol Chem 15(42):8888–8893
6. Nasrollahzadeh M, Soheili Bidgoli NS, Shafiei N, Soleimani F, Nezafat Z, Luque R (2020) Low-cost and sustainable (nano)catalysts derived from bone waste: catalytic applications and biofuels production. Biofuels, Bioprod Biorefining 14(6):1197–1227
7. Arifvianto B, Zhou J (2014) Fabrication of metallic biomedical scaffolds with the space holder method: a review ii:3588–3622
8. Gunawan, Arifin A, Yani I, Arian SD (2019) The fabrication porous hydroxyapatite scaffold using sweet potato starch as a natural space holder the fabrication porous hydroxyapatite scaffold using sweet potato starch as a natural space holder
9. Series IOPC, Science M (2020) Development and characterization of porous hydroxyapatite-alumina composite for engineering application development and characterization of porous hydroxyapatite-alumina composite for engineering application
10. Arifin A, Gunawan, Priyadi A, Sanjaya FA (2020) Development and characterization of porous hydroxyapatite-Alumina composite for engineering application. IOP Conf Ser Mater Sci Eng 857:12005

11. Taha MA, Youness RA, Ibrahim M (2020) Biocompatibility, physico-chemical and mechanical properties of hydroxyapatite-based silicon dioxide nanocomposites for biomedical applications. Ceram Int 46(15):23599–23610
12. Musić S, Filipović-Vinceković N, Sekovanić L (2011) Precipitation of amorphous SiO_2 particles and their properties 28(01):89–94

Fabrication of Titanium-Matrix Composite with 40 wt% Hydroxyapatite by Powder Injection Molding

Aditya Reza Haswendra, Amir Arifin, Abu Bakar Sulong, Norhamidi Muhamad, Gunawan, and Barlin

Abstract In this work, the performance of composites feedstock HA/Ti for metal injection molding is investigated by rheological characterization with powder loading 65%. Titanium and Hydroxyapatite (HA) powder are mixed with a composite binder, which consists of Palm Stearin (PS) and Polyethylene (PE). The rheology properties are investigated by Shimadzu CFT-500D rheometer. Thermal debinding is utilized for removing the binder system under argon gas. The sintering process is performed under argon conditions at temperature 1200 °C for 2 h. The feedstock 60 wt%Ti and 40 wt%HA show *pseudopalstic* behaviour which is indicating suitable for MIM application. On the sintered part, Ca:P ratio of HA has changed based on the standard value of HA(1.67) as an indication decomposition of HA. Cracks have been observed on part of composite HA/Ti by SEM due to differences in thermal expansion of the two materials and not a good diffusion between HA and Ti. For further work, modification in the composition of mixture and sintering parameters are required to reach an optimal result.

Keywords PIM · Composite HA/Ti · Palm stearin

1 Introduction

Powder Injection Molding (PIM) is one part of powder metallurgy, which has advantages in fabricate small parts and have complex shapes in large numbers. PIM is usually comprised of several steps such as mixing, injection, debinding, and ending with sintering [1].

A. R. Haswendra · A. Arifin (✉) · Gunawan · Barlin
Department of Mechanical Engineering, Sriwijaya University, Indralaya, Sumatera Selatan 30662, Indonesia
e-mail: amir@unsri.ac.id

A. B. Sulong · N. Muhamad
Department of Mechanical and Material Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

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Titanium alloys and Hydroxyapatite are well-known materials for application biomedical [2–6]. Titanium has well in specific strength, corrosion resistance and lower young's modulus close to cortical bone young's modulus (10–30 GPa). Beside some advantage that mentions previously, Titanium has poor biocompatibility properties. Hydroxyapatite (HA) has chemical and structure properties being similar to the human bone. HA has excellent on biocompatibility properties but has weakness in mechanical properties, additional of HA into Titanium Alloy is expected to enhance the biocompatibility properties of Titanium. Moreover, the combination of titanium and HA can be applied to load-bearing applications.

In these experiments, the binder system used comes from Natural Binder, namely palm stearin. It will be combined with Polyethylene who served as the backbone to keep the shape of the specimen. The use of palm stearin as a binder has been widely used by some previous researchers [7–9]. Palm stearin has the advantage of easily removed via solvent debinding in addition to its environmentally friendly [10].

Some author has performed to combine HA and titanium alloy using plasma spraying and powder metallurgy (PM) [8–12]. In term of Powder metallurgy (PM) technique. Fabrication HA/Ti composite tend to rare although PIM itself has many advantages compared to other PM technique. PIM has the advantage when producing small part with complex shapes in large amounts [11, 12].

This paper is the initial step in the development of HA/Ti composite using MIM. Characterization was performed on the powder and binder including feedstock characterization and some stage subsequently such as debinding and sintering.

2 Methodology

Figure 1a shows Ti6Al4V powder with an average size 20 μm which was kindly supplied by TLS Technik GmbH & Co. Hydroxyapatite powder with average size

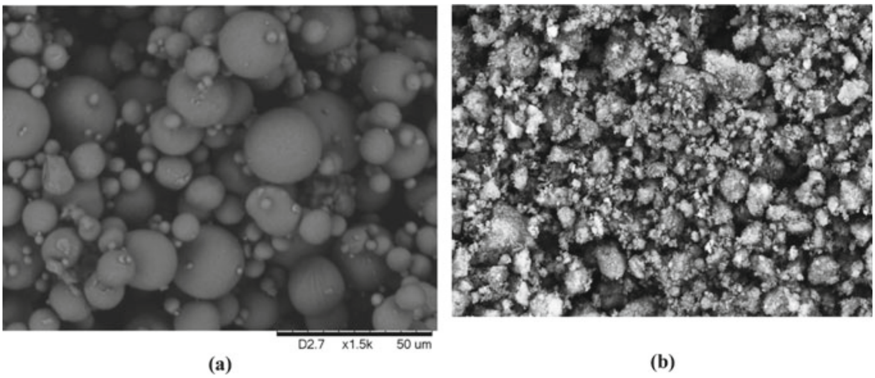


Fig. 1 Scanning electron micrograph of Ti6Al4V powder (**a**) and Hydroxyapatite (**b**)

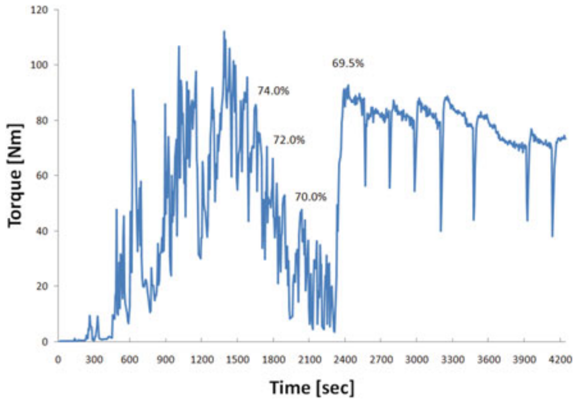


Fig. 2 Critical volume percentage of composite HA/Ti with 60 wt%Ti and 40 wt% HA

Table 1 Binder system

Binder	Type	Melting temperature (°C)	Density (g cm^3)
Palm Stearin (PS)	Primary, surfactant, lubricant	61	0.89
Polyethylene (PE)	Backbone	127	0.91

5 μm has been purchased by Sigma-Aldrich as shown on Fig. 2b. Ratio powder between titanium and hydroxyapatite is 60wt%Ti: 40wt%HA.

Binder systems were utilized in this work consist of 60 wt% palm stearin and 40 wt% Polyethylene as shown on Table 1. Brabender® was used to mix powders and binder at temperature mixing 150 °C and mixing speed 30 rpm. The mixing temperature was determined by the result of Differential Scanning Calorymetry (DSC) test for both binders. Mixing temperature should be higher than the melting point of the binder to make sure binder system easy to mix with powders. Melting temperature of palm stearin and polyethilene are 53.97 °C and 124.75 °C, respectively.

Powder loading value was determined by critical powder volume percentage (CPVP) test, According to German and bose [1] optimal powder loading value 2–5% less than the critical value. To obtain critical value, oleic acid was added into the composite powder HA/Ti mixture in 1 mL for every 5 min. The volume of oleic acid correlates with torque value can be defined as

$$CPVP = 100 \times \frac{V_f}{V_f + V_o}(\%) \qquad (1)$$

Binder system on the part was removed using thermal debinding with two stages. Brown part was sintered using a tube furnace under argon condition at temperature 1200 °C for 2 h. The sintered part was characterized by scanning electron micrograph and EDX to investigate morphology and phase.

3 Results and Discussion

3.1 *Critical Solid Loading*

Critical solid loading is a situation of powder particles that are packed as tightly as possible without involving external pressure and the gap between particles has been filled by the binder. Parameters powder such as particle size distribution and particle shape tend to influence of critical solid loading of powders [1]. In the case of bimodal powder, the different sizes of powder, the maximum of packing density can be reached due to the space formed by large particles are filled by small particles. Moreover, the ratio both of powders tends to play an important role to determine their packing density [13].

Figure 2 shows maximum torque was reached on 69.5% when oleic acid is added at in 1 mL for every 5 min. Optimal powder loading according to German and Bose [1] is lower than 2–5% from critical solid loading. Powder loading 65% was chosen for investigation in terms of shear rate and viscosity.

3.2 *Rheology*

Homogeneity of feedstock can be evaluated using the rheological test. Commonly, the method to measure feedstock for metal injection molding is capillary rheometry. It can capable to characterize the flow behavior of shear rate in a wide range [14, 15].

Figure 3 shows the capillarity rheometry testing result for composites HA/Ti at temperatures 160, 180, 200, and 220 °C. Composite HA/Ti feedstock at every temperature testing tends to in pseudoplastic condition which is viscosity decrease with shear rate. It was indicating no separation between powder and binder. Figure 3 also shows viscosity tends to decrease with increasing temperature due to expansion thermal of binder and disentanglement of the molecular chain [16]. At the highest

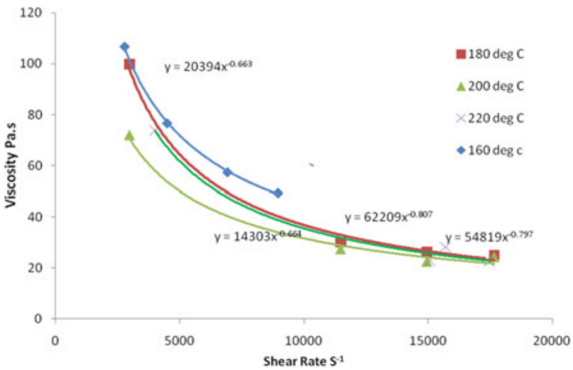


Fig. 3 Correlation of viscosity and shear rate at temperature 160, 180, 200 and 220 °C

Table 2 Flow behavior index, n

Temperature (°C)	Flow behaviour index (n)
160	0.337
180	0.197
200	0.336
220	0.203

temperature (220 °C) there was no decrease in viscosity. It was believed due to the saturated condition of the binder.

This phenomenon can be expressed with the power law equation (Eq. 2) and flow behavior index n where η is the viscosity and K is the constant.

$$\eta = K\gamma^{n-1} \tag{2}$$

Pseudopalstic behavior can be identified if flow behavior index n is less than 1. Table 2 shows all of the values of n less than 1. Feedstock at temperature 160 °C has the highest value of 0.337 that indicating has better rheological stability and greater pseudoelasticity.

The sensitivity of feedstock also can be measured based on activation energy, E, using the Arrhenius equation. Feedstock with low energy activation tends to be more suitable for application MIM due to produce fewer defects. Arrhenius equation can be defined as;

$$\eta = \eta_0 \exp\left(\frac{E}{RT}\right) \tag{3}$$

where η_o is viscosity, R is gas constant and T is the temperature in Kelvin. Based on a calculation using Arhenius equation, the lowest energy activation was 23.29 kJ/mol at temperature 160 °C and the highest value was 38.89 kJ/mol at temperature 180 °C. As shown in Fig. 4, feedstock under temperature 160 °C tends to have a lower gradient value.

3.3 Injection Process

The injection process was performed using an injection molding machine (DSM Xplore Injection Molding) as shown of Fig. 5a. The injection process was performed successfully under powder loading 65 vol% at 100, 150 °C, and 5 bar for mold temperature, melt temperature, and injection pressure, respectively. Figure 5b presents an injected part composite HA/Ti. Determination of the injection molding process parameter is based on the highest melting point temperature of the binder. In addition, rheological results are also used as a factor in determining the temperature of the injection.

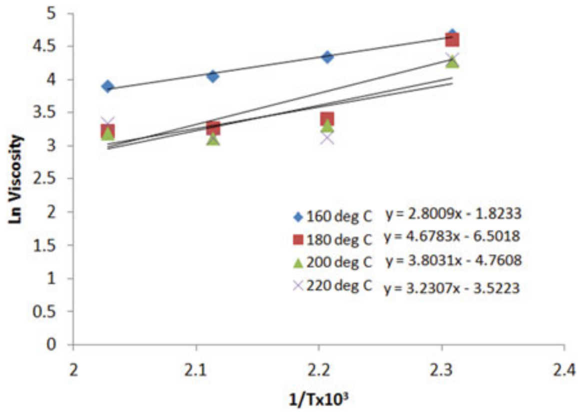


Fig. 4 Temperature vs dependence of viscosity

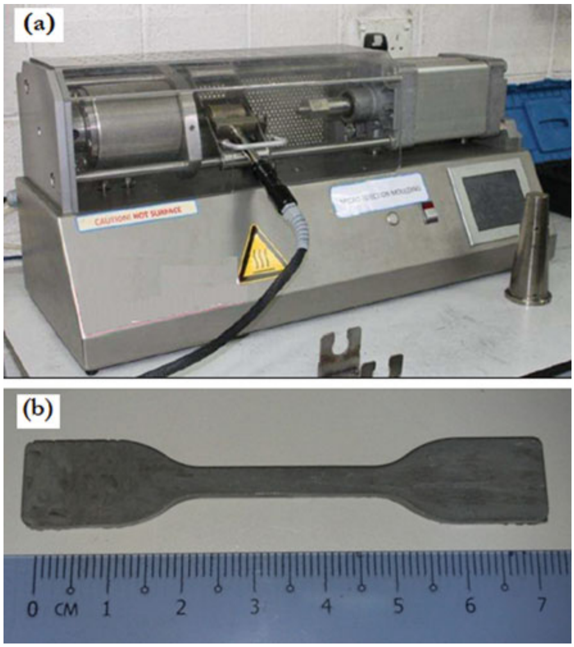


Fig. 5 DSM Xplore Injection Molding (**a**) Injected part composite HA/Ti (**b**)

3.4 Debinding Process

The main objective of debinding process is removing the binder in a short time without defect on the part [17]. 60 wt% palm stearin and 40 wt% Polyethylene were removed through thermal debinding under argon flow.

Debinding process was performed successfully using thermal debinding with two stages was utilized to remove binder with debinding temperature 320 and 500 °C. In the first stages, low heating rate 3 °C/min was used to remove palm stearin, which has lower molecular weight components. A low heating rate in the early stage was required to avoid defects on debound part. At the next stage higher heating rate was used (5 °C/min).

3.5 Sintering Process

SEM result shows the structure of composite Titanium alloy and HA which Titanium alloys particles as reinforced and the matrix is HA. Titanium alloys particles uniformly distributed on the surface of the sintered part. Moreover, on the surface of sintered part has been observed cracks. The initial crack was started from titanium particles as shown on the Fig. 6. It was believed as a result of the difference of thermal expansion titanium and hydroxyapatite. Moreover, between titanium and HA particles, there is no good diffusion bonding due to the secondary phase resulted by Titanium and HA interaction. The presence of a secondary phase on the surface of the titanium particles prevents the occurrence of diffusion.

Energy Dispersive X-Ray Analysis (EDX) is an x-ray technique used to identify the elemental composition of materials. In this work, EDX was conducted on the surface composite HA/Ti to identify elements particularly on the surface of titanium particles. EDX results for composite HA/Ti are shown on Fig. 7.

Figure 7 shows on the sintered part have occurred secondary phase of hydroxyapatite, on the vicinity of titanium particle as shown on the pink box, the composition ratio of Ca/P is 2.36. On the surface of titanium particle EDX analysis also was conducted to identify the composition of elements. EDX result revealed that the composition ratio of Ca/P is 0.58. Ca/P ratio phase standard for HA is 1.67 however on elevated temperature HA tend to decompose become secondary phases such as TTCP, TCP, and some amorphous phase [18–20]. Another author also reported occurred some phases such as $Ca_2Ti_2O_5$, TiO_2, and $CaTiO_3$ as a result of interaction Ti and HA at elevated temperature [21, 22].

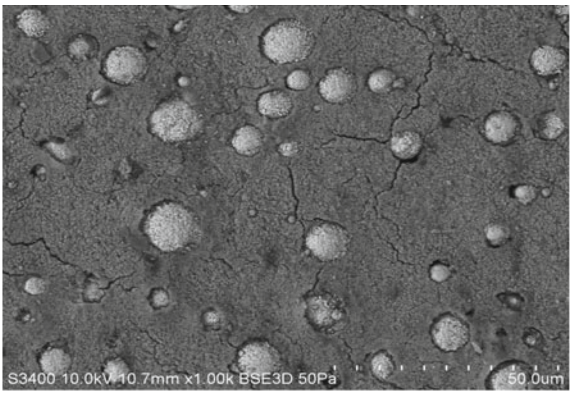
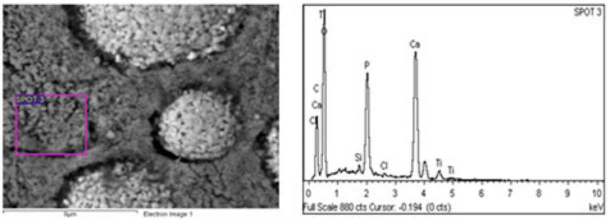


Fig. 6 Sintered part of composite HA/Ti with sintering temperature 1200 °C, heating rate 7 °C/min, and holding time 2 h

Element	Weight%	Atomic%
C K	11.04	19.77
O K	38.27	51.45
Si K	0.55	0.42
P K	11.24	7.81
Cl K	0.51	0.31
Ca K	34.35	18.44
Ti K	4.03	1.81
Totals	100.00	

Ca: P = 2.36



Element	Weight%	Atomic%
C K	7.70	17.20
O K	21.49	36.06
P K	18.31	15.87
Ca K	13.96	9.35
Ti K	35.83	20.08
V K	2.71	1.43
Totals	100.00	

Ca: P = 0.58

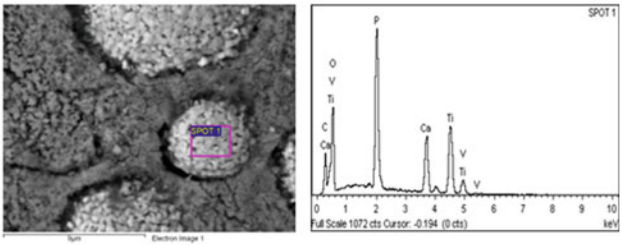


Fig. 7 EDX result of composites HA/Ti

4 Conclusion

Composite HA/Ti with binder system palm stearin and hydroxyapatite has shown pseudoplastic behavior. Dilatants behavior on feedstock was not observed as an indication of homogeneity of feedstock. Removal of binder using thermal debinding with two stages has been performed successfully without defect on debound part. Crack on the surface of sintered part has been observed due to differences in thermal expansion and both Ti and HA were not diffuse well. A new phase on the sintered part has been observed as a result of the decomposition of HA and a result of interaction HA and Ti. To achieve the optimal result on the sintered part modification in powders composition and parameter on the sintering process is required.

References

1. German RM, Bose A (1997) Injection molding of metals and ceramics. Metal Powder Industries Federation
2. Chu CL et al (2004) Mechanical and biological properties of hydroxyapatite reinforced with 40 vol. % titanium particles for use as hard tissue replacement. J Mater Sci Mater Med 15(6): 665–670
3. Arifin A et al (2014) Material processing of hydroxyapatite and titanium alloy (HA/Ti) composite as implant materials using powder metallurgy: a review. Mater Des 55:165–175
4. Arifin A et al (2017) Porous titanium alloy/hydroxyapatite composite using powder compaction route. J Mech Eng Sci 11(2):26779–32692

5. Niespodziana K et al (2010) Fabrication and properties of titanium–hydroxyapatite nanocomposites. Mater Chem Phys 123(1):160–165
6. Zhang L et al (2016) Rapidly sintering of interconnected porous Ti-HA biocomposite with high strength and enhanced bioactivity. Mater Sci Eng C Mater Biol Appl 67:104–114
7. Ramli MI et al (2012) Powder injection molding of SS316L/HA composite: rheological properties and mechanical properties of the green part. J Appl Sci Res 8(11):5317–5321
8. Nor NHM et al (2011) Optimization of injection molding parameter of Ti-6Al-4V powder mix with palm stearin and polyethylene for the highest green strength by using Taguchi method. Int J Mech Mater Eng 6(1):126–132
9. Ibrahim R et al (2010) Injection molding of titanium alloy implant for biomedical application using novel binder system based on palm oil derivatives. Am J Appl Sci 7(6):811–814
10. Arifin A et al (2014) Palm stearin as alternative binder for MIM: a review. J Ocean, Mech Aerosp Sci Eng 7:18–23
11. Froes FH (1991) Powder metallurgy in aerospace and defense technologies. Jom 43(12):20–21
12. Groover MP (2010) Fundamentals of modern manufacturing: materials, processes, and systems. Wiley
13. German RM (1992) Prediction of sintered density for bimodal powder mixtures. Metall Trans A 23(5):1455–1465
14. Wright M, Hughes L, Gressel S (1994) Rheological characterization of feedstocks for metal injection molding. J Mater Eng Perform 3(2):300–306
15. Park JM, Park SJ (2011) Rheology and processing of suspensions with fiber, disk and magnetic particles. Korea-Aust Rheol J 23(4):219–226
16. Liu L et al (2005) Mixing and characterisation of 316L stainless steel feedstock for micro powder injection molding. Mater Charact 54(3):230–238
17. Omar MA et al (2003) Rapid debinding of 316L stainless steel injection moulded component. J Mater Process Technol 140:397–400
18. Dorozhkin S (2009) Calcium orthophosphate-based biocomposites and hybrid biomaterials. J Mater Sci 44(9):2343–2387
19. Dorozhkin SV (2010) Bioceramics of calcium orthophosphates. Biomaterials 31(7):1465–1485
20. Ye H, Liu X, Hong H (2009) Characterization of sintered titanium/hydroxyapatite biocomposite using FTIR spectroscopy. J Mater Sci Mater Med 20(4):843–850
21. Yang Y et al (2004) Interaction of hydroxyapatite–titanium at elevated temperature in vacuum environment. Biomaterials 25(15):2927–2932
22. Egorov A et al (2010) High-temperature hydroxyapatite-titanium interaction. Inorg Mater 46(2):168–171

Analysis of the Influence of Service Quality and Audience Loyalty Interest in the Volleyball Tournament Events: A Case Study of Tulungagung Regency

Tito Pangesti Adji, Mansur, Kukuh Hardopo Putro, Kukuh Wahyudin Pratama, and Aida Mustapha

Abstract Tulungagung Regency is one of the districts whose people are very enthusiastic about volleyball. The main research aim for this paper is to examine the service quality by the volleyball tournament organizer at Tulungagung and its relationships towards satisfaction and audience loyalty in the game of volleyball. This research adopts a descriptive methodology with mixed qualitative and quantitative approaches. The population in this study were a total of 100 volleyball viewers in Tulungagung Regency taken by random sampling. The data collection technique is using a questionnaire. From the analysis, the level of audience satisfaction towards event organizers involved in the arena is 46%, while for the influential category it reached 54%. Security is very influential, reaching 55%. The quality of the national level professional players who competed was very influential, reaching 72%. The ticket to the match has less effect alone, reaching to 25%. Means for entertainment are also very influential, reaching 33%. Regarding doorprize, it is less influential, whereby 63% has no effect. The quality of the field, the influential category reached 72, 24% is effective, and 4% had no effect. The findings are hoped to be beneficial to every event organizer that will hold volleyball tournament events in terms of ensuring quality of services and retaining audience loyalty.

T. P. Adji (✉) · Mansur · K. H. Putro
Sport Science Faculty, Yogyakarta State University, Yogyakarta, Indonesia
e-mail: titopangesti.2019@student.uny.ac.id

Mansur
e-mail: mansur@uny.ac.id

K. H. Putro
e-mail: Kukuhhardopo.2020@student.uny.ac.id

K. W. Pratama
Research and Development, Institute of Advanced Science, Engineering, and Education (IASEE), Shah Alam, Malaysia
e-mail: kukuh.pratama@iasee.org

A. Mustapha
Faculty of Computer Science and Information Technology, Universiti Tun Hussein Onn Malaysia, Parit Raja, Malaysia
e-mail: aidam@uthm.edu.my

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Keywords Service quality · Professional athletes · Interests · Loyalty · Volleyball tournament events

1 Introduction

The progress and development of the world of sports in the current phase have begun to enter various fields, including one in the industrial world. This moment can be observed clearly and we can prove it by increasing the variety of sports industry products such as shoes, sports clothes, fitness equipment or in the form of services in the sports sector. The growing development of the world of business in the field of sports like this is a promising profit opportunity for the community in meeting the needs for equipment and entertainment in the sports field [1]. It does not always have to be a user, but the opportunity to be part of the progress and development of this open sports business has enormous opportunities.

So in brief we can conclude that the progress and development of the world of sports is not limited to its role as a tool for the development of physical and mental fitness, in a healthy body, a means of recreation, or limited to competition. But in this case sport can also be a source of income in generating economic coffers for the income of the community itself, and can also be a means to raise the dignity and degree of the state [2]. In the current era of globalization, the sports industry has become a promising business opportunity to be developed and even become one of the main commodities that is inevitable, and has become the most frequently discussed in everyday life.

The development of business in the service sector in the current period has increased so rapidly and its development has resulted in tighter competitiveness among private companies, thus making service-oriented companies obliged to work more effectively and efficiently [3]. In the business, especially in the sport of volleyball, it has experienced a very rapid increase, both in terms of quality and quantity in Tulungagung. In terms of the quality presented, you can see for yourself its application in the field with better service, suitability of costs and facilities provided to customers [4].

Customers here are the spectators and connoisseurs of volleyball as users of facilities and services who pay fees, many influenced by several internal and external factors. In the current competitive power of many companies in various sports industries, it seems that the competition for customers or spectators or even athletes themselves affects their needs in the market [5]. A volleyball event or tournament in terms of its activities will become mandatory to manage it properly, so having professional management in marketing, human resources, integrity of these factors will be the key to success in improving business performance.

The progress that is getting better in all these fields has resulted in a change in mindset in society. Nowadays society is becoming increasingly critical, both in thinking and for taking action [6]. This is a great opportunity for event organizers who are engaged in services or services in sports, one of which is volleyball. Tulungagung Regency is one of the districts where the majority of the people are very enthusiastic about the sport of volleyball, even from every volleyball match event that is held always filled with spectators. This paper aimed to examine with the following research objectives (1) to determine the effectiveness of service quality on volleyball tournament organizer service in Tulungagung on service satisfaction and loyalty of volleyball viewers, (2) to determine the effectiveness of volleyball audience loyalty, (3) to determine the effectiveness of interest on audience loyalty towards volleyball and, (4) to determine the effectiveness of professional athletes on the loyalty of volleyball audiences.

This research is very important because it can find out the strengths and weaknesses of a volleyball tournament event organizer in Tulungagung in holding a tournament, so that it can be a reference to improve and prepare to be more mature in preparing every time a volleyball competition event will be held, as well as to improve the quality of service on a regular basis. On the national level, the organizer has been implemented this method. The maximum for volleyball lovers in Tulungaung in every time they hold a volleyball tournament.

2 Literature Review

2.1 Service Quality

Service quality can briefly be interpreted as a level of satisfaction with customers or consumers [7]. Service quality is a form of behavior provided by service providers to meet the needs and desires of each customer as well as a way to meet the expectations of customer needs [8]. As for the level of consumer satisfaction, this can be obtained through a comparison of the types of services that are actually received by consumers with the types of services desired by the consumers themselves [9]. This type of good service quality is a type of service that satisfies consumers and is in accordance with the service desired by the consumers themselves [10]. However, if a service provided is able to exceed the expectations or expectations of consumers, then this type of service quality can be categorized as very good service and has high service quality and is arguably very satisfying [11]. On the other hand, poor service quality is a type of service that is far below the predetermined standard or not in accordance with the service expectations desired by consumers [12].

The quality of this service is very important because it will have a direct impact on the image or even the good name of the company or event organizer that provides these services to consumers [9]. Providing good quality service to consumers will be a big advantage for the company or even organizer [13]. How not, if a company or event organizer has received a positive value in the eyes of every consumer, then the consumer will provide good feedback to the company or event organizer, and it is not impossible that the consumer will become a repeat customer [14]. Therefore, in providing quality service to consumers, it is very important to consider all aspects of satisfaction for these consumers related to the level of service quality provided in serving [15].

There are many types of services that can be done and provided to consumers, such as the ease, speed, ability, and hospitality shown through ethics and direct action to these consumers in providing services [16]. Whereas service quality itself is all forms of providing service activities carried out by companies or event organizers to meet consumer desires [17]. Providing services in this phase has the meaning of providing services or services provided by service owners in the form of ease, speed, relationship, ability and hospitality aimed at ethics in providing services for customer satisfaction [16]. In assessing the quality of service (service quality), it can be seen by comparing the opinions of each consumer on the services they have obtained in real and direct ways with the services desired by each consumer for the service infrastructure of a company [15].

The quality of service is an effort to meet the needs and desires of customers as well as how to meet the expectations of these customers [18]. The quality of service itself here has the following definition, the level where excellence is in accordance with the wishes and is controlled for the level of excellence to fulfill customer desires [19]. Quality has the meaning of the beginning of the formation of a perception arising from a person's sensory process to assess an object with the aim in the business field to seize market share which will result in the level of satisfaction that not only needs to be maintained but also needs to be improved to face competition [20]. Therefore, a company or event organizer that is engaged in sports must be able to mobilize, organize, and coordinate all activities of various professional, semi-professional and non-professional personnel in all aspects concerned to achieve the same goal.

Audience satisfaction is the main factor in developing a behavior model for buyers or connoisseurs of a product [21]. In addition, audience satisfaction will be the main benchmark for making a tournament event organizer successful and successful if it can meet the needs of the audience so that there will be a sustainable competitive advantage [22]. The satisfaction of the audience for all the services provided by the tournament event organizer is known if the event organizer takes a measurement and testing of the audience [23]. Satisfaction measurement is important in providing good service, efficient service and effective service. The use of service quality as a measuring tool is expected for a tournament event organizer to determine the level of audience satisfaction, especially in the field of sports, especially here in the field of volleyball in Tulungagung.

By knowing the results of measuring satisfaction tests to the audience, a tournament event organizer can prepare strategies to be implemented in creating consumer loyalty. In the real results in the field, we often see that audience satisfaction is often overlooked or not given good attention by every individual in the organization. From the mindset of the audience, there are often many complaints regarding the quality of the matches being contested, the quality of infrastructure for the spectators, the price of tickets which tend to be expensive, and the safety level of the spectators in enjoying a match [24]. There are four determinants of service quality including direct evidence of equipment, staff, price and programs. The various variables mentioned above greatly affect the level of customer satisfaction with the quality of service provided by a tournament event organizer and have an impact on efforts to create audience loyalty to the tournament being held.

2.2 Interest

In a broad definition, the notion of interest itself is a special concern that contains elements of feeling in it [25]. Interest is also a desire in a person for a certain object [26]. One example, such as, interest in lessons, sports, or a sporting event. Own interest has a characteristic personal character (individual) [27]. The definition of the understanding is that everyone has their own interests which may differ from one another [28].

Interests have a very close correlation with a person's desires, interests are also things that can be learned and can also change over time according to needs, experiences, and trending modes, not inherited from birth [29]. Factors that influence the emergence of a person's interest depend on physical, social, emotional, and experiential needs [30]. Interest begins with feelings of pleasure and also a positive attitude [31]. In a service-oriented behavior, it must always coincide with the information and explanation given because it is very important to foster one's interest and to reduce negative perceptions of an object [32].

Therefore, the sports tournament organizer must be able to use this factor as a reference for how to give a positive impression to attract the audience's interest in the events they organize. For the fans themselves continue to hold interest to the extent that it has become part of their daily interests. Sports enthusiasts try to form a relationship between clubs and fans, but the formation of social loyalty empowers fans to increase influence on interests [33]. The level of interest of sports fans with the club above all stakeholders in the club network plays a major role in creating value, which is achieved through the ability to influence social aspects [34]. The relationship between fans and the team is known as loyalty [35].

2.3 Loyalty

Loyalty is one of the things that money cannot buy [36]. Loyalty like this can only be obtained with one's own awareness, but cannot be bought [37]. Getting loyalty from someone is not an easy matter because it does arise from the person's awareness to be loyal to what they like [38]. In contrast to the difficulty in gaining loyalty, to lose one's loyalty becomes something that is very easy to do [39]. If defined more broadly, the notion of loyalty is a quality of one's loyalty (loyalty), whereas loyalty itself is defined as an action that shows firm and constant support and obedience to a person or institution [40]. Loyalty is an emotional thing [41]. To be able to get someone's loyal attitude, there are many factors that will influence it. Loyalty can be applied by everyone in various ways.

Relationships that are shared and strong in the process with correlated partners are more likely to increase trust and level of commitment [42]. As a consumer can be loyal because of the belief in goods and it is proven by their behavior patterns that are committed to the goods. The object of attitude in fulfilling loyalty is the provision of services, activities oriented towards attractiveness to consumers [43]. In a context like this, when measuring the level of quality of the match, the result is how much loyalty the audience watched the match. In this sense, attitude fidelity is similar to the concept of attachment to place or object [44]. On the relationship between psychological commitment, resistance to change, and behavioral fidelity, it is more appropriate to switch from service provider behavior as an attitude object to treat the attitude object setting within the context of recreation [45].

2.4 Professional Athlete

A professional in a field requires a special expertise in a particular field to carry out tasks with certain financial implications [46]. Meanwhile, a person whose activities carried out on the basis of pleasure and not for earning a living, for example, people who play music, paint, dance, play boxing, soccer as fun are called amateurs [47]. Amateurs may produce unfavorable results [48]. In the essence, a professionalism requires a special skill that requires a fee to implement it while amateurs treat the tasks as a hobby and pleasure, therefore has little to do with the abilities of the person. A professional athlete is an athlete who has been trained with a certain training intensity to improve his ability above the average person [49]. Professional athletes are trained with the aim of improving their abilities in order to get a target of achievement [50].

3 Methodology

This research adopts a descriptive methodology with mixed qualitative and quantitative approaches. The population in this study were volleyball viewers in Tulungagung Regency, with a total of 100 responders. The research sample was determined by random sampling and the data collection technique used a questionnaire. In order to analyze the factors that affect the loyalty interest of volleyball tournament spectators in Tulungagung Regency, four variables are formulated as follows.

- Service Quality Variable
- Professional Athlete Variable
- Interests Variable Volleyball Tournament Audience in Tulungagung
- Loyalty Variable of audience Volleyball Tournament in Tulungagung.

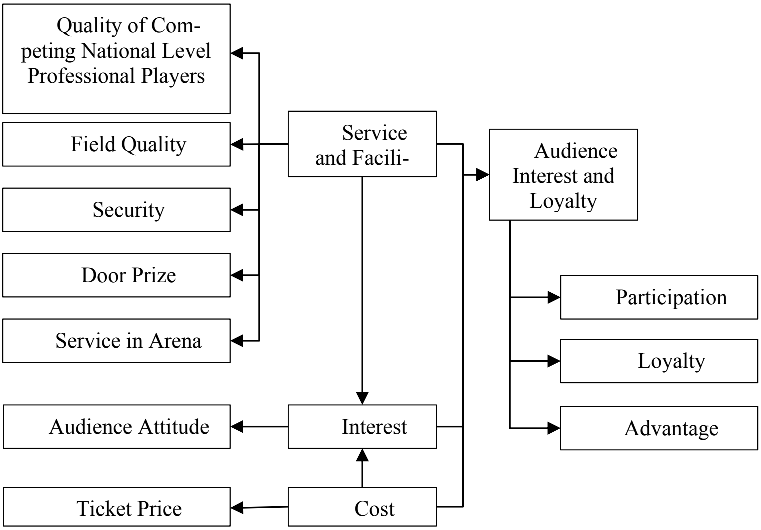

Fig. 1 Research model

Figure 1 shows the research model to undertake the study. Participation, loyalty, and advantage in a sports competition are related to the service and facilities, interest cost. In this study, there are several factors that can influence it the quality of national level professional players competing, field quality, security, door prize, service in the arena, audience attitude, ticket price.

4 Result and Discussion

The questionnaires are analyzed in the context of level of audience satisfaction with regards to services and security level in the arena, the quality of national level professional players, the tickets admission to the volleyball matches, entertainment, door prizes, and quality of the fields.

Figure 2 shows the findings for the level of audience satisfaction towards the service arena. Very influential category achieved 46% while for the influential category it reached 54%. There were no spectators who gave a score for the category that was less influential and had no effect on their assessment of the volleyball tournament event organizer. This shows that the influence of service in the arena of the tournament event organizer is significantly effective on the satisfaction and comfort of the audience in watching a match.

Figure 3 shows the findings for the level of audience satisfaction towards the security. The level of audience satisfaction with the safety-related tournament organizer event for the very influential category reached 55% while for the influential category it reached 45%. There were no spectators who gave a score for the category that was

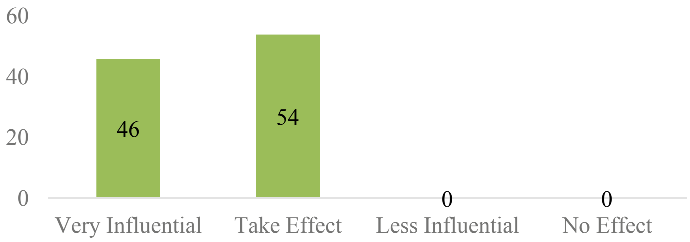

Fig. 2 Service in the arena

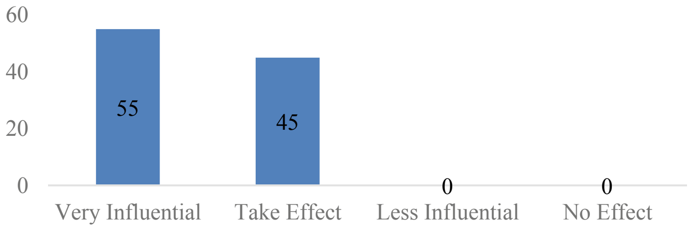

Fig. 3 Security

less influential and had no effect on their assessment of the volleyball tournament event organizer. This shows that the effect of security from the tournament event organizer has a very significant effect on the satisfaction and comfort of the audience when watching a match.

Figure 4 shows the findings for the level of audience satisfaction towards the quality of national level professional players who competed. For the very influential category reached 72% while for the influential category it reached 28%. There were no spectators who gave a score for the category that was less influential and had no effect on their assessment of the volleyball tournament event organizer. This shows that the influence of the quality of national level professional players from what

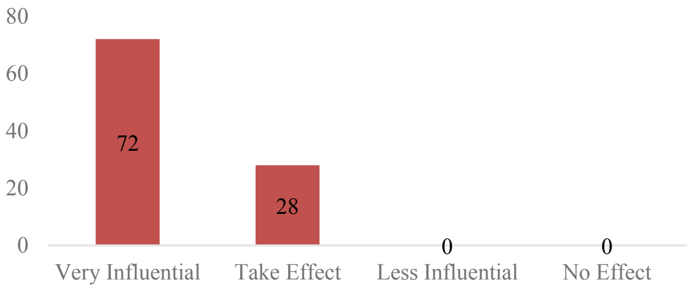

Fig. 4 Quality of national level professional players

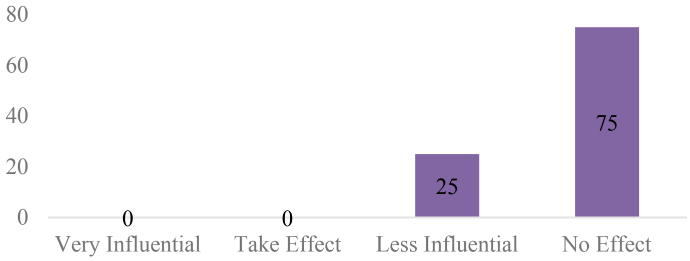

Fig. 5 Tickets admission to the match

is presented by the tournament event organizer has a very significant effect on the satisfaction and comfort of the audience in watching a match.

Figure 5 shows the findings for the level of audience satisfaction towards the match entry ticket. For the category is very influential and the category is influential, there is no audience who gives a value for that category, while for the less influential category itself reaches 25% and for the category has no effect it reaches 75%. This shows that the effect of the ticket price for the match does not affect the audience to always come and watch every match that is competed.

Figure 6 shows the findings for the level of audience satisfaction towards entertainment. The level of audience satisfaction with the tournament organizer event as a means for entertainment, for the very influential category reached 33% while for the influential category it reached 67%. There were no spectators who gave a score for the category that was less influential and had no effect on their assessment of the volleyball tournament event organizer. This shows that the influence of the means as entertainment has a considerable effect on the satisfaction and comfort of the audience in watching a match.

Figure 7 shows the findings for the level of audience satisfaction towards door prizes. The level of audience satisfaction with the event organizer tournament related to doorprize for the very influential category and for the influential category, no audience gave a value for that category, while for the less influential category itself it reached 37% and for the non-influential category it reached 63%. This shows that

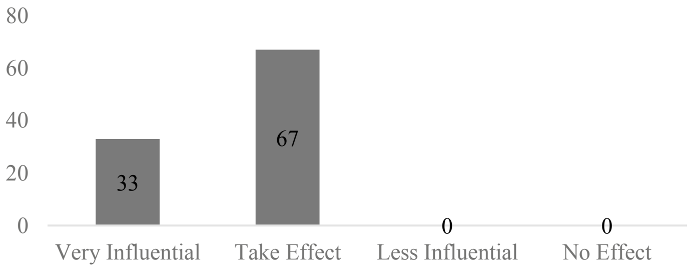

Fig. 6 Entertainment

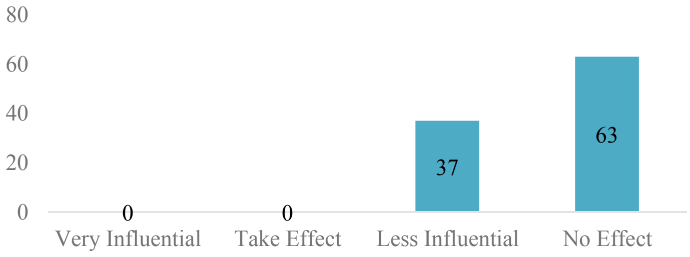

Fig. 7 Door prizes

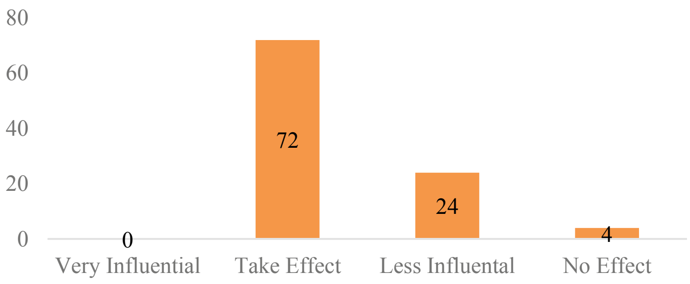

Fig. 8 Field quality

the influence of the door prize in the match does not affect the audience to always come and watch every match that is contested.

Finally, Fig. 8 shows the findings for the level of audience satisfaction towards the quality of field. For the very influential category, not the audience who gives an assessment, while for the influential category it reaches 72, 24% less influences, and does not affect 4%. This shows that the influence in terms of field quality has a considerable effect on the satisfaction and comfort of the audience in watching a match.

5 Conclusion

The main research aim for this paper is to examine the service quality by the volleyball tournament organizer at Tulungagung and its relationships towards satisfaction and audience loyalty in the game of volleyball. The questionnaires are analyzed in the context of level of audience satisfaction with regards to services and security level in the arena, the quality of national level professional players, the tickets admission to the volleyball matches, entertainment, door prizes, and quality of the fields. Based on the analysis of the questionnaires, the research concludes as follows.

- The level of audience satisfaction with the tournament event organizer related to service in the arena for the very influential category reached 46% while for the influential category it reached 54%.
- With regards to safety, for the very influential category it reached 55% while for the influential category it reached 45%.
- With regards to the quality of national level professional players who competed, for the very influential category reached 72% while for the influential category it reached 28%.
- With regards to the entrance ticket to the match, for the very influential category and the influential category, there was no audience who gave a value to that category, while for the less influential category itself it reached 25% and for the non-influential category it reached 75%.
- With regards to means for entertainment, for the very influential category it reached 33% while for the influential category it reached 67%.
- With regards to the doorprize, for the very influential category and the influential category, there was no audience who gave a value to that category, while for the less influential category itself it reached 37% and for the non-influential category it reached 63%.
- In terms of field quality, for the very influential category, it was not the audience who gave the assessment, while for the influential category it reached 72, 24% less influential, and did not affect it reached 4%.

The findings are hoped to be beneficial to every event organizer that will hold volleyball tournament events in terms of ensuring quality of services and retaining audience loyalty. It is important that organizers provide experience for quality viewing for the audience supported by facilities and adequate infrastructure.

References

1. Shilbury D, Quick S, Funk D, Westerbeek H, Karg A (2020) Strategic sport marketing. Routledge
2. Mair J, Whitford M, Davies L, Coleman R, Ramchandani G (2013) Evaluating event economic impact: rigour versus reality? Int J Event Fest Manag
3. Ghani E, O'Connell SD (2014) Can service be a growth escalator in low-income countries? The World Bank
4. Farooq MS, Salam M, Fayolle A, Jaafar N, Ayupp K (2018) Impact of service quality on customer satisfaction in Malaysia airlines: A PLS-SEM approach. J Air Transp Manag 67:169–180
5. Avourdiadou S, Theodorakis ND (2014) The development of loyalty among novice and experienced customers of sport and fitness centres. Sport Manag Rev 17(4):419–431
6. Cunliffe AL (2016) Republication of "On becoming a critically reflexive practitioner." J Manag Educ 40(6):747–768
7. Dahlgaard-Park SM, Dahlgaard JJ, Yuen KF, Van Thai V (2015) Service quality and customer satisfaction in liner shipping. Int J Qual Serv Sci
8. Putro KH, Aman MS (2020) Analysis of effects of service quality and loyalty on interest rates of basketball athletes in sahabat basketball club Yogyakarta. HOLISTICA–J Bus Public Adm 11(2):151–160

9. Orel FD, Kara A (2014) Supermarket self-checkout service quality, customer satisfaction, and loyalty: empirical evidence from an emerging market. J Retail Consum Serv 21(2):118–129
10. Kadir AR, Kamariah N, Saleh A (2017) The effect of role stress, job satisfaction, self-efficacy and nurses' adaptability on service quality in public hospitals of Wajo. Int J Qual Serv Sci
11. Lau MM, Cheung R, Lam AYC, Chu YT (2013) Measuring service quality in the banking industry: a Hong Kong based study. Contemp Managw Res 9(3)
12. Chen R, Guo J, Bao F (2014) Trust management for SOA-based IoT and its application to service composition. IEEE Trans Serv Comput 9(3):482–495
13. Bolton RN, Gustafsson A, McColl-Kennedy J, Sirianni NJ, Tse DK (2014) Small details that make big differences: a radical approach to consumption experience as a firm's differentiating strategy. J Serv Manag 25(2):253–274
14. Plewa C, Conduit J, Quester PG, Johnson C (2015) The impact of corporate volunteering on CSR image: a consumer perspective. J Bus Ethics 127(3):643–659
15. David Mc AB (2013) Service quality and customer satisfaction in the airline industry: a comparison between legacy airlines and low-cost airlines. Am J Tour Res 2(1):67–77
16. Cao Y, Kim K (2015) How do customers perceive service quality in differently structured fast food restaurants? J Hosp Market Manag 24(1):99–117
17. Murali S, Pugazhendhi S, Muralidharan C (2016) Modelling and investigating the relationship of after sales service quality with customer satisfaction, retention and loyalty–a case study of home appliances business. J Retail Consum Serv 30:67–83
18. Kasiri LA, Cheng KTG, Sambasivan M, Sidin SM (2017) Integration of standardization and customization: impact on service quality, customer satisfaction, and loyalty. J Retail Consum Serv 35:91–97
19. Al-Hawary SIS, Abu-Laimon AAA (2013) The impact of TQM practices on service quality in cellular communication companies in Jordan. Int J Prod Qual Manag 11(4):446–474
20. Mizuno S (2020) Management for quality improvement: the 7 new QC tools. CRC Press
21. Lee JS, Kang J-H (2015) Effects of sport event satisfaction on team identification and revisit intent. Sport Mark Q 24(4):225
22. Brown S, Getz D, Pettersson R, Wallstam M (2015) Event evaluation: definitions, concepts and a state of the art review. Int J Event Festiv Manag 6(2):135–157
23. Kim MK, Kim S-K, Lee D, Judge LW, Huang H (2013) Service quality and satisfaction perspectives at the 2011 international amateur athletic federation (IAAF) world championships. ICHPER-SD J Res 8(2):39–44
24. Oakland JS (2014) Total quality management and operational excellence: text with cases. Routledge
25. Habermas J (2015) Knowledge and human interests. Wiley
26. Korsgaard CM, Korsgaard CM (2014) The constitution of agency: essays on practical reason and moral psychology. Oxford University Press, USA
27. Renninger KA, Hidi S (2015) The power of interest for motivation and engagement. Routledge
28. Alvesson M, Sandberg J (2013) Constructing research questions: doing interesting research. Sage
29. Gregory RL (2015) Eye and brain: the psychology of seeing, vol 80. Princeton University Press
30. Reiter U, Brunnström K, De Moor K, Larabi M-C, Pereira M, Pinheiro A et al (2014) Factors influencing quality of experience. In: Quality of experience. Springer, pp 55–72
31. Vitters J, Overwien P, Martinsen E (2009) Pleasure and interest are differentially affected by replaying versus analyzing a happy life moment. J Positive Psychol 4(1):14–20
32. Bakker AB, Bal MP (2010) Weekly work engagement and performance: a study among starting teachers. J Occup Organ Psychol 83(1):189–206
33. Williams J, Chinn SJ (2010) Meeting relationship-marketing goals through social media: a conceptual model for sport marketers. Int J Sport Commun 3(4):422–437
34. Walters G, Tacon R (2010) Corporate social responsibility in sport: stakeholder management in the UK football industry. J Manag Organ 16(4):566
35. Wu S-H, Tsai C-YD, Hung C-C (2012) Toward team or player? How trust, vicarious achievement motive, and identification affect fan loyalty. J Sport Manag 26(2):177–191

36. Chan M, Kemp S, Finsterwalder J (2016) The concept of near money in loyalty programmes. J Retail Consum Serv 31:246–255
37. Makanyeza C (2015) Consumer awareness, ethnocentrism and loyalty: an integrative model. J Int Consum Mark 27(2):167–183
38. De Graaf G (2011) The loyalties of top public administrators. J Public Adm Res Theory 21(2):285–306
39. Mandhachitara R, Poolthong Y (2011) A model of customer loyalty and corporate social responsibility. J Serv Market
40. Foust MA (2012) Loyalty to loyalty: Josiah Royce and the genuine moral life: Josiah Royce and the genuine moral life. Fordham Univ Press
41. Kassim N, Abdullah NA (2010) The effect of perceived service quality dimensions on customer satisfaction, trust, and loyalty in e-commerce settings. Asia Pacific J Market Logist
42. Aurier P, N'Goala G (2010) The differing and mediating roles of trust and relationship commitment in service relationship maintenance and development. J Acad Mark Sci 38(3):303–325
43. Brashear-Alejandro T, Kang J, Groza MD (2016) Leveraging loyalty programs to build customer–company identification. J Bus Res 69(3):1190–1198
44. Amerson K, Rose J, Lepp A, Dustin D (2020) Time on the trail, smartphone use, and place attachment among Pacific Crest Trail thru-hikers. J Leis Res 51(3):308–324
45. Kim JW, James JD, Kim YK (2013) A model of the relationship among sport consumer motives, spectator commitment, and behavioral intentions. Sport Manage Rev 16(2):173–185
46. Edwards A, Lunt I, Stamou E (2010) Inter-professional work and expertise: new roles at the boundaries of schools. Br Edu Res J 36(1):27–45
47. Fisher CD (2010) Happiness at work. Int J Manag Rev 12(4):384–412
48. Herzberg F (2017) Motivation to work. Routledge
49. Faigenbaum AD, French DN, Lloyd RS, Kraemer WJ (2019) 7 Strength and power training for young athletes. In: Strength and conditioning for young athletes: science and application
50. Thomas DT, Erdman KA, Burke LM (2016) Position of the academy of nutrition and dietetics, dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. J Acad Nutr Diet 116(3):501–528

The Influence of Ball Impact Angle on the Brain Deformation in Soccer Heading: A Finite Element Analysis

Mohd Hasnun Arif Hassan, Mohd Alimin Mohd Anni, Fu Yang Tan, Nasrul Hadi Johari, and Mohd Nadzeri Omar

Abstract Soccer is the most popular sport in the world. One of the manoeuvres in a soccer game is known as heading, in which the player uses the head to hit the ball. There have been concerns as to whether this purposeful head impact may lead to brain injury. Studies have shown some compelling evidence that purposeful heading of a soccer ball may cause adverse effect to the brain. One of the contributing factors that may lead to head injury when heading a soccer ball is the improper heading technique. This study investigates the effect of ball impact angle on the brain deformation, a parameter used to evaluate head injury. A series of finite element simulations were performed with various ball inbound velocities and impact angles. It was found that heading at an angle resulted in higher brain deformation as opposed to central impact heading. The impact angle of 45° was found to produce the highest brain deformation. This study shows that a proper heading technique is essential to prevent brain injury when performing soccer heading.

Keywords Soccer heading · Impact angle · Finite element analysis · Brain deformation

1 Introduction

Heading is one of the manoeuvres used by soccer players in the game to direct the ball to a teammate or to score goal. This purpose head impact with the ball has raised concerns as to whether it may harm the brain. Many studies have been conducted to determine the potential of sustaining brain injury due to heading a soccer ball. Many found that there is compelling evidence that heading a soccer ball might be harmful to the brain, nonetheless some found that this is not the case.

Levitch et al. [1] used questionnaire to assess recent and long-term heading exposure on the neuropsychological function in amateur soccer players. They found that

M. H. A. Hassan (✉) · M. A. Mohd Anni · F. Y. Tan · N. H. Johari · M. N. Omar
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: mhasnun@ump.edu.my

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heading exposures resulted in poorer neuropsychological function of the players. Stewart et al. [2] used similar method to study the exposure to brain injury due to purposeful and unintentional heading in soccer. Poorer cognitive performance was observed in players who purposefully head the ball frequently as opposed to the unintentional head impact with the ball.

Apart from questionnaire, magnetic resonance imaging (MRI) was also used to evaluate the brain function of soccer players with high heading exposure [3, 4]. It was found that heading may cause an abnormal microstructure of the brain that can result in poor neurocognitive performance. In addition, fluid biomarker was also used as a measure to evaluate the effect of soccer heading on the brain [5]. Based on their study, it was found that repetitive soccer heading may lead to axonal damage.

Mathematical model of soccer heading was also developed to study the head response due to the impact with the ball [6]. Mass-spring-damper model was used to model the ball, head, and brain. In addition to mathematical model, finite element (FE) modelling has also been used to study the impact of soccer heading to the head [7, 8]. Nonetheless, these studies did not consider the brain deformation occurs due to the limitation of the model.

The objective of this study is to investigate the effect of ball impact angle during soccer heading on the brain deformation. For this purpose, validated FE models of soccer ball and human head were used to simulate soccer heading. The following section explains the FE models used and the simulations conducted.

2 Methodology

To study the influence of ball impact angle on the brain deformation due to soccer heading, FE simulations were performed. For the simulation to be reliable, validated models of soccer ball and human head are required. This section discusses the FE models used in this study and how the simulations were performed.

2.1 Soccer Ball FE Model

A validated soccer ball FE model developed by Taha and Hassan [9] was used to simulate soccer headings in this study. The ball was developed using a sphere shell partitioned into an octahedral sphere. This was done to obtain a structured quadrilateral mesh. The ball was meshed with 1,756 linear quadrilateral elements of type S4R in Abaqus/CAE as shown in Fig. 1. Shell element was used to reduce computational cost while still maintaining the accuracy when it comes to bending behaviour.

The ball comprises of two layers, namely the inner bladder (0.8 mm thick) made of latex and the outer panel (2.2 mm thick). The material properties of both layers were obtained from uniaxial tensile test data published by Price and colleagues [10].

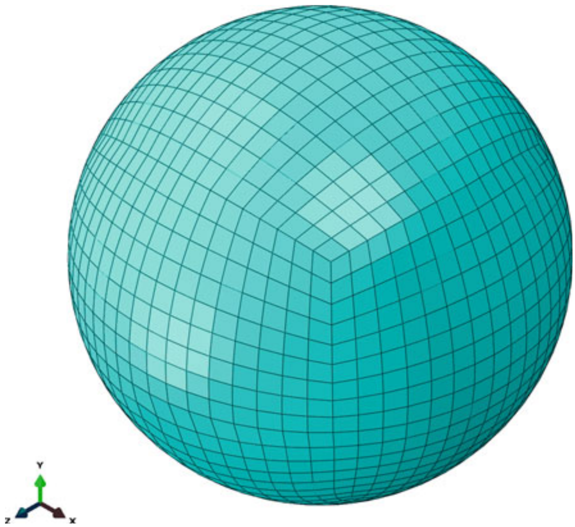

Fig. 1 FE model of soccer ball meshed into uniform quadrilateral elements

Stress–strain data of both materials were input into the software to represent the mechanical properties of both layers (Fig. 2).

The pressurization of the ball was achieved through a surface-based fluid cavity technique. In this method, a node was created at the centre of gravity of the ball and was used as the reference point of the cavity, that is the inner surface of the ball. The pressurization process was performed gradually to prevent the ball from exploding due to a sudden increase in pressure. The ball was pressurized to 90 kPa in all simulations.

Taha and Hassan [9] have validated the ball model against a more advanced model of Price and colleagues [10] as well as against ball impact experiments. With a good agreement presented by Taha and Hassan, the FE ball model is considered as a valid model and can provide a reliable simulation results, close enough to an actual soccer ball.

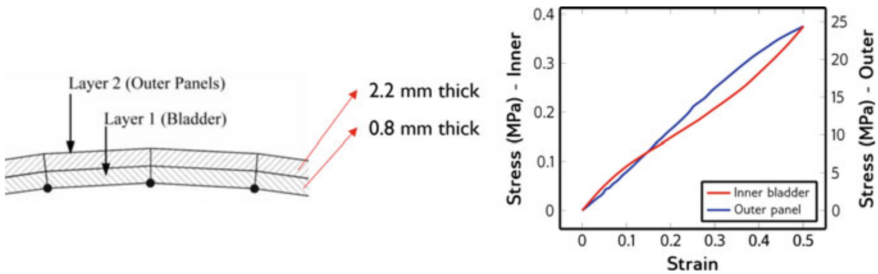

Fig. 2 Material properties of the ball model

Table 1 Material properties of UCDBTM

Component	Young's modulus (MPa)	Density (kg/m^3)	Poisson's ratio
Scalp	16.7	1130	0.42
Trabecular bone	1000	1300	0.24
Cortical bone	15,000	2000	0.22
Pia	11.5	1130	0.45
Dura	31.5	1140	0.45
Falx/tentorium	31.5	1140	0.45
CSF	0.015	1000	0.499989
Brain	0.123	1040	0.499991

2.2 University College Dublin Brain Trauma Model (UCDBTM)

As for the head model, the UCDBTM was used. The model was obtained from the International Society of Biomechanics website. The model, which was developed by Horgan and Gilchrist [11], comprises of 8 components, namely the scalp, cortical and trabecular bones, dura, pia, falx and tentorium, cerebrospinal fluid (CSF) facial bone and the brain. The material properties of each component were obtained from published literature [12–16] as listed in Table 1.

The brain was defined as viscoelastic material in Abaqus/CAE using the Prony series parameters $\overset{\_P}{g_1} = 0.815$, $\overset{\_P}{k_1} = 0$, and $\tau_1 = 0.00143$. $\overset{\_P}{g_1}$ is the modulus ratio in the first term in the Prony series expansion of the shear relaxation modulus, $\overset{\_P}{k_1}$ is the modulus ratio in the first term in the Prony series expansion of the bulk relaxation modulus, and τ_1 is the relaxation time for the first term in the Prony series expansion.

2.3 Soccer Heading Simulation

Both soccer ball model and UCDBTM were assembled in Abaqus/CAE. The ball was positioned 220 mm away from the head's centre of gravity in *x*-axis. In *y*-axis, the ball was positioned in such a way that the impact occurs on the forehead of the model to replicate an actual heading (50 mm from the head's centre of gravity). Figure 3 shows the positioning of the ball and UCDBTM for the case of central impact ($\theta = 0°$).

Figure 3 shows the positioning of both models for central impact, which serves as the baseline of the analysis. However, the objective of this study is to vary the impact angle. Hence the ball was translated in y-axis to obtain different angles θ of 30°, 45° and 60°, as shown in Fig. 4. The velocity of the ball was defined such that the resultant inbound velocities (red arrows in Fig. 4) are 9, 12, 15, 18 and 21 m/s.

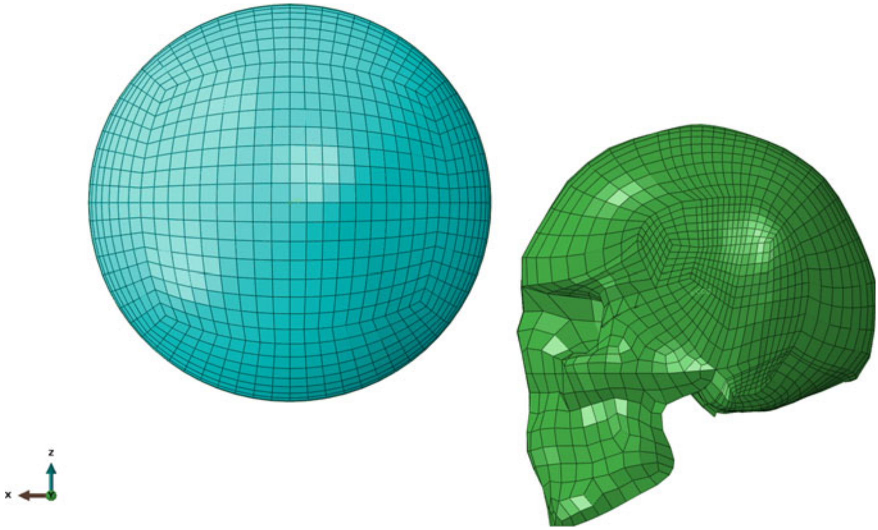

Fig. 3 The assembly of ball model and UCDBTM

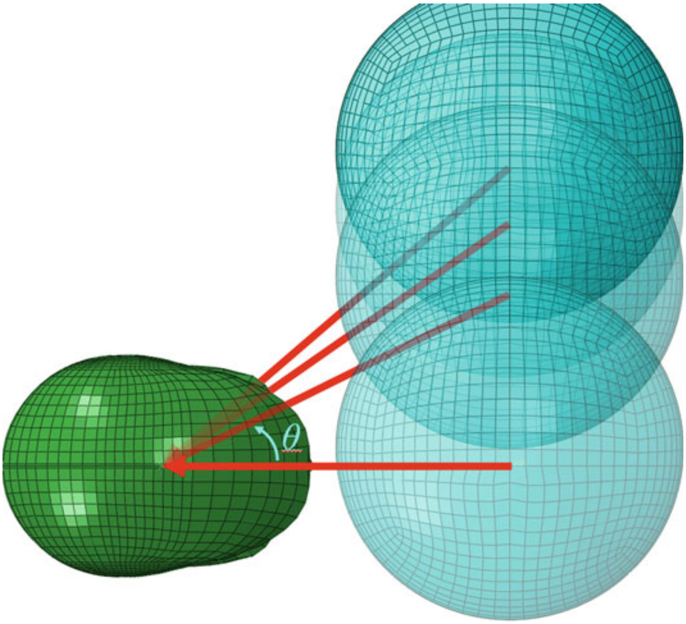

Fig. 4 The ball impact angle varied in the simulations

Altogether, 20 soccer heading simulations were conducted for a series of ball velocities and impact angles as mentioned previously. The output of the simulations are the von Mises stress and the maximum principal strain in the cerebrum.

3 Results and Discussions

The aim of this study is to investigate the effect of ball impact angle on brain deformation, one of the measures used to quantify the severity of brain injury. Brain deformation is determined by two parameters: the maximum von Mises stress (VMS) and the maximum principal strain (MPS) in the cerebrum. Figures 5 and 6 depict the VMS and MPS in the cerebrum for a series of ball inbound velocities and impact angles.

It is apparent from both figures that the brain deformation increases with the increase of ball inbound velocity. This is a very straight forward finding. However, when the impact angle was varied, more interesting findings were observed. The impact angle of 45° was found to cause the highest brain deformation as compared to other impact angles. The impact angle of 30° and 60° were seen to produce almost identical brain deformation. The VMS of 30° impact angle is slightly higher than that of 60° impact angle, while the MPS of 60° is slightly higher than that of 30°.

When compared to the central impact (0° impact angle), it is apparent that heading the ball at an angle causes higher brain deformation. This shows that the heading technique is very important to prevent any adverse effect to the brain. A proper execution of heading may reduce the chances of sustaining brain injury as a result of lower brain deformation it induced. In addition, the trendline of a central impact

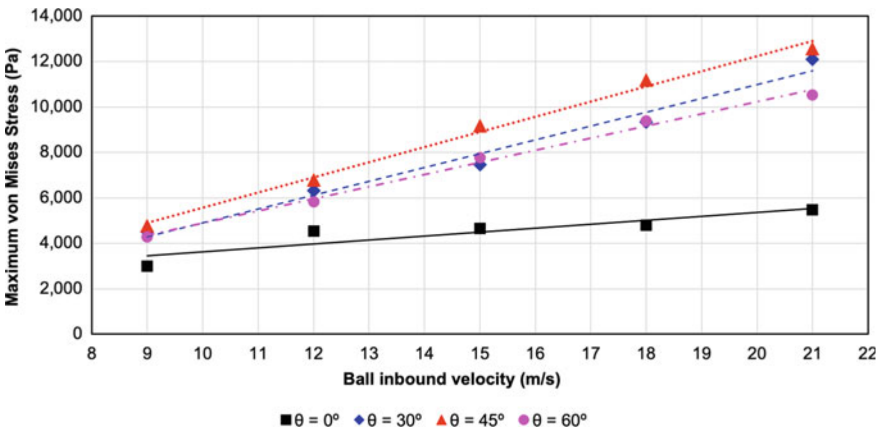

Fig. 5 Maximum von Mises stress in the cerebrum of different ball inbound velocities and impact angles

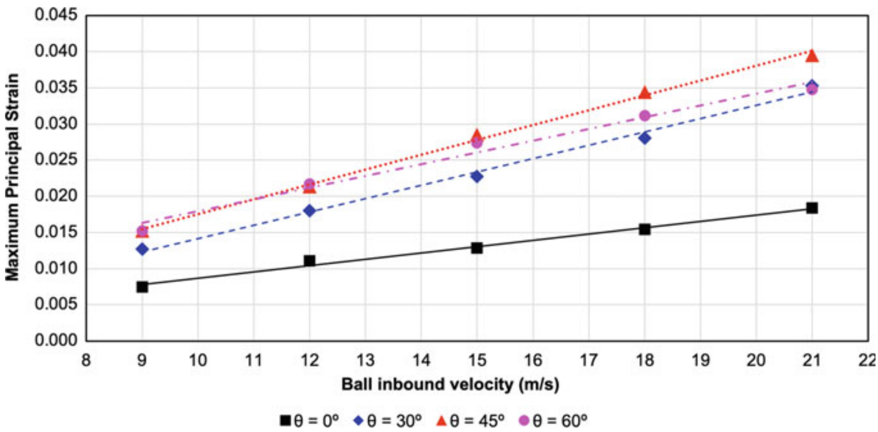

Fig. 6 Maximum principal strain in the cerebrum of different ball inbound velocities and impact angle

is less steep as compared to when impact angles are introduced in the simulation. When the heading occurs at an angle, the gradient of the trendline notably increases.

This finding might be attributed by the higher rotational accelerations the head experiences in angled impacts. This agrees with previous study, which stated that the rotational head acceleration is the main cause of head injury as compared to the linear head acceleration [17]. It also further supports the claim that a proper heading technique is very important to prevent head injury [18].

4 Conclusions

The objective of this study was to simulate soccer headings at various impact angles and inbound ball velocities to investigate the effect of these parameters on brain deformation. Validated soccer ball and human head models were used in the simulations. A total of 20 soccer heading simulations were performed. Von Mises stress and maximum principal strain of the cerebrum were recorded throughout the impact. Introducing impact angle in the simulation has shown to increase the brain deformation as compared to the central impact (direct impact on the forehead). The impact angle of 45° produced the highest brain deformation. This study shows that a proper heading technique is important to prevent from sustaining brain injury. Soccer players performing heading should avoid heading the ball at an angle to minimise the probability of sustaining concussion.

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References

1. Levitch CF, Zimmerman ME, Lubin N, Kim N, Lipton RB, Stewart WF, Kim M, Lipton ML (2018) Recent and long-term soccer heading exposure is differentially associated with neuropsychological function in amateur players. J Int Neuropsychol Soc 24:147–155. https://doi.org/10.1017/S1355617717000790
2. Stewart WF, Kim N, Ifrah C, Sliwinski M, Zimmerman ME, Kim M, Lipton RB, Lipton ML (2018) Heading frequency is more strongly related to cognitive performance than unintentional head impacts in amateur soccer players. Front Neurol 9:1–10. https://doi.org/10.3389/fneur.2018.00240
3. Lipton ML, Kim N, Zimmerman ME, Kim M, Stewart WF, Branch CA, Lipton RB (2013) Soccer heading is associated with white matter microstructural and cognitive abnormalities. Radiology 268:850–857. https://doi.org/10.1148/radiol.13130545
4. Rubin TG, Catenaccio E, Fleysher R, Hunter LE, Lubin N, Stewart WF, Kim M, Lipton RB, Lipton ML (2018) MRI-defined white matter microstructural alteration associated with soccer heading is more extensive in women than men. Radiology 289:478–486. https://doi.org/10.1148/radiol.2018180217
5. Wallace C, Smirl JD, Zetterberg H, Blennow K, Bryk K, Burma J, Dierijck J, Wright AD, Van Donkelaar P (2018) Heading in soccer increases serum neurofilament light protein and SCAT3 symptom metrics. BMJ Open Sport Exerc Med 4:433. https://doi.org/10.1136/bmjsem-2018-000433
6. Taha Z, Hassan MHA, Hasanuddin I (2015) Analytical modelling of soccer heading. Sadhana Acad Proc Eng Sci 40:1567–1578. https://doi.org/10.1007/s12046-015-0383-5
7. Hassan MHA, Taha Z (2015) Finite element analysis of soccer heading. Procedia Eng 46–51. https://doi.org/10.1016/j.proeng.2015.07.174
8. Hassan MHA, Taha Z, Hasanuddin I, Mohamed Mokhtarudin MJ (2018) Simulation of soccer heading manoeuvre. In: SpringerBriefs in applied sciences and technology, pp 29–37. https://doi.org/10.1007/978-981-13-0271-8_4
9. Taha Z, Hassan MHA (2017) A reaction-force-validated soccer ball finite element model. Proc Inst Mech Eng Part P J Sport Eng Technol 231:43–49. https://doi.org/10.1177/1754337115626636
10. Price DS, Jones R, Harland AR (2006) Computational modelling of manually stitched soccer balls. Proc Inst Mech Eng Part L J Mater Des Appl 220:259–268. https://doi.org/10.1243/14644207JMDA83
11. Horgan TJ, Gilchrist MD (2003) The creation of three-dimensional finite element models for simulating head impact biomechanics. Int J Crashworthiness 8:353–366. https://doi.org/10.1533/ijcr.2003.0243
12. Kleiven S, von Holst H (2001) Consequences of brain size following impact in prediction of subdural hematoma evaluated with numerical techniques. In: Proceedings of the international conference on the biomechanics of impact (IRCOBI'01), pp 161–172
13. Ruan JS (1994) Impact biomechanics of head injury by mathematical modeling
14. Willinger R, Taleb L, Kopp CM (1995) Modal and temporal analysis of head mathematical models. J Neurotrauma 12:743–754. https://doi.org/10.1089/neu.1995.12.743
15. Zhang L, Yang KH, Dwarampudi R, Omori K, Li T, Chang K, Hardy WN, Khalil TB, King AI (2001) Recent advances in brain injury research: a new human head model development and validation. Stapp Car Crash J. 45:369–394
16. Zhou C, Khalil TB, King AI (1995) A new model comparing impact responses of the homogeneous and inhomogeneous human brain. SAE Trans 104:2999–3015
17. King AI, Yang KH, Zhang L, Hardy W (2003) Is head injury caused by linear or angular acceleration? In: Proceedings of the international research conference on the biomechanics of impacts (IRCOBI), pp 1–12
18. Bunc G, Ravnik J, Velnar T (2017) May heading in soccer result in traumatic brain injury? A review of literature, /pmc/articles/PMC5723188/. https://doi.org/10.5455/medarh.2017.71.356-359

Classification of Sepak Takraw Kicks Using Machine Learning

Fu Yang Tan, Mohd Hasnun Arif Hassan, Anwar P. P. Abdul Majeed, Mohd Azraai Mohd Razman, and Muhammad Amirul Abdullah

Abstract Sepak Takraw has gained popularity over the years. Kinematics of the leg determine the quality and accuracy of the kick. However, the classification of Sepak Takraw kick using machine learning has never been explored. This study aims to classify the most typical kicks in Sepak Takraw namely the serve (or known as tekong), feeder and spike based on the leg's kinematics using machine learning. Collegiate sepak takraw players participated in the data collection. The participants wore the inertial measurement unit sensor on their shank while performing the kicks. From the kinematics data recorded, several mathematical features were extracted and calculated. Machine learning algorithms such as the *k*-nearest neighbors (*k*NN), support vector machine (SVM), artificial neural networks (ANN), naive bayes (NB), random forest (RF), and logistic regression (LR) were applied to classify the types of kicks performed using fivefold cross-validation technique with 70% train data and 30% test data. It was found that ANN predicts all the test data correctly with 100% accuracy, followed by NB, SVM, RF and LR with 1 misclassification at 96.3% accuracy, *k*NN has the lowest prediction accuracy at 77.78%. This study shows that machine learning model is capable of classifying sepak takraw kicks. This can be used in training young athletes to ensure they perform the kicks properly, with correct skills.

Keywords Sepak takraw kicks · Leg's kinematics · Machine learning · Classification

F. Y. Tan · M. H. A. Hassan (✉)
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia
e-mail: mhasnun@ump.edu.my

A. P. P. Abdul Majeed · M. A. Mohd Razman · M. A. Abdullah
Innovative Manufacturing, Mechatronics and Sports Laboratory, Faculty of Manufacturing and Mechatronics Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia

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1 Introduction

Motion analysis studies are conducted to improve athlete's performance and analyze movement deficiencies that may result in injuries [1]. Traditionally, to capture athlete's movement, optoelectronic systems is used where multiple cameras were applied to detect retro-reflective markers in three-dimensional space [2]. However, this method can only be conducted in constrained environments such as in laboratory [3].

Kos et al. [4] detected and classified 3 different types of tennis stroke: serve, backhand and forehand using a miniature wearable IMU device mounted on the forearm of the participants. The IMU device consist of MEMS-based accelerometer and gyroscope with 6 degree of freedom (DOF). Graphical representation was used to classify the three tennis strokes such as by identifying the minimum/maximum value and acceleration curves. Moreover, the point of impact and abrupt changes can be detected by observing the data generated by accelerometer after calculating a simple 2-point derivative of the acceleration curves. The derivative average of the x, y and z-axes of gyroscope was calculated and it was found that the accuracy of tennis stroke classification was 98.1%.

With the advancement of technologies, the size and mass of electronic equipment has been reduced without compromising the reliability of the recorded data. Inertial measurement units (IMU) have been widely used in human movement analysis [5–10] due to its small size, affordable price, portability, light weight (do not alter/interrupt natural movement patterns), non-invasiveness, and can be used in almost any environments [11]. IMU consists of accelerometer, gyroscope, and magnetometer and can be used to determine the kinematics of human body part that is attached to [12].

Shapiee et al. [13] classified 5 different types of skateboarding flat ground tricks consist of Frontside 180, Kickflip, Nollie, Ollie and Shove-it using inertial measurement unit (IMU) and machine learning algorithm such as naive bayes (NB), logistic regression (LR), artificial neural networks (ANN), support vector machine (SVM), random forest (RF) and k-nearest neighbors (KNN). From the data generated by the IMU, a number of mathematical features were extracted and calculated. The result shows the classification accuracy of NB and LR were the highest at 95.0%, secondly were ANN and SVM at 90.0%, followed by RF at 85.0% and finally KNN with the lowest classification accuracy of 75.0%.

The objective of this study is to record the kinematics of player's leg during sepak takraw kicks and formulate a machine learning algorithm to classify these motions. To the best of our knowledge, the motion of sepak takraw kicks has never been analysed and the use of machine learning will allow for classification of different type of kicks in sepak takraw.

2 Methodology

2.1 Device Development

The instrumented wearable device was designed using computer aided design (CAD) software and converted into stereolithography (STL) file format and printed using 3D printer. The material selected for printing is acrylonitrile butadiene styrene (ABS) due to its high tensile strength and resistance to physical impacts as the device will be prone to sepak takraw ball impact (Figs. 1 and 2).

The instrumented wearable device is composed of an Arduino Pro-Mini microcontroller, Bluetooth module (HC-06), IMU unit (MPU6050) which consist of gyro and accelerometer, toggle switch, reset button and 3.7 V lithium polymer (LiPo) battery. The kicks were identified through the acceleration (m/s^2) recorded by the accelerometer and angular velocity (°/s) recorded by the gyroscope. The signals recorded were transferred to a personal computer (PC) via Bluetooth.

A velcro tape was used to mount the device on subject's right shank with the toggle switch pointed up. It is also necessary to ensure the device is attached tightly so the device is stable and not sliding up and down during the data collection process. The positioning of the device on the shank is non-trivial as it will not interrupt the movement of the leg when performing kick other than decrease the possibility of the device being damaged during the experiment.

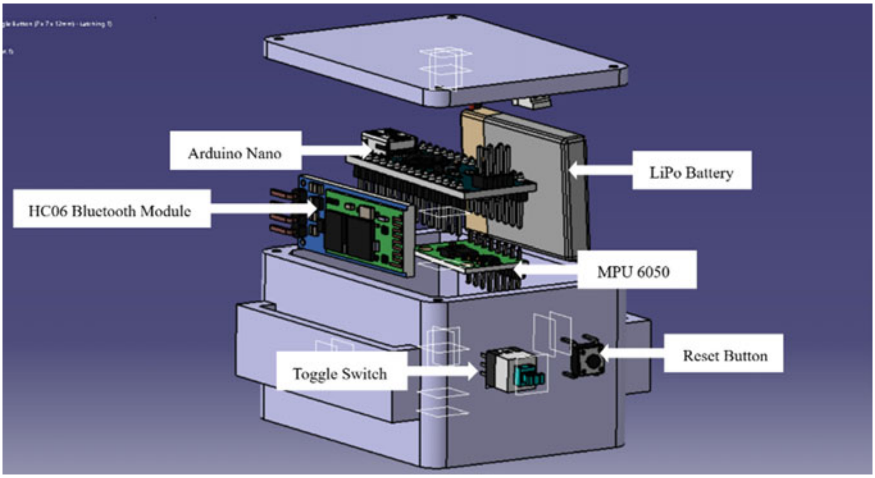


Fig. 1 Exploded view of instrumented wearable device

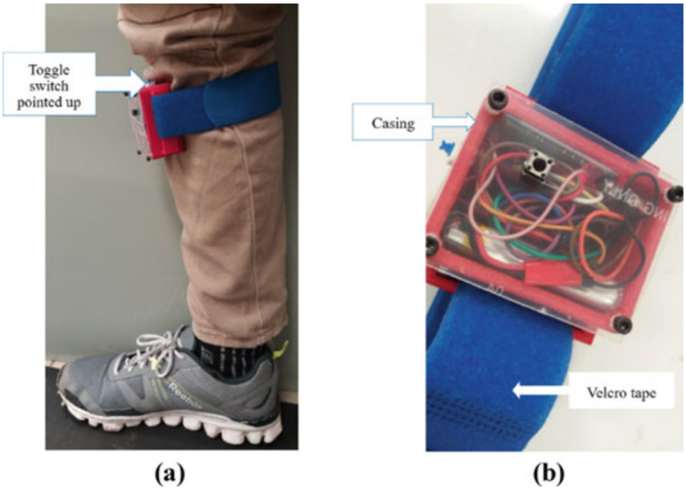


Fig. 2 **a** The attachment of the instrumented wearable device at the shank with the toggle switch pointed up. **b** The 3D printed instrumented wearable device with velcro tape

2.2 Data Collection

Collegiate sepak takraw players comprises of 3 feeders, 3 tekongs, and 3 spikers participated in the experiment with each player was asked to perform 10 kicks. At the time of data collection, all players were free from any injuries. The experiment was conducted at the sepak takraw court inside the campus as shown in Fig. 3. Figures 4, 5 and 6 show the examples of leg's kinematics data recorded by the device.

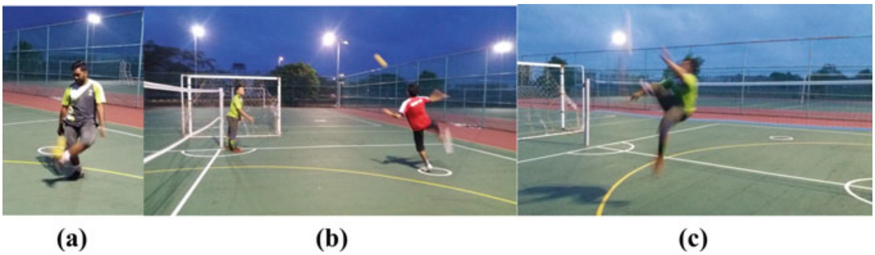


Fig. 3 **a** Sepak Takraw player is performing feeding kick. **b** Sepak Takraw player (in red shirt) is performing serve (tekong) while another player tossing the ball. **c** Sepak Takraw player is performing a spike kick

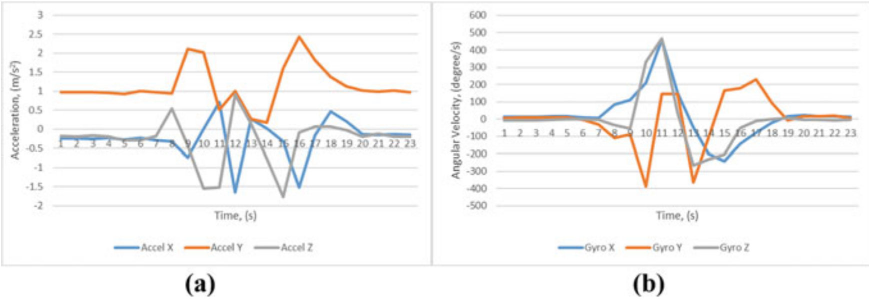


Fig. 4 **a** Accelerations and **b** angular velocities recorded for a feeder kick

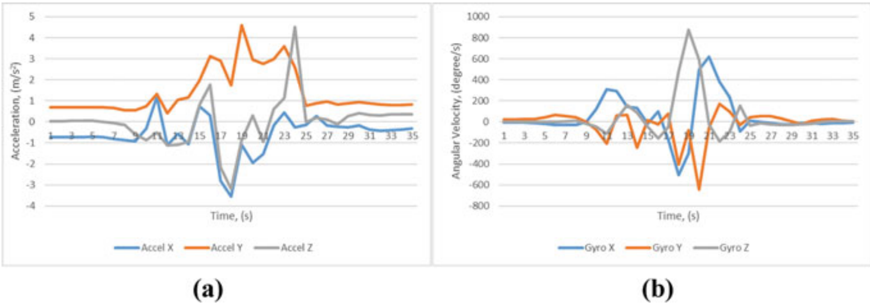


Fig. 5 **a** Accelerations and **b** angular velocities recorded for a serve (tekong) kick

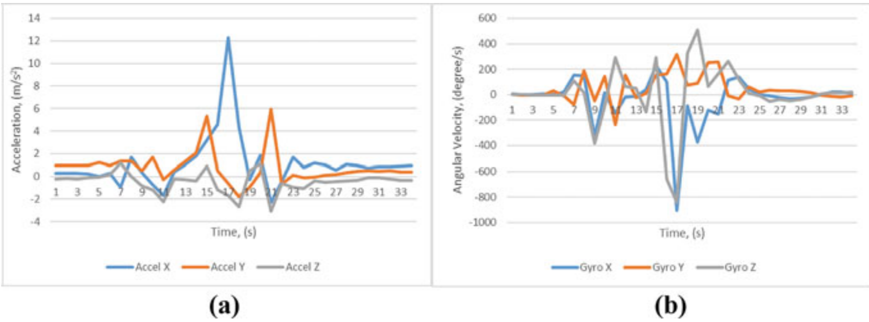


Fig. 6 **a** Accelerations and **b** angular velocities recorded for a spike kick

2.3 Machine Learning

The data extracted from the sensor were then processed in Microsoft Excel to calculate the mathematical features consist of 6 times domain features: mean, median, standard deviation, maximum value, minimum value, variance, correlation, and 2 frequency domain features: kurtosis and skewness [14]. These mathematical features were calculated for both linear accelerations in x, y, and z-axes as well as the angular velocities in all three axes. Orange Data Mining software (V3.11) was used to perform the classification using the extracted data.

In this study, supervised learning technique was used because the data was tagged, and the algorithms learns to determine the result of the input data. There are 6 supervised Machine Learning algorithms used in the classification: k-Nearest Neighbors (KNN), Support Vector Machine (SVM), Artificial Neural Networks (ANN), Naïve Bayes (NB), Random Forest (RF) and Logistic Regression (LR) [13]. The algorithms used are taken originally from the Orange data mining software. The performance of the algorithms was determined based on area under the curve (AUC), classification accuracy (CA), F1-score, precision, and recall. Thus, fivefold cross-validation was applied ($k = 5$) where the data set is split into five folds. In the first iteration, the first fold 63 data (70% from all the data) were used to test the model and the remaining 27 data (30% from all the data) were used to train the model. In the second iteration, second fold is used as the testing set while the rest serve as the training set. This process was repeated until each fold of the five folds have been used as the testing set.

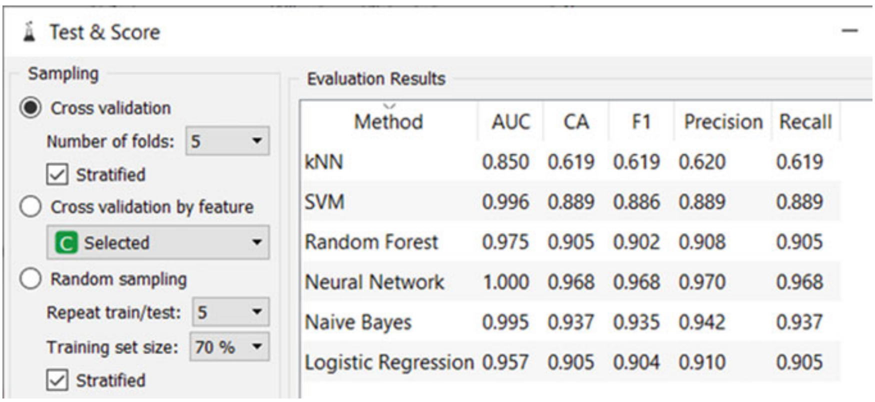
3 Result and Discussion

A total number of 90 kicks were performed by the sepak takraw players (consist of 30 feeders, 30 serves, and 30 spikes). From the recorded data, 9 mathematical features were extracted. The features that were finally used upon taking into consideration of the sensitivity test via the information gain are all the six original data generated by sensor (linear acceleration X, Y, Z and angular velocities in gyro X, Y, Z) as well as the mathematical algorithms (mean, median, standard deviation, kurtosis, maximum value, minimum value, variance, correlation, and skewness).

The result generated from 63 training data, shows the value of CA and recall is exactly the same, with ANN algorithm yielded the highest CA and recall at 96.8% follow by NB algorithm at 93.7%. RF and LR algorithm both have the same value of CA and recall at 90.5%, while KNN algorithm yielded the lowest 61.9%, SVM algorithm obtained second lowest CA and recall at 88.9%. The precision of ANN algorithm is the highest at 97%, follow by NB 94.2% and LR at 91%. KNN algorithm recorded the lowest precision at 62%, and SVM algorithm second lowest at 89% while RF algorithm at 90.2%. ANN algorithm recorded the highest F1-score at 96.8%, follow by NB algorithm second highest at 93.5%. RF and LR algorithm both recorded similar F1-score at 90.2% and 90.4%. The F1-score of KNN algorithm is also the lowest at 61.9%, while SVM algorithm is second lowest at 88.6%. Finally, for the value of AUC, ANN algorithm yielded the highest at 100%, followed by SVM algorithm at 99.6% while NB algorithm at 99.5%. KNN algorithm yielded the lowest AUC at 85%, LR algorithm recorded the second lowest at 95.7%, while RF algorithm at 97.5%.

Further investigation on the confusion matrix found out the misclassification of ANN algorithm (highlighted in pink) is the lowest came from the 2 serves were misclassified as 1 feeder and 1 spike. In the meanwhile, NB algorithm also misclassified 4 serves as 2 feeders and 2 spikes. Whilst RF and LR algorithm both recorded a total number of 6 misclassification. Misclassification of RF algorithm came from the 5 serves were misclassified as 3 feeders and 2 spikes while 1 feeder was misclassified as serve. In the meantime, LR algorithm misclassified 1 feeder as serve, 1 spike as feeder and 4 serves as 3 feeders, 1 spike. There are 7 recorded misclassifications of SVM algorithm, with 2 spikes were misclassified as serve and 5 serves were misclassified as 2 feeders and 3 spikes. KNN algorithm recorded the most misclassification with 24 in total, where 7 feeders were misclassified as serves, 5 spikes were misclassified as serves and 12 serves were misclassified as 5 feeders, 7 spikes.

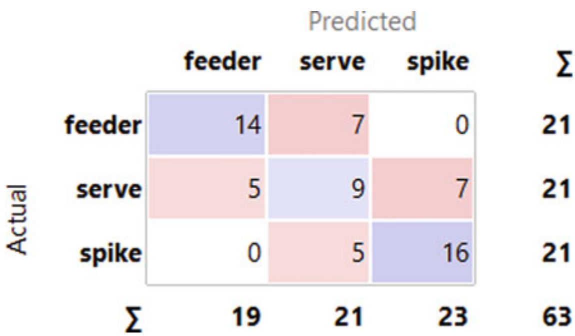
It could be concluded from this method proposed in this study by combining several selected mathematical features and 6 different machine learning algorithms produced a high classification accuracy in identifying the performed sepak takraw kicks (Figs. 7, 8, 9, 10, 11, 12 and 13).



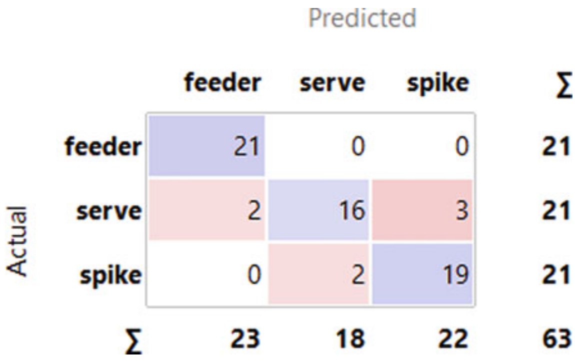
Method	AUC	CA	F1	Precision	Recall
kNN	0.850	0.619	0.619	0.620	0.619
SVM	0.996	0.889	0.886	0.889	0.889
Random Forest	0.975	0.905	0.902	0.908	0.905
Neural Network	1.000	0.968	0.968	0.970	0.968
Naive Bayes	0.995	0.937	0.935	0.942	0.937
Logistic Regression	0.957	0.905	0.904	0.910	0.905

Fig. 7 Evaluation of the developed classifiers

Fig. 8 Confusion matrix of the k-nearest neighbor algorithm

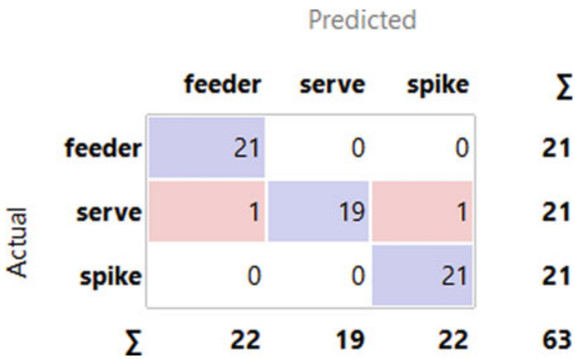


	feeder	serve	spike	Σ
feeder	14	7	0	21
serve	5	9	7	21
spike	0	5	16	21
Σ	19	21	23	63



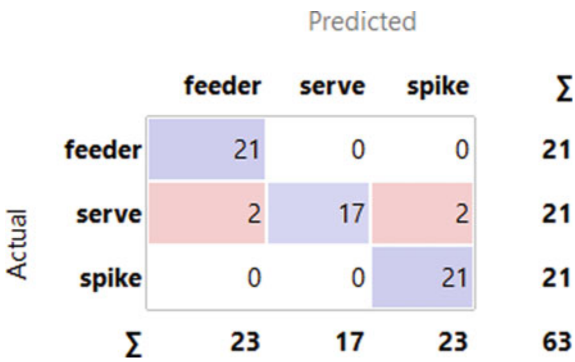
Actual \ Predicted	feeder	serve	spike	Σ
feeder	21	0	0	21
serve	2	16	3	21
spike	0	2	19	21
Σ	23	18	22	63

Fig. 9 Confusion matrix of the support vector machine algorithm



Actual \ Predicted	feeder	serve	spike	Σ
feeder	21	0	0	21
serve	1	19	1	21
spike	0	0	21	21
Σ	22	19	22	63

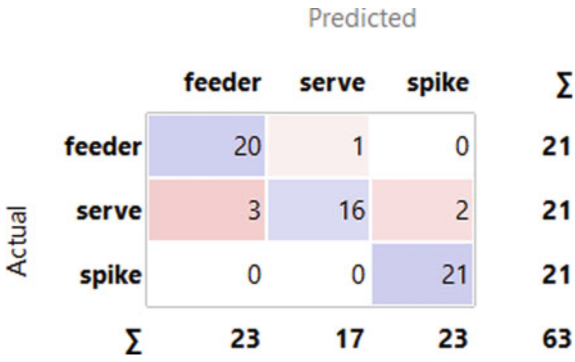
Fig. 10 Confusion matrix of the artificial neural network algorithm



Actual \ Predicted	feeder	serve	spike	Σ
feeder	21	0	0	21
serve	2	17	2	21
spike	0	0	21	21
Σ	23	17	23	63

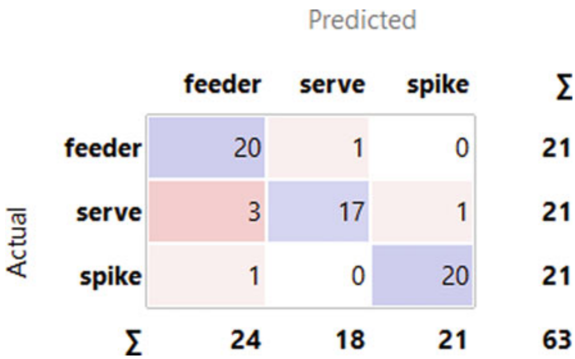
Fig. 11 Confusion matrix of the Naive Bayes algorithm

Meanwhile, for the predictions of testing data, ANN algorithm predicts all the 27 kicks correctly with 100% accuracy. NB, SVM, RF and LR algorithm each recorded 1 misclassification from 27 test data with NB misclassified 1 feeder as serve, SVM misclassified 1 serve as spike, RF misclassified 1 feeder as serve, and LR misclassified 1 spike as serve.



Actual \ Predicted	feeder	serve	spike	Σ
feeder	20	1	0	21
serve	3	16	2	21
spike	0	0	21	21
Σ	23	17	23	63

Fig. 12 Confusion matrix of the random forest algorithm



Actual \ Predicted	feeder	serve	spike	Σ
feeder	20	1	0	21
serve	3	17	1	21
spike	1	0	20	21
Σ	24	18	21	63

Fig. 13 Confusion matrix of the logistic regression algorithm

NN algorithm had the highest misclassification with total number of 6 which came from 2 feeders were misclassified as serves, 3 serves were misclassified as 1 feeder and 2 spikes while 1 spike was misclassified as serve (Fig. 14).

4 Conclusion

In this study, an offline sepak takraw identifying method was created. This was presented from the experiment that the selection of the features is non-trivial in producing a high classification accuracy of the evaluated sepak takraw kicks. The results showed ANN algorithm yielded the highest accuracy at 100%, follow by NB, SVM, RF and LR algorithm with 1 misclassification at 96.3% accuracy, while kNN algorithm had the 6 misclassification with lowest accuracy at 77.78%. This shows the results further suggest the reliability of the proposed method in providing an objective based judgement on sepak takraw kicks. The reason why ANN algorithm yielded the highest accuracy due to its intention to simulate the behavior of biological systems composed of “neurons”. ANNs are computational models inspired by central nervous systems. It is capable of machine learning as well as pattern recognition.

Fig. 14 The predictions for 27 testing data

Future work will be looking into classification of the quality of the kicks of different level of athletes including the use of more test subjects, more mathematical features, and peforming hyperparameter optimisation on different machine learning algorithms. This will help the coaches in providing a more accurate evaluation of kick performance as opposed to the subjective and conventional techniques currently applied in sepak takraw.

References

1. Bartlett R (2007) Abstracts of the 55th annual scientific session of the Japanese College of Cardiology, Maihama, Japan, September 10–12, 2007. J Cardiol 50(Suppl):1
2. Vergara-Jimenez M, Missimer A, Diana MD, Catherine JAAGM, Fernandez ML (2015) Evaluation of family history, antioxidant intake and activity level as indicators for chronic disease in a healthy young population. EC Nutr 1(4):164–173. https://doi.org/10.1044/2014
3. Menolotto M, Komaris DS, Tedesco S, O'flynn B, Walsh M (2020) Motion capture technology in industrial applications: a systematic review. Sens (Switzerland) 20(19):1–25. https://doi.org/10.3390/s20195687
4. Kos M, Ženko J, Vlaj D, Kramberger I (2016) Tennis stroke detection and classification using miniature wearable IMU device. In: International conference on systems, signals, and image processing, pp 16–19. https://doi.org/10.1109/IWSSIP.2016.750276
5. Gjoreski H, Luštrek M, Gams M (2011) Accelerometer placement for posture recognition and fall detection. In: Proceedings—2011 7th international conference on intelligent environments, IE 2011, pp 47–54. https://doi.org/10.1109/IE.2011.11
6. Yang CC, Hsu YL (2010) A review of accelerometry-based wearable motion detectors for physical activity monitoring. Sensors 10(8):7772–7788. https://doi.org/10.3390/s100807772
7. Preece SJ, Goulermas JY, Kenney LPJ, Howard D, Meijer K, Crompton R (2009) Activity identification using body-mounted sensors—a review of classification techniques. Physiol Measure 30(4). https://doi.org/10.1088/0967-3334/30/4/R01

8. Godfrey A, Conway R, Meagher D, ÓLaighin G (2008) Direct measurement of human movement by accelerometry. Med Eng Phys 30(10):1364–1386. https://doi.org/10.1016/j.medengphy.2008.09.005
9. Taraldsen K, Chastin SFM, Riphagen II, Vereijken B, Helbostad JL (2012) Physical activity monitoring by use of accelerometer-based body-worn sensors in older adults: a systematic literature review of current knowledge and applications. Maturitas 71(1):13–19. https://doi.org/10.1016/j.maturitas.2011.11.003
10. Mannini A, Sabatini AM (2010) Machine learning methods for classifying human physical activity from on-body accelerometers. Sensors 10(2):1154–1175. https://doi.org/10.3390/s100201154
11. Engenharia ED (2017) Nuno Miguel Ferrete Ribeiro IMUs—validation, gait analysis and system's implementation
12. McManamon P (2015) Inertial measurement units. Field Guide to Lidar. https://doi.org/10.1117/3.2186106.ch115
13. Shapiee MNA, Ibrahim MAR, Mohd Razman MA, Abdullah MA, Musa RM, Hassan MHA, Abdul Majeed APP (2020) The classification of skateboarding trick manoeuvres through the integration of image processing techniques and machine learning. In: Lecture notes in electrical engineering, vol 632. Springer, Singapore. https://doi.org/10.1007/978-981-15-2317-5_29
14. Takata M, Nakamura Y, Torigoe Y, Fujimoto M, Arakawa Y, Yasumoto K (2019) Strikes-Thrusts activity recognition using wrist sensor towards pervasive kendo support system. In: 2019 IEEE international conference on pervasive computing and communications workshops, PerCom Workshops 2019, pp 243–248. https://doi.org/10.1109/PERCOMW.2019.8730861

Preliminary Study on Drivers Satisfaction and Continuance Intention to Use Automatic Emergency Braking in Malaysia

Nuruzzakiyah Mohd Ishanuddin, Nur Ezzati Rusli, Ezrin Hani Sukadarin, Hanida Abdul Aziz, Mirta Widia, Nur Syafiqah Fauzan, Junaidah Zakaria, Hairunnisa Osman, Ahmad Azad Ab. Rashid, Zulhaidi Mohd Jawi, Nur Syazwani Mohd Nawi, Eida Nadirah Roslin, and Yassierli

Abstract The automobile industry has been one of the most open industries to new technologies throughout history. Due to evolvement of technology, automated driving systems has been introduced. This has also influenced the whole spectrum of human driver operation in newer cars. Even so, the issue remains as to whether or not customers can consider emerging technologies. In this study, one of the prominent vehicle technology is focused. It is the Automatic Emergency Braking (AEB). Recently, carmakers are competing with each other to produce the AEB that is efficient. Since 2015, consumers in Malaysia started to get the opportunity to buy AEB equipped vehicles. So, it is important to understand how vehicle customers or potential customers choose to use or not to use AEB and what they expect or understand about AEB. This study aims to explore consumer's expectation, experiences, and outcome of technology continuance intention to use. A sum of 204 respondents were gathered via online survey. Data collected were then analysed by using Statistical Package for Social Science (SPSS) version 26. Results show that out of 204 respondents, only 70 people has experienced the function of AEB. 89.7% of respondents

N. Mohd Ishanuddin · N. E. Rusli · E. H. Sukadarin (✉) · H. Abdul Aziz · M. Widia · N. S. Fauzan · J. Zakaria · H. Osman
Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang, Malaysia
e-mail: ezrin@ump.edu.my

A. A. Ab. Rashid · Z. Mohd Jawi
Malaysian Institute of Road Safety Research (MIROS), Kajang, Malaysia

N. S. Mohd Nawi
Technology Management and Logistics, UUM College of Business, Changlun, Malaysia

E. N. Roslin
Universiti Kuala Lumpur Kampus Cawangan Malaysia France Institute, Bandar Baru Bangi, Malaysia

Yassierli
Faculty of Industrial Technology, Institut Teknologi Bandung (ITB), Bandung, Indonesia

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have high expectations of AEB functionality while driving and 21.6% of them would still using the AEB feature even if they do not favour it.

Keywords Automatic emergency braking · Drivers' satisfaction · Continuance intention to use

1 Introduction

During the early years of the last century, an automobile was seen as a common item of luxury. Nevertheless, the amount of technology and human energy being implemented by the vehicle industry to produce high-quality vehicles is evident in the present days, but still affordable for the average person. It can be clearly seen that automobiles had evolved throughout the years and equipped with various advanced technologies that not limited to luxury cars only. From only cruise controls units, power windows and remote lock-unlock devices in the vehicles, now these vehicles are equipped with navigation systems, voice-command operating systems, adaptive cruise control systems as well as automated parking control systems [1].

Researchers are designing autonomous vehicles (AVs) and transport authorities in many countries enact inter-vehicle communications to improve safety. For example, the United States Department of Transportation initiated the Connected Vehicle development project, collaborating with automakers and research universities to provide more automobile communication and technology [2]. In addition, automakers are equipping vehicle dashboards with more equipment, while regulators such as the National Highway Traffic Safety Administration (NHTSA) are moving towards new regulations restricting automotive technology, citing safety reasons [3].

AVs are expected to have significant impacts on potential transportation systems and have drawn broad attention in the development [4]. However, AVs or self-driving cars are not used widely anywhere except in a few countries as a taxi that is still not completely used. Yet advanced technology like Advanced Driver Assistance Systems (ADAS) is a safer way for drivers to drive carefully with an automated system that can help identify different adverse situations and warn the driver in good time. This technology is a kind of additional function that is trained on the basis of AI and machine learning concepts to make driving experience smooth and trouble-free [5]. Among vital safety critical ADAS applications includes automatic emergency braking (AEB), pedestrian detection, lane departure warning, traffic sign recognition and blind spot detection [6].

Advances in electronics and sensor technology have resulted in the creation of a number of ADAS and Crash Avoidance Systems (CAS) in today's vehicles. Such electronic technologies, combined with the mechanical systems of the vehicle, can provide automatic control of the movement of the vehicle. According to NHTSA, there are five eras of vehicle safety which includes safety features (1950–2000), advanced safety features (2000–2010), advanced driver assistance features (2010–2016), partially automated safety features (2016–2025) and fully automated safety features (2025–). Some of the first popular driver assistance systems introduced in the early 1970s was Anti-Lock Brakes (ABS), followed by Electronic Stability Control (ESC) in the late 1980s and early 1990s. The advent of more sophisticated sensors and faster computers has enabled engineers to extend the scope of ADAS and CAS systems, providing visual, auditory and tactile feedback to the driver along with automated vehicle braking, powertrain and chassis control systems, as well as the steering system. The restricted or partially allowed use of AEB in production vehicles began to appear in some 2003 models, but the widespread use of AEB did not emerge until 2010 and later. This research investigates the driver's satisfaction and continuance intention to use AEB using 10 developed constructs.

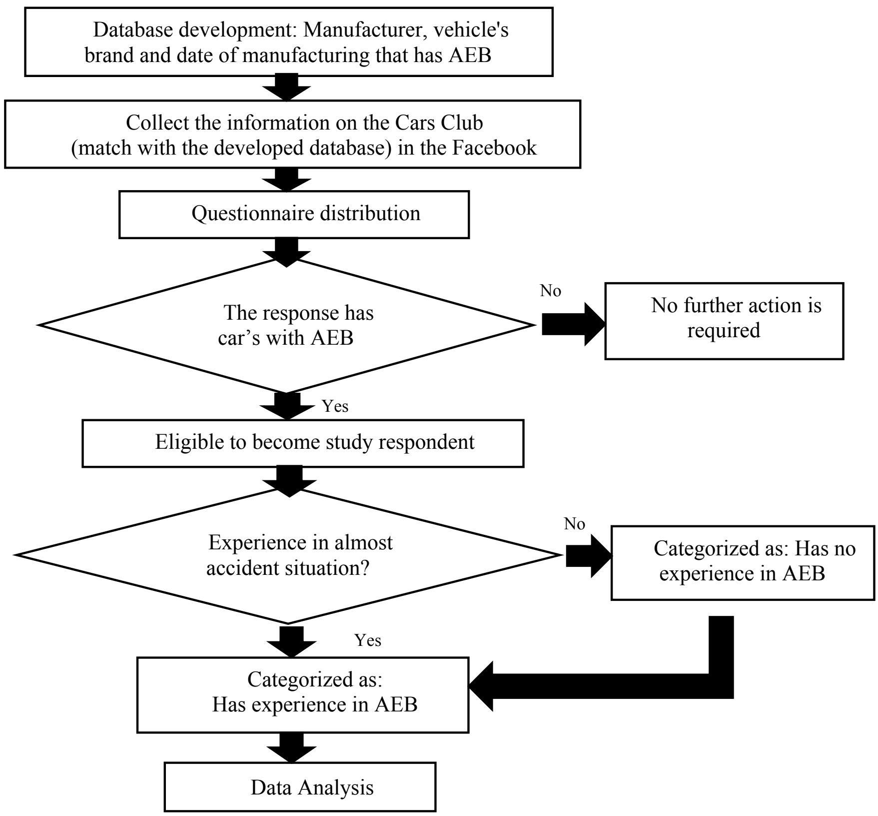

Fig. 1 Framework of study methodology

2 Methodology

Figure 1 shows the study methodology framework. Because of this study is to explore the drivers' perception regarding the satisfaction and continuance to use the AEB, drivers who have the experiences need to be searched. The purposive sampling strategy is adopted to ensure drivers with the AEB related experiences participate in this study. However, considering only for those who are having the AEB equipped vehicles is not enough to confirm, he or she is experienced in AEB, but the researchers also need to ensure that the participated respondents are experienced with experience in almost accident situation, and if the answer is "YES", it is indicate that, he or she is really has experience in AEB as the AEB system on will be activated, if the mentioned situation happen.

2.1 Sample and Procedures

This study's questionnaires are designed to examine the experience, satisfaction, and continuance intention to use of the AEB system of Malaysian drivers. The questionnaires are then distributed to the respondent which are selected group of cars' owner via the online platform. The questionnaires are translated into Malay to fit the respondents' first language. There are several selected car manufacturers to be included in this study which are Proton, Perodua, Honda, Hyundai, Toyota, and Nissan.

2.2 Instrument

In the study, multiple self-administered questionnaires were applied, tweaked and rephrased to suit the study's objectives. All the items were adapted and adopted from the Social Exchange Theory (SET) and the Expectation Confirmation Model (ECM). In the first step, domain determination, sampling (item making) and instrument formation. Meanwhile, the second step is the content validity ratio, content validity index and altered kappa statistics to be performed. Expert panel recommendations and item impact scores will be used to check the face validity of the instrument. Then, the questionnaires were made on Google Form and distributed on Facebook group that was joined. This questionnaire consists of two parts. In Part A, demographic information of respondents was gathered for better comprehension of the study. Meanwhile in Part B, there are about 10 constructs consist of 84 items (see Appendix in this chapter, for the complete constructs and items). Researchers applied 7-point Likert scale format which ranging from (1) strongly disagree; (2) disagree; (3) slightly disagree; (4) neutral; (5) slightly agree; (6) agree; and lastly, (7) strongly agree.

2.3 Data Analysis

Data obtained were analysed by SPSS version 26, and the responses that does not meet the requirements are excluded from the study. Descriptive statistics were initially performed to identify the characteristic of respondents. Then, the reliability test was conducted for pilot test and real data collection. The Cronbach's alpha value of 0.70 or higher is deemed acceptable and the elements analysed are compared with another element in each category [7]. In this analysis, the output of Cronbach's alpha for all ten constructs was well above 0.70. Therefore, this indicated that the measurement scales used for construct measurement were precise and reliable, so the constructs' reliability was confirmed.

3 Result and Discussions

3.1 Demographic Data

A total of 204 respondents were included in the final analysis. The respondents' socio-demographic includes 11 items which are gender, age, state, marital status, educational levels, years of working, car model, year of production, driving experience, level of satisfaction of current car and experience with AEB. Table 1 shows the respondents' profile.

From 204 respondents, 77.9% are male, while female is only 22.1%. Majority of these respondents are range between 36 and 45 years old (37.3%). This survey was distributed to Malaysian and most of the respondents are residing in Peninsular Malaysia. In terms of marital status, 78.4% of respondents are married while the remaining 21.6% are single. As for educational levels, 66 people (32.4%) have Certificate, 47 people (23.0%) have Diploma, 66 people (32.4%) have Bachelor's Degree, 16 people (7.8%) have Master, and 9 people (4.4%) have Ph.D. Based on data recorded, the majority of respondents have been working for 11 years and above (67.2%) as seen in Table 1. This group was more likely to have the spending power to purchase a new vehicle. Moreover, from 204 respondents, 38.7% of them have driving experience for more than 20 years.

In terms of satisfaction of the current car, 91.9% of respondents have a high level of satisfaction with the current car they are using. Among type of cars used by these respondents are Proton: Proton X70 (Premium and Premium X) and Proton X50 Flagship; Perodua: Perodua Axia Advance 2020, Perodua Aruz 2019 Advance, Perodua Myvi 1.3X 2020, Perodua Myvi 1.5 H 2020 and Perodua Myvi 1.5 Advance 2020; Honda: Honda Civic 2020 TC-P, Honda Accord 2020 TC-P and Honda CR-V 2016 TC-P; Hyundai Ioniq, Nissan; X-trail, Almera, Grand Livina, and, Toyota; Wish, C-HR, and Avanza. Statically, most respondents who are satisfied with their vehicles are using vehicles produced in 2015 and above. Lastly, it is found that, about

Table 1 Respondents' profile (Number of respondents = 204)

Variables	Level	Frequency	Percentage (%)
Gender	Male	159	77.9
	Female	45	22.1
Age	17–25 years old	24	11.8
	26–35 years old	61	29.9
	36–45 years old	76	37.3
	46–65 years old	43	21.1
State	Johor	5	2.5
	Kedah	20	9.8
	Kelantan	9	4.4
	Melaka	7	3.4
	Negeri Sembilan	6	2.9
	Pahang	9	4.4
	Perak	71	34.8
	Perlis	1	0.5
	Pulau Pinang	6	2.9
	Sabah	5	2.5
	Sarawak	3	1.5
	Selangor	41	20.1
	Terengganu	9	4.4
	Wilayah Persekutuan Kuala Lumpur	9	4.4
	Wilayah Persekutuan Putrajaya	3	1.5
Marital status	Married	160	78.4
	Single	44	21.6
Educational levels	Certificate	66	32.4
	Diploma	47	23.0
	Bachelor's degree	66	32.4
	Master	16	7.8
	Ph.D.	9	4.4
Years of working	0–5 years	34	16.7
	6–10 years	33	16.2
	11 years and above	137	67.2
Driving experience	1–5 years	25	12.3
	6–10 years	28	13.7
	11–15 years	33	16.2
	16–20 years	39	19.1

(continued)

Table 1 (continued)

Variables	Level	Frequency	Percentage (%)
	20 years and above	79	38.7
Level of satisfaction of current car	Very dissatisfied	1	0.5
	Dissatisfied	2	1.0
	Neutral	15	7.4
	Satisfied	78	38.2
	Very satisfied	108	52.9
Experience with AEB	No	134	65.7
	Yes	70	34.3

70 respondents have engagement (experienced) with the AEB system fitted in their car.

3.2 *Construct 1: Customer Trust*

This construct consists of 12 items which function to investigate respondents' trust towards AEB-equipped vehicles. By referring to Table 2, each scoring is presented by separating the respondent that having experience with AEB as indicated as "w"

Table 2 Percentage for customer trust (CT) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
CT1	2.9	0.7	0.0	0.0	2.9	0.7	4.3	17.9	22.9	27.6	44.3	34.3	22.9	18.7
CT2	0.0	0.0	0.0	0.0	0.0	0.7	4.3	7.5	10.0	25.4	34.3	31.3	51.4	35.1
CT3	0.0	0.0	0.0	1.5	1.4	3.0	4.3	8.2	18.6	31.3	37.1	32.1	38.6	23.9
CT4	0.0	0.0	0.0	0.0	4.3	3.7	1.4	9.0	14.3	26.9	44.3	38.1	35.7	22.4
CT5	0.0	0.0	0.0	0.0	0.0	2.2	2.9	9.7	17.1	21.6	41.4	38.1	38.6	28.4
CT6	4.3	5.2	15.7	9.0	10.0	11.2	14.3	28.4	27.1	20.9	17.1	17.2	11.4	8.2
CT7	0.0	0.0	1.4	1.5	1.4	3.0	7.1	12.7	25.7	34.3	40.0	38.1	24.3	10.4
CT8	0.0	0.0	0.0	0.7	1.4	0.7	2.9	11.2	18.6	27.6	35.7	36.6	41.4	23.1
CT9	1.4	0.0	0.0	0.0	0.0	0.0	11.4	14.2	28.6	26.1	30.0	41.0	28.6	18.7
CT10	4.3	3.0	7.1	1.5	7.1	6.7	15.7	20.1	22.9	24.6	31.4	29.9	11.4	14.2
CT11	0.0	0.7	0.0	0.0	0.0	2.2	7.1	12.7	25.7	29.9	45.7	38.8	20.0	15.7
CT12	0.0	0.0	0.0	3.0	2.9	2.2	5.7	11.2	25.7	27.6	47.1	41.0	18.6	14.9

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

and not having AEB as tells with “w/o”. Both group of respondents basically agree with the ‘claimed’ AEB capability. Majority of the group “w” respondents agreed that “(CT2) cars equipped with AEB have my best interest in mind” with the score of strongly agree is 51.4%, agree = 34.4% and agree = 10%. The group of “w/o” also recorded the highest percentage of strongly agree for the same item. Item CT4 is about “Cars equipped with AEB are functioning very well to prevent any crashes from happening”, It was found that 44.3% of group “w” agree with that item, and 35.7% of them is strongly agree. It shows an excellent indicator to support why most of the group “w” respondents agree with the item which mentioned AEB is reliable (CT11) and AEB seem dependable (CT12).

3.3 Construct 2: Customer Expectation

This construct consists of 6 items which prepared to investigate respondents’ expectation towards AEB-equipped vehicles. By referring to Table 3, each scoring is presented by separating the respondent that having experience with AEB as indicated as “w” and not having AEB as tells with “w/o”. From the results it shows that, majority of “w” respondents (25.7% strongly agree, 45.7% agree and 20% slightly agree), with the item CE 5 (The AEB effectiveness to prevent impending forward crashes fits my expectation). Same goes to the responses for item CE4 (The AEB functionality when driving fits my expectation) is basically agreed by the experienced respondents. However, there is a low number of percentage both both group of respondents answered disagree with the item CE3 which mentioned about “things could go wrong (AEB error) when driving using AEB”.

Table 3 Percentage for customer expectation (CE) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
CE1	0.0	0.0	0.0	1.5	0.0	2.2	4.3	9.7	24.3	28.4	47.1	40.3	24.3	17.9
CE2	0.0	0.7	0.0	0.0	0.0	0.0	7.1	13.4	30.0	27.6	35.7	42.5	27.1	15.7
CE3	4.3	2.2	7.1	4.5	8.6	9.0	17.1	27.6	27.1	31.3	24.3	16.4	11.4	9.0
CE4	0.0	0.0	0.0	0.0	0.0	3.0	8.6	23.1	28.6	23.9	44.3	38.8	18.6	11.2
CE5	0.0	0.0	0.0	0.0	0.0	0.7	8.6	17.9	20.0	27.6	45.7	38.8	25.7	14.9
CE6	0.0	0.7	0.0	1.5	0.0	2.2	17.1	26.1	15.7	29.1	35.7	26.1	31.4	14.2

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

Table 4 Percentage for confirmation (C) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
C1	0.0	1.5	0.0	0.0	2.9	3.0	7.1	22.4	11.4	29.1	48.6	26.9	30.0	17.2
C2	0.0	1.5	0.0	0.0	1.4	1.5	11.4	20.1	15.7	34.3	47.1	26.9	24.3	15.7
C3	0.0	1.5	0.0	0.0	1.4	2.2	2.9	13.4	14.3	29.9	51.4	32.8	30.0	20.1
C4	0.0	1.5	0.0	0.7	1.4	2.2	7.1	17.9	15.7	26.1	48.6	32.8	27.1	18.7
C5	17.1	11.2	27.1	15.7	20.0	17.9	8.6	19.4	10.0	14.9	14.3	13.4	2.9	7.5
C6	0.0	0.7	1.4	0.0	0.0	2.2	7.1	14.9	14.3	27.6	48.6	33.6	28.6	20.9
C7	0.0	0.7	0.0	0.0	1.4	1.5	7.1	14.9	14.3	29.9	41.4	30.6	35.7	22.4

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

3.4 Construct 3: Confirmation

There is a total of 7 items in this construct to investigate the confirmation of expectations among two group of respondents (w: have experience with AEB; w/o: no experience with AEB). Table 4 shows the results obtained the construct. The highest percentage of both group for strongly agree (“w” = 35.7%, “w/o” = 22.4%) is for the item C7 (The AEB equipped car fits my needs.) and followed by C3 (Overall, most of my expectations in using AEB are confirmed.) with the percentage of strongly agree for both group are 30% for “w” and 20.1% for “w/o”. Based on the results, the columns of disagreement is filled by the percentage consistently for the item C5. The C5 is the item for investigating whether or not the AEB is out from the expectation. Looking at the number of disagreement percentage of that items confirms that AEB meets the user expectation.

3.5 Construct 4: Satisfaction

Construct 4 explores respondents’ satisfaction, and it consists of 8 items (as presented in Table 5). Each scoring is presented by separating the respondent that having experience with AEB as indicated as “w” and not having AEB as tells with “w/o”. Item S3 (Overall, I am satisfied with AEB), recorded high percentage of agreement for both group of respondents, although as can be seen that the “w/o” group is recorded higher (strongly agree 34.3% for “w/o” compared to 17.9% for “w” group.; for the agree score, 50% from “w/o” group and 30.6% from “w” group. From the finding in the Table 5, most of the respondents are satisfy with the AEB overall experience (item S2), satisfy with the feeling of enjoyment (item S6) and fun interaction (item S7).

Table 5 Percentage for satisfaction (S) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
S1	0.0	0.0	0.0	0.7	2.9	0.7	5.7	17.9	15.7	30.6	34.3	50.0	15.7	25.7
S2	0.0	0.7	0.0	0.7	1.4	0.0	8.6	20.1	11.4	28.4	34.3	48.6	15.7	27.1
S3	0.0	0.7	0.0	0.7	1.4	0.7	7.1	16.4	7.1	32.8	30.6	50.0	17.9	34.3
S4	0.0	1.5	0.0	0.7	1.4	0.0	5.7	20.9	10.0	27.6	30.6	48.6	18.7	34.3
S5	0.0	1.5	1.4	0.0	0.0	1.5	5.7	17.2	10.0	33.6	29.1	45.7	17.2	37.1
S6	0.0	3.0	1.4	0.0	1.4	1.5	10.0	20.1	21.4	28.4	29.1	37.1	17.9	28.6
S7	0.0	2.2	1.4	0.7	1.4	1.5	14.3	19.4	20.0	28.4	26.9	37.1	20.9	25.7
S8	1.4	1.5	1.4	0.7	1.4	0.7	14.3	23.1	20.0	26.1	29.1	40.0	18.7	21.4

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

3.6 Construct 5: Perceived Performance

Table 6 shows the construct 5 which explores respondents perceived performance and it consists of 13 items. Each scoring is presented by separating the respondent that

Table 6 Percentage for perceived performance (PP) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
PP1	0.0	0.7	0.0	0.7	1.4	1.5	4.3	8.2	8.6	23.1	37.1	37.3	47.1	28.4
PP2	4.3	3.7	14.3	6.0	7.1	7.5	18.6	19.4	17.1	31.3	21.4	19.4	15.7	12.7
PP3	1.4	3.7	2.9	2.2	4.3	6.0	17.1	17.9	14.3	25.4	38.6	29.1	21.4	15.7
PP4	0.0	2.2	0.0	0.7	2.9	1.5	15.7	17.2	14.3	26.1	44.3	34.3	22.9	17.9
PP5	0.0	0.7	0.0	0.0	1.4	0.7	5.7	14.9	5.7	22.4	40.0	34.3	47.1	26.9
PP6	1.4	0.7	1.4	1.5	0.0	1.5	11.4	17.9	10.0	26.9	40.0	28.4	35.7	23.1
PP7	0.0	0.7	0.0	0.0	1.4	1.5	1.4	14.2	20.0	24.6	38.6	35.1	38.6	23.9
PP8	8.6	9.0	11.4	6.7	11.4	9.0	20.0	24.6	17.1	16.4	17.1	23.1	14.3	11.2
PP9	17.1	11.2	17.1	9.7	15.7	17.2	12.9	22.4	11.4	15.7	17.1	16.4	8.6	7.5
PP10	0.0	1.5	0.0	0.7	2.9	0.0	8.6	22.4	21.4	26.1	41.4	35.1	25.7	14.2
PP11	0.0	1.5	1.4	0.0	0.0	0.0	5.7	20.1	18.6	23.1	44.3	41.8	28.6	13.4
PP12	0.0	1.5	0.0	0.0	1.4	0.0	4.3	16.4	14.3	26.9	45.7	40.3	34.3	14.9
PP13	0.0	1.5	0.0	0.0	1.4	0.7	10.0	19.4	17.1	28.4	44.3	32.8	27.1	17.2

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

having experience with AEB as indicated as "w" and not having AEB as tells with "w/o". Majority for both group respondents strongly agree with the item PP1. PP1 is asking the respondents' agreement for the function of AEB (I find AEB a useful technology to reduce road accidents). The high percentage of the agreement also found for item PPF, "I think the implementation of AEB will become an important part of existing car components". In line with that it also good to know the respondents that having AEB in their cars are less agree with item PP9 (There is no advantage associated with the use of AEB in driving.). For details about how respondents perceived about AEB designs (PP10), standard quality (PP11), the effectiveness of functionality (PP12) and stability of the operation (PP13) can be found in the Table 6.

3.7 Construct 6: Perceived Usefulness

Table 7 displays the construct 6 that represent perceived usefulness. The response from the respondents were measured to analyses the degree that using AEB equipped vehicle is useful. From the result, 5 construct of the items were presented in percentage. Each scoring is presented by separating the respondent that having experience with AEB as indicated as "w" and not having experience with AEB as "w/o". Item PU1 measure the safer driving experience with AEB in vehicle. Majority for both of group of the respondent agree that AEB in vehicle can ensure safer driving experience. Items PU2 measure the effectiveness of AEB function in vehicle to prevent and mitigate collision. The respondents of both of the group agree the effectivity of the AEB in vehicle to perform such function. Next, item PU3 which used to measure the in general usefulness of the AEB system. Most of the respondent agree with the usefulness of the AEB system in vehicle. While items PU4 and PU5 used to measure driving productivity.

Table 7 Percentage for perceived usefulness (PU) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
PU1	1.4	1.5	1.4	0.0	1.4	0.7	10.0	20.1	21.4	28.4	38.6	32.8	25.7	16.4
PU2	0.0	0.7	0.0	0.7	1.4	2.2	7.1	14.2	18.6	26.1	42.9	39.6	30.0	16.4
PU3	0.0	0.7	0.0	0.0	2.9	1.5	7.1	17.2	17.1	25.4	37.1	37.3	35.7	17.9
PU4	2.9	1.5	0.0	0.0	0.0	0.7	10.0	15.7	15.7	23.1	42.9	40.3	28.6	18.7
PU5	1.4	2.2	0.0	0.0	1.4	1.5	8.6	20.1	20.0	23.1	38.6	32.8	30.0	20.1

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

Table 8 Percentage for perceived ease of use (EU) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
EU1	0.0	1.5	0.0	0.0	1.4	0.7	5.7	17.9	18.6	26.9	41.4	36.6	32.9	16.4
EU2	2.9	3.0	0.0	0.0	2.9	3.7	12.9	21.6	21.4	25.4	30.0	32.8	30.0	13.4
EU3	0.0	2.2	0.0	0.7	0.0	2.2	8.6	14.2	18.6	20.9	34.3	36.6	38.6	23.1
EU4	1.4	2.2	0.0	0.0	0.0	0.7	10.0	17.9	12.9	24.6	41.4	34.3	34.3	20.1
EU5	1.4	2.2	0.0	0.0	0.0	0.7	7.1	17.9	17.1	24.6	40.0	34.3	34.3	20.1
EU6	0.0	2.2	0.0	0.0	1.4	1.5	8.6	17.9	14.3	21.6	38.6	38.8	37.1	17.9

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

3.8 Construct 7: Perceived Ease of Use

Table 8 shows the results of the construct perceived ease of use. This construct used to measure the level of easiness as perceived by the respondents. There are six items in the construct which ranging from EU1 to EU6. The response from the respondents were represented in percentage. Each scoring is presented by separating the respondent that having experience with AEB as indicated as "w" and not having experience with AEB as "w/o". Majority of the respondents from the both group agree with the item EU1. The item asking regarding the clarity to use the AEB system. The high percentage of agreement were also found in the rest of the items. This indicate that the respondents perceived AEB system in car as easy to use.

3.9 Construct 8: Complacent Behavior

This construct consist of 9 items ranging from CC1 to CC9. Complacent behaviour construct measure the tendency of the drivers to be too comfortable or complacent with the AEB system to the extent unaware of the potential hazard. Each scoring is presented by separating the respondent that having experience with AEB as indicated as "w" and not having experience with AEB as "w/o". Most of the respondent of the both group were agree with the item CC1. In contrast, item CC2 indicated that the respondent with the AEB experienced tend to disagree with the item, while the respondent without AEB experienced tend to agree with the item. While, items CC3, CC4 and CC5 had majority of the both respondent group agree with them. CC6 had majority of "w" group of respondent slightly agree and "w/o" group of respondent agree with the item. Next, item CC7 asking whether monitoring the AEB system waste of time. The "w" group of respondent perceived the items as strongly disagree while "w/o" group remain neutral. For the item CC8, most of the respondent from both

Table 9 Percentage for complacent behaviour (CC) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
CC1	11.4	3.7	8.6	2.2	4.3	3.7	8.6	16.4	18.6	26.9	27.1	30.6	21.4	16.4
CC2	18.6	9.0	12.9	6.0	5.7	6.7	18.6	21.6	12.9	18.7	17.1	25.4	14.3	12.7
CC3	1.4	2.2	2.9	0.7	1.4	2.2	11.4	13.4	18.6	29.9	40.0	34.3	24.3	17.2
CC4	17.1	11.9	12.9	4.5	5.7	6.7	12.9	17.9	12.9	21.6	22.9	25.4	15.7	11.9
CC5	0.0	0.7	0.0	0.0	0.0	0.0	4.3	12.7	14.3	19.4	40.0	34.3	41.4	32.8
CC6	12.9	6.0	10.0	4.5	8.6	8.2	8.6	17.2	18.6	28.4	21.4	22.4	20.0	13.4
CC7	21.4	12.7	18.6	14.2	8.6	14.2	11.4	21.6	10.0	16.4	20.0	14.9	10.0	6.0
CC8	4.3	0.7	4.3	0.0	7.1	1.5	14.3	24.6	15.7	20.9	30.0	36.6	24.3	15.7
CC9	12.9	7.5	17.1	3.7	4.3	10.4	15.7	27.6	12.9	20.9	25.7	20.1	11.4	9.7

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

of the group answered the question as agree. Eventually, for the item CC9 majority of the respondent from both group remained neutral as their responses (Table 9).

3.10 Construct 9: Value for Money

Table 10 show the result for the percentage of the responses for the construct value for money. There are 7 items in this construct coded as VM1 to VM7. This construct used to measure the perception of the respondent whether the AEB equipped vehicle

Table 10 Percentage for value-for-money (VM) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
VM1	4.3	1.5	0.0	2.2	5.7	6.7	11.4	29.9	17.1	21.6	41.4	24.6	20.0	13.4
VM2	0.0	1.5	2.9	0.7	4.3	0.7	7.1	24.6	12.9	27.6	52.9	27.6	20.0	17.2
VM3	5.7	3.0	5.7	3.7	12.9	10.4	12.9	29.9	22.9	24.6	27.1	17.9	12.9	10.4
VM4	1.4	1.5	2.9	0.0	7.1	3.0	7.1	28.4	24.3	25.4	37.1	27.6	20.0	14.2
VM5	4.3	3.7	5.7	3.0	7.1	6.0	24.3	30.6	18.6	24.6	27.1	18.7	12.9	13.4
VM6	2.9	3.0	8.6	2.2	7.1	5.2	14.3	23.9	22.9	23.1	22.9	28.4	21.4	14.2
VM7	4.3	4.5	8.6	3.0	8.6	3.7	15.7	17.9	20.0	27.6	24.3	29.1	18.6	14.2

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

reasonable to the effectiveness of the function to mitigate the crash. Each scoring is presented by separating the respondent that having experience with AEB as indicated as “w” and not having experience with AEB as “w/o”. There are high percentage of agreement among “w” group respondents towards the VM1, VM3, VM4 and VM5. While, “w/o” group remained neutral. Majority of the respondents for both groups agree with item VM2, VM6 and VM7.

3.11 Construct 10: Continuance Intention to Use

There are 10 items in the continuance intention to use. This construct measures the intention of the respondent to continually use the AEB system after experience using the vehicle. Each scoring is presented by separating the respondent that having experience with AEB as indicated as “w” and not having experience with AEB as “w/o”. In general, the result of the items in the construct 10 had the respondents answer as agree to strongly agree to the questions asked. This indicated that, the respondent perceived AEB equipped vehicle as very functional and they confirmed with the experience using the system and intended to continue using it (Table 11).

Table 11 Percentage for continuance intention to use (IU) results

N = 204; Have experienced with AEB (w) = 70; No experienced with AEB (w/o) = 134														
	1		2		3		4		5		6		7	
	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o	w	w/o
IU1	0.0	1.5	0.0	0.7	0.0	0.7	8.6	21.6	14.3	19.4	37.1	37.3	40.0	18.7
IU2	0.0	1.5	0.0	0.7	2.9	1.5	7.1	20.9	14.3	25.4	41.4	29.9	34.3	20.1
IU3	0.0	0.7	0.0	0.0	1.4	1.5	8.6	23.1	14.3	19.4	41.4	34.3	32.9	20.9
IU4	1.4	0.7	0.0	0.0	1.4	0.7	7.1	15.7	12.9	21.6	40.0	36.6	37.1	24.6
IU5	0.0	1.5	0.0	0.0	0.0	2.2	8.6	19.4	17.1	21.6	35.7	34.3	38.6	20.9
IU6	0.0	0.7	0.0	0.7	0.0	0.0	10.0	18.7	15.7	23.1	37.1	33.6	37.1	23.1
IU7	1.4	2.2	1.4	1.5	2.9	0.0	8.6	17.9	17.1	23.9	34.3	32.1	34.3	22.4
IU8	0.0	2.2	4.3	2.2	1.4	1.5	12.9	16.4	12.9	25.4	34.3	29.9	34.3	22.4
IU9	5.7	4.5	8.6	6.0	8.6	1.5	14.3	26.1	17.1	22.4	25.7	25.4	20.0	14.2
IU10	0.0	2.2	1.4	1.5	2.9	2.2	8.6	17.9	12.9	20.1	34.3	32.1	40.0	23.9

1 = Strongly disagree; 2 = Disagree; 3 Slightly disagree; 4 = Neutral; 5 = Slightly agree; 6 = Agree; 7 = Strongly agree

4 Conclusion

Out of 204 respondents, 89.7% of respondents have high expectations of AEB functionality while driving. 88.2% of people do expect that the usage of AEB can avoid them from collision and impact mitigations. Furthermore, 31.4% of respondents are satisfied with AEB system equipped in their cars. They also claimed that their driving effectiveness were enhanced when AEB system is activated. A sum of 174 people (85.2%) responses that they likely to choose car that equipped with AEB if they about to purchase another car. In addition, 44 people claimed that they will still continue using the system of AEB even they do not like it. Overall, this system usefulness is well perceived by the drivers. The usage of AEB system is convenient and easy to use according to the users. With the usage of AEB system, these users believed their driving performance are alleviated.

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Appendix

Customer trust	
CT1	This AEB vendor (car manufacturer) gives the impression that it keeps promises and stay to commitments
CT2	I believe that cars equipped with AEB have my best interest in mind
CT3	I feel that I can trust cars equipped with AEB
CT4	Cars equipped with AEB are functioning very well to prevent any crashes from happening
CT5	Cars equipped with AEB make me feel safe and confident to drive
CT6	In my opinion, AEB cannot be trusted at times
CT7	In my opinion, cars equipped with AEB can be trusted to do what is right
CT8	In my opinion, cars equipped with AEB effectively prevent crashes or mitigate impacts
CT9	When the car dealer suggests that I buy a car equipped with AEB, it is because it is the best for my situation
CT10	I will not incur the risks of financial losses by installing AEB in cars
CT11	AEB functionality seems reliable
CT12	AEB equipped cars seem dependable
Customer expectation	
CE1	Do you have high expectations in general regarding the functionality of AEB usage when driving?

(continued)

(continued)

CE2	How well will the AEB functionality prevent you from collision and impact mitigations?
CE3	I expect that things could go wrong (AEB error) when driving using AEB
CE4	The AEB functionality when driving fits my expectation
CE5	The AEB effectiveness to prevent impending forward crashes fits my expectation
CE6	My experience in using AEB when driving will be better than I expected
Confirmation	
C1	My experience when using the AEB equipped car is better than what I have expected
C2	The functionality provided by AEB when driving is better than what I have expected
C3	Overall, most of my expectations in using AEB are confirmed
C4	The efficiency of AEB when driving the car is better than what I have expected
C5	Overall, this AEB equipped car functionality is worse than expected
C6	The AEB equipped car meets my needs
C7	The AEB equipped car fits my needs
Satisfaction	
S1	The expectations that I have regarding AEB are correct
S2	Do you have a good feeling about your overall experience of the use of AEB?
S3	Overall, I am satisfied with AEB
S4	I am very pleased with my experience driving the AEB equipped car
S5	Driving the AEB equipped car make me feel very satisfied
S6	Driving the AEB equipped car gives me a sense of enjoyment
S7	Using AEB makes me feel very content
S8	Interacting with AEB operation is fun
Perceived performance	
PP1	I find AEB a useful technology to reduce road accidents
PP2	Using AEB will help me reach my destination more quickly
PP3	Using AEB would increase my driving performance
PP4	I find AEB enable me to drive more conveniently and effectively
PP5	I think the implementation of AEB will become an important part of existing car components
PP6	I am convinced that using AEB will add value to my driving
PP7	In general, I find AEB useful
PP8	The use of AEB does not improve my driving performance
PP9	There is no advantage associated with the use of AEB in driving
PP10	AEBs in cars are well designed
PP11	AEB has an acceptable standard of quality
PP12	AEB offers effective functions
PP13	The system of AEB operation is stable
Perceived usefulness	

(continued)

(continued)

PU1	Using AEB enables me to accomplish a safer driving activity compared to other ways of driving (i.e., I can improve my driving activity performance)
PU2	Using AEB enhances my effectiveness in driving (i.e., I can reduce the severity of accident that can happen)
PU3	Overall, an AEB equipped car is useful
PU4	Using AEB increases my driving productivity (i.e., I can make my car stop before it crashes into objects)
PU5	Driving an AEB equipped car would help me to detect any impending forward crashes in time
Perceived ease of use	
EU1	My interaction with AEB operation is clear and understandable
EU2	Interacting with AEB does not require mental effort
EU3	I find AEB easy to use
EU4	Learning to use AEB is easy for me
EU5	The use of AEB for driving is not frustrating
EU6	It is easy for me to become skilful at using AEB
Complacent behaviour	
CC1	When I have a lot to do, it makes sense to let AEB stop the car to prevent collisions
CC2	If I drive aggressively, I would let AEB to prevent collisions for me
CC3	AEB should be used to ease people's driving performance
CC4	If AEB is available to help me with collision prevention, it makes sense for me to pay more attention to my other tasks while driving
CC5	Even if AEB can help me with a crash prevention system, I should pay attention to its operation
CC6	Distractions and interruptions while driving is less of a problem for me when I have an AEB to cover the impact mitigation and collision prevention
CC7	Constantly monitoring an AEB system's performance is a waste of time
CC8	Even when I have to focus on driving, I am likely to watch AEB operation carefully for errors
CC9	It is not usually necessary to pay much attention to drive when AEB is running
Value for money	
VM1	AEB equipped vehicle are reasonably priced
VM2	AEB equipped vehicle offer value for money in terms of accident prevention
VM3	AEB equipped vehicle are economical
VM4	The functionality of AEB equipped vehicle is good in relation to the price
VM5	There are financial barriers to use AEBs in cars
VM6	I think AEB equipped vehicle are expensive
VM7	Overall, using AEB equipped vehicle costs me a lot of money
Continuance intention to use	
IU1	I am likely to continue to use AEB while driving

(continued)

(continued)

IU2	I intend to consistently use AEB as much as possible
IU3	I intend to continue using AEB rather than discontinue using them
IU4	If I were to buy a car again, I would likely buy an AEB equipped car
IU5	I feel comfortable using AEB while driving
IU6	I would recommend an AEB equipped car to a friend
IU7	I like driving AEB equipped car
IU8	My intention is to continue using an AEB equipped car rather than a non-AEB equipped car
IU9	I have to continue using AEB equipped car although I do not like it
IU10	I will always try to use AEB while driving in my daily life

References

1. Kamalanathsharma RK, Rakha HA, Zohdy IH (2015) Survey on in-vehicle technology use: results and findings. Int J Transp Sci Technol 4(2):135–149
2. Kamalanathsharma RK, Zohdy IH, Rakha HA (2013) Public perception on increasing use of technology in automobiles: survey findings. In: IEEE conference on intelligent transportation systems, proceedings, ITSC, pp 815–820
3. National Highway Traffic Safety Administration (2013) Visual-manual NHTSA driver distraction guidelines for in-vehicle electronic devices, vol 78, no 81
4. Wu J, Liao H, Wang JW (2020) Analysis of consumer attitudes towards autonomous, connected, and electric vehicles: a survey in China. Res Transp Econ 80:100828
5. Singh Bisen V (2019) What is ADAS technology and how it works in car for safe driving? [Online]. Available: https://medium.com/vsinghbisen/what-is-adas-technology-and-how-it-works-in-car-for-safe-driving-62395883310b. Accessed 24 Jan 2021
6. "What is ADAS (Advanced Driver Assistance Systems)?—Overview of ADAS Applications | Synopsys." [Online]. Available: https://www.synopsys.com/automotive/what-is-adas.html. Accessed: 24 Jan 2021.
7. Mokhtar NH, Hamzah L, Mamat HC, Nor MKM, Munir FA (2019) Priority factor influencing public interest in owning vehicle with AEB system. J Soc Automot Eng Malaysia 3(2):139–147

The Association Between Rear Impact Crash Characteristics and Risk of Injury

Afiqah Nadhirah, Mirta Widia, Nur Syafiqah Fauzan, Yassierli, Ahmad Azad Ab. Rashid, Hanida Abdul Aziz, Ezrin Hani Sukadarin, Hairunnisa Osman, Zulhaidi Mohd Jawi, Eida Nadirah Roslin, Hilma Raimona Zadry, Yogi Tri Prasetyo, and Manida Swangnetr Neubert

Abstract Rear-end collisions are among the most common types of crashes on the highway, where Malaysia also has one of the highest fatality rates for traffic in the region. This research aimed to determine the association between the characteristics of rear-impact crash and the risk of injury. The accident rate data during 2016–2018 were collected from Bukit Aman Traffic Investigation and Enforcement (JSPT), Royal Malaysia Police (RMP) Pol 27. A Chi-square test was applied to achieve the study objectives. A total 271 of single-vehicle rear-impact crashes were recorded in the dataset. Passenger car contributed the highest number of rear impact crash with 70% compared to other types of vehicles such as 4-wheel drives and lorry. The injury-severity level showed that the rear impact crash fatalities represent about 11% of total rear impact crash, followed by 9% of a slight injury, 6% of severe injury, and 74% with no injury. The result highlighted that six characteristics were found to be significantly associated with the risk of injury. They are driver's age, road system, road surface condition, light condition, main vehicles' part damage, and speed limit.

A. Nadhirah · M. Widia (✉) · N. S. Fauzan · H. A. Aziz · E. H. Sukadarin · H. Osman
Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang, Gambang, Malaysia
e-mail: mirta@ump.edu.my

Yassierli
Faculty of Industrial Technology, Institut Teknologi Bandung (ITB), Bandung, Indonesia

A. A. Ab. Rashid · Z. M. Jawi
Malaysian Institute of Road Safety Research (MIROS), Kajang, Malaysia

E. N. Roslin
Universiti Kuala Lumpur Malaysia France Institute (UNIKL-MFI), Bandar Baru, Bangi, Malaysia

H. R. Zadry
Faculty of Engineering, Universitas Andalas, West Sumatra, Indonesia

Y. T. Prasetyo
School of Industrial Engineering and Engineering Management, Mapua University, Manila, Philippines

M. S. Neubert
Faculty of Technology, Khon Kean University, Khon Kaen, Thailand

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This analysis has provided a useful new perspective on rear-end impacts crashes in Malaysia.

Keywords Rear impact crash · Driver's characteristics · Vehicle characteristics · Road and environmental characteristics · Risk of injury

1 Introduction

ASEAN countries have shown high road crash fatality rates and continuously on the increase (ASEAN Road Safety Strategy, 2016). Malaysia's road accident death rate is the third highest in ASEAN countries after Thailand and Vietnam. According to Tatem and Gabler [1] vehicle to vehicle crashes have been classified into four categories based on the type of collision; collisions at the rear end, side sweep, head-on and right angle. Rear end collisions are among the most common types of crashes on highway, and scenario most relevant is the alarming number of the associated injuries and mortality. It has been shown, for example, that rear-end crashes account for 30% of all injuries and 29.7% of all property damages in the USA [2].

Previous research revealed that various factors are affecting the causes of rear-end crashes such as driver characteristics (gender, age, alcohol use), environment (time, weather conditions), roads (surface condition, physical characteristics) [3], vehicle type [4] and the number of traffic lanes [5–7]. Occupant age, gender, roadway speed limit and a vehicle mass term were the factors that have a statistically significant effect on the likelihood of serious or fatal injury [8]. Moreover, a study by Chen et al. [4], showed that the severity of injury among drivers were due to the rear impact crash was influenced by many contributing factors such as roadways alignment, features of the environment, driver characteristics and flow of traffic.

Data from WHO revealed that, Malaysia's estimated fatality rate was among the highest in the world in year 2013 [9]. According to previous research the speed limit, mass ratio, gender and age are statistically significant predictors of fatality or serious injury to belted drivers in rear impacts [8]. However, the study on the analysis of rear-end impact crash and risk of injury in ASEAN countries especially in Malaysia is scarce. The investigation on characteristics of rear-end impact crash and the risk of injury among driver based on accident reported to the police in Malaysia have not been fully recognized and has not yet well studied as compared to other countries.

Therefore, this research aimed to determine the association between the characteristics of rear impact crash and the risk of injury, as preliminary data to plan for future programmes for rear-end crash preventive in Malaysia.

Table 1 Information item on characteristics of rear impact crash in Malaysia

Characteristics	Variables
Driver	Gender Age Race Alcohol influence
Road and environmental	Road system Intersection-related Road surface condition Weather Light condition
Vehicle	Vehicles' damage part Type of vehicle Speed limit

2 Methods

2.1 Data Source

The primary database of road accidents' data that occurred during 2016 to 2018 was gathered from Bukit Aman Traffic Investigation and Enforcement (JSPT), the department under The Royal Malaysia Police (RMP) POL 27. All the accident data were based on the first impact of a rear-end collision.

There were 271 cases of single rear-end collision. As vehicle data had to be considered in this analysis, driver, vehicle, road and environmental characteristics were added to the dataset. Table 1 shows the rear impact crash characteristics.

2.2 Data Analysis

Statistical analysis was carried out to analyze the data using SPSS software (v25.0, IBM Corp., New York, USA). Descriptive analysis in terms of frequency, percentage, was used to investigate the distribution of rear-end impact characteristics and chi-square test analysis was used to determine the association between rear impact characteristics and risk of injury.

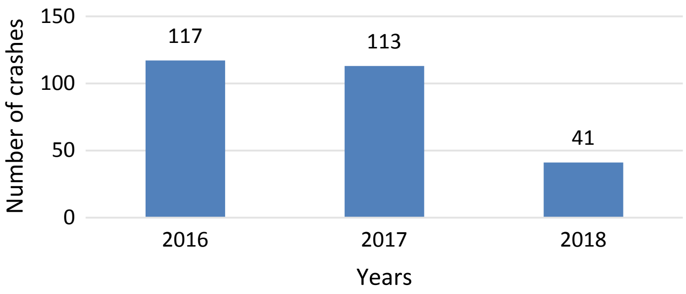

Fig. 1 Rear impact crashes contribution in three years

3 Result and Discussion

3.1 Rear Impact Characteristics

Figure 1 shows the number of cases for the three years from 2016 to 2018 respectively. A total 271 of single-vehicle rear-impact crashes were recorded in the dataset between the year 2016 and 2018.

Table 2 illustrates the characteristics of rear-impact crashes that occurred in Malaysia. It was found that the majority of the rear-impact crash occurred on two ways road system (51.3%) and dry road surface condition contribute the greatest number of accidents with 239 or 88.2% of total crashes. The data reveals that 90.4% of the rear impact crashes happened in a straight way more common than in intersections or junctions. Furthermore, the rear impact crashes increase in the daytime (55.0%) which is synchronized with the peak periods. The majority of the crashes occurred on clear weather conditions with 248 cases compared with only 7.7% crashes during rainy.

The data shows that the most crashes occurred at the area with 70 km/h speed limit. Passenger car contributed the highest number of rear impact crash with 70% compared to the type of vehicles such as 4-Wheel drives and lorry. The other type of vehicles which are included buses and van showed only 13 crashes occurred of the total number. Data also revealed that the rear part was the most frequently damaged part of vehicles. In other studies, it was also found that the road features, environmental condition, and vehicle were preliminarily selected as the important factors that might affect the rear impact crashes [10].

3.2 Risk Injury Level

Figure 2 showed the severity levels of casualties resulted from traffic crashes are classified into four classes; (1) fatal. (2) severe injury, (3) slight injury, (4) no injury.

Table 2 Characteristics of rear impact crash occurred in Malaysia

Variables (road/environments/vehicle)		Category	Frequency	Percentage
Road features	Road system	One way	67	24.7
		Two ways	139	51.3
		Three-lanes	42	15.5
		≥ Double-lanes	23	8.5
	Road surface condition	Dry	239	88.2
		Wet	30	11.1
		Sand	2	0.7
	Intersection-related	Straight	245	90.4
		Curve	7	2.6
		Roundabout	1	0.4
		Crossover	7	2.5
		Y-Intersection	9	3.3
		Staggered junction	1	0.4
		Interchange road	1	0.4
Environmental	Weather	Clear	248	91.5
		Clear	248	91.5
		Rain	21	7.7
	Light condition	Day time	149	55.0
		Dawn	19	7.0
		Night with high illumination	54	19.9
		Night without illumination	49	18.1
Vehicle	Type of vehicle	Occupant car	190	70.1
		4-wheel drive	12	4.4
		Lorry	56	20.7
		Others	13	4.8
	Vehicles' damage part	Undamaged	6	2.2
		Front	103	38.0
		Rear	129	47.6
		Right side	4	1.5
		Left side	5	1.8
		Various	24	8.9
	Speed limit	50 km/h	32	11.8
		70 km/h	64	23.6

(continued)

Table 2 (continued)

Variables (road/environments/vehicle)		Category	Frequency	Percentage
		80 km/h	27	10.0
		90 km/h	50	18.5
		110 km/h	54	19.9
		> 110 km/h	44	16.2

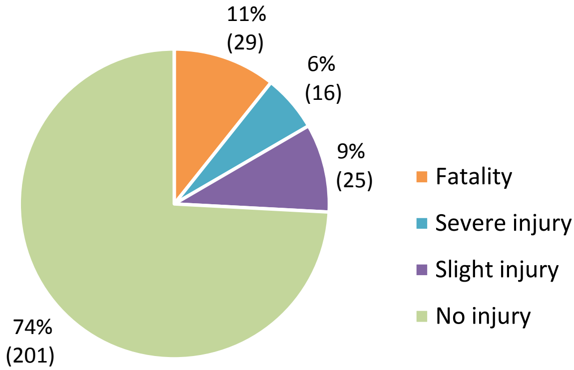

Fig. 2 Distribution of drivers' injuries of rear impact crash (N = 271)

Most of the drivers involved in the crashes had no injury with 201 (74%) from a total number of cases. The injury-severity level resulted from the rear impact crashes showed that the rear impact crash fatalities represent about 11% of total road fatalities, followed by 9% of slight injury and 6% of severe injury.

The result showed that almost 90% of the drivers are uninjured. The absence of injury indicates that the body parts that were not injured might be only affected by the condition damage of the vehicle. Furthermore, the distribution recorded head, leg, and other parts of injuries percentage at 1.5%, 3.0%, and 4.1% respectively. The body part including the chest, hand, and back at least in the lower range which reveals a reduced frequency of injury only about 0.7% of total numbers.

3.3 Association Between Rear-Impact Crash Characteristics and Injury Risk

Table 3 shows the association between rear-impact crash characteristics and the injury risk. The result attained also shows the association between rear impact characteristics with the risk of injury. The driver's age was significantly associated with the risk of injury ($p < 0.05$). Meanwhile, the gender, race, and alcohol infection which are the driver's characteristics had no significant association with the risk of injury where the P values obtained were 0.201, 0.492, and 0.867 respectively ($p > 0.05$).

Table 3 Chi-square test

Rear impact characteristics		Cases (n = 271)%		Significant
		No Injury	Injury	
Driver characteristics	*Gender*			
	Male Female	71.3% 85.5%	28.7% 14.5%	0.201 p > 0.05
	Age			
	17–30 31–40 41–50 51–60 >60	72.2% 73.9% 81.0% 81.8% 43.8%	27.8% 26.1% 19.0% 18.2% 56.2%	0.032* p < 0.05
	Race			
	Malay Chinese Indian Other	73.5% 71.0% 83.3% 100.0%	26.5% 29.0% 16.7% 0.0%	0.492 p > 0.05
	Alcohol influence			
	Not suspected Positive tested	74.2% 71.4%	25.8% 28.6%	0.867 p > 0.05
Road and environmental characteristics	*Road system*			
	One way Two ways Three-lanes ≥Double-lanes	67.2% 81.3% 59.5% 78.3%	32.8% 18.7% 40.5% 21.7%	0.034* p < 0.05
	Road surface condition			
	Dry Wet Sandy	76.6% 60.0% 0.0%	23.4% 40.0% 100%	0.008** p < 0.01
	Intersection-related			
	Straight Curve Roundabout Crossroad Y-Intersection Staggered junction Interchange road	74.3% 57.1% 100.0% 100.0% 66.7% 0.0% 100.0%	25.7% 42.9% 0.0% 0.0% 33.3% 100% 0.00%	0.291 p > 0.05
	Weather			
	Clear Unclear Rain	75.4% 100.0% 57.1%	24.6% 0.0% 42.9%	0.131 p > 0.05
	Light condition			

(continued)

Table 3 (continued)

Rear impact characteristics		Cases (n = 271)%		Significant
		No Injury	Injury	
	Day time Dawn Night with high illumination Night without illumination	77.9% 84.2% 75.9% 57.1%	22.1% 15.8% 24.1% 42.9%	0.023* p < 0.05
Vehicle characteristics	*Type of vehicle*			
	Occupant car 4-wheel drive Lorry Others	74.2% 100.0% 70.6% 75.0%	25.8% 0.0% 29.4% 25.0%	0.324 p > 0.05
	Vehicles' damage part			
	Undamaged Front Rear Right side Left side Various	83.3% 66.0% 83.1% 100.0% 80.0% 20.8%	16.7% 34.0% 10.9% 0.0% 20.0% 79.2%	0.000** p < 0.01
	Speed limit			
	50 km/h 70 km/h 80 km/h 90 km/h 110 km/h >110 km/h	84.4% 81.2% 77.7% 68.0% 51.9% 88.6%	15.6% 18.8%22.2% 32.0% 41.8% 11.4%	0.000** p < 0.01

*p < 0.05 = was considered statically significant at 5% level
**p < 0.01 = was considered statically significant at 1% level

Regarding the road and environmental characteristics, it was determined that the risk of injury had a significant association ($p < 0.05$) with the following characteristics; road system ($p = 0.034$), road surface condition ($p = 0.008$), and light condition ($p = 0.023$). The result obtained showed a similar trend with previously researched by which emphasized that condition and type of road either highways or main road become one of the higher causes of road accident cases that have killed lives [11].

From the data tabulated in Table 3, it also can be recognized that no significant association between the type of vehicle with the risk of injury due to the 0.324 of significant value ($p > 0.05$) but other vehicle characteristics such as the vehicles' damage part and speed limit had a strong association with the risk of injury ($p < 0.001$). This is supported by the work of previous research which indicated that the impact configuration of each individual passenger car involved in a traffic accident is important and 90% of the striking cars have an impact speed lower than 55 km/h and most of these impacts occur on urban roads [12]. Finding also suggested that to reduce the occurrence of freeway rear-impact crashes, the drivers should always comply with traffic regulations and standardize their driving behavior, continuous control driving time and arrange adequate rest time [10].

Therefore, it can be concluded that the probability of rear impact crash increased significantly with the speed limit. This statement is similar to Mohamed et al. who also show that road system, road surface condition, and vehicle characteristics are significantly associated with the risk of injury of rear impact crash [13].

4 Conclusion

Three characteristics of rear impact crash which are driver, road, and environmental, and vehicle characteristics were recognized. The highest percentage of crashes were recorded among Malays, males, and age around 17–30 years old. In terms of road and environmental factors, the most frequent crashes occurred at two ways road system that represents 51.3% of total cases on the straight and dry road surface. Overall, as shown in the distribution of drivers' injuries of the rear-impact crash, most of the drivers involved in the crashes had no injury. The results also showed that a few variables were found to be significantly associated with the risk of injury of the rear-impact crash. This analysis has provided a useful new perspective on rear-end impacts crashes in Malaysia and a better understanding of their characteristics and its association with the level of injury risk.

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References

1. Tatem WM, Gabler HC (2019) Differential fatality risk between rear and front seat passenger vehicle occupants in frontal crashes. In: Conference proceedings of international research council biomechnical inject IRCOBI, vol 1, no 610, pp 554–560
2. Zhang K, Hassan M (2019) Identifying the factors contributing to injury severity in work zone rear-end crashes, vol 2019
3. Méndez ÁG, Izquierdo FA (2010) Quasi-induced exposure: the choice of exposure metrics. Accid Anal Prev 42(2):582–588. https://doi.org/10.1016/j.aap.2009.10.003
4. Bazarian JJ, Fisher SG, William F, Robert L, Knox KL, Pearson TA (2001) Factors influencing pediatric injury in side impact collisions. J Trauma Inj Infect Crit Care 51(3):469–477. https://doi.org/10.1097/00005373-200109000-00008
5. Chipman ML, Desapriaya E, Brussoni M, Han G, Gane J (2005) The risk of injury and vehicle damage in intersection right-angle crashes. SAE Tech Pap 29(2):60–66. https://doi.org/10.4271/2005-01-0285
6. Meng Q, Qu X (2012) Estimation of rear-end vehicle crash frequencies in urban road tunnels. Accid Anal Prev 48:254–263. https://doi.org/10.1016/j.aap.2012.01.025

7. Kim SK, Song TJ, Rouphail NM, Aghdashi S, Amaro A, Gonçalves G (2016) Exploring the association of rear-end crash propensity and micro-scale driver behavior. Saf Sci 89:45–54. https://doi.org/10.1016/j.ssci.2016.05.016
8. Padmanaban J, Burnett R, Levitt A (2016) Seatback strength as a predictor of serious injury risk to belted drivers and rear seat occupants in rear-impact crashes. SAE Tech. Pap., vol. 2016-April, no. April, 2016. https://doi.org/10.4271/2016-01-1512
9. Idri A, Oukarfi M, Boulmakoul A, Zeitouni K, Masri A (2017) A new time-dependent shortest path algorithm for multimodal transportation network. Procedia Comput Sci 109:692–697. https://doi.org/10.1016/j.procs.2017.05.379
10. Xi J, Guo H, Tian J, Liu L, Sun W (2019) Analysis of influencing factors for rear-end collision on the freeway. Adv Mech Eng 11(7):1–10. https://doi.org/10.1177/1687814019865079
11. Khairul Amri Kamarudin M et al (2018) Road traffic accident in Malaysia: trends, selected underlying, determinants and status intervention. Int J Eng Technol 7(4.34):112. https://doi.org/10.14419/ijet.v7i4.34.23839
12. Eis V, Fay P (2015) A detailed analysis of the characteristics of european rear characteristics of european rear (2015)
13. Mohamed SA, Mohamed K, Al-Harthi HA (2017) Investigating factors affecting the occurrence and severity of rear-end crashes. Transp Res Procedia 25:2098–2107. https://doi.org/10.1016/j.trpro.2017.05.403

Aircraft Noise Exposure and Effects on the Health of Nearby Residents: A Review

B. Athirah and M. S. Nurul Shahida

Abstract Noise exposure is a prevalent issue, where the people exposed to loud sources of sound. This paper presents a concise review on aircraft noise exposure and its effects on the health of people in nearby residences and public areas, particularly on the health problems resulting from prolonged aircraft noise exposure and the noise levels that can cause disturbance to human hearing. For this review, 27 key works published from 2010 to 2020 was studied to find out the issues regarding the effect from aircraft noise exposure. Based on the growing number of published studies in this area, there is growing concern on noise pollution worldwide, with aircraft noise being one of the major types of noise pollution. Thus, the key findings were extracted from the published literature into the following categories: (1) source of noise and propagation of noise, (2) recommendation of noise level from various boards, (3) effect and impact on nearby residents, and (4) remedial actions to mitigate the effects of aircraft noise. This paper provides insight on aircraft noise, including ways to reduce the effects of aircraft noise based on the guidelines set by the authorities.

Keywords Noise exposure · Aircraft noise · Airport · Environment · Exposure level · Noise level · Residence

1 Introduction

Environmental noise exposure is responsible for a range of health problems. People continuously exposed to environmental noise may experience hearing discomfort. Aircraft noise is one of the major contributors to environmental noise which affects the health and well-being of the people living/working within vicinity of the airport. Aircraft noise is not only generated from the aircraft engines but also involved the airframe noise induced by the aerodynamic surfaces and surrounding turbulent flow [1]. This paper presents a concise review on aircraft noise and its effects on the health of people within vicinity of the airport. By reviewing papers pertaining to the effects

B. Athirah (✉) · M. S. Nurul Shahida
Collage of Engineering, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Kuantan, Pahang, Malaysia

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of aircraft noise exposure and the area exposed, a number of health problems have been identified as a result of aircraft noise exposure. In general, the findings of most studies indicate that the presence of an airport close to residential areas will influence the residents' health and well-being. Hence, the distance between the airport area and residency area played significant role in level of noise exposure exposed.

Aviation offers some economic and social advantages, which leads to a higher demand for aviation services and a rapid growth of airport development around the globe which is lead to advanced economic plans. This in turn, promotes aircraft noise pollution. Thus, guidelines from the International Civil Aviation Organization (ICAO), Department of Environment (DOE), World Health Organization (WHO), Occupational Safety and Health Administration (OSHA), National Institute of Occupational Safety and Health (NIOSH) and other standard safety organisation must be emphasized in airport vicinity. In addition to the extension of airport areas, the development of residential areas and cities is also influenced by the presence of airport in the area. If the area of development is extended close to the airport, this will increase of risk of aircraft noise exposure owing to the reduced distance between humans and the source of noise pollution. If the airport is surrounded by skyscrapers and mountains, the airport is not suitable for aircraft operations. There is a need for thorough design planning or airport relocation, taking into account government offices, institutions, community facilities, residential and commercial areas, as well as an extensive open space network.

Health problems resulting from aircraft noise exposure seem to more prevalent. However, most people may be unaware of the health risks associated with aircraft noise exposure. People who suffer from noise-related health problems are those who live near the airport or those exposed to loud sources of noise over prolonged periods. Aircraft noise causes more annoyance and disturbance compared with noise from road and railway traffic. People who live/work within present of airports are more affected mentally and physically from aircraft noise. For instance, they may suffer from cardiovascular disease, sleep disorders, learning impairment, hypertension, ischemic heart disease, irritability, psychological stresses owing to long-term exposure to aircraft noise [2, 3].

Besides physical effects, people may also suffer from psychological effects. Fujiwara et al. (2017) points out that these effects were measured by considering the condition of the individuals' health either in physically or emotionally effect, where the individuals stated their feeling and health states due to this noise disturbance. In general, those affected by aircraft noise face difficulties and they feel stressed from this environment. Some studies have shown that prolonged exposure to aircraft noise increases the risk of noise-induced hearing loss (NIHL) [4]. NIHL is an occupational disease caused by long-term exposure to high noise levels and therefore, those living/working near the airport are at risk of NIHL. The standards used to estimate the risk of NIHL are assumed to be appropriate for daily exposures up to 12 h and the risk of NIHL is dependent on the magnitude of the noise exposure.

Hence, it is necessary to improve the health and well-being of people living/working near the airport. With this in mind, a concise review of aircraft noise and its effects on the health and well-being of nearby residents was presented. This paper also presents the remedial actions that can be taken to mitigate the detrimental impact of aircraft noise.

2 Literature Study

2.1 Literature Survey

The studies were conducted by doing research from database in websites. The findings from articles, journals, news and encyclopedias act as references for the literature search related to this title. Keywords or terminologies such as 'noise exposure', 'aircraft noise', 'airport near the residency', 'noise that effect the residence area', 'effect of residence near the airport' and other related terms were used during literatures search. A comprehensive search was performed on databases such as ScienceDirect, Google Scholar, Web of Science, and Scopus to ensure that the research articles were relevant to the theme of this review.

Basner (2018) were studying a systematic review for environmental noise and there were criteria followed as a guidance for formal meta-analysis as:

(1) Type of study: cross-sectional or longitudinal surveys, using an explicit protocol to select the respondents.
(2) Participants: Studies including members of the general population (mainly residents of noise-exposed areas).
(3) Type of exposure: Long-term outdoor noise levels, which are expressed as LAeq, 24h, Ldn, Lden, or its components (Lday, Levening, Lnight), and the duration in hours of night or can be easily converted from similar acoustic variables and any variable or formulae calculated to find out the noise level. The duration of noise exposure has limited time or time recorded and the meteorology was necessary involved and included also.
(4) Confounders: Articles containing a potential second risk factor besides noise (e.g. vibrations in case of railway noise close to the tracks) are included and there are special remarks in the list of included articles.

These criteria were used as a guideline to ensure the relevancy of the articles for a critical literature survey.

2.2 Extraction of Data

The literature survey conducted by reviewing scientific and experimental studies published from 2010 to 2020. These studies were chosen to ensure the currency of the findings related to aircraft noise. From the screening process, 145 articles were selected to assess their eligibility for the literature survey. For this assessment, it referred to specific criteria such as the method of participant selection, procedure used to calculate the noise levels, and/or method of noise measurement, the health effects or annoyance caused by aircraft noise, and the actions taken to mitigate the detrimental impact of aircraft noise. A table was constructed where the information was organized into categories.

As shown in Fig. 1, after thorough screening, 81 articles excluded from the literature survey. By reducing the number of research articles, the studies could focus more on the relevant ones. Studies related to infrastructural changes and military airports were excluded. This decision was made independently by us. However, if there were disagreements regarding the papers to be included/excluded, it will be discussed the problem in order to reach a consensus. After the eligibility assessment, 37 articles that related to aircraft noise were obtained. From each screening, more details that can be used as the guidelines for this study obtained. The study collected and compiled the data such as the type of study, the main causes of noise exposure, sources of noise, survey data, location of study, rationale for the site selection, survey

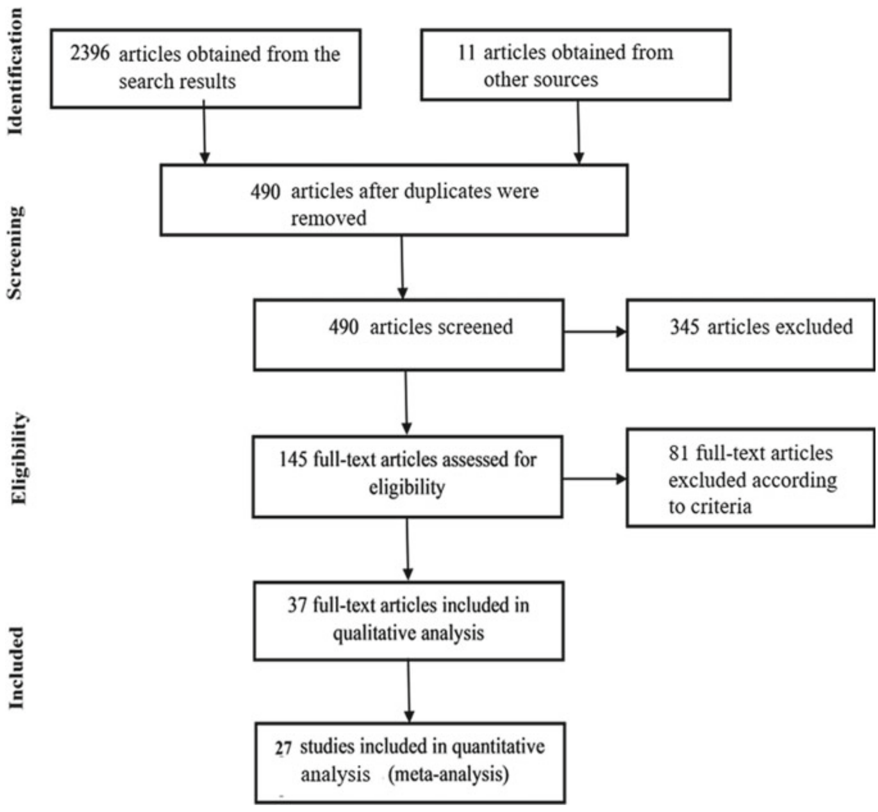

Fig. 1 Flowchart for the literature survey selection

method, responses from the people, main outcome measures, and the counteracting measures for aircraft noise exposure.

Debate or discussion papers also provide insight for this literature survey such as the population of the study, assessment of aircraft noise exposure, causes of the illness or the illness itself, confounding factors about the illness, statistical analysis of aircraft noise exposure, and ethics towards the people faced with this problem. According to the WHO, the permissible noise limit for environmental noise is 75 dBA. Noise levels exceeding this limit are detrimental to human hearing. With the escalating human population growth and rapid industrialization, noise pollution from transportation is more prevalent. This review paper is focused on aircraft noise and its effects on those living near the airport. After the screening and assessing the eligibility of the articles, only 27 articles were selected for the review.

3 Results

From the graph, it shows that the studies regarding this aircraft noise issue was increasing by year. In year 2010 and 2020 shows the highest publication rates about the aircraft noise studies. Most likely it indicates that there is awareness among the scientific community regarding aircraft noise and its impact. In early days when aviation was still in its infancy, aircraft noise was a rare case; however, this issue is more prevalent nowadays because of the escalating population growth and rapid industrial development (Fig. 2).

The key findings of these studies are elaborate in below sentence which it focused on the studies contents and the relation with the aircraft issues. Enneveer (2010) conducted the study at Tallinn Airports and Tartu Airport, Estonia area where the

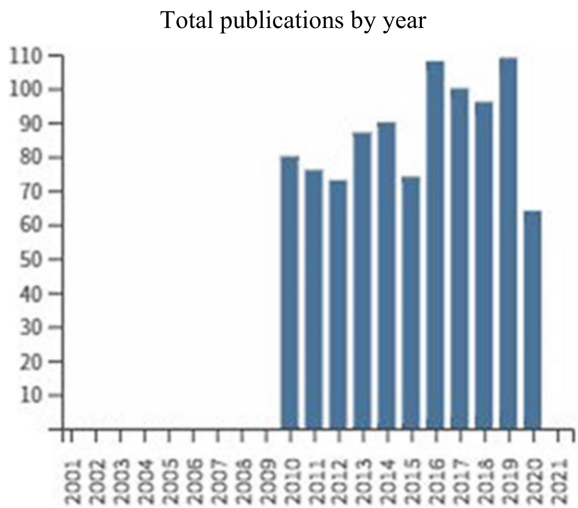

Fig. 2 Number of publications related to aircraft noise obtained from Web of Science from 2010 to 2020

monitoring process taken placed by installed a stationary noise monitoring equipment at the airport. They analysed the operating noise and aircraft noise through the monitoring system. About 18% of take-offs and approaches take place above the city, west of the airport, and 82% above the not densely built-up land east of the airport [5]. From the annual average traffic report, the traffic scattered from western direction and the area exposed to the noise smaller than east region. Due to the increasing of air traffic, it caused a concern that the amount of aircraft noise produced increase and mitigation measure take place by maintain the take-offs and landings from eastern direction. This study shows the significant of aircraft routes analysis and the frequency of aircraft movement in order to control the aircraft noise exposure. This supported by the studies from [6], that with the relocation of Athens Airport where people experience changes in noise level due to the introduction or removal of aircraft noise. This paper reports the survey result by offering actual inter-temporal noise change scenarios rather than hypothetical variations. The survey conducted by adapt the people with real life situation where there was some variation in values of noise during airport closure and opening. It acts as remarkably difference between the old airport and new airport. It is found that there was a significant variation in aircraft noise values between different areas.

A paper tittle 'Analysis of Acceptable Flight Frequency under the Effects of Other People's Noise-Situations' [7], points out the influenced of flight frequency and it effects to the people. By considering the people's noise-situations on an individual's maximum acceptable flight frequency (MAFF). Using two MAFF models, one that tests for effect of available noise information and another testing for effect of other people living in different noise-affected zones. Results from first model shows the importance effect on available noise information on MAFF. Thus, people situation regards the aircraft noise present differ based on their awareness. This indicates the situation where people who have less noise information about the expansion plan may not carefully consider their future noise situations, which may be the reason why they are willing to accept more flights. Next, Ozkurt et al. (2013) conducted a study by calculating the level of aircraft noise exposure around İstanbul Atatürk Airport using the European Noise Directive. There were significant numbers of people were potentially exposed to excessive noise levels. From the result, total of 4% resident population exposed to 55 dB(A) or higher noises during daytime in İstanbul. At night-time, 1.3% of the population is exposed to 55 dB(A) or higher noise levels [8]. It found that, the noise measurement different for day and night gave different reading that differently effected the people. The exposure needs to be control and minimize either by regulation terms or technology of aircraft itself.

In 2014, Hui Xie et al. published a paper in which they investigate the features and control strategies of aircraft noise in China. From the investigation, it found that China had experience increasing 3% of hearing loss per year [9]. Also, aircraft noise was noticed as a potential threat to other physiological systems, such as the cardiovascular system. It also shows the arising in number of complaints due to disturbance from the aircraft noise and this aircraft noise also can induced annoyance at different levels. The through study helps to identify the aircraft activities and the different of each airport management. There also found that certain airports prohibited the flight night schedule in order to reduce the noise exposure issues. Besides that, the noise in everyday life can caused both auditory and non-auditory health effects. Noise-induced hearing loss was remained as one of the impacts from the noise exposure. An analysis conducted and studied for both auditory and non-auditory health effect from the noise pollution such for auditory; noise induced hearing loss, annoyance, occupational noise-induced hearing loss, and non-auditory; cardiovascular disease, cognitive performance, sleep disturbance and hospital noise [10]. This study helps to identify the specific effect from the noise exposure and determine the risk due to this noise exposure situation. This review emphasize that non-auditory health effects seriously occurred due to the environmental noise exposure.

The field study or cross-sectional study also conducted for the past years. In 2015, a paper about the noise pollution that caused by the Birjand Airports on the residents nearby it was conducted. This paper observed the noise pollution on residents of Birjand airport area where the area experienced development of the city and increase in flight schedule. Calibration of the sound produced with the sound intensity in every 250–250 m^2. Questionnaire distribution to 500 peoples residing in those areas to find out the impact of road traffic [11]. Results represent the noise pollution with the distance region and in the case of sleep disorders (55.57% of the population) have the most adverse impact on residents over these areas and the others parameter such as stress, nervous mode and mental illness does not come as a factor of the influence. It shows that the distance of aircraft or airport from residency areas it affects the sleep mode but not affect the nervous- ness, stress and mental illness and interfere with speech. Currently, the cause of aircraft noise exposure or the source of noise itself is being investigated and being improved. A study by Bertsch et al. (2015) involved the discussion and findings about the noise reduction technologies that developed todays. The idea was basically to reduce the noise system by 8 dB along a take-off and by 10 dB along an approach flight. Thus, to accomplish this study four key point was formulated: (1) identification of main aircraft noise sources on-board, (2) assessment of simulation capabilities for noise prediction, (3) identification and assessment of promising noise reduction concepts for the reference vehicle, and (4) integration of these measures on-board of the reference vehicle [12]. From the discussion, on engine noise sources it should focused on the core noise sources such combustor and turbine. The significant level of reduction for jet and fan noise was found achievable. Also, the noise source from counter-rotating open rotor concept (CROR) also can be reduce by doing reduction in fuel consumption. This example of noise reduction method can be implemented in order to minimize the noise effect.

The study continued on finding the impact of aircraft noise exposure towards the people nearby. The exposure that occur gave different impact on each subject. This supported by the paper from Lawton et al. (2016) that studied about the relationship between airports and multiple subjective wellbeing. This study conducted by combine the national population statistics with the noise measurement maps for 17 English airports. The study design by merging the national household-level data (APS) with geographical location data on airport proximity (within 5 km) and measurement of aviation noise contour (dB) [13]. The daytime aviation operation noise was negatively affecting the five subjective wellbeing measures while the night time noise contour show no significant issue towards the subject. It concludes that, with living under aircraft traffic negatively impact the people. Next, mostly people effected emotionally towards this noise exposure. By evaluating the tolerance by individuals who is affected by the noise when they compare their situation with others who more severely affected by the noise. It found that individuals tolerated more overhead flights when they considered the situations of other people worse affected by the noise than they were [14]. The aircraft noise tolerability and the consideration of noise exposure situations of other people appeared to be a vital aspect to be considered in airport noise management and policy.

With the present of housing area or public spots in the vicinity of airport area, a concise action should be taken to countermeasure this noise pollution problem. A paper was discussed about the efficiency of noise mitigation measures at European airports [15]. The paper purposed to identify the noise regulations either it has been fully applied or not by the airports with the aim to reduce the noise that caused by the aircraft. In order to find out about the issue they study six different airports (Frankfurt, Heathrow, Zurich, Madrid, Barcelona, and Malaga) during 2003–2013. The noise evolution was analysed in details and it evaluated on how effective the noise regulations at the airports. Positive noise reduction found was possibly due to the development of new aircraft technologies. The action on noise regulation also fulfilled by each airport but it still has long way to go as there still complain reported by residents. However, the noise control can be fulfilled completely if people aware about this pollution. This view is supported by Gasco et al. (2017) that presents an overview of the different initiatives undertaken to promote awareness and inform citizens about aircraft noise. The main objective is to communicate noise information to the public and from that the communication of airport noise was classified into three groups: noise maps, periodic reports, and noise monitoring systems [16]. The maximum sound level (Lmax) and the sound exposure level (LE) were the main indicators used to describe these sound events, which are defined by International Organization for Standardization (ISO) in the ISO 1996-1 and ISO 20906 standards. Thus, the maximum level of allowable noise exposure was identified and it also related to the community acceptance about the noise exposure.

Air traffic should be improved in order to minimize the aircraft movements. Air traffic assignment strategies is a method to proposed a better way in reducing the noise exposure. A mathematical model and a heuristic algorithm that could assign aircraft to departure and arrival routes was developed so that number of people exposed to noise is as low as possible, taking into account temporal and spatial variations in population in an airport's vicinity [17]. This approached was demonstrated at Belgarde airport. This model purposed to describe the process of assigning aircraft operations to routes. Input data collected for this study were air traffic data, departure and arrival routes, noise data for each location, population data and human mobility patterns. This is an initiative to minimize the number of people exposed to the aircraft noise by changing the routes of flight. With the present of airport, the market value of the property having a changed. This situation was indicated in a recent study by Trojanek and Huderek-Glapska (2018) where they study the change of property values respect to the air transport development policy and the relation with Limited Use Area (LUA) in terms of aviation noise towards the local. A model for pricing system called Hedonic price modelling was applied to evaluate the effect on LUA and with the predicted noise experience. The housing market price also keep changing based on demand by people and technologies. This paper reported that Noise Depreciation Indices (NDI) found at 0.8 means it will be given 0.80% price discount per decibel of exposure [18]. It shows that people prefer a comfortable surrounding and willing to pay for a better environment. Thus, airport planning and mitigation from the aircraft noise need to be done in order to fulfil market demand.

The health effect from this noise exposure was mostly reported that it caused disturbance or annoyance with this exposure. It become worse by effecting the life style or resting time of the people. A laboratory studies shows that there changing in heart rate during sleep after exposure to road or railway noise. This study aims to investigate the relationship between the sound pressure level (SPL) of aircraft noise and heart rate during sleep in populations living near airports in France [19]. The heart rate shows increasing when the more SPL from all sources (LAeq, 15 s) and the SPL exceeded for 90% of the measurement period (LA90, 15 s) increased. The aircraft activities during night time should be reduce to ensure that people have a good rest. Thus, health issue such stress, annoyance, hypertension and heart problem can be avoided. This supported with the review from Fajersztajn et al. (2019) that performed a comprehensive search about the effects of pollution by the airport activities towards the residents nearby São Paulo–Guarulhos (GRU) International Airport and other airports. The study measured both the exposure (air pollution or noise pollution) and the outcomes (health). All of the evaluation regarding the effects of air pollution on the health of the population living near airports was conducted in developed countries. The noise pollution in areas within proximity of six major European airports, there was a relationship between chronic noise exposure with an increased risk of hypertension among residents [20]. It shows that people mentally effected by the noise exposure and lead to others physical diseases such heart problem and hearing issues.

Todays, with the development and high demand from the market. The flight operation recorded increasing in number of operations. A recent study evaluates either the flight frequency giving positive contribution on the air pollution and the data referred to the monthly data of aircraft movements from 59 major airports in China from January 2014 to December 2017 [21]. This paper found that the aircraft and its emission mainly effect the community during the aircraft rides. The indicator of the air pollution was based on the atmospheric particular matter (PM2.5) level was used to measure the air pollution caused by the aircraft. From it, PM2.5 level is significantly showing positive result and effecting people. Thus, a policy on the aircraft control was established to make sure people safe from the exposure. Firstly, it about the authority's action in reducing the air pollution that caused by aviation transportation by control and planning the aircraft movement or airport location. Second, about the condition of airport area regarding it meteorology condition and environmental factors in order the to expand or build the airport. In conclusion, those findings of the aircraft noise exposure and their effects proven that this aircraft noise effected people in terms of health, surrounding condition and life style.

Table 1 shows the total number of similarities between the research articles reviewed in this work according to the following keywords: aircraft noise, environmental noise, health, noise annoyance/disturbance, community engagement, sleep disturbance, and awareness. It can be seen most of the articles share similarities in terms of the keywords. Based on the results, most of these articles are related to aircraft noise, which is the main focus of this review. Noise annoyance/disturbance comes in second, indicating that there is growing concern on noise annoyance/disturbance caused by noise pollution. The highest keyword search used was about aircraft noise which is it relevant with the theme of this study and second is about the community engagement as the study include the community preference, opinion and response. Most of the study also relate that this aircraft noise caused noise annoyance and disturbance towards people.

3.1 Source of Noise and Propagation of Noise

The sources of noise are typically discussed in the research articles reviewed in this work. In any investigation, it is first essential to identify the causes of a problem. Hence, the causes of noise were identified before discussing the measures that can be taken to mitigate the detrimental impact of aircraft noise. Aircraft noise is contributed by non-acoustic factors as well as noise from the engine or aircraft system itself. Scientists and engineers are still working on ways to reduce engine noise. During take-off, aircraft noise is primarily determined by the engine thrust. Although take-off noise dominates other forms of noise in airports, it can be expected that the noise during take-off and landing will be significantly reduced with advances in technology. According to FAA the level of noise produced by the aircraft may reach 110 dBA, which is hazardous to people exposed to such noise levels.

The high levels of noise produced from the aircraft during take-off, flight, and landing, as well as during ground operations, threaten the well-being of the community and workers exposed to such noise. Therefore, governments, traffic controllers, and authorities aim to minimize this threat by enacting and enforcing policies and laws. According to the Federal Aviation Administration (FAA), the noise levels can be measured at different locations of interest and plotted as contour maps, where a contour line is used to indicate a single decibel (dBA). The noise contour map shows how noise varies across broad areas. Similar to topography, these noise contours are useful to measure the noise levels of an aircraft in the entirety of an environment. Figure 3 shows the measured noise levels for different conditions (flight arrival, flight departure, and runway), presented in a noise contour map. The different blue lines indicate differences in the noise levels.

This work is focused on noise exposure near the airport and its surroundings, knowing that there are many residential, commercial, and public areas within vicinity of the airport. A few case studies have been carried out on noise issues nearby airports in Malaysia, indicating that is some awareness regarding aircraft noise. The latest study was carried out by concerning occupational noise exposure among airport

Table 1 Similarities between the research articles reviewed in this work according to keywords

	Keywords						
	Aircraft noise	Environmental noise	Health	Noise annoyance/disturbance	Community engagement	Sleep disturbance	Awareness
Number of keywords	23	12	10	15	17	7	12

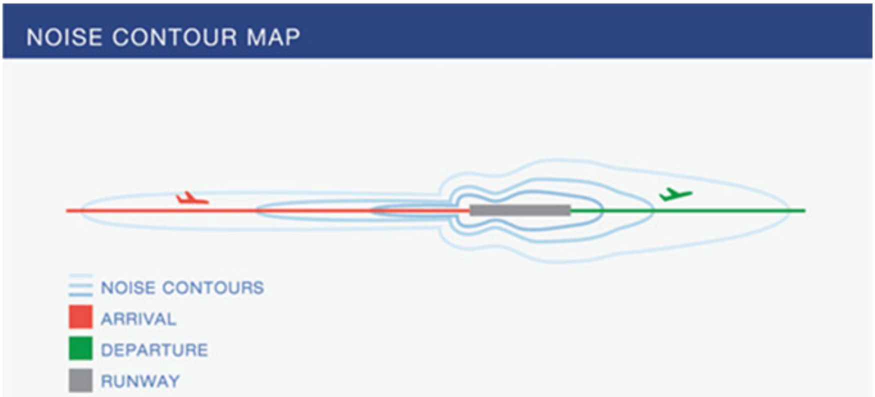

Fig. 3 Noise contour map. *Source* FAA

workers at Kuantan Airport, Pahang. They studied the noise emitted by the aircraft and the effects of this noise on the airport workers or those managing ground handling services [4]. The results indicated that aircraft noise exposure was hazardous on human hearing.

An experimental assessment of human exposure levels to aircraft noise hazards in the neighbouring environments of four Nigerian Airports [22]. They conducted a scientific assessment of the hazard noise exposure levels by the aircraft suffered by people living/working within the neighbourhoods of four Airport in Nigeria. Physical measurements were carried out on selected aircraft and environmental noise parameters such as the Ambient Noise Level (ANL), Sound Pressure Level (SPL), Aircraft Take-off Noise-level (ATNL) and Aircraft Landing Noise-level (ALNL). The results showed that SPL, ANL, ATNL, and ALNL were within a range of 103–115 dBA, 52.3–64.1 dBA, 69.6–87.7 dBA, and 66.2–82.7 dBA, respectively. These results were alarming because the values have exceeded WHO's recommended maximum noise levels of 35 dBA (indoors) and 55 dBA (outdoors) to prevent speech unintelligibility, noise annoyance, and sleep disturbance. It shall be noted that 90 dBA is the permissible noise level/limit for 8-h daytime safe human exposure.

It has been reported that the noise pollution of United States airport affected the nearby residents [23]. The trade-offs between the direct cost of changing the regulatory day-night average sound level (DNL) from 65 to 55 dB versus the medical costs, loss of health, and loss of lives associated with failing to do so. The impact of aircraft noise pollution on the health of the community and workers within proximity of the Abu Dhabi International Airport [24]. The study was carried out within a 25-km radius from the airport, which had high exposure to aircraft noise.

3.2 Recommendation of Noise Level from Various Boards

Rules and regulation were established to protect people from any harm. The noise exposure caused by the surrounding noise was differ by the sources of noise itself. Due to this there were responsible organization established a guidelines or reference of recommended or permissible noise exposure limit for exposure. Table 2 shows the table of recommended noise level by various boards.

3.3 Effect and Impact on Nearby Residents

Subjects play a vital role in a case study. By recruiting the suitable subjects, researchers may identify the causes and effects of aircraft noise. Subjects of different age groups have been recruited for such studies, and the results indicated that the aircraft noise has a pronounced effect on the subjects' health and well-being if no actions are taken to mitigate the effects. In Malaysia, the location of airports closer to residential and commercial areas is both advantageous and disadvantageous to the people.

Most of the studies found that the airport is located nearby residential areas and public places (e.g. school, field, shopping complex). In addition, airports also serve as a workplace for workers. Therefore, people of different age groups are exposed to high levels of noise such as residents, students, children, infants, and workers. These people are vulnerable to the health risks of aircraft noise exposure. A revealed-preference face-to-face interview survey among the residents and workers near and far from Abu Dhabi International Airport indicates the method in identifying the noise exposure problem at there [24].

Health problems are a major concern nowadays. However, people tend to take actions only after they have suffered from the health problem rather than taking preventive actions. Long-term noise exposure leads to health problems such as cardiovascular disease, sleep disorders with frequent awakening, learning impairment, hypertension, ischemic heart disease, annoyance, and psychological stresses [3, 19, 20, 27]. By conducting a questionnaire survey, observations, and analysis of the effects of noise pollution, the research initiative, Noise-Related Annoyance, Cognition, and Health (NORAH) studied the impact of transportation noise on the noise annoyance and health-related quality of life (HQoL) [28]. The results showed that the mean values of aircraft noise annoyance increased with an increase in the aircraft sound levels at the Frankfurt Airport. The expansion of the airport including the opening of the fourth runway (runway Northwest) increased the noise levels, which in turn, affected the well-being of the people.

Direct or indirect noise exposure by the aircraft has been measured to determine how it causes mental HQoL and annoyance. Although other factors may influence noise annoyance and mental health (e.g. noise sensitivity, indicating the individual's vulnerability to environmental stressors), the results showed a statistically significant

Table 2 List of recommended noise level by various boards

No.	Organization	Recommended noise level		
		Specific environment	LAeq (dB)	Time base (h)
1	World Health Organization (Guidelines for Community Noise) [25]	Outdoor living area	55	16
			50	16
		School, playground outdoor	55	During play
		Industrial, commercial, shopping and traffic areas, indoors and outdoors	70	24
2	Department of Environmental Malaysia (Guidelines for Environmental Noise Limits and Control) [26]	Low density residential, noise sensitive receptors, institutional (school, hospital, worship)	60 (day time)	24
			55 (night time)	
		Suburban and urban residential, mixed development Commercial	65 (day time)	24
			60 (night time)	
		Commercial business zones	70 (day time)	24
			65 (night time)	
		Industrial zone	75 (day time)	24
			75 (night time)	
3	National Institute of Occupational Safety and Health (NIOSH) and Occupational Safety and Health Act (OSHA) [4]	Exposure level per NIOSH REL	85	8
			88	4
			91	2
			94	1
			97	30 min
			100	15 min
		Exposure level per OSHA PEL	90	8
			95	4
			100	2
			105	1
			110	30 min
			115	15 min
4	Federal Aviation Administration (FAA)	Shouting, garbage disposal, food blender	80–90	24
		Noise urban daytime	70–80	24
		Normal speech	60–70	24
		Large business office	50–60	24
		Library, bedroom at night	30–40	24

effect of aircraft noise on mental HQoL in the first year after the opening of the runway. The effect of aircraft noise exposure on the heart rate of the population living near the airport during sleeping. They measured the SPL of aircraft noise and heart rate during sleeping for 15 s and the results showed that there was a higher SPL from all sources (LAeq, 15 s) [19]. When the SPL for 90% of the measurement period (LA90, 15 s) increased, the heart rate also increased. The results also showed that there was a positive response between the maximum level of aircraft noise and the heart rate amplitude during the aircraft noise event.

The risk that caused NIHL was also was discussed to promote awareness among people regarding the effects of aircraft noise pollution. NIHL is an occupational disease resulting from long-term exposure to high levels of noise. NIHL may be more common among the public as the public is exposed to this noise on an ongoing basis. The standards used to estimate the risk of NIHL are assumed to be appropriate for daily exposures up to 12 h and the risk of NIHL is also dependent on the magnitude of the noise exposure. This indicates that the risk of getting NIHL is high for people living the near the airport because they are exposed to aircraft noise every day.

In general, the results of previous studies indicate that the public is at risk of health problems if they are constantly exposed to aircraft noise in the long term. Hence, there is a need to implement remedial actions to mitigate the detrimental impact of aircraft noise.

3.4 Remedial Actions to Mitigate the Effects of Aircraft Noise

It is crucial for the government, traffic controllers, or authorities to implement remedial actions to mitigate aircraft noise-related problems. Based on the literature survey, it found that there are measures that can implemented to reduce the detrimental impact of aircraft noise on the people's health and well-being. To reduce the impact of aircraft noise on the health and well-being of the community, it is important to issue a standard code of practice, which includes installing sound insulation in residential buildings to reduce the effect of noise exposure.

Guidelines, rules, and regulations also play an important role to minimize aircraft noise exposure. According to the WHO's Community Noise Guidelines, during teaching sessions, the background SPL in classrooms should not exceed 35 dBL to prevent speech unintelligibility and disturbance of information extraction. According to this guideline, the noise levels of outdoor playgrounds of schools should not exceed 55 dBL during the recess period to prevent noise annoyance. The following recommendations to reduce aircraft noise exposure for residents near the airport [22]:

- Professional experts such as urban and regional planners should conduct geophysical planning for cities/towns hosting the airport.
- Establish an aero polis instead of a simple airport, which has been done in most developed countries.

- The architectural designs and orientation of buildings must be adaptive based on local prevalent wind directions.
- Use anechoic and soundproof wedges as wall claddings.
- Further research should be carried out to improve existing aircraft technology in order to minimize noise emissions.

These actions will likely reduce the detrimental impact of aircraft noise. With this literature survey, there are opinions and beliefs based on the results of previous studies. By this findings people can be more aware and take precaution when they near to the aircraft noise.

4 Conclusions

In this paper, it presented a concise review on aircraft noise exposure and its effect on the health of residents within proximity airports. Health issues such as noise annoyance, sleep disturbance, cardiovascular disease, sleep disorders with frequent awakenings, learning impairment, hypertension, ischemic heart disease, and psychological stresses may occur to those exposed to aircraft noise in the long term. Based on a review on the studies pertaining to aircraft noise and the quality of life of residents within vicinity of a busy airport, the effects of aircraft noise exposure on the nearby residents can be identified.

In general, there are numerous measures and indicators for aircraft noise. Noise maps have been used to determine the noise levels, where each contour indicates the noise level in decibels (dB). This review is specifically limited to studies pertaining to aircraft noise and airport neighbourhood. The best way to establish any causality between exposure and disease is to conduct analytic epidemiological studies such as case–control study, cohort study, or clinical trial. The articles that fulfil this criterion include 'Traffic noise and hypertension—Results from a large case–control study' [29], 'Longitudinal effects of aircraft noise exposure on children's health and cognition: A six-year follow-up of the UK RANCH cohort' [30] and 'Effects of aircraft noise exposure on heart rate during sleep in the population living near airports' [19]. Based on the findings of this literature survey, the following conclusions can be drawn: (1) prolonged exposure to aircraft noise is associated with chronic noise annoyance, which may lead to stress, and (2) this stress significantly contributes to the prevalence of hypertension and in worse cases, may lead to cardiovascular disease. In addition, most people exposed to aircraft noise suffered from noise annoyance and sleep disturbance. The remedial actions that can be taken to mitigate the effects of aircraft noise have also been presented in this paper.

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References

1. Snellen M, Merino-Martinez R, Simons DG (2015) Assessment of aircraft noise sources variability using an acoustic camera. Ceas 19:1–12
2. Bartels S, Rooney D, Müller U (2018) Assessing aircraft noise-induced annoyance around a major German airport and its predictors via telephone survey—the COSMA study. Transp Res Part D: Transp Environ 59:246–258
3. Tezel MN, Sari D, Erdol M, Hamamci SF, Ozkurt N (2019) Evaluation of some health impact indices in two airports' domain. Appl Acoust 149:99–107
4. Athirah B, Nurul Shahida MS (2019) Occupational noise exposure among airport workers in Malaysia: an ergonomic investigation. J Phy: Conf Ser 1262(1). https://doi.org/10.1088/1742-6596/1262/1/012010
5. Enneveer M, Vanker S (2010) Evaluating airport noise and its impact on neighbouring residential districts—example of Estonia. Int Inst Acoust Vib
6. Thanos S, Wardman M, Bristow AL (2011) Valuing aircraft noise: stated choice experiments reflecting inter-temporal noise changes from airport relocation. Environ Resource Econ 50(4):559–583
7. Yai T, Phun V, Hirata T (2013) Analysis of acceptable flight frequency under the effects of other people's noise-situations. J East Asia Soc Transp Stud 10:2147–2160
8. Ozkurt N, Sari D, Akdag A, Kutukoglu M, Gurarslan A (2013) Modeling of noise pollution and estimated human exposure around Istanbul Atatürk Airport in Turkey. Sci Total Environ 482–483(1):486–492
9. Xie H, Li H, Kang J (2014) The characteristics and control strategies of aircraft noise in China. Appl Acoust 84:47–57
10. Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S (2014) Auditory and non-auditory effects of noise on health. Lancet 383(9925):1325–1332
11. Araghi M, Yaghobi MM (2015) The study of noise pollution caused by Birjand airport on the surrounding residents. Indian J Sci Technol 8(11)
12. Bertsch L, Simons DG, Snellen M (2015) Aircraft noise: the major sources, modelling capabilities, and reduction possibilities. (March).
13. Lawton RN, Fujiwara D (2016) Living with aircraft noise: airport proximity, aviation noise and subjective wellbeing in England. Transp Res Part D: Transp Environ 42:104–118
14. Phun VK, Hirata T, Yai T (2016) Effects of noise exposure of other people on aircraft noise tolerability using a reference point approach. Transp Res Part D: Transp Environ 48:171–186
15. Alonso G, Benito A, Boto L (2017) The efficiency of noise mitigation measures at European airports. Transp Res Procedia 25:103–135
16. Gasco L, Asensio C, de Arcas G (2017) Communicating airport noise emission data to the general public. Sci Total Environ 586:836–848
17. Ganić E, Babić O, Čangalović M, Stanojević M (2018) Air traffic assignment to reduce population noise exposure using activity-based approach. Transp Res Part D: Transp Environ 63:58–71
18. Trojanek R, Huderek-Glapska S (2018) Measuring the noise cost of aviation—the association between the limited use area around Warsaw Chopin airport and property values. J Air Transp Manag 67:103–114
19. Nassur A-M, Léger D, Lefèvre M, Elbaz M, Mietlicki F, Nguyen P, Ribeiro C, Sineau M, Laumon B, Evrard A-S (2019) Effects of aircraft noise exposure on heart rate during sleep in the population living near airports. Int J Environ Res Public Health 16(2):269
20. Fajersztajn L, Guimarães MT, Duim E, da Silva TGV, Okamura MN, Brandão SLB, Cardoso MRA (2019) Health effects of pollution on the residential population near a Brazilian airport: a perspective based on literature review. J Transp Health 14:100565
21. Dong Q, Chen F, Chen Z (2020) Airports and air pollutions: empirical evidence from China. Transp Policy 99:385–395

22. Ibhadode O, Oyedepo OS, Ogunro AS, Azeta J, Solomon BO, Umanah II, Apeh ES, Ayoola AR (2018) An experimental-assessment of human exposure-levels to aircraft noise-hazards in the neighbouring-environments of four Nigerian airports. IOP Conf Ser: Mater Sci Eng 413:012080
23. Jiao B, Zafari Z, Will B, Ruggeri K, Li S, Muennig P (2017) The cost-effectiveness of lowering permissible noise levels around U.S. airports. Int J Environ Res Public Health 14(12)
24. Alkaabi K (2017) Studying the effects of aircraft noise around Abu Dhabi International Airport, UAE on the surrounding residential and work places. Civ Eng Urban Plan: Int J (CiVEJ) 4(2):59–78
25. Berglund B, Lindvall T, Schwela DH (1999) WHO guidelines for community noise. Noise Vib Worldw 31(4):24–29
26. Department of Environmental Malaysia (2019) Guidelines for environmental noise limits and control, p 31
27. Holt JB, Zhang X, Sizov N, Croft JB (2015) Airport noise and self-reported sleep insufficiency, United States, 2008 and 2009. Prev Chronic Dis 12(4):1–12
28. Schreckenberg D, Benz S, Belke C, Möhler U, Guski R (2017) The relationship between aircraft sound levels, noise annoyance and mental well-being: an analysis of moderated mediation. In: Proceedings of ICBEN
29. Zeeb H, Hegewald J, Schubert M, Wagner M, Dröge P, Swart E, Seidler A (2017) Traffic noise and hypertension—results from a large case–control study. Environ Res 157:110–117
30. Clark C, Head J, Stansfeld SA (2013) Longitudinal effects of aircraft noise exposure on children's health and cognition: a six-year follow-up of the UK RANCH cohort. J Environ Psychol 35:1–9
31. Kroesen M, Molin EJE, Miedema HME, Vos H, Janssen SA, van Wee B (2010) Estimation of the effects of aircraft noise on residential satisfaction. Transp Res Part D: Transp Environ 15(3):144–153
32. Babisch W, Swart W, Houthuijs D, Selander J, Bluhm G, Pershagen G, Hansell AL (2012) Exposure modifiers of the relationships of transportation noise with high blood pressure and noise annoyance. J Acoust Soc Am 132(6):3788–3808
33. Márquez-Molina M, Sánchez-Fernández LP, Suárez-Guerra S, Sánchez-Pérez LA (2014) Aircraft take-off noises classification based on human auditory's matched features extraction. Appl Acoust 84:83–90
34. Goetz AR (2019) The airport as an attraction: the airport city and aerotropolis concept. In: Air transport: a tourism perspective. https://doi.org/10.1016/b978-0-12-812857-2.00016-6
35. Smith MG, Rocha S, Witte M, Basner M (2020) On the feasibility of measuring physiologic and self-reported sleep disturbance by aircraft noise on a national scale: a pilot study around Atlanta airport. Sci Total Environ 718:137368. https://doi.org/10.1016/j.scitotenv.2020.137368

Anxiety Performance Among Athlete in Response to Theories and Standard Instruments: A Systematic Review

Wan Nurlisa Wan Ahmad, Zakri Ghazalli, and Mohd Azrul Hisham Mohd Adib

Abstract Successful sports performance is determined on how skillful the athlete perceives the anxiety into positive performance. This study purposely assesses the background of recent studies on anxiety theory, assessment instrument and map the anxiety literature survey into a simple taxonomy. Current research intends to identify the vital aspects that affect athlete performance in the sports field that remain a challenge nowadays. Most related articles on (1) anxiety theory (2) athlete (3) sports performance through three (3) popular databases are searched on Clarivate Analytics, Scopus, and PubMed. These databases are deemed broad to cover both relevant theoretical and technical literature. Thirty-three studies (N = 33) were selected after screening process and biddable to the inclusion criteria mentioned. Background data of studies provided varying samples, sports, and conditions. The study finding has highlighted the functional of anxiety theory to measure anxiety performance assisted with an anxiety assessment. The ability of the anxiety theories getting robust toward athlete performance by integrating with anxiety assessment.

Keywords Anxiety theory · Assessment instrument · Anxiety performance · Anxiety assessment

1 Introduction

Enhancing performance is a significant concern for coaches and athlete [1]. One of the factors that distorted the performance is anxiety. Anxiety is a natural human reaction to the stress that involves interaction between the mind and the physical body [2]. Anxiety begins with the state of being worried when dealing with danger or an unfamiliar situation that produce aversive emotion [3]. The association between

W. N. Wan Ahmad (✉)
College of Engineering, Universiti Malaysia Pahang, 26300 Pahang, Gambang, Malaysia
e-mail: nurlisa@ftv.upsi.edu.my

Z. Ghazalli · M. A. H. Mohd Adib
Faculty of Technical and Vocational, Universiti Pendidikan Sultan Idris, Tanjong Malim, 35000 Perak, Malaysia

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anxiety and performance in sport has obtained great consideration from researchers, especially in sports physiology and psychology [4]. Competitive anxiety is bounded as a tension and apprehension feeling during the tournament [5]. Competitive anxiety affects athletes feeling and lead to worse performance. On the other hand, performance anxiety is defined as the failure to reach the athletes' optimal performance due to the increase of the anxiety under perceived pressure [6, 7]. When anxiety performance is debilitating to the athlete performance, they will produce poor and inconsistent performance. As well as elevated levels of chocking can lead to inadequate performance in competition. Thus, anxiety and competitive sports are deeply related to each other [8]. Failure to manage these anxieties result in poor's performance [9]. Hence, managing anxiety is crucial to maintain and enhance athlete performance during the competition [10]. Anxiety is distinguished between somatic and cognitive anxiety [11]. Somatic anxiety deals with the changes in physiology such as an increase in heartbeat, inconsistent pulse rate, butterflies in the stomach, muscle tension, brain wave, elevated blood pressure and so on [12].

Cognitive anxiety refers to the negative expectation about performances, worries about performance, inability to concentrate and pressure to win [7]. The underperformance may take place if athletes unable to manage with their anxieties [13]. Many researchers presented their works on assessing the anxiety and athletes' performances such as Inverted-U Hypothesis [14–16], Multidimensional anxiety theory [17–19], Catastrophe Theory [1, 19, 20], Attentional Control Theory [10, 20] and Individual Zones of Optimal Functioning Theory (IZOF) [21–23]. However, none of the above authors discusses how to access anxiety using the tools to support the theory of anxiety among sports athletes. The instruments were used to quantify the athlete's anxiety for different performance settings to support the anxiety theories, as mentioned earlier. Anxiety assessment consists of Competitive State Anxiety Inventory-2 (CSAI-2) [24, 25]. While for revised version is known as CSAI-2R [26, 27], State-Trait Anxiety Inventory (STAI-2) [28], Sport Competition Anxiety Test (SCAT) [4, 9] and Sport Anxiety Scale-2 (SAS-2) [29, 30].

Nevertheless, these tools can be more workable if they paired together with anxiety theories as listed above. Ensure that, the result of the performance setting from anxieties will be more precise and equitable. Therefore, this paper aims to conduct systematic review and meta-analysis to identify the taxonomy and classify research studies to discuss the importance of anxiety theories and standard instruments in enhancing the athlete's performance. A secondary aim is to highlight the potential merging theories comply with the best-selected assessment instrument. Our primary outcome of interest was to grant additional space on researchers' efforts in discovering the anxiety theories and assessment literature into an anxiety sports performance taxonomy and their purpose. Thus, this review provides a simple capture of the integration result between anxiety theories, anxiety assessment, and athlete performance of the sport and psychology literature published in the latest of 10 years recently.

2 Methodology

2.1 The Review Protocols

This study was guided by an established guideline on conducting a systematic literature review [31]. This established guideline was designed for rigorous systematic review for literature, providing steps and summarize the typology of literature review by producing complete taxonomy of the literature.

2.2 Formulation of Research Questions

The formulation of a research question for this study was based on PICo. It is a model used in evidenced-based practice to frame and answer the research question. The acronyms of PICo based on three main concepts, namely Problem or Population, Interest and Context. Referring to these three concepts, the authors have chosen athletes for Population, performance anxiety for Interest, and the Context is anxiety theory and standard anxiety instrument. This tool guides the researcher to develop the research question throughout this study -How the anxiety theory and standard anxiety instrument affect anxiety performance among the sports athletes.

2.3 Information Sources

A search of titles, abstracts, and keywords was conducted in the midst of 2019 for the following three relevant digital databases: (1) MEDLINE databases, which provides life sciences and biomedical literature through the PubMed search engine, (2) Clarivate Analytics databases that are offering access to Web of Science core collection, KCI-Korean Journal databases, Russian Science Citation Index and SciELO Citation Index, and (3) Scopus is the largest abstract and citation databases of literature which delivering a comprehensive overview in the fields of science, technology, medicine, social sciences, arts and humanities. These digital databases cover both scientific studies and medical literature and provide an extensive broader view into researchers' influence on studies' relevant background.

Table 1 The frame of search string in databases

Databases	Search string option
Clarivate Analytics	TS=((“sport* performanc*” OR “athlet* performanc*” OR “competitive spor*”) AND (“sport* anxiet*” OR “competitive anxiet*” OR “athlet* anxiet*” OR “athlet* nervou*” OR “sport* nervou*” OR “competitive athlet*” OR “anxiet* theor*” OR “anxiet* instrumen*” OR “anxiet* assessmen*”))
Scopus	TITLE-ABS-KEY ((“sport* performanc*” OR “athlet* performanc*” OR “competitiv* sport*”) AND (“sport* anxiet*” OR “competitiv* anxiet*” OR “athlet* anxiet*” OR “athlet* nervous*” OR “sport* nervous*” OR “competitiv* athlet*” OR “anxiet* theor*” OR “anxiet* instrument*” OR “anxiet* assessment*”))
PubMed	((((((((((sport performance) OR (athlete performance)) OR ((competitive sport))) AND (sport anxiety)) OR (competitive anxiety)) OR (athlete anxiety)) AND (athlete nervous)) OR (sport nervous)) OR (competitive athlete)) AND (anxiety theory)) OR (anxiety instrument)) OR (anxiety assessment)) AND (sport))

2.4 *Systematic Searching Strategies*

2.4.1 Identification

Identification is the first stage of finding essential articles based on an appropriate keyword related to the research. This process identifies the synonyms from the related terms. Researcher enriches the terms, which are the primary keywords from the research questions, and categorized it into a specific domain [32]. The authors use variation source such as online thesaurus and refer to the keyword used by previous studies. The keyword option indicated by the database also includes in this identification process—enriching the primary keywords by searching the search string (based on Boolean operator which is the most effective keyword followed by truncation, phrase searching, wild card and field code functions). The primary keyword identifies based on the three databases, namely Clarivate Analytics, Scopus, and PubMed, shown in Table 1. These three essential databases possess the article’s quality and have great multidisciplinary focus, including sports performance and psychological (anxiety).

2.4.2 Screening

During this process, the author undergoes four screening steps that include all the 1290 selected articles by choosing various criteria required for articles selection. The process still ground on the research question similarly as an identification process. However, for screening process involved a specific requirement to ensure the articles about the research objective. It is quite a struggle for authors to review all the selected published articles from the identification process. Therefore, the authors limiting the articles timeline publication between 2009 and 2019. The main reason for limiting the searching process to 2019 was that the searching process started in June 2019, and the year still has another six months to end. Due to many irrelevant articles still included in this process, the author scanned the title and abstract and only accepted the relevant criteria for this study. The authors controlled the quality of article selection by stated the inclusion criteria. The criteria are the articles that only published in a journal and consists of empirical data will be listed in this study. The endnote system was used to organize and store the selected articles extraction from those three databases. A spreadsheet was used to create a table of data extracted from each selected article. This process removed 70 duplicated articles, excluded 560 articles for titles and abstract, and eliminated another 382 published in the selected Journal as they did not fill the inclusion criteria. The remaining 33 articles will undergo further process.

2.4.3 Eligibility

Eligibility is a necessary process where the articles are manually checked and tracking the authors' remaining articles. This process began with reading the surface of the article (abstract and method). Three hundred eighty-two articles (382) were excluded due to emphasize on anxiety theory and anxiety standard instrument rather than emotional, focus on anxiety performance rather than emotional performance, focus on the healthy athlete in the sport rather than disability and unhealthy athlete. The authors covered the inclusion and exclusion criteria in this process, as listed in Table 2. Altogether, there were only 33 selected articles.

2.5 Quality Appraisal

The quality appraisal process is performed to evaluate each article and follow the general checklist proposed by Kitchenham [33]. The remaining articles were presented to three experts for quality assessment by performed a full-text reading for every single article. The experts ranked the articles into three quality categories according to high, moderate, and low. Articles with high and moderate categories will be included in this review process. To verify the rank of the quality categories, the authors focused more on the articles' methodology. This ranking process required at least two authors to agree with the articles' level of quality mutually. The third authors' arguing decision will be normalized resulted in numerous collections of highlighted and notes during the reviewing works. Every single comment was saved as a soft or hard copy versions depending on the author's preferred style. This process had graded 20 articles as high and 13 articles as moderate. Thus, all the remaining 33 articles were eligible for the review.

Table 2 The listed inclusion and exclusion criteria for the systematic review

The inclusion criteria	
1	All articles must be written in English for ease understanding and published between 2009 and March 2019
2	Quantitative methodology
3	Athlete samples with no restriction for age group criteria
4	Both individual and team sports are included in this review
5	The focus on athlete performance, in either one or more of the following aspects: • Reviewing the new trend of utilizing the anxiety theories. • Surveying the developing anxiety assessment. • Proposing a new combination of anxiety theories with the anxiety assessment. • Analysis the athlete performance through scientific study for both theories and instrument
The exclusion criteria	
1	Non-English abstract, articles, and manuscript
2	Outside of scope study
3	Articles aimed that do not focus on anxiety sport performance
4	Articles that not related to publication categories
5	Intervention description without including the athlete participation
6	Studied that do not involve anxiety theory or assessment

2.6 Data Synthesis

The researcher chooses this study as an integrative review. The integrative review allowed diverse research designs in this review, namely quantitative, qualitative, and mixed-method techniques. The present study selected is a qualitative technique by referring to Whittemore and Knafl [34]. He discussed the best way to synthesis the integrative data is by using qualitative or mixed-method techniques. This enables them to conduct an iterative comparison across the primary data sources. Based on this study, the authors thoroughly read 33 articles in the main section of abstract, method, result, and discussion. All the essential data were compiled in a single Microsoft Excel file for a fast retrieval process. These findings are provided in the relevant information as a complete reference for the result described in the next subsequent section. Sets of the applicable and relevant result were employed with Cochran's Q test using SPSS as a statistics tool. The statistics data provide the percentages or proportions of selected articles with the respective purpose categories, type of anxiety theories and anxiety assessment instruments—article distribution based on objectives from the listed relevant digital databases. Then, the researchers ran the articles' classification by following all the three crucial process, as shown in (see Fig. 1).

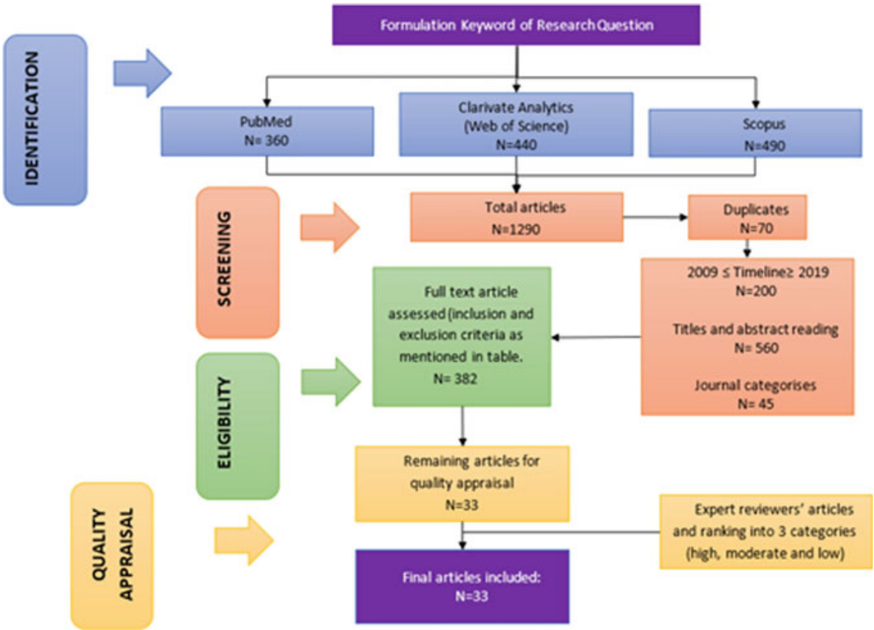


Fig. 1 Flow diagram for systematic literature review. Adapted from Xiao [31]

3 Result

3.1 *Background of the Selected Articles*

Initial query search resulted in 1290 articles categorized as follows: 360 articles from the PubMed database, 440 articles from Clarivate Analytics, and 490 articles from Scopus from 2009 to 2019 (see Fig. 2).

Seventy (70) articles were duplicates from three popular library databases. After a full scan of titles and abstracts of the articles, 560 articles were excluded. Forty-five (45) articles from unrelated publication categories and article types that consist of incomplete information such as non-English as the primary language, in-depth screening on sports types, selected anxiety theories and assessment instrument was excluded 1257 articles. Therefore, the final set of articles included were 33 selected. Every single of 33 selected papers were reading meticulously. Our main objective to determine the background of recent studies on anxiety theory, assessment instrument and map the literature survey into a taxonomy based on our research topic. A complete set of articles (33) discussed the first category, which is the purpose of the research articles for anxiety sports performance. However, this category was divided into three subcategories: anxiety and arousal-based, type of sport-based and athlete experienced-based. All these subcategories were classified according to the essential factor that affected the researcher's scope of the study. The second categories

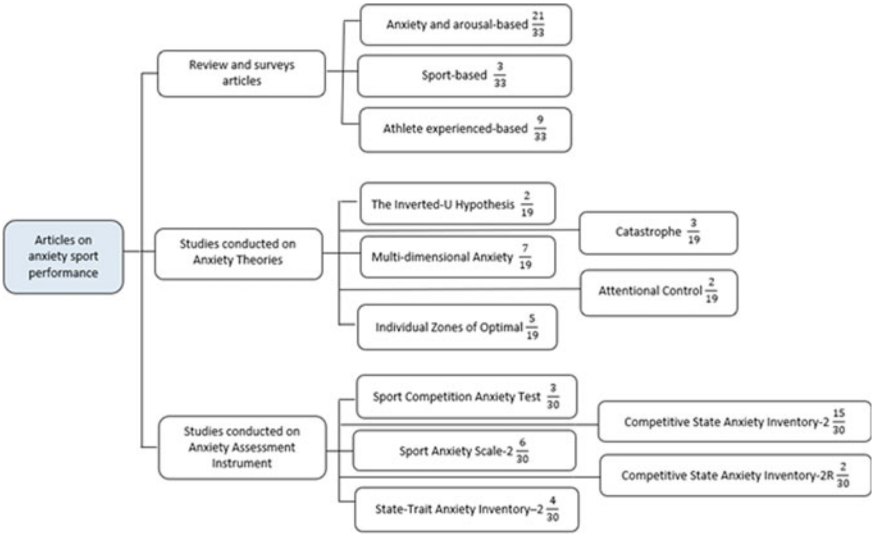


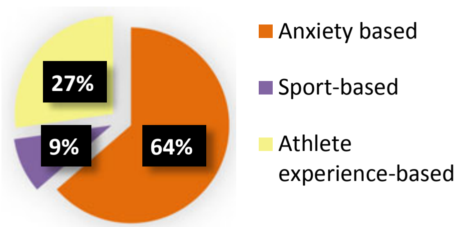
Fig. 2 A taxonomy of research literature on anxiety sports performance

listed were the types of selected anxiety theories and the listed of the anxiety assessment instrument. Both categories were limited to five anxiety theories and anxiety assessment, with the intention of preferable studies within these recently ten years by the respective researchers in psychological sports (see Fig. 2) shows the informative taxonomy on anxiety sports performance based on anxiety theories and anxiety assessment divided as follows.

3.2 *Purpose of Research Articles*

This review articles' primary aim on anxiety theories and sports performance is to capture current understanding in this field and justify the requirement for future research. This section listed three subsections about the purpose of research articles, as shown in (see Fig. 3). Anxiety-based, followed by athlete experienced-based and sport-based are the predominant factors found in the literature.

Fig. 3 Percentage distribution of the purpose of research articles



3.2.1 Athlete Anxiety-Based

Anxiety-based describe the level of state anxiety that has been shown to affect the athlete performance. It categorized into a high, medium, and low level of anxiety. Mabweazara et al. [26] describe the high anxiety state as debilitative once the anxiety exceeds the average reading of anxiety. The anxiety state level can be affected by the various conditions and sources of environment that are commonly seen in real life. Athlete anxiety-based focused on three main scenarios affected mainly to anxiety state: social pressure, peer pressure and monetary incentives [35, 36]. In social pressure scenarios that incriminate the judgment by coaches, teammates, family hopes give high pressure and elevate him/her anxiety level led to worse performance as loss of athlete focusses. At the same time, peer pressure may generate in the team category. The success of team category is determined by individual achievement, as one of the members the pressure to get high scores lead to unstable of anxiety state [37]. Lastly, it involves the monetary incentives that the athlete necessary to win their game in every competition.

3.2.2 Sport Performance-Based

Sport performance-based is clarified into two classifications in sports areas: individual games and team games (more than two members in a game). Mahmoodreza et al. [38] stated that the competitive anxiety level was higher in individual sports than team games. Archery is one of the individual sports since it only involves an individual result of the shooting arrow to the targeting set [39]. A concurrent study has been discussed about the individual athlete having a higher tendency to generate anxiety due to self-depending on the game [40]. Consequently, anxiety management technique is essential in an individual athlete rather than team games by putting aside the athlete skills factor.

3.2.3 Athlete Experienced-Based

Athlete experienced-based elucidate the level of athlete expertise in their respective sports. It can be classified into novice, intermediate and expert categories. Each category plays a different role and requires variation approach to tackle the anxiety problem. Apart from that, Modroño and Guillen [41] claimed the relation between age and anxiety level in sports performance. Since the older athletes having more experience than young athletes, they will have different exposure in handling the anxiety. Hagan et al. [24] specified that athlete in the elite category has high self-confidence due to their strong background in skills and previous experience in attending the competition. For this reason, elite athlete proficient at interpreting their anxiety into facilitative anxiety and resulting in an excellent performance.

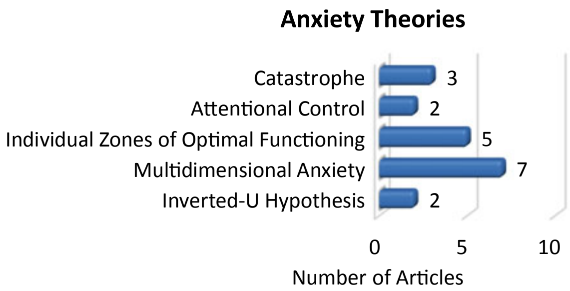


Fig. 4 Number of studies conducted on anxiety theories

3.3 Previous Studies on Anxiety Theories

Development of anxiety theories resulted in the effect of sports performance. Krane [42], McNally [43] and Zhang et al. [15] have extensively studied these emerging anxiety theory through variety scope of the literature. Majority of the researchers focused on the pertained scope related to anxiety, athlete, sport, and performance. Studies that conducted on anxiety theories give a considerable impact on athlete performance. Patel et al. [44] reported that there is a significant relationship between anxiety theories and sports performance (see Fig. 4) showed five types of theories that getting attention from researchers recently. These anxiety theories were discussed meticulously in terms of theory, functioning, characteristics, and significance in anxiety athletes and sports. Multidimensional anxiety theory indicates the most selected studied with seven articles by the researcher, followed by IZOF with five articles, Catastrophe with three articles and two articles by Attention Control and Inverted-U Hypothesis. These theories involved various sports types, such as football, basketball, hockey, tennis, running, archery, table tennis, swimming, dart, and skeet shooter. Regarding the sport classification, there are different approaches between the individual and team categories.

3.4 Anxiety Assessment Tools

Using the anxiety assessment tool is to measure the level of anxiety and quantify the data for further analysis. This review listed five types of anxiety assessment that consist of Sport Competitive Anxiety Test (SCAT), Competitive State Anxiety Inventory–2 (CSAI-2), Competitive State Anxiety Inventory–2R (CSAI-2R), Sport Anxiety Scale-2 (SAS-2) and State-Trait Anxiety Inventory (STAI). Figure 5 showed the number of the CSAI-2 specify the most selected by the researcher in these anxiety study. The anxiety assessment consists of questionnaires and Likert-type scale that required the respondent to answer the questions. CSAI-2 specify the most prevalent studied with recorded 15 articles followed behind by SAS-2 with six articles, STAI-2 with four articles, SCAT with three articles and two articles for CSAI-2R.

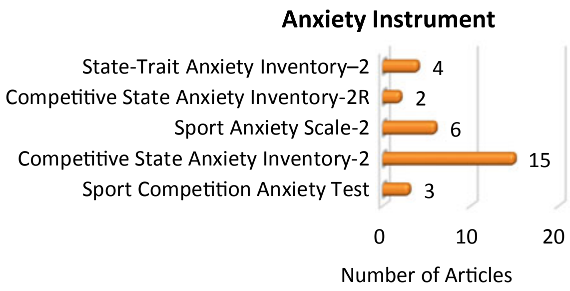


Fig. 5 Number of studies conducted on anxiety instrument

3.5 *Integration of Anxiety Theory and Anxiety Instrument*

This review emphasizes the utilization of anxiety theory are functioning well if there is a combination with a standard instrument to measure the anxiety level in quantifying data. Table 3 showed the research works that expressed the profiles on the integration of anxiety theories and anxiety. Most of the finding showed a positive response to this integrated anxiety theories and assessment. On the other hand, 6 out of 12 articles in these categories recorded the combination of Multidimensional Anxiety Theory and Competitive State Anxiety Inventory-2 (CSAI-2). This integration is the most functional in assessing competitive anxiety state in sport psychology in terms of athlete performance [14].

4 Discussion

This systematic review aimed to examine the trends of literature article related to anxiety theories and anxiety instrument that the researcher commonly studied—this review identifying the role of psychological factors among athletes in sports performance. From 33 studies, the trends focus on three categories: anxiety theories, anxiety assessment, and the integration of anxiety theories and standard instrument. This study also comprehends the sport psychological background with all categories of sport, either individual or team category. The author sought to synthesize the list of articles related to the latest selection of anxiety theories and assessment. Each theory and assessment address a different limitation and have their complexities. The integration between these anxiety theories and assessment brought a significant factor in enhancing the sport performance in terms of psychological problems. The integration was aiding each other to verify the anxiety towards sports performance result. The data listed in this review provides researchers and coaches with a complete summary of the evidence to this topic. Reviewing the integration of anxiety theory and anxiety assessment also acts as a medium or functional to guide research and enhance future sports psychological practice especially for individual sport categories such as archery, running, swimming, cycling and other sport that focuses on individual

Table 3 Summary results from studies in the combination of anxiety theory and instruments

Author	Purpose	Anxiety theory	Assessment instrument	Participant description
[35]	To investigate the importance of the mild level of anxiety training towards the consistent performance in athletes	Attentional Control Theory (ACT)	State-Trait Anxiety Inventory (STAI)	24 dart athletes (16 men, 8 women)
[44]	To evaluate management principles of performance anxiety symptoms in young athletes	Drive, Inverted-U Hypothesis Multi-Dimensional Anxiety, Individual Zone of Optimal Function, Reversal, and Catastrophe	SAS, CSAI-2, CSAI (Children), CSAT, STAI, STAI (Children)	Young female athletes
[10]	To examine the influence of anxiety level on the gun barrel kinematics, quite an eye concentration, and performance in elite athlete levels	Attentional Control Theory (ACT)	Competitive State Anxiety Inventory–2 (CSAI-2)	16 skeet shooter elite-level
[45]	To examine the effect of both somatic and cognitive anxiety level during sport competition among athletes	Drive theory and Multidimensional Anxiety Theory	Competitive State Anxiety Inventory–2 (CSAI-2)	112 athletes from football, silat, swimming, takraw, basketball and hockey
[46]	To identify somatic anxiety and sport performances among football athletes with various skills and techniques	Drive theory	Competitive State Anxiety Inventory–2 (CSAI-2)	119 Football players
[47]	To determine somatic anxiety and sport performances among Running athletes of different techniques and skills	Multidimensional Anxiety Theory	Competitive State Anxiety Inventory–2 (CSAI-2)	107 running athletes

(continued)

Table 3 (continued)

Author	Purpose	Anxiety theory	Assessment instrument	Participant description
[48]	To apply treatments intended to regulate athletes' anxiety levels before the competition by maximizing the performance	1. Multidimensional theory 2. Individual Zone of Optimizing Functional (IZOF)	1. Competitive State Anxiety Inventory–2 (CSAI-2) 2. State-Trait Anxiety Inventory (STAI)	7 Professional volleyball
[24]	To examine an irregular patterning of anxiety, dimensions of intensity, and frequency of intrusions in athletes across gender and skill level for competition	Multidimensional anxiety theory	Competitive State Anxiety Inventory–2 (CSAI–2)	90 table tennis athletes
[26]	To determine the division of anxiety level and anxiety state that effected to swimming performance	Multidimensional anxiety theory	Competitive State Anxiety Inventory–2 (CSAI–2)	61 male swimmers
[49]	To identify elite athletes' performance-related emotions and emotional profiles	Individual Zone of Optimizing Functional (IZOF)	Borg's Category Ratio (CR-10) scale	13 elite athletes
[7]	To investigate the motivational profiles among table tennis players	Self-determination theory	Sport Anxiety Scale-2 (SAS-2)	323 table tennis athletes

performance. Due to this reason, individual sport commonly experienced a high level of anxiety than in a team sport.

This review covered various anxiety theories: inverted-U hypothesis, multidimensional anxiety, catastrophe theory, individual zones of functioning, and anxiety attentional theory. In total, nineteen (19) studies leveraged a different persuasion on how the anxiety perceived, and seven (7) articles used Multidimensional anxiety theory (MAT) that composed of both elements of anxiety which are cognitive and somatic anxiety. MAT hypothesizes that there is a negative linear relationship between cognitive state anxiety toward athlete performance. While five (5) studies investigated the optimal level of pre-competitive anxiety level and how anxiety functioning created around the competitive situation. This study covered in Individual Zone of Optimal

Functioning. Only two studies were covering the Inverted-U Hypothesis and Attentional Theory for each. A vast majority from sport psychology researcher prefers to include anxiety assessment in their research. In total, 28 articles selected for anxiety assessment. There are fourteen studies on CSAI-2, five studies on SAS-2, four studies for STAI-2 and three SCAT studies. However, somatic anxiety and cognitive anxiety must work together in some interactive way to affect performance. It is crucial importance for a better understanding effect on anxiety performance. Multidimensional Anxiety Theory has received considerable criticism due to limited functionality in term of independent effects between cognitive and somatic anxiety upon athletic performance in sport.

Moreover, less explanation on MAT gives bad influences of anxiety interpretation on athlete performance [28]. Afterwards, the integration between anxiety theory and anxiety assessment is the best component to describe anxiety performance. MAT theory and the integration of CSAI-2, showing the best pairing and getting more attention from this research. This integration recorded the highest used by the researcher with six articles. The rest of the integration is between ACT theory with STAI anxiety assessment, IZOF theory with STAI anxiety assessment and ACT theory with CSAI-2 anxiety assessment.

5 Conclusion

A recent disruptive trend in anxiety theories and assessment is the wave of development in psychological sports performance. This systematic review focuses on the current studies on anxiety theories, anxiety assessment, and the integration of both anxiety theories and assessment to the athlete performance. The work presented here is essential for assessing both functions of anxiety theory and anxiety assessment together. So, the coaches can arrange the strategy on cognitive and somatic training to the athlete and evaluate the anxiety level among athletes. The functional of the anxiety theories getting extensively by using an anxiety assessment to step up the athlete performance. The tested result becomes more precise as it inspects from two sides of cognitive and somatic anxiety components. The authors highlight the most pressing of anxiety theory and assessment for current trends from a researcher in sport psychology area. However, this study addresses the importance of the integration of both anxiety theories and assessment. However, less attention has been paid to the anxiety situation, participant, types of sport and all aspects. Consequently, further studies should focus on filling the gap that keeps practitioners or researcher of sport psychology and coaches in enhancing the anxiety performance among athletes.

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References

1. Gorgulu R, Cooke A, Woodman T (2019) Anxiety and ironic errors of performance: task instruction matters. J Sport Exerc Psychol 41:82–95
2. Gross C, Hen R (2004) The developmental origins of anxiety. Nat Rev Neurosci 5(7):545–552
3. Balyan K, Tok S, Tatar A, Binboğa E, Balyan M (2016) The relationship among personality, cognitive anxiety, somatic anxiety, physiological arousal, and performance in male athletes. J Clin Sport Psychol 10:48–58
4. Judge L et al (2016) The impact of competitive trait anxiety on collegiate powerlifting performance. J Strength Cond Res 30:1
5. Fry J (2019) Sport and the anxious mind. J Philos Sport 46(2):177–190
6. Mesagno C, Garvey J, Tibbert S, Gröpel P (2019) An investigation into handedness and choking under pressure in sport. Res Q Exerc Sport 90:1–10
7. Chu A, Zhang T, Hung T-M (2018) Motivational profiles in table tennis players: relations with performance anxiety and subjective vitality. J Sports Sci 36:2738–2750
8. Ortín-Montero F, Martínez-Rodríguez A, Reche C, Fayos-Ruiz E, Gonzalez Hernandez J (2018) Relationship between optimism and athletic performance. Systematic review. An Psicol 34
9. Merino Fernández M, Dal Bello F, Brabec L, Brito C, Miarka B, López Díaz de Durana A (2019) State-trait anxiety and reduced emotional intelligence in combat sport athletes of different genders and competitive levels. J Phys Educ Sport 19:363–368
10. Causer J, Holmes P, Smith N, Williams A (2011) Anxiety, movement kinematics, and visual attention in elite-level performers. Emotion (Washington, DC) 11:595–602
11. Jones MV, Uphill M (2004) Responses to the Competitive State Anxiety Inventory-2(d) by athletes in anxious and excited scenarios. Psychol Sport Exerc 5(2):201–212
12. O'Brien K, O'Keeffe N, Cullen H, Durcan A, Timulak L, McElvaney J (2017) Emotion-focused perspective on generalized anxiety disorder: a qualitative analysis of clients' in-session presentations. Psychother Res 29:1–17
13. Kaplánová (A) Self-esteem, anxiety and coping strategies to manage stress in ice hockey. Acta Gymnica 49
14. Ağaoğlu YS (2016) Responses to the competitive state anxiety inventory–2 by the athletes participated in the (IJF) judo grand prix competition. Samsun 2015 in Turkey, vol 11, pp 3259–3275
15. Zhang S, Woodman T, Roberts R (2018) Anxiety and fear in sport and performance. In: Oxford research encyclopedia of psychology
16. Bugos J, Lee W (2014) Perceptions of challenge: the role of catastrophe theory in piano learning. Music Educ Res 17(3):312–326
17. Danthony S, Mascret N, Cury F (2019) Test anxiety in physical education: the predictive role of gender, age, and implicit theories of athletic ability. Eur Phys Educ Rev
18. Correia M, Rosado A (2019) Anxiety in athletes: gender and type of sport differences. Int J Psychol Res 12(1):9–17
19. Jones ES, Mullen R, Hardy L (2019) Measurement and validation of a three factor hierarchical model of competitive anxiety. Psychol Sport Exerc 43:34–44
20. Turker H, Sze H (2013) Surface electromyography in sports and exercise. In: Electrodiagnosis in new frontiers of clinical research
21. Gillham A, Doscher M (2019) Using sport psychology research to address commonly overlooked strength and conditioning coaching problems. Strength Cond J 41(2):38–45
22. Ruiz M, Raglin J, Hanin Y (2015) The individual zones of optimal functioning (IZOF) model (1978–2014): historical overview of its development and use. Int J Sport Exerc Psychol
23. Ring C, Kavussanu M, Al-Yaaribi A, Tenenbaum G, Stanger N (2019) Effects of antisocial behaviour on opponent's anger, attention, and performance. J Sports Sci 37(8):871–877
24. Hagan JE Jr, Pollmann D, Schack T (2017) Interaction between gender and skill on competitive state anxiety using the time-to-event paradigm: what roles do intensity, direction, and frequency dimensions play? Front Psychol 8:692

25. Bebetsos E (2018) How important is the role of national division and experience on water-polo players' levels of anxiety and aggression? Pol Psychol Bull 49
26. Mabweazara SZ, Leach L, Andrews BS (2016) Predicting swimming performance using state anxiety. South Afr J Psychol 47(1):110–120
27. Elliott D, Polman R, Taylor J (2014) The effects of relaxing music for anxiety control on competitive sport anxiety. Eur J Sport Sci 14:S296–S301
28. Wagstaff C, Neil R, Mellalieu S, Hanton S (2012) Key movements in directional research in competitive anxiety. Routledge online studies on the Olympic and Paralympic games: book chapters, vol 1, pp 143–166
29. Silva-Rocha VV, de Sousa DA, Osorio FL (2019) Psychometric properties of the Brazilian version of the Sport Anxiety Scale-2. Front Psychol 10:806
30. Pons J, Viladrich C, Ramis Y, Polman R (2018) The mediating role of coping between competitive anxiety and sport commitment in adolescent athletes. Span J Psychol 21:E7 (in English)
31. Xiao Y, Watson M (2017) Guidance on conducting a systematic literature review. J Plan Educ Res 39(1):93–112
32. Brereton P, Kitchenham BA, Budgen D, Turner M, Khalil M (2007) Lessons from applying the systematic literature review process within the software engineering domain. J Syst Softw 80(4):571–583
33. B. Kitchenham (2004) Procedures for performing systematic reviews
34. Whittemore R, Knafl K (2005) The integrative review: updated methodology. J Adv Nursing 52(5):546–553. https://doi.org/10.1111/j.1365-2648.2005.03621.x
35. Oudejans RRD, Pijpers JR (2010) Training with mild anxiety may prevent choking under higher levels of anxiety. Psychol Sport Exerc 11(1):44–50
36. Hill DM, Shaw G (2013) A qualitative examination of choking under pressure in team sport. Psychol Sport Exerc 14(1):103–110
37. Soltani H, Hojati Z, Hosseini S (2016) Comparative analysis of competitive state anxiety among team sport and individual sport athletes in Iran. Phys Educ Stud 20:57–60
38. Mahmoodreza M, Alireza A, Zahra R (2012) The relationship between coaches' and athletes' competitive anxiety, and their performance. Iran J Psychiatry Behav Sci 7(2)
39. Ahmad Z, Taha Z, Hassan HA, Hisham MA, Johari NH, Kadirgama K (2014) Biomechanics measurements in archery. J Mech Eng Sci 6:762–771
40. Kolayis H, Sariade I, Sarı I (2011) Anxiety, self-esteem and competition ranking of judokas. Arch Budo 7:11–15
41. Modroño C, Guillen F (2011) Anxiety characteristics of competitive windsurfers: age, gender, performance outcome. J Sport Behav 34:281–294
42. Krane V Conceptual and methodological considerations in sport anxiety research: from the inverted-U hypothesis to catastrophe theory. Quest 44(1):72–87
43. McNally IM (2002) Contrasting concepts of competitive state-anxiety in sport: multidimensional anxiety and catastrophe theories. Online J Sport Psychol 4(2):10–22
44. Patel D, Omar H, Terry M (2010) Sport-related performance anxiety in young female athletes. J Pediatr Adolesc Gynecol 23:325–335
45. Parnabas VA, Mahamood Y, Parnabas J (2013) The relationship between cognitive and somatic anxiety on performance of student-athletes of Universiti Malaysia Perlis (UNIMAP). Sport Art 3:61–66
46. Parnabas VA, Mahamood Y (2013) Cognitive and somatic anxiety among football players of different ethnics groups in Malaysia. Procedia Soc Behav Sci 85:258–266
47. Parnabas V, Parnabas J, Parnabas AM (2015) The relationship between somatic anxiety and sport performance on running athletes.Eur Acad Res 2(10)
48. Nogueira F, Filho M, Lourenço L (2019) Application of IZOF model for anxiety and self-efficacy in volleyball athletes: a case study. Revista Brasileira de Medicina do Esporte 25:338–343
49. Cooper JJ, Johnson M, Radcliffe J, Fisher J (2018) Optimal emotional profiles for peak performance in strength and conditioning. J Strength Cond Res (2018)

The Association of Socio-demographic Characteristics Towards Driver Behaviour and Traffic Fatality in Selangor, Malaysia

Nurul Qastalani Radzuan, Mohd Hasnun Arif Hassan, Khairil Anwar Abu Kassim, Ahmad Azad Ab. Rashid, Intan Suhana Mohd Razelan, and Nur Aqilah Othman

Abstract There are more than 6,000 road traffic fatalities each year in Malaysia since 2004, although the index of road traffic fatality per 100,000 population is decreasing steadily each year. Selangor, one of the states in Malaysia, has recorded the highest road traffic fatalities in 2019. Since traffic accidents and driver's behaviour is correlated, this study aims to understand the association between the socio-demographic characteristics and driver's behaviour, and the correlation between these parameters and road fatality. Road traffic accidents in Selangor in the year 2019 were used as the input data in this study. The selected socio-demographic characteristics are gender, age group, ethnicity, level of education, job specification, and type of driving licence. The statistics show that most of the fatalities involve employed young Malay drivers with more than five years driving experience. A classification model was formulated to classify the driver's behaviour based on the socio-demographic characteristics and vehicle type data. In addition, another classification model was developed, combining the aforementioned parameters as independent variables to classify the occurrence of fatal accidents. The supervised machine learning analysis was conducted using classifiers such as Random Forest, Classification Tree, Neural Network, Support Vector Machine, and Naïve Bayes using Orange data mining software. Random Forest was found to produce the most accurate classification of both

N. Q. Radzuan · M. H. A. Hassan (✉)
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
e-mail: mhasnun@ump.edu.my

K. A. Abu Kassim · A. A. Ab. Rashid
Malaysian Institute of Road Safety Research, 43000 Kajang, Selangor, Malaysia

I. S. Mohd Razelan
Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

N. A. Othman
Faculty of Electrical and Electronics Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

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driver's behaviour based on the socio-demographic characteristics, and the occurrence of fatal accidents as compared to other classifiers. This study shows that socio-demographic characteristics are indeed associated with driver's behaviour, and both socio-demographic characteristics and driver's behaviour are among the causes of fatal accidents.

Keywords Driving behaviour · Socio-demographics · Traffic fatality · Supervised machine learning

1 Introduction

Selangor is one of the states with a very dense population in Peninsular Malaysia alongside Johor and Kedah. The population in Selangor is approximately 6.53 million. The state comprises of Klang Valley and Greater Kuala Lumpur which offers massive job opportunities that attract people from other states. The rapid development in the Federal Territory of Kuala Lumpur increases the land prices, living cost, as well as creating a level of service (LOS) F congestion, therefore people who work in Kuala Lumpur prefer to live outside of Kuala Lumpur, for instance in Selangor. In addition, the Federal Territory of Putrajaya is also located in the vicinity of Selangor, thus contribute to the traffic activities in and out of Selangor. According to Department of Statistics Malaysia, Selangor has the highest road traffic fatality cases in 2019 as shown in Fig. 1.

Traffic accidents can be linked to driver's behaviour, but driver's behaviour does not necessarily focused on driver's personality as in reckless driving. Yet, it may also

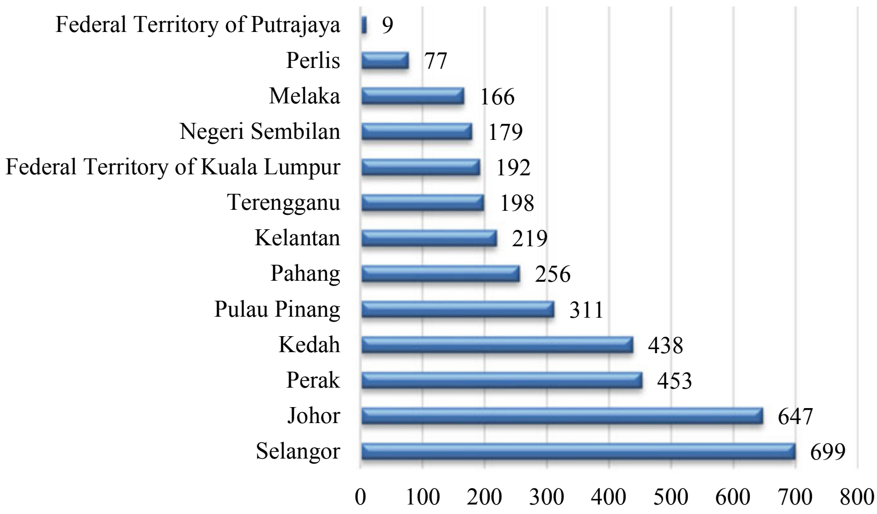

Fig. 1 Traffic fatality cases in all states and federal territories of Peninsular Malaysia in 2019

be related to driving patterns. For example, the driving pattern at start-up signalized junction [1] or at on-ramp/off-ramp [2]. Driver's behaviour information is beneficial to traffic authorities in designing guidelines to avoid traffic conflict. In general practice, driver's behaviour is normally observed through self-report surveys, analysis of police report data, using driving simulator, and video capturing method.

Self-report survey usually associated with Driver Behaviour Questionnaire (DBQ) that later the researcher may learn the driver personality behaviour. DBQ and police report data is widely used in the evaluation of driver behavioural personality and assessment of traffic violation performed by the driver [3–11]. Personal information customarily collected such as age, gender, ethnicity, years' experience of driving, marital status, education level among others to classify and understand the driver. This is important for the traffic authorities to justify which focus group that needs to be prioritised before other types of groups. Then, the campaign, education, and training can be executed in focus.

For Selangor case study, Nazlin and Siti Zawiah constructed Malaysian Driving Behaviour Questionnaire to investigate ageing-population-drivers who probably have cognitive deterioration along with visual and hearing impairment [12]. Rosli et al. revealed violations section have contributed the highest score among others (violations, errors, and lapses) which demonstrated drivers may have committed potentially dangerous acts that could result in traffic collisions. This survey was performed through DBQ distribution at several Rest & Relaxation (R&R) centres in Klang Valley [13].

On the other hand, Borhan et al. focused on motorcyclists' socio-demographics and risk-taking behaviour at signalized junction in Sungai Buloh, Selangor. It appeared that young adults aged 16–25 years old with low income and low education level violated traffic rules at signalized junctions despite the result not claiming to represent the whole Malaysian motorcyclist population [14]. In earlier years, Ramli et al. investigated the effectiveness of helmet wearing behaviour towards facial injuries using police reports and hospital medical records. A crucial finding was that the visors of motorcycle safety helmets were not designed for impact absorption thus unable to protect facial injuries [15].

Radzuan investigated the effect of merging and diverging lane length towards driving patterns at the Federal Highway in Shah Alam, Selangor through a recorded video. The study concluded the lane length may influence the speed behaviour and variation [16]. Any method of driver behaviour data collection can be combined as performed by Makhtar et al. who used the combination of self-report survey and video recording to investigate distracted driving behaviour [17]. The authors later reported the result of distracted activities was far less than previous surveys performed by Abu Bakar and Osman [18].

2 Objective and Methodology

This study aims to understand the association between the driver's socio-demographic characteristics and driver's behaviour in Selangor based on Selangor's road traffic accident data of 2019. These characteristics include gender, age group, ethnicity, level of education, career status, and type of driving licence. The list of driver behaviours which is also the same as traffic violations and errors then later was analysed to investigate their influence in resulting traffic fatality. The traffic collision data as well as drivers' details that were provided by the Traffic Division, Royal Malaysian Police, Bukit Aman were analysed. The driver's detail was collected through a police report made pertinent to the traffic collision occurrence.

A total of 1,490 traffic collisions was recorded by Royal Malaysia Police Data in 2019 in Selangor. Data screening was performed to remove any redundancy and incomplete data. After that, the traffic collision data was tabulated to synchronize with police report data to retrieve the socio-demographic characteristics data. The actual police report data was 2,058 reports including both traffic offenders and the witnesses for 2019. Traffic violations and errors that were listed were decided by the investigation officers. The listed traffic violations and errors made by drivers among others are (1) careless driving, (2) improper traffic signal, (3) improper vehicle park, (4) reckless driving, (5) tailgating closely, (6) exceeding road speed limit, (7) disobeying traffic light, and (8) others. After excluding the non-guilty persons, a total of 258 data remained to be further analysed.

The balance of 258 traffic collision data comprises of accidents that resulted in fatalities, serious injuries, slight injuries, and no-injury/vehicle damaged. The victim caused by the traffic collision could be either one or multiple victims, either the driver, passenger, or pedestrian meanwhile there could be multiple drivers resulting in traffic fatality. Therefore, this study may select only one driver detail from the case summary provided in the police report that we think has a high possibility of causing traffic fatality.

2.1 Classification Model

Classification model is a developed model in which the datasets were processed so that it can be described and recognized in its data classes. Supervised classification models are generated based on the training data whose independent variables and target variables are known, and then, they are used on a new dataset to predict the target variable. There are different methods of classification: neural networks, decision trees and regression. When a decision tree is used to classify a nominal target variable, it is called a "classification tree", and when it is used to predict a continuous one, it is called a "regression tree".

The analysis of this study was conducted using Orange Data Mining Software Version 3.20.1. Orange is a machine learning tool that is able to perform data analysis and visualization of the given data. It is very easy to perform analysis using the data mining software as its analysis does not need complex coding writing but widget placement only. As any developed model normally will be split into proportion of 70% of train data and another 30% of test data, the data sampler widget of the software may automatically select the fixed proportion of the test data as requested.

The input data set was performed a ranking score in the Orange software to ensure the most informative features will be selected for several classifiers. Several supervised classification models were chosen to compare the ability of independent variables in classifying eight types of driver behaviour as well as classifying the fatal and non-fatal collision. The classifiers among others are Random Forest, Classification Tree, Neural Network, Support Vector Machine, and Naïve Bayes.

Random Forest was discovered by Leo Breiman in 2001 [19] which at the beginning was influenced by his own bagging technology articles [20, 21] and randomized tree by Amit and Geman [22]. It consists of many decision trees together in its group therefore weak estimators were improvised and became accurate during the model development process. As a random forest generates many small-depth and random subset trees, it then combines or aggregates the subtrees to avoid overfitting. Random forest is also able to give a precise prediction when being used for large datasets.

Classification Tree in earlier history first appeared in Theta Automatic Interaction Detection (THAID) as the first classification tree algorithm by Messenger and Mandel in 1972 [23]. Then later the Classification and Regression Tree (CART) algorithm was developed by Berkeley and Stanford professors [24]. As discussed earlier, a target variable in categorical group form may make it be called a Classification Tree where the model tends to identify in which class the independent variables may fall into. Meanwhile a target variable in continuous data may be called Regression Tree. In general, the dataset may keep on dividing at a node based on the value of a variable until the branch is terminal and cannot be split any longer.

Neural Network was first described by Warren McCulloch and Walter Pitts as connectionism in the manner of neurons in the brain's activity [25]. Donald O. Hebb then proposed the neural pathways intensify in every succeeding use, particularly between neurons that have a tendency to fire within the point. Thus it begins a process towards expressing the complex processes of the brain [26]. The first neural machine, Mark 1 Perceptron, has the ability to self-learn was successfully developed by Frank Rosenblatt [27]. A typical neural network topology consists of input layers which are determined by independent variables, hidden layer where neurons are positioned, and the output layer correspond to target variable as shown in Fig. 2. Example of multi-input single output (MISO) ANN model with a network topology.

Support Vector Machine is a supervised machine learning classifier that was concluded from statistical learning theory of Vapnik and Chervonenkis [28]. It can be used either for classification or regression problems. In classification problems, Support Vector Machine optimally distinct data into two or more categories then constructing N-dimensional hyperplane from a margin in a data plane. The larger distance of the margin, the better support vector would be. Once the hyperplane has

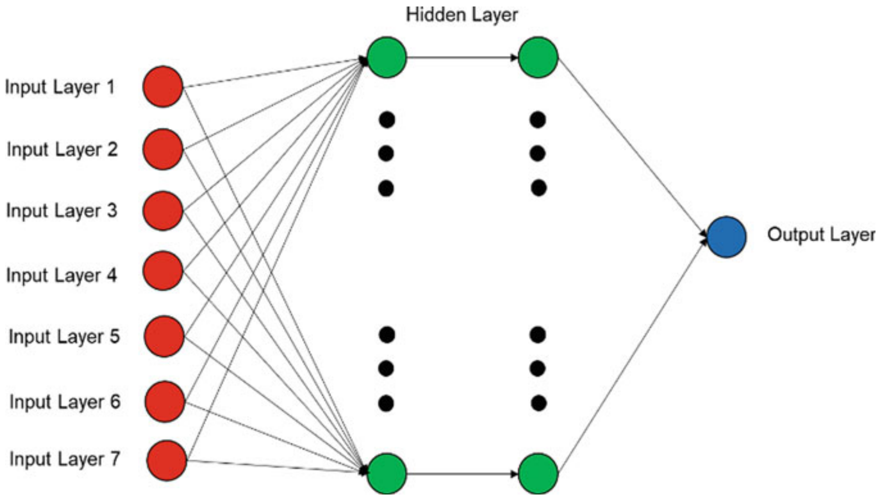

Fig. 2 Example of multi-input single output (MISO) ANN model with a network topology

been distinct and classifying points have been separated, the support vector may define kernel function to take the data as an input then modify it into the required form.

Naïve Bayes was named after Thomas Bayes whose Bayes Theorem's founder became the base of Naïve Bayes classifier in 1973 [29]. The theorem explains methods in computing a distribution for a probability parameter in binomial distribution. In the classification model of machine learning, Naïve Bayes classifier calculates the probability of a class variable given in independent variables and then predicts the class of the target variable with the highest following probability. As the name is naïve, the classifier is robust to noise data and insensitive towards irrelevant data attributes.

The Orange workflow is depicted in Fig. 3.

3 Result and Discussion

According to the data, over 70% of the fatal accident frequently occured in evening hours between 12 noon and 6 pm, on Thursdays. Young Malay male, with secondary school as the highest education level are among the traffic victim characteristics that are frequently seen in the police report. The socio-demographic characteristics fit the characteristics of 'Mat Rempit', a term used in Malaysia to describe daredevils rider who mostly involved in illegal motorcycle street racing among other illegal activities [30–34]. Ismail et al. and Ibrahim et al. reported that most of the unemployed and low-skilled workers engaged in risky riding aggression in a way for cheap

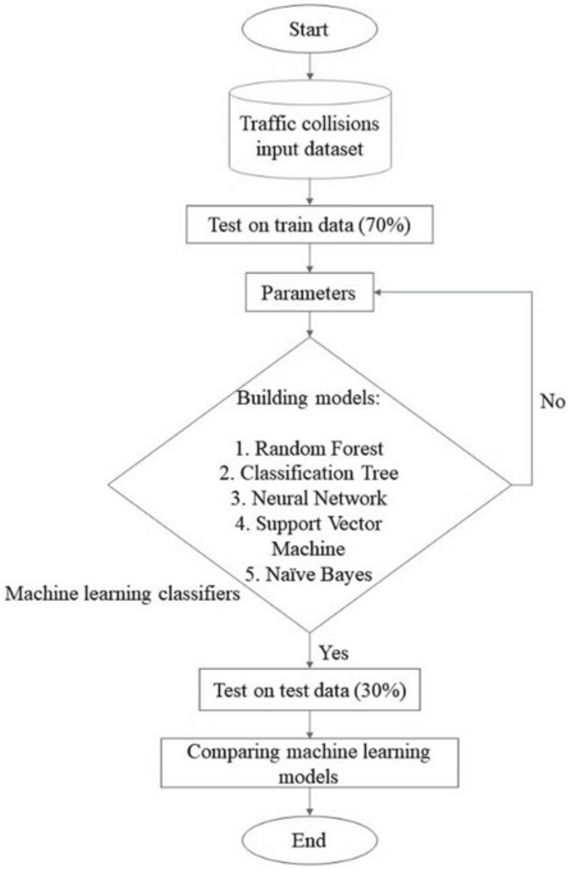

Fig. 3 Classification model development through Orange software

amusement and sensation seeking pleasure [35, 36]. However, according to Table 1, most of the vehicles involved in the 258 accident cases were passenger cars, and not motorcycle.

We speculated that the socio-demographic data in the police report is incomplete, probably due to the fact that some of the drivers involved in road traffic accidents did not file a report to the police. Many of these cases may occur in an accident between a passenger car and a motorcycle. Motorcycle collision is a national road traffic issue as reported in Malaysia traffic fatality statistics [37]. Moreover, there are an abundance of underbone-type and scooter-type motorcycles in Malaysia due to its affordable price, low fuel consumption, and congestion friendly. The trend is the same for highly populated neighbouring countries such as Indonesia, Vietnam, and Cambodia.

The most repetitive data of traffic fatality collisions had a full license with over 5 years of experience. The minimum and maximum age of fatal victims are newborn babies and 92 years old respectively. It is worth to mention that the legal age to

Table 1 Socio-demographic characteristics of traffic offenders in Selangor for 2019

Characteristics	Median	Mode
Vehicle year make	2019	
Vehicle type	Passenger car	
Foreign drivers	Singaporean	Not related
Gender	Male	
Age range	31–41 years old	16–30 years old
Ethnicity	Malay	
Type of license	Full license > 5 years old	
Highest education level	Secondary school	
Employment status	Employed	

obtain a riding and driving license in Malaysia is 16 years old and 17 years old respectively therefore a full license holder with 5 years of experience could be as young as 21–22 years old victim.

3.1 *Variables Association Towards Drivers' Behaviours*

A set of socio-demographic characteristics and vehicle type data was analysed using Orange data mining software to determine the ability of these characteristics to classify the driver's behaviour based on the socio-demographic characteristics. Table 2 shows method used and the classification accuracy between the train and test data.

As presented in Table 2, Random Forest classifier outperformed Classification Tree, Neural Network, Support Vector Machine, and Naïve Bayes in predicting drivers' behaviours. This shows that Random Forest has a good ability to dispute noise data and able to generate plenty of classification trees. The classification accuracy of 70% generated by Random Forest as listed in Table 2 also shows that there is indeed a correlation between the socio-demographic characteristics and driver's behaviour.

Table 2 Classification accuracy among classifiers in classifying driver behaviour

Classifier	Classification accuracy of train data	Classification accuracy of test data
Random Forest	0.760	0.707
Classification Tree	0.673	0.673
Neural Network	0.600	0.600
Support Vector Machine	0.573	0.573
Naïve Bayes	0.327	0.327

Table 3 Classification accuracy among classifiers in predicting traffic fatality cases

Classifier	Classification accuracy of train data	Classification accuracy of test data
Random Forest	0.804	0.784
Classification Tree	0.763	0.763
Neural Network	0.722	0.711
Naïve Bayes	0.649	0.649
Support Vector Machine	0.598	0.598

3.2 Variables Association Towards Traffic Fatality Cases

In addition to the previous classification model, drivers' behaviours data was included in a variable list to determine the ability of these variables to predict traffic fatality cases. Table 3 shows that Random Forest once again is able to achieve highest classification accuracy.

The evaluations shows that Random Forest can classify fatal or non-fatal collisions with 80.4% accuracy while Classification Tree, Neural Network, Naïve Bayes, and Support Vector Machine gives accuracy percentages of 76.3%, 72.2%, 64.9%, and 59.8% respectively. It is shown that with an almost 80% accuracy, the socio-demographic characteristics and driver's behaviour do influence the severity of the accidents, that is fatal or non-fatal.

4 Conclusion

The study was performed with an intention to understand the association between socio-demographic characteristics and vehicle type data, and driver's behaviour based on the road traffic accidents data reported in Selangor in 2019. Our first analysis shows that Random Forest is the best classifier with an accuracy of 70%. This also shows that there is a strong correlation between socio-demographic characteristics and driver's behaviour. Further, our second analysis again shows that Random Forest provided the best classification of fatal accidents, with an accuracy of 80%. This shows that socio-demographic characteristics and drive's behaviour indeed determine the outcome of an accident, whether it is going to be fatal or not. Therefore, an intervention project focusing on these variables is needed to overcome the traffic fatality cases in Selangor. Future work should focus more on the socio-demographic characteristics to determine which are the most relevant characteristics that influence the driver's behaviour, hence resulted in a fatal accident.

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References

1. Almallah M, Alfahel R, Hussain Q, Alhajyaseen WKM, Dias C (2020) Empirical evaluation of drivers' start-up behavior at signalized intersection using driving simulator. Procedia Comput Sci 170:227–234
2. Radzuan NQ, Adnan MA (2014) Macroscopic merging model development. In: 2014 IEEE colloquium on humanities, science and engineering, 2014, pp 599–604
3. Li L, Shults RA, Andridge RR, Yellman MA, Xiang H, Zhu M (2018) Texting/emailing while driving among high school students in 35 states, United States, 2015. J Adolesc Health 63(6):701–708
4. Monroe K, Nichols M, Crew M, Brown L, King W (2020) Evaluating teen driving knowledge and behaviors following educational outreach. Inj Epidemiol 7(Suppl 1):1–6
5. Bazargan-Hejazi S et al (2017) The theory of planned behavior (TPB) and texting while driving behavior in college students. Traffic Inj Prev 18(1):56–62
6. Rudisill TM, Smith G, Chu H, Zhu M (2018) Cellphone legislation and self-reported behaviors among subgroups of adolescent U.S. drivers. J Adolesc Health 62(5):618–625
7. Rudisill TM, Zhu M (2017) Hand-held cell phone use while driving legislation and observed driver behavior among population sub-groups in the United States. BMC Public Health 17(1):1–10
8. Trivedi N, Beck KH (2018) Do significant others influence college-aged students texting and driving behaviors? Examination of the mediational influence of proximal and distal social influence on distracted driving. Transp Res Part F Traffic Psychol Behav 56:14–21
9. Elias W, Shiftan Y (2017) Ethnic groups differences in regard to social networks, daily activity patterns, and driving behavior. Transp Res Part F Traffic Psychol Behav 46:316–328
10. Jahanfar S (2018) Driving habits—a Canadian study. Trauma (United Kingdom) 20(3):225–229
11. Putranto LS, Alyandi YF (2019) The relationship between children education in the family and car driving and motorcycle riding behaviour in Indonesia. Int J Integr Eng 11(6):254–267
12. Nazlin H, SitiZawiah M (2016) The cross cultural study on driving behaviour of Malaysian. Malaysian J Public Health Med 16(2):121–127
13. Rosli NS, Yunus JM, Hanan SA (2017) Testing the Driving Behavior Questionnaire (DBQ) on Malaysian drivers. In: The 12th Malaysian universities transport research forum conference, 2017, vol 15
14. Borhan MN, Ibrahim ANH, Aziz A, Yazid MRM (2018) The relationship between the demographic, personal, and social factors of Malaysian motorcyclists and risk taking behavior at signalized intersections. Accid Anal Prev 121:94–100
15. Ramli R, Oxley J, Hillard P, Mohd Sadullah AF, McClure R (2014) The effect of motorcycle helmet type, components and fixation status on facial injury in Klang Valley, Malaysia: a case control study. BMC Emerg Med 14(1):1–11
16. Radzuan NQ (2015) A study on expressway merging and diverging traffic operation. Universiti Teknologi MARA
17. Makhtar AK, Latib MHA, Isa MH (2019) Observation study on distracted driving behaviour in Shah Alam area. J Soc Autom Eng Malaysia 3(2):185–197
18. Abu Bakar A, Osman S (2016) Using mobile phone while driving as a contributing factor to road crashes among motorist in Klang Valley: a self-reported study, Kajang, Selangor
19. Breiman L (2001) Random forests. Mach Learn 45(1):5–32
20. Breiman LEO (1996) Bagging predictors. Mach Learn 26(2):123–140

21. Breiman L (2000) Randomizing outputs to increase prediction accuracy. Mach Learn 40(3):229–242
22. Amit Y, Geman D (1997) Shape quantization and recognition with randomized trees. Neural Comput 9(7):1545–1588
23. Messenger R, Mandell L (1972) A modal search technique for predictive nominal scale multivariate analysis. J Am Stat Assoc 67(340):768–772
24. Breiman L, Friedman JH, Olshen RA, Stone CJ (1984) Classification and regression trees. Biometrics 40(3)
25. Warren SM, Walter P (1943) A logical calculus of the ideas immanent in nervous activity. Bull Math Biophys 5:115–133
26. Hebb DO (1949) The organization of behavior. Wiley, New York
27. Rosenblatt F (1957) The perceptron: a perceiving and recognizing automaton (Project PARA). Report No. 85-460-1. Cornell Aeronautical Laboratory, New York
28. Chervonenkis AY (2013) Early history of support vector machines. Emper Inference 13–20
29. Dale AI (1999) A history of inverse probability: from Thomas Bayes to Karl Pearson, 2nd edn. Springer, New York
30. Wong LP (2011) Socio-demographic and behavioural characteristics of illegal motorcycle street racers in Malaysia. BMC Public Health 11
31. Ramli R et al (2014) Fatal injuries among motorcyclists in Klang Valley, Malaysia. J Forens Leg Med 26:39–45
32. Ismail R, Din C, Lee OL, Ibrahim N, Sukimi F (2015) Theme: Knowledge for social transformation & development in the 21st century Role of sensation seeking and aggression on risk riding behaviors among motorcycle street racers in Malaysia. e-Bangi 1(1):169–179
33. Amit N, Ismail R, Ibrahim N, Said Z, Ghazali SE (2016) Sensation seeking and self-esteem differences among illegal street racers in Malaysia. Mediterr J Soc Sci 7(1):96–102
34. Abdullah H et al (2016) The effect locus of control on driving behaviour among Malaysian young drivers. J Adolesc Health 11(1):1895–1903
35. Ismail R, Din NC, Lee OL, Ibrahim N, Sukimi F (201) Role of sensation seeking and aggression on risk riding behaviors among motorcycle street racers in Malaysia. J Soc Sci Hum (1):169–179
36. Ibrahim N, Ismail R, Halim MRTA, Amit N (2015) Personality, high-risk activities and aggressive behaviour among illegal street racers. Mediterr J Soc Sci 6(5S1):527–533
37. JKJR (2020) Buku Statistik Keselamatan Jalan Raya

Design and Instrumentation

The Development of Golden Apple Snail Eggs Picker

Wan Zaiyana Yusof, Azmir Mamat Nawi, and Puteri Fadzline Muhamad Tamyez

Abstract Several potential benefits of Golden Apple Snail, or GAS have been reported, including its use as a source of food, use in the trade of aquariums, biological control of plants, as a source of protein for fish, ducks and crocodiles, and as a liquid biofertilizer. However, its physiological adaptability and capacity to travel a long distance within a water system has become an invader of new habitats. Thus, GAS is now a major pest in the cultivation of rice. Numerous research have shown that GAS can be managed at various stages of cultivation by combining chemical, mechanical, and biological steps. Nevertheless, GAS eradication has become a laborious and expensive task. This study aims to design the biological tool or prototype to eradicate this major pest. More particularly, the invention relates to a tool that adapts hand-picking method in controlling and eradicating the eggs of these pests. This study provides a society implication for paddy farmers, in which the creation of this tool is effective and important to drive the farmers to better productivity with the eradication of GAS eggs.

Keywords Golden apple snails · Paddy farmers · Picking tool

1 Introduction

Pomacea canaliculate, also referred to as golden apple snails (GAS), was first detected in Malaysia in 1991, and it took almost 10 years before it became one of the country's main rice pests. These snails reproduce quickly and usually lay eggs on any plants, leaves and other items above the surface of the water at night, with

W. Z. Yusof
Faculty of Art and Design, Universiti Teknologi MARA, Shah Alam, Malaysia

W. Z. Yusof · P. F. M. Tamyez (✉)
Faculty of Industrial Management, Universiti Malaysia Pahang, Kuantan, Malaysia
e-mail: fadzline@ump.edu.my

A. M. Nawi
Art and Design Department, Universiti Teknologi MARA, Merbok, Kedah, Malaysia

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a quantity of 1000–1200 eggs per month. The eggs normally take just 7–14 days to hatch and the hatchlings develop and mature rapidly, and this is the primary reason that causes these snails to spread widely. These golden apple snails have spread with rapid reproduction to almost all rice granaries and non-granary areas in Malaysia, targeting paddy seedlings and young paddy plants [6]. These snails usually kill young paddy stems and leaves and may consume 7–24 rice seedlings per day, resulting in severe damage to the area of rice cultivation and causing paddy farmers a huge loss [4]. Various management methods for paddy farmers, such as the use of chemical, cultural and biological control techniques have been developed in order to control and eliminate the invasion of golden apple snails.

1.1 Research Problem

One of the most common methods of golden apple snail control is to apply pesticides to the paddy plants. The use of pesticides, however will contaminate the water, further destroying biodiversity in the waterways. In addition, another important burden for paddy farmers is the cost of using the pesticide [1]. On the other hand, some paddy farmers have introduced biological control that allows the snails and their egg masses to strike and consume natural predators such as red ants, rodents, wild bird species and domestic ducks. The paddy farmers would have to spend another amount on buying and feeding the natural predators by using this strategy. Paddy farmers tend to practice hand-picking instead of chemical and biological methods to avoid paying extra costs on eradicating the golden apple snails [2]. In the morning and afternoon, when the snails are most busy, paddy farmers can easily find, pick and collect the snails and their egg masses. However, the paddy farmers could unintentionally kill the egg masses while hand-picking the egg masses, and this will cause some of the eggs to be removed from the egg masses and left on the paddy field. In addition, the paddy farmers also have to gather the egg masses in a tub, either basket or plastic bag, after selecting the egg masses [3]. As a result, paddy farmers would spend much of their time, rather than at home, in the paddy field. In order to monitor and eliminate the invasion of the golden apple snails, there is a high need to develop a tool that can efficiently select and collect the egg masses of the golden apple snails at the same time [5]. Thus, this research focuses on the design of the prototype GASP.

2 Literature Review

The main strategy is egg selection and destruction to monitor the invasion of the golden apple snails. Several instruments have been developed to help monitor the snail invasion by using the picking method to capture the golden apple snails' egg. For instance, [7, 9] revealed a hand-picking tool for golden apple snail eggs using the concept of scissor mechanism, comprising a pair of baskets that can be moved in an open condition where the baskets are separated.

This picking tool can be easily used by users to grasp the egg masses attached to plant surfaces and pull the entire picking tool up to collect the egg clusters in the baskets. This picking tool, however is inefficient since users can unintentionally clamp on some parts of the egg mass, which may either cut the egg mass in half or separate the eggs from the egg mass. A snail or snail's egg collector called *Salaan Snail Collector*, which includes a long handle and a scorpion-shaped plate attachment, is disclosed in an eBook entitled 'Low-external input rice processing (LIRP): a technology information package,' whereby these two parts are attached to the front and back of a collecting basket [8].

Without tiresome bending, the long handle allows users to quickly catch the snails and their egg masses, while the scorpion-shaped plate attachment allows users to scoop or scrape the snails and their egg masses from walls or plants without damaging them. This collector is inefficient because during the scooping or scraping operations, the snails or the egg masses will easily slip out of the attachment and fall back to the soil or plant area.

It would therefore be desirable to develop a tool that would control and eradicate the invasion of pests, especially the golden apple snails, with a simple and efficient working activity. More especially, there is a need for a method designed to imitate the technique of hand-picking in the selection and picking of the egg masses of the snails. The shortcomings of the above-mentioned revealed inventions are overcome by such an instrument.

3 Methodology

In this study, an interview protocol was adapted to answer the research objective: To create a prototype design in eradicating GAS eggs. Observations werealso conducted on the farmers and agriculture officers to explore the nature of GAS ecology, an assessment of historic and existing snails control methods and the impact of GAS to environmental, agriculture and economic. It is important to understand the farmers' behavior using the proposed hand-picking tool in order to propose a solution to identified problem.

The observations were recorded using some note-taking and visual recorded to record limiting values which must not be exceeded if users are to carry out the actions required without error, injury or discomfort. Since the data gained from literature review and interviews will be sufficient, the researcher began the process of sketching the concept ideation of the hand-picking tool through sketch modelling or maquette making instead of starting the ideation through drawing. At this stage, the researcher will be more interested to test the practicality of the concept.

4 Results and Discussion

This innovation reveals a two-part form collector which consists of a pair of pivotally linked receptacles. It move between an open condition in which the receptacles pivot away from each other and a closed condition in which the receptacles meet. There is also an opening formed between the receptacles for clamping an elongated article in the closed condition, which are attached to an external surface of the elongate article into the receptacles, in the closed condition, when the collector is moved along the elongate article. The collector can preferably be made of polymer or rubber that is recyclable. The opening can preferably be positioned at a portion where the two receptacles meet as depicted in Fig. 1.

Thus, this innovation is able to control and eradicate GAS eggs. More specifically, the invention relates to a tool that adapts the method of hand-picking to collect the egg masses of the pests as it is the most effective method of control in eradicating the pests. By using this tool, without the issue of damaging the egg masses or detaching the eggs from the egg masses, users can more easily and effectively pick and collect the egg masses.

Fig. 1 The GAS eggs picker prototype design

In addition, the egg masses can be selected and collected at the same time, which, compared to conventional collection methods, significantly reduces the collection time. As an innovative yet economical solution to overcome the invasion of harmful snails such as golden apple snails that will attack paddy seedlings and young paddy plants in the paddy fields, this tool can help paddy farmers by easily select and collect the egg masses of the harmful snails that are attached to the containers on the surfaces of paddy plants. This is done upon clamping on the paddy plants by pulling the collector up along the paddy plants.

5 Conclusions

Within 7 days of planting his rice, the Golden apple snail attacks the young plants. There are about one snail selves underground for 6 months and survive without eating. Hence, the farmers rely on pesticide only to control it. Sometimes when there's a high infestation of snails, the paddy has to be planted all over again which is also a big loss for the farmer. Therefore, the idea of GAS eggs picker is to minimize the problem that the paddy farmer faced. This tool is designed to assist the paddy farmers as an innovative solution yet economical to overcome the invasive of Apple Snails in Malaysia. GASP adapts the cultural control which is the handpicking.

The present study hopes to contribute in several ways to the existing body of knowledge on GAS. First of all, it is by improving the current prevention technique of GAS control. This research concerns the method of controlling the GAS, particularly the hand-picking technique. It is hoped that the results of this study will benefit farmers in relation to the GAS attack. This finds the researcher seeking to understand and adapt to socio-cultural circumstances by integrating hermeneutics with empiricism, and checking the outcome of the analysis in situ to verify the effectiveness. This will therefore benefit designers and provide a new platform for business opportunities as well. Ultimately, the methodology developed will also benefit the Malaysian government particularly Muda Agricultural Development Authority, by promoting different product design categories. The prototype tested among the paddy farmers will potentially assist them in less relying on pesticides which in return will reduce expenses on pesticides and prevent from generating wastes at the paddy field due to the current method they are using to eradicate the Golden apple snail eggs.

References

1. Yusa Y, Wada T (1999) Impact of the introduction of apple snails and their control in Japan. Naga ICLARM Q 22(3):9–13
2. Ranamukhaarachchi L, Wickramasinghe S (2006) Golden apple snails in the world: introduction, impact, and control measures. Global advances in ecology and management of golden apple

snails. Philippine Rice Research Institute, Nueva Ecija, pp 133–152
3. Robert HC (2002) Apple snails (Ampullariidae) as agricultural pests: their biology, impacts and management. Barke. Centre for Agriculture and Bioscience International, pp 145–192
4. Sin TS (2003) Damage potential of the golden apple snail *Pomacea canaliculata* (Lamarck) in irrigated rice and its control by cultural approaches. Int J Pest Manag 49(1):49–55
5. San Martin R, Mackenna AV (2006) Recent development in the use of botanical molluscicides against golden apple snails (*Pomacea canaliculata*)
6. Yahaya H, Nordin M, Hisham MNM, Sivapragasam A, Joshi RC, Cowie RH, Sebastian LS (2017) Invasive apple snails in Malaysia. Biology and management of invasive apple snails, 2nd edn. Philippine Rice Research Institute, pp 169–195
7. Mamat Nawi A (2011) Design through research: handpicking tools case study as facilitator to collaborative product development/Azmir Mamat Nawi and Wan Zaiyana Mohd Yusof. Universiti Teknologi MARA, Kedah
8. International Rice Research Institute (IRRI) (1990) Low-external input rice production (LIRP) Technology Information Kit, p 292
9. Nawi AM, Karim ISA, Rahim R (2002) New tool for golden apple snails eradication: case study Kuala Muda Area. In: I-CAST 2012, international conference on arts, social sciences and technology

Validity and Reliability of Instruments to Measure Knowledge, Motivation and Mindset Among Industrial Design Students in Universiti Malaysia Kelantan

Azmul Fadhli Kamaruzaman, Ahmad Rasdan Ismail, and Khairul Azhar Mat Daud

Abstract The principal goal of this article is to discuss the validity of the instrument with its reliability index in measuring knowledge, motivation and mindset among industrial design students in Universiti Malaysia Kelantan throughout Makerspace learning environment session. This article also will explain the procedure taken in ensuring the reliability and validity of the instrument which has been developed and adapted from previous research. The result indicates that the internal consistency of instruments (Cronbach Alpha) surpass the threshold value of 0.7. Throughout the face validity process, experts have shown that the level of high validity regarding the construct and the instrument itself. Besides, correlation values between items and total scores exceed the value of 0.3, which is the bare minimum index of correlation.

Keywords Instruments reliability · Industrial design · Knowledge · Motivation · Mindset

1 Introduction

Starting with Maker movement, which celebrated the arts of making and D.I.Y attitude, makerspace has been hailed to be one of the most conducive environment upon cultivating creativity through innovation and invention [1]. Maker movement is built upon ideas of sharing and collaboration which permits and encourage the user to share ideas, innovation and invention which are then used by another user in generating, creating and innovating new ideas ranging from craftsmanship, circuit building and microcontroller programming and other D.I.Y making entities. Twenty-first century learning demand for a student, mainly industrial design student who combine arts and engineering practices to be highly creative in solving a design problem. In addition to that, makerspace which comes into two modes of approach which are online and physical space are the most conducive parts in the process of development of a

A. F. Kamaruzaman (✉) · A. R. Ismail · K. A. Mat Daud
Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, 16300 Bachok, Malaysia
e-mail: azmul@umk.edu.my

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student to comply with twenty-first century teaching and learning goal. The methods are ranging from experiential learning, problem-based learning and collaborative learning are integrating with the conducive environment such as makerspace upon scaffolding students need technically and socially. Steinberg listed the working environment as one of the factors that contribute to the creativity alongside motivation, knowledge, mindset, personality and intellectual abilities [2]. This paper listed three dimensions which include motivation, knowledge and mindset together with each construct that explain those three dimensions. Most of the instruments were adapted from the other established instrument where there is a need to validate instruments to suit the purpose of the current research.

2 Research Instrument Validity

Research instrument validity is referred to as an ability of a questionnaire in measuring construct or variable [3]. Face validity or content validity is referred to as an ability of a questionnaire/instruments in collecting data that will meet the objective and requirement of the studies and the instrument is said to have high validity if it can measure what is required to be measured. Questionnaire validity is referred to the specific use of a questionnaire in this case will be about the measurement of specific respondent/samples/students whose are industrial design students in Universiti Malaysia Kelantan and is not valid to be used for a respondent/samples/students in other programmed which are beyond the industrial design discipline.

The instruments are also designed to conduct pre-test and post-test research and did not includes the involvement of exploratory construct development and the validity is done through face validity process. This paper also dealt with contents and construct validity through face validity process and not the internal and external validity of the experimental research design.

Validity of a questionnaire also can be explained by the value of correlation of item scores with the value of total score [4]. This study utilize the value of Pearson correlation in analyzing the score of each question/item with the sum score of a construct. Earlier research classifies that the value of correlation into 3 categories which are high (0.50–1.00), medium (0.30–0.49) and small (0.10–0.29) [5]. The value of instrument's validity in measuring the Knowledge, Motivation and mindset used two methods which are item/question correlation with sum of item score and corrected item/question correlation with sum of item/question score [6].

In constructing Nomological network which serves as the theoretical model between related variables, three variables are developed based on the theory of creativity proposed by Steinberg. Theory of creativity proposed that the factor that contribute to creativity comprises of knowledge, intellectual abilities, motivation, mindset, personality and environment. All of the factor is consider to be an internal factor of a person while the environment is the external factor that contribute to the creativity. Since two of the dimension which are intellectual abilities and personality required separate methods and instrument, the other four factor except for the environment which is the treatment condition of this particular research has been developed to suit the objective.

Knowledge dimension comprises of 2 construct which are digital fabrication and electronic prototyping construct while Motivation dimension comprises of 3 construct namely self-efficacy, situational interest and achievement emotion. Self-efficacy instruments are adapted from general self-efficacy scale [7] while situational interest are adapted from Situational Interest instruments [8]. The last construct in motivation dimension are adapted from Achievement emotion instruments [9]. Mindset dimension and construct are taken from the earlier research that explains the maker mindset [10] which are playfulness [11], collaborative [12], Asset-growth oriented [13] and Resilient [14]. Table 1 summarized the definition of each construct taken from the systematic literature review search using Scopus Elsevier and Google scholar search engine.

Table 1 The definition of each construct taken from its spurce

Construct	Definition	Source
Digital fabrication	The knowledge and ability of a person in handling, designing and creating an artefact with the help of Computer Aided Design Software and Additive/subtractive manufacturing tools for examples in using 3D printing machine, CNC router and Laser cutter machine	[15–17]
Electronic prototyping	The knowledge of a person in designing and constructing an electronic circuit consist of microcontroller unit and various type of sensor, actuator and electronic components as well as literacy in computer programming	[18–20]
Self-efficacy	A person belief that his/her capabilities can encourage action, cognitive capabilities and motivation in demanded situation	[21]
Situational interest	Engaging effect of characteristics of certain activities on individuals	[22]
Achievement emotion	A type of emotion which is the result of an achievement in certain activities	[9]
Playfulness	A spontaneous attitudes of an individual with a tendency to do something/take an action in a fancy and non-serious way to elevate enjoyment, mood and work satisfaction	[11, 21]
Asset-growth oriented	Mindset of an individual who consider that their capacity can be developed over hardwork and dedication which in turn cultivates passion for learning	[23]
Resilient	An adaptation of an individual through various process and capacity in the face of challenge to became successful	[24]
Collaborative	Learning approach taken by more than one person in an attempt to learn, understanding and designing together	[25]

2.1 Face Validity

Face validity is a process where the instruments are subjectively reviewed normally by an expert in the field to make sure the purpose of the instruments and item is clear and understandable to a respondent [26]. The developed instrument to measure the level of knowledge, motivation and mindset are referred to the reviewers comment (qualitative verification and correction) consists of 4 senior lecturers in various field in Faculty of Creative Technology and Heritage (FTKW) Universiti Malaysia Kelantan in the field of industrial design, education and social sciences. Form of verification are provided to the expertise to verify the instruments. Feedback from experts are taken into a great consideration in improving the instruments. Some of the comments from experts includes inaccuracies of the term used, clarity of the question, suggestion in adding certain pertaining issues, formatting, language, clarity of the question, deletion, substitution, addition of item and grammatical correction. All reviewers comment are taken into a great consideration in the correction phase. Table 2 summarized all of the comments by reviewers while Table 3 summarized the total item for each construct before and after the revision of the instruments together with the type of instrument development.

For the development of new instrument (Digital Fabrication and Electronic Prototyping), most of the item are developed through a sythesized and identification of activities which are essential in design and has been reported in the literature which govern the used of a makerspace as an environment of teaching and learning through a systematic literature review procedure while the rest of the construct are adapted from a literature.

Table 2 Summary of comments from reviewers for contents and face validity

Reviewer	Reviewer field of expertise	Reviewer comments
A	Industrial design	Grammatical error
		Clarity of question
		Some additional item should be added in highlighting pertaining issues
B	Industrial design	Grammatical error and formatting issues
		Deletion some of the item which are repetitive
		Usage of an appropriate words
C	Social sciences	Grammatical error
		Clarity of question
D	Education	Grammatical error
		Some sentences need to be paraphrase for clarity and understanding
		Items substitution
		Some items has double barrel question
		Usage of an appropriate words

Table 3 Number of items before and after deletion, type of instrument development and its source

Variables	Construct	Number of item before face validity	Number of item after face validity	Type of Instrument development	Adaptation From
Knowledge	Digital fabrication	4	5	New development	–
	Electronic prototyping	5	6	New development	–
Motication	Self-efficacy	8	5	Adaptation	[26]
	Situational interest	23	17	Adaptation	[8]
	Achievement emotion	24	20	Adaptation	[9]
Mindset	Playfulness	23	20	Adaptation	[11]
	Asset-growth oriented	12	10	Adaptation	[13]
	Resilient	17	17	Adaptation	[13]
	Collaborative	18	15	Adaptation	[12]

3 Pilot Test

The instrument is first developed based on the dimension and construct taken from the literature review and undergo face validity. After undergo a face validity process, the instruments are then given to the 60 student from Faculty of Creative Technology and Heritage which undergo a 4 years degree in Industrial Design. Students from year 2 and year 3 from Industrial Design degree programmed are then selected to fill the questionnaire in February 2019 semester years. Data taken are then analyzed using IBM Statistical package which permits the calculation of Reliability of the instruments and correlation of the item.

Figure 1 shows the overall process flow in developing the questionnaire taken from the previous research. Establishment of the construct through literature review consists of 2 common stage namely synthesis of the literature and content validation based on the AMEE guidelines [28] while the overall process consist of the determination of Cronbach Alpha's index(reliability index) in the pilot test stage before the actual data collection stage [27].

4 Reliability of Research Instruments

Generally, the Alpha Cronbach index is the measure of the internal consistency of the instrument and explain how well the interaction of the given item which correspond to the given construct and dimension. There are 3 dimensions that need

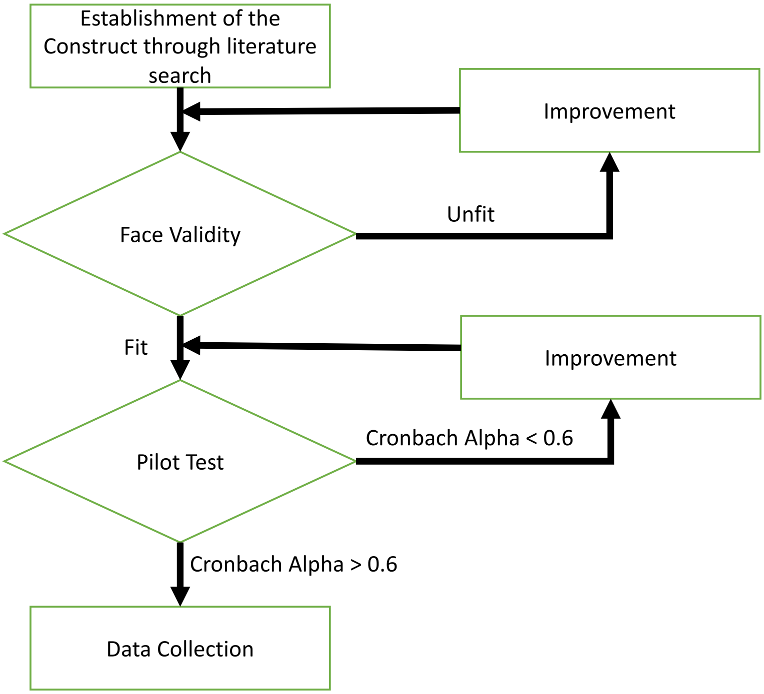

Fig. 1 The process flow chart of instruments validity and reliability taken before the data collection stage [27, 28]

to be measured which are Knowledge, Motivation and Mindset. The construct are then established based on each dimension. Noted that Item in Knowledge dimension is developed solely for this particular research whereas other construct for the following dimension are adapted from an established instrument. Table 4 shows the summary

Table 4 Cronbach Alpha reliability index for every construct in measuring the level of Knowledge, Motivation and Mindset among Industrial Design Students in Universiti Malaysia Kelantan

No.	Construct	Alpha Cronbach
1	Digital fabrication	0.862
2	Electronic prototyping	0.927
3	Self-efficacy	0.865
4	Situational interest	0.889
5	Achievement emotion	0.941
6	Playfulness	0.941
7	Asset growth oriented	0.943
8	Resilient	0.941
9	Collaborative	0.953

Table 5 Cronbach alpha reliability index of instrument in measuring digital fabrication

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Digital fabrication	1	0.687	0.791	0.834	0.862
	2	0.654	0.776	0.840	
	3	0.689	0.782	0.838	
	4	0.728	0.837	0.820	
	5	0.740	0.871	0.831	

values of Cronbach alpha of all construct. Values ranging from 0.862 to 0.953 which are considered to be high.

4.1 Knowledge Dimension

Knowledge dimension consist of two important construct which are knowledge of digital fabrication and knowledge of electronics prototyping among industrial design students in Universiti Malaysia Kelantan. Digital fabrication and electronic prototyping has been reported to be 2 most important skills and activities in maker education [29–32].

The values of reliability index for Digital Fabrication construct shown in Table 5. The overall value of Cronbach Alpha is 0.862 which is consider to be high which suggest the high internal consistency of the scale produced. The value of correlation between item score with total score and corrected item with total correlation ranging from 0.776 to 0.871 and 0.654 to 0.740 respectively which suggest the higher correlation value between item with the total score of the instrument.

For electronic prototyping knowledge construct, it is reported in Table 6 that the value of correlation between items and sum of score lies between 0.847 and 0.907 whereas the correlation between corrected item and the total score lies between 0.646 and 0.915. The reliability index of this construct are 0.927.

4.2 Motivation Dimension

For Self-efficacy construct, it is reported in Table 7 that the value of correlation between items and sum of score lies between 0.489 and 0.613 whereas the correlation between corrected item and the total score lies between 0.596 and 0.779. The reliability index of this construct are 0.865.

Table 6 Cronbach alpha reliability index of instrument in measuring electronic prototyping knowledge

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Electronic prototyping	1	0.811	0.874	0.911	0.927
	2	0.776	0.847	0.915	
	3	0.851	0.9	0.906	
	4	0.646	0.748	0.931	
	5	0.864	0.907	0.904	
	6	0.790	0.861	0.914	

Table 7 Cronbach alpha reliability index of instrument in measuring self-efficacy

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Self-efficacy	1	0.714	0.506	0.833	0.865
	2	0.779	0.611	0.813	
	3	0.679	0.489	0.86	
	4	0.679	0.495	0.839	
	5	0.713	0.613	0.834	

For Situational Interest construct, it is reported in Table 8 that the value of correlation between items and sum of score lies between 0.47 and 0.767 whereas the correlation between corrected item and the total score lies between 0.41 and 0.733. The reliability index of this construct are 0.865.

For Achievement emotion construct, it is reported in Table 9 that the value of correlation between items and sum of score lies between 0.452 and 0.814 whereas the correlation between corrected item and the total score lies between 0.507 and 0.835. The reliability index of this construct are 0.941.

4.3 Mindset

For playfulness construct, it is reported in Table 10 that the value of correlation between items and sum of score lies between 0.3 and 0.868 whereas the correlation between corrected item and the total score lies between 0.94 and 0.947. The reliability index of this construct are 0.947.

For Asset-Growth Oriented construct, it is reported in Table 11 that the value of correlation between items and sum of score resides between 0.672 and 0.937

Table 8 Cronbach alpha reliability index of instrument in measuring student's situational Interest

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Situational interest	1	0.552	0.608	0.883	0.889
	2	0.41	0.47	0.888	
	3	0.41	0.484	0.888	
	4	0.572	0.624	0.883	
	5	0.41	0.519	0.891	
	6	0.572	0.627	0.882	
	7	0.577	0.636	0.882	
	8	0.533	0.592	0.884	
	9	0.545	0.611	0.883	
	10	0.64	0.707	0.879	
	11	0.628	0.688	0.88	
	12	0.659	0.703	0.88	
	13	0.584	0.638	0.882	
	14	0.733	0.767	0.878	
	15	0.499	0.578	0.885	
	16	0.566	0.653	0.883	
	17	0.445	0.522	0.887	

whereas the correlation between corrected item and the total score lies between 0.57 and 0.918. The reliability index of this construct are 0.943.

For Resilient construct, it is reported in Table 12 that the value of correlation between items and sum of score lies between 0.649 and 0.856 whereas the correlation between corrected item and the total score lies between 0.58 and 0.836. The reliability index of this construct are 0.941.

For Collaborative construct, it is reported in Table 13 that the value of correlation between items and sum of score resides between 0.935 and 0.862 whereas the correlation between corrected item and the total score lies between 0.71 and 0.841. The reliability index of this construct are 0.953.

The correlation of items score with the sum of scores are between 0.935 and 0.862 while the corrected item score with total correlation resides in between 0.71 and 0.841 as The reliability index reported to be 0.953.

Table 9 Cronbach alpha reliability index of instrument in measuring student's achievement emotion

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Achievement emotion	1	0.759	0.781	0.937	0.941
	2	0.723	0.755	0.937	
	3	0.572	0.635	0.94	
	4	0.579	0.628	0.939	
	5	0.646	0.69	0.938	
	6	0.72	0.765	0.937	
	7	0.668	0.718	0.938	
	8	0.765	0.788	0.937	
	9	0.649	0.68	0.938	
	10	0.698	0.741	0.937	
	11	0.749	0.774	0.937	
	12	0.731	0.754	0.938	
	13	0.648	0.704	0.939	
	14	0.452	0.507	0.941	
	15	0.648	0.678	0.939	
	16	0.643	0.696	0.939	
	17	0.814	0.835	0.936	
	18	0.719	0.745	0.938	
	19	0.556	0.597	0.94	
	20	0.692	0.72	0.938	

5 Conclusion

Through Table 5 to Table 13, it is observed that the value of correlation of the item score with the total score are greater than 0.3 and also the value of corrected item with total score exceed 0.3. Therefore the item represent a higher validity index as proposed by [33, 34]. On the other hands, it is observed that the value of Cronbach Alpha are greater than 0.6 which gives us the information that the instrument have a high stability and high internal consistency [35, 36]. In General, Instrument that will be used in a quantitative research is one of the crucial element that gives credibility in research finding. In addition, to get a good research results and findings, a comprehensive Pilot Test must be conducted which includes the face validity procedure and the determination of item correlation and Reliability index that will ensure the reliability and the validity of an instrument.

Table 10 Cronbach alpha reliability index of instrument in measuring digital the level of playfulness in learning

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Playfulness	1	0.554	0.599	0.946	0.947
	2	0.705	0.392	0.943	
	3	0.829	0.471	0.942	
	4	0.834	0.399	0.941	
	5	0.809	0.373	0.942	
	6	0.839	0.336	0.941	
	7	0.669	0.32	0.945	
	8	0.489	0.442	0.947	
	9	0.565	0.618	0.946	
	10	0.517	0.3	0.946	
	11	0.441	0.337	0.947	
	12	0.569	0.382	0.946	
	13	0.868	0.608	0.94	
	14	0.583	0.684	0.946	
	15	0.795	0.333	0.942	
	16	0.806	0.366	0.942	
	17	0.814	0.429	0.941	
	18	0.603	0.591	0.945	
	19	0.551	0.483	0.946	

Table 11 Cronbach alpha reliability index of instrument in measuring student's asset-growth orientation

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Asset-growth oriented	1	0.608	0.672	0.943	0.943
	2	0.912	0.928	0.932	
	3	0.703	0.765	0.94	
	4	0.71	0.781	0.941	
	5	0.57	0.631	0.945	
	6	0.918	0.937	0.929	
	7	0.854	0.886	0.932	
	8	0.794	0.837	0.935	
	9	0.852	0.884	0.933	
	10	0.788	0.84	0.936	

Table 12 Cronbach alpha reliability index of instrument in measuring student's Resilient

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Resilient	1	0.817	0.84	0.936	0.941
	2	0.836	0.856	0.935	
	3	0.722	0.754	0.937	
	4	0.728	0.76	0.937	
	5	0.745	0.775	0.937	
	6	0.794	0.819	0.936	
	7	0.714	0.746	0.938	
	8	0.68	0.716	0.938	
	9	0.675	0.714	0.938	
	10	0.697	0.735	0.938	
	11	0.707	0.744	0.937	
	12	0.684	0.726	0.938	
	13	0.635	0.697	0.94	
	14	0.611	0.673	0.94	
	15	0.58	0.661	0.944	
	16	0.697	0.745	0.938	
	17	0.602	0.649	0.939	

Table 13 Cronbach alpha reliability index of instrument in measuring student's collaborative effort

Construct	Item number	Corrected item-total correlation	Item correlation with sum score	Reliability index if item deleted	Reliability index
Collaborative	1	0.731	0.766	0.95	0.953
	2	0.829	0.851	0.949	
	3	0.738	0.789	0.951	
	4	0.723	0.744	0.95	
	5	0.778	0.802	0.95	
	6	0.82	0.841	0.949	
	7	0.742	0.778	0.95	
	8	0.834	0.855	0.949	
	9	0.767	0.794	0.95	
	10	0.745	0.777	0.95	
	11	0.841	0.862	0.948	
	12	0.755	0.792	0.95	
	13	0.682	0.735	0.952	
	14	0.768	0.802	0.949	
	15	0.71	0.763	0.952	

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References

1. Okpala HN (2016) Making a makerspace case for academic libraries in Nigeria. New Libr. World
2. Sternberg RJ (2006) The nature of creativity. Creat Res J 18:87
3. Creswell JW, Creswell JD (2017) Research design: qualitative, quantitative, and mixed methods approaches. Sage publications, Thousand Oaks, CA
4. Kirk J, Miller ML, Miller ML (1986) Reliability and validity in qualitative research. Sage, Thousand Oaks, CA
5. Cohen J (1988) Statistical power analysis for the social sciences
6. Norusis M (2008) SPSS 16.0 advanced statistical procedures companion. Prentice Hall Press, Upper Saddle River, NJ
7. Chen G, Gully SM, Eden D (2001) Validation of a new general self-efficacy scale. Organ Res Methods 4:62–83
8. Chen A, Darst PW, Pangrazi Chen RP (2001) An examination of situational interest and its sources in physical education. Br J Educ Psychol 71:383–400
9. Pekrun R, Goetz T, Frenzel AC, Barchfeld P, Perry RP (2011) Measuring emotions in students' learning and performance: the Achievement Emotions Questionnaire (AEQ). Contemp Educ Psychol 36:36–48

10. Martin L (2015) The promise of the maker movement for education. J Pre-Coll Eng Educ Res 5:4
11. Chang CP, Hsu CT, Chen IJ (2013) The relationship between the playfulness climate in the classroom and student creativity. Qual Quant 47:1493–1510
12. Dewiyanti S, Brand-Gruwel S, Jochems W, Broers NJ (2007) Students' experiences with collaborative learning in asynchronous Computer-Supported Collaborative Learning environments. Comput Hum Behav 23:496–514
13. Duckworth AL, Peterson C, Matthews MD, Kelly DR (2007) Grit: perseverance and passion for long-term goals. J Pers Soc Psychol 92:1087–1101
14. Cassidy S (2016) The Academic Resilience Scale (ARS-30): a new multidimensional construct measure. Front Psychol 7:1–11
15. Saorín JL, Melian-Díaz D, Bonnet A, Carbonell Carrera C, Meier C, De La Torre-Cantero J (2017) Makerspace teaching-learning environment to enhance creative competence in engineering students. Think Skills Creat 23:188–198
16. Hansen AK, Langdon TR, Mendrin LW, Peters K, Ramos J, Lent DD (2020) Exploring the potential of 3D-printing in biological education: a review of the literature. Integr Comp Biol 60:896–905
17. Parisi N (2020) "Do It Yourself" and "digital fabrication" for new way of founding life. IOP Conf Ser Earth Environ Sci 588
18. Recktenwald GW, State P, Hall DE, Tech L (2011) Using Arduino as a platform for programming. Des Am Soc Eng Educ 1:3
19. Knörig A, Wettach R, Cohen J (2009) Fritzing—a tool for advancing electronic prototyping for designers. In: Proceedings of the 3rd international conference on tangible and embedded interaction, p 351
20. Wang C, Yeh H-M, Wang B, Wu T-Y, Tsai H-R, Liang R-H, Hung Y-P, Chen MY (2016) CircuitStack. UIST '16: proceedings of the 29th annual symposium on user interface software and technology, pp 687–695
21. Wood R, Bandura A (1989) Impact of conceptions of ability on self-regulatory mechanisms and complex decision making. J Pers Soc Psychol 56:407
22. Krapp A (1992) Interest, learning and development. In: Krapp A, Hidi S, Renniger KA (eds) The role of interest in learning and development
23. Dweck CS (2015) Carol Dweck revisits the "growth mindset." Educ Week 35:20–24
24. Masten AS (2011) Resilience in children threatened by extreme adversity: frameworks for research, practice, and translational synergy. Dev Psychopathol 23:493–506
25. Dillenbourg P (1999) Collaborative learning: cognitive and computational approaches. Advances in learning and instruction series. ERIC
26. Holden RR (2010) Face validity. Corsini Encycl Psychol 1–2
27. Daud KAM, Khidzir NZ, Ismail AR, Abdullah FA (2018) Validity and reliability of instrument to measure social media skills among small and medium entrepreneurs at Pengkalan Datu River. Int J Dev Sustain 7:1026–1037
28. Artino Jr AR, La Rochelle JS, Dezee KJ, Gehlbach H (2014) Developing questionnaires for educational research: AMEE Guide No. 87. Med Teach 36:463–474
29. Seo-Zindy R, Heeks R (2017) Researching the emergence of 3D printing, makerspaces, hackerspaces and fablabs in the global south: a scoping review and research agenda on digital innovation and fabrication networks. Electron J Inf Syst Dev Ctries 80:1–24
30. Blikstein P, Martinez SL, Pang HA Meaningful making: projects and inspirations for Fab Labs + Makerspaces
31. Logler N (2018) Arduino and access: value tensions in the maker movement. Ethics Inf Technol
32. Kamaruzaman AFB, Ismail ARB, Daud KABM (2019) Potensi makerspace dalam menghubungkan jurang pengetahuan pelajar rekabentuk perindustrian beraliran seni dengan bidang penghasilan prototaip elektronik. TENIAT (Int J Creat Feature Heritage) 7:117–128
33. Nunnally, Bernstein IR (1994) Psychometric theory. Tata McGraw-Hill Education
34. Cohen J (2013) Statistical power analysis for the behavioral sciences. Academic, New York

35. Pallant J (2020) SPSS survival manual: a step by step guide to data analysis using IBM SPSS. Routledge
36. Sekaran U, Bougie R: Research methods for business: a skill building approach. Wiley (2016)

Design and Development of the E-Bonang Musical Instrument as an Integration of Music and Electronic Prototyping for Educational Purposes

Azmul Fadhli Kamaruzaman, Raja Iskandar Raja Halid, Ezran Zainal Abdullah, Mohd Hilmi Harun, Hawari Berahim, and Tan Tse Guan

Abstract *Bonang* is one of the instruments used in the gamelan orchestra, which is one of the most valuable cultural heritage of Malaysia. However, due to its high price and bulkiness of the traditional design, the Gamelan is beyond the reach of many schools and musicians in terms of affordability, space and mobility. Development of the E-Bonang is an innovative approach to solve these issues as well as sustaining and promoting this musical heritage through technology to a wider audience, especially the younger generation. The aim of this paper is to highlight the design and developmental process of the E-Bonang musical instrument and the potential of the device in integrating both music education and electronic prototyping education. One of the main contributions of this design approach is that the instrument's weight will be reduced up to 60% and can be manufactured with much lower cost. The product has the potential of introducing students to traditional music education (gamelan) while emphasizing the D.I.Y feature of electronic prototyping as an experiential education which includes circuit building, microcontroller programming, sound experimentation and product assembly.

Keywords *Bonang* · Electronic gamelan · Industrial design · Education

1 Introduction

Bonang is one of the instruments of the gamelan orchestra, a traditional musical ensemble found in Indonesia and Malaysia [1]. Usually, the *bonang* leads the orchestra by playing the introductory melody and setting up the tempo of a piece. Like most of the other instruments in the ensemble, the metal parts of the bonang are made of copper or bronze, and teak wood is used for the woodwork. Sure enough, a gamelan set can cost up to hundreds of thousands of ringgit and takes months to

A. F. Kamaruzaman (✉) · R. I. Raja Halid · E. Z. Abdullah · M. H. Harun · H. Berahim · T. T. Guan
Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia
e-mail: azmul@umk.edu.my

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produce, not to mention the bulkiness of the instruments [2]. This makes gamelan beyond the reach of most schools and learning institutions in Malaysia, thus depriving our younger generation access to their own heritage. The E-Bonang is designed not in any way to replace the traditional *bonang*, but to provide an alternative for students, to at least have a feel of how the instrument is played and sounded. Besides solving the traditional problems of size and price, the E-bonang is also designed to expand the musical boundaries of the traditional *bonang* in particular and the gamelan ensemble in general, to include science education. This is in line with the government's efforts in developing science and technology while inculcating the appreciation for traditional arts.

While earlier research in preserving traditional music such as gamelan took a digital approach [3, 4], this project took an approach into the combination of heritage and science education for the younger generation. Emphasis will be on playing technique, sound sampling and reproduction, product design and physical computing. Ultimately, the E-Bonang can be expanded to include all other instruments in the gamelan orchestra such as the *gambang*, *gong*, *saron* and *kenong* or even other traditional instruments such as the *caklempong*. Students and young adults can learn about their cultural heritage through the use of technology in a fun and creative way.

2 Design and Development Process

The E-Bonang is a musical sound MIDI (Musical Instrument Digital Interface) controller comprising of a rectangular body mounted with circular pads on the upper surface upon which a number of piezoelectric transducers are mounted. The signals produced by the transducers are transferred using MIDI interface that transmits standard MIDI data through an Arduino set-up to a Digital Audio Workstation (DAW) or sound reproduction device (module) using sampled sounds or audio generator. The identity of the transducer provides the pitch information for the MIDI interface and the velocity is calculated from the time rate of change of the output voltage from the piezoelectric transducers. The instrument uses the DIY concept in which users learn to assemble the instrument and its electronics components while learning some basic programming using Arduino.

The development can be divided into 4 phases which are Circuit and Microcontroller development process, design and development of housing unit, audio sampling and testing. The first stage includes the development of piezo transducers circuit and microcontroller programming process and followed by fine tuning of the sensitivity and the threshold frequency of the piezo transducers. The second stage includes the development of housing unit by using a much lighter material. The third stage is Audio Mapping, audio sampling and sound modification. The last stage is final testing and evaluation of sound production and feel.

2.1 Circuit and Microcontroller Development Process

The design starts with the development of the circuitry used to trigger the sounds. Piezo sensors have been used as a device to generate electrical signals, triggered using physical force (knocking or tapping), that are then sent as analog signals into a microcontroller unit. The communication between the piezo sensors and microcontroller is then established using serial communication via USB. This product consists of 10 piezo sensors and 3 potentiometers, 1 microcontroller unit and 1 proto board. The role of potentiometer is to send signals of control change which is embedded in the MIDI protocol for controlling other sound effects in the Digital Audio Workstation (DAW). The sounds generated in the DAW are then amplified through a pair of speakers. Piezo transducer signals are channeled through an input analog pin and each pin variables are assigned to a MIDI 'Note On' key which corresponds to Table 1. Traditionally the Malay gamelan and *bonang* uses the *slendro* scale (five notes per octave) [5]. This traditional scale does not match exactly the equal temperament used in western music, but it is approximately equivalent to the major pentatonic scale. In order to get the exact tuning of the *slendro* scale, sound samples of the *bonang* have to be mapped into the MIDI key or by relaying MIDI using the Scala program [6]. For a start, this project uses the key of D and the pads are mapped into 5 musical notes in 2 octaves respectively.

Figure 1 shows the schematics diagram developed in this project, noted that the use of Zener Diode and 1 M Ohm resistor to limit the current entering the analog input signal of microcontroller unit. Voltage is limited up to 5.1 V by the zener diode, higher values generated by piezo transducer will posed a malfunction of a microcontroller. Arduino Mega is used in this product development due to its availability, usability and by taking advantages of its open source capability. The circuit is then multiplied into 9 more similar connection which used 10 Analog input of the microcontroller namely pin A0 to A9. The rest of the analog input is then reserve for a 10 kΩ potentiometer for MIDI control change function. The midi control change command

Table 1 *Slendro* approximation of western equal temperament of major pentatonic scale

MIDI value	Analog pin assignment	Musical note	Frequency (Hz)
62	A0	D4	293.66
64	A1	E4	329.63
66	A2	F#4	369.99
69	A3	A4	440
71	A4	B4	493.88
50	A5	D3	146.83
52	A6	E3	164.81
54	A7	F#3	185
57	A8	A3	220
59	A9	B3	246.94

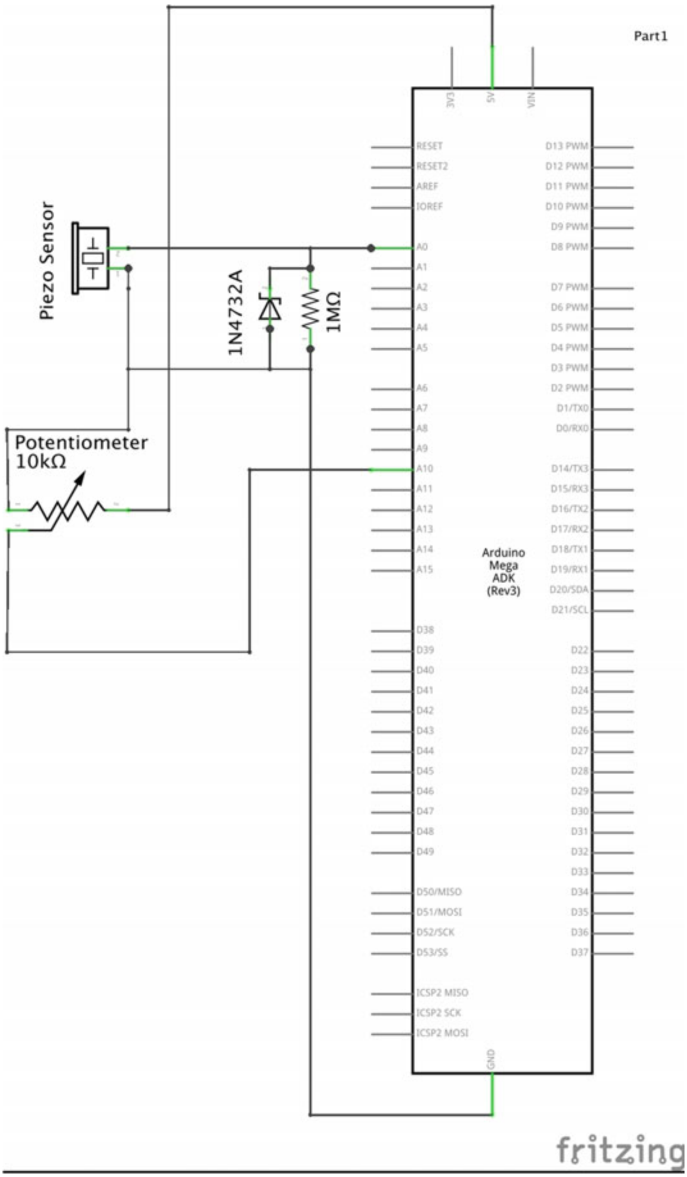

Fig. 1 Schematics diagrams of circuit connection consist of piezo sensor, zener diode, resistor and Arduino Mega microcontroller

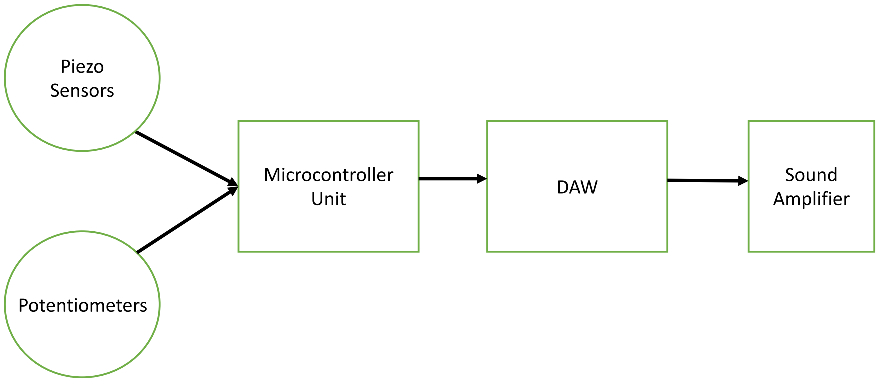

Fig. 2 Flow diagram of E-bonang sound generator process

is used by mapping analog potentiometer value (1023) into 127 of MIDI values. This will permit the communication of the potentiometer with D.A.W and the function can be mapped to suit the purpose such as volume, tone and delay values in the D.A.W signal chain. All the programming is done in Arduino IDE (integrated development environment) written in C programming language and C++ for the MIDI library. The malleability and its open source features is one of the great features for an Arduino to be embed in the student's learning module that will be developed in the future.

Figure 2 shows the sound generator process starting from the force transfer from knocking to electrical signal generator in pieezo sensor. The electrical signal are then sent to an Arduino microcontroller unit for signal detection and processing. Raw signal from analog input are then sent into a computer via serial Communication (USB) and relay into a D.A.W and the rest is an audio amplification process.

2.2 Design and Development of the Housing Unit

The design of the body begins with sketches which underwent several design reviews between the designer, musician and engineers, and the final design was then produced using the 3D CAD software. The design details were then developed in CAD software complete with technical drawing and assembly parts. However due financial and technical constraints, only the upper body part of the design was used. The data from the CAD software were then transferred to CAM for the fabrication of the body. The body used foam board as it greatly reduces the weight and is effective in isolating the vibration between each pad. Circular Perspex boards installed with piezo sensors were then glued together with foam pads. The Perspex boards effectively transmit vibrations to the piezo transducers while the soft foam pads (glued to the Perspex) reduce hitting stick sounds by absorbing them. Sponge was placed under the glued pads to body of the instrument in order to reduce vibrations between the neighboring

Fig. 3 Perspective view of the first prototype of E-Bonang musical instrument

pads to avoid triggering unnecessary sounds and notes. The other useful features of foam is to separate the vibration in each pad and therefore unwanted vibration from each pad and the housing unit can be separated.

Figure 3 and 4 show the perspective view of the first e-bonang prototype which consist of a hitting mallet, 10 pad and housing body. Figure 5 and 6 show the 3D rendered model of the product in earlier design stage. Due to the limitation of budget and manufacturing capabilities, The first prototype will serve as a testing of a whole function of the design and the electronic circuit. The second generation will look into an improvement of the product that will be explained in details in the following section.

2.3 Audio Mapping and Sampling

In this stage, there are two methods to generate audio in DAW, either by using a synthesizer instrument rack or audio samples. The most preferred choice is to use audio recording samples. The sound of the actual *bonang* is first recorded using a condense microphone and the audio are then processed in DAW to eliminate noise. Sound samples are then mapped onto keyboard keys in D.A.W. Next, audio effects such as echoe, reverb, and chorus are added in the signal chain. The potentiometer values are then mapped onto the DAW to gain access of real time audio effect value control change and also volume control.

Fig. 4 The other perspective view of the first prototype of E-Bonang musical instrument

Fig. 5 Perspective view of the first 3D rendered of E-Bonang instrument

Fig. 6 Front view of 3D rendered of E-Bonang Instrument

Table 2 Summary of the observation and feedback from the respondent

Number	Characteristics	Observation/feedback	Improvement
1	Playability	Easy to play	–
		No delay and latency	–
		Velocity sensitive is absent	Reprogramming the velocity sensitive algorithm
2	Sound Characteristics	Average sound characteristic with synthetic quality	Using higher quality sampled sounds of the bonang
		Knocking sound from mallet and pad can be heard	The used of the lighter mallet and experimentation of various type of padding material
3	Ergonomics	Less arm muscle strain if the pad is placed a little bit slanted	The need for an adjustment of the slanted design of the housing unit to reduce muscle strain The need for an Ergonomic analysis (Ex RULA Ergonomic Asessment)
4	Overall design	The used of Proto board make the controller unit bulkier	The need for a PCB/Custom shield to replace the huge proto board
5	Aesthetics	The pad design is not in proper shape	Redesigning the pad which resembles the original shape of Bonang using different substitute material other than copper

2.4 Testing

The E-bonang was then tested by an experienced gamelan player for its playability, sound characteristics and ergonomics. Table 2 summarised the observation and feedback from the respondent that will serve as a guideline for future improvements of the second-generation prototype.

3 Comparison with the Traditional Bonang Instrument

One of the notable features of E-Bonang is the weight difference compared to the traditional instrument. The overall weight itself has been reduced approximately 60% compared to the traditional instrument which is heavy and bulky as a result of material change of the housing body from solid hard wood to hard PVC foam board and from brass to Perspex for the hitting pad. The traditional *bonang* instrument uses brass or copper knobs that vibrate to generate sounds as opposed to the E-Bonang which uses Piezo sensors to trigger the assigned sounds in the DAW. These sounds can be further controlled and modified in terms of pitch and added with effects such as reverb and delay. The E-bonang uses MIDI as a communication protocol within the D.A.W which is the standard protocol used in electronic music. Since the main communication protocol is MIDI, the sounds can be replaced by any other instruments in the D.A.W sound generator for experimentation purposes which is widely used in various modern music genres.

4 Potential in Electronic and Music Education

This product has the potential not only in traditional music education but also electronics and computer science, which include circuitry building and programming. Since the product uses open-source hardware and software, it can be easily replicated and manipulated to create endless and more complex musical projects. Earlier research shows that the usage of the Arduino hardware and software can be used to encourage students to learn more about electronics and programming [7] while one researcher proposes that the use of Arduino can be embedded in music education in schools [8]. This paper also suggests that the use of an open-source electronic D.I.Y product, particularly one that resembles a traditional instrument is part of experiential learning which encourages students to explore various type of sounds generated by D.A.W. At the same time, the E-Bonang introduces students and the younger generation to our musical heritage, which is beyond the reach of many due its price.

5 Future Direction

The future direction of this research project is to develop a full gamelan ensemble using the same concept as discussed above and to conduct continuous improvements on key aspects of the product's design which include ergonomics, aesthetics and functionality. This is in order for the E-Bonang and eventual E-Gamelan to reach more students, musicians and institutions, not only in this country but beyond our borders. Another future plan is the development of the E-Bonang mobile phone learning Apps and the circuit bending learning modules and experimentation guide. This is to encourage students to experiment with various kinds of sounds produced and generated via DAW and not limited to gamelan sound only. The availability of the open source hardware such as Arduino or MIDI device compliant microcontroller such as teensy has opened up new possibilities and accelerate the development of the MIDI controller device [9]. The Arduino MEGA consists of 15 analog input pin which can be multiplied using Multiplexers which can be used to develop the full gamelan ensemble which includes other instruments such as the *gong*, *saron*, *kenong* and *gambang*.

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References

1. Becker J (2019) Traditional music in modern Java: Gamelan in a changing society. University of Hawaii Press
2. Miller LE, Lieberman F (1999) Lou Harrison and the American Gamelan. Am Music 146–178
3. Dharma NS, Sudarma M, Suyadnya MA (2015) Rancang Bangun Aplikasi Gamelan Gender Berbasis Android. E-J SPEKTRUM 18–23
4. Yuda YP, Azis MNL (2019) 3D modeling the gamelan of saron as a documentation of cultural heritage preservation efforts. J Phys Conf Ser 12036
5. Hamdan S, Musib AF, Musoddiq IA, Sawawi M (2020) Timbre spectrum of gamelan instruments from four Malay gamelan ensembles. Pertanika J Sci Technol 28:459–476
6. Schiemer G, de Coul MO (2007) Pocket gamelan: tuning microtonal applications in Pd using Scala
7. Galadima AA (2014) Arduino as a learning tool. In: 2014 11th international conference on electronics, computer and computation (ICECCO). IEEE, pp 1–4
8. Atilgan DS, Gürman Ü (2020) Material design in music education using Arduino Platform. Eğitimde Nitel Araştırmalar Derg 8:1377–1402
9. Edstrom B (2016) Arduino for musicians: a complete guide to Arduino and Teensy microcontrollers. Oxford University Press, Oxford

Sustainability Implications of Additive Manufacturing

Nabila Afif Mohmd Arifin, Muhamad Zameri Mat Saman, Safian Sharif, and Nor Hasrul Akhmal Ngadiman

Abstract Additive manufacturing is the industrial production name for 3D printing, which is one of the advanced technologies in the fourth industrial revolution. 3D printing involves the production of a 3D product using a layer by layer technique. Complex structures can be produced through AM which was no possible using conventional method as it has the potential to assemble parts, consequently minimizing the production process. In addition, through the AM process, less waste is generated during manufacturing and lightweight components can be produced which makes it beneficial in terms of materials and costs. Therefore, additive manufacturing is seen to have an impact on sustainability. This paper will review the implications of AM on sustainability, which includes the environmental, economic and social aspects. Clear understanding of sustainability impacts of AM is crucial in order to assist companies and researchers to make the best decisions before switching to AM.

Keywords Sustainability · Industry 4.0 · Sustainable manufacturing · Additive manufacturing · Environment · Economic · Social

1 Introduction

Industry 4.0 has greatly influenced the manufacturing sector through the introduction of technologies such as cyber physical system (CPS), internet of things (IoT), big data, system integration and additive manufacturing (AM). These developments are seen to open up opportunities to produce sustainable manufacturing (SM) [1]. US EPA 2017 [2] defined SM as the manufacturing of products using economical processes which reduce negative impacts towards the environment while conserving energy and natural resources. Sustainable manufacturing improves energy efficiency, reduces manufacturing waste and enhances employee, community and product safety [2]. Despeisse et al. [3] reported that AM promotes the concept of sustainability as it

N. A. M. Arifin (✉) · M. Z. M. Saman · S. Sharif · N. H. A. Ngadiman
School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
e-mail: nabilaafif@graduate.utm.my

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produces products efficiently with shorter time. Its usage is undeniably beneficial in the field of engineering Besides, AM uses common tools, consequently is capable of reducing waste of material. However, despite its abundant benefits, its impact on the industrial system should be explored [4]. In this regard, it is essential to include all the triple bottom line elements (environment, economic and social) in sustainability assessment. Therefore, this paper aims to review the sustainability implications of AM focusing on three pillars (environment, economic and social). The paper is organized as follows; the background of additive manufacturing is explained in Sect. 2, followed by the review of the sustainability impacts of AM in Sect. 3. Finally, Sects. 4 and 5 provide the discussion and conclusions for the current study.

2 Additive Manufacturing Background

Additive manufacturing (AM) or 3D printing is a technique of producing three-dimensional (3D) objects from a digital model or computer-aided design (CAD) model by adding layer upon layer of material. Since it was first introduced in 1980s, AM has proven to be able to replace traditional method of manufacturing due to its capability of producing complex structures that seemed almost impossible using the traditional technique. Besides, it is capable of manufacturing products with lower cost. Among the most widely adopted technologies are fused deposition modelling (FDM), selective laser melting (SLM), stereolitography (SLA), selective laser sintering (SLS), and digital light processing (DLP). Many materials can be utilized for AM such as polymers, ceramics and composites. The choice of material depends on the type of AM process being used [5]. Nevertheless, AM does have a few limitations such as high energy consumption, a slow printing process, and limitation in terms of materials and sizes that can be 3D printed [6]. AM comprises a number of steps from the virtual CAD description to the product. Different products will require AM to be implemented in various ways. For example, small and simple products might only utilize AM for visualization mode, while more complex products may require AM to be involved during various stages and iterations across the development process. Furthermore, AM is utilized in the initial stages of the product development process because of the speed in which they can be fabricated. At subsequent stages, AM is applied where the parts may need post-processing before they can be used because of the complexity that can be made without considering tooling. Most AM processes involve at least the following eight steps which are 3D CAD modelling, conversion to STL, transfer to AM machine, machine setup, building the part, removal, post-processing, and application [7]. AM is widely implemented in several industries including aerospace, medical, automotive, electronics and consumer product [8].

3 Sustainability Implications of AM

Additive manufacturing has been identified as having sustainable advantages such as reducing waste during manufacturing, optimizing geometry and producing lightweight components. Nonetheless, AM has not been adequately explored from the sustainability point of view. Previous studies mostly focused on energy consumption of AM. The AM technology promises better sustainability particularly in terms of economic impacts for small to medium production. Machining cost per part contributes to the major cost out of the total cost. Therefore, replacing the traditional method wit AM will certainly reduce the production cost. In addition, AM is likely to become more cost-effective as higher volume of production becomes more economically achievable than at present. However, the impact of AM on social sustainability remains poorly understood as most of studies only focus on work condition and worker's health [9].

3.1 Environmental Impact

Environmental protection awareness has led to more concerns on the sustainability of the product. The government, society and research organizations should have focused more on the impacts of manufacturing on the environment. Table 1 presents the environmental impacts of AM. Different types of materials have been utilized for the productions of AM parts such as steel, acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyamide, nylon and epoxy resin. In terms of AM technologies, fused deposition modelling (FDM), selective laser sintering (SLS), electron beam melting (EBM), wire arc additive manufacturing (WAAM), laser additive manufacturing (LAM) was considered. According to Rejeski et al. [10], AM offers environmental benefits such as minimizing resource waste and energy generation, and decreasing transport effects as compared to the existing method. Also, AM is said to promote sustainable development. Nevertheless, there is no guarantee that this could occur. In their study of effect of AM on global energy demand, Verhoef et al. [11] concluded that AM creates its own environmental impact as the energy usage of latest technologies such as AM has always been overlooked. Garcia et al. [12] carried out a literature survey on the environmental performance of AM and identified that most research had only focused on the energy estimation, and only several research had been done on life cycle assessment (LCA) of AM process. Krieger et al. [13] quantified the environmental impact of distributed manufacturing (DM) using 3D printers. A life cycle analysis was performed on plastic products. The results indicated that DM with 3D printers posed lesser environmental impact compared to traditional method. Kellens et al. [14] presented a parametric model for environmental assessment of selective laser sintering (SLS). They performed multiple linear regression analysis to figure out the relationship between product design features

Table 1 Environmental sustainability studies in additive manufacturing

Related work	AM process	Material	Methodology
[13]	3D printing	ABS, PLA	LCA
[14]	SLS	Polyamide	Parametric model
[15]	SLM, EBM	Stainless steel, Ti	Experiment
[16]	WAAM	Stainless steel	LCA
[17]	LAM	Metal	LCA
[18]	SLM, DMLS, EBM, FDM	Steel, Ti, Ni, and Aluminium alloys	Process-based model
[19]	SLM	Aluminium	LCA
[20]	LAM	Metal	Experiment
[21]	FDM	PLA	LCA
[22]	SLA	Epoxy resin	LCA
[23]	EBM	Titanium alloy	LCA
[24]	SLS	Titanium	Conceptual model
[25]	FDM	ABS, PLA	Mathematical model
[26]	EBM	Titanium alloy	LCA
[27]	SLM	Aluminium	Fuzzy-based
[28]	FDM, SLS, MJF	Nylon	LCA
[29]	PBF	Low-alloy steel	LCA
[30]	FDM	ABS	Analytical model
[31]	3D printing	Novel material, ABS	LCA
[32]	LENS, SLA, FDM	Inconel, resin, ABS	LCA
[33]	SLA	Resin	Experiment, mathematical model
[34]	Binder Jetting	Stainless steel	LCA
[35]	WAAM	Titanium, steel	LCA
[36]	WAAM	Steel	Experiment
[37]	EBM	Titanium alloy	LCA
[38]	FDM	ABS	LCA
[39]	EBM	Titanium	LCA

and production time. The model also demonstrated opportunities to reduce environmental impact. Taking into account the impacts and also the development of AM, it is relevant to quantify the possible effects towards the environment and resource implication of AM execution.

3.2 Economic Impact

Cost is a significant factor for decision making to analyze the economic viability of every technology or product. Therefore, it is important to consider cost-effectiveness of this technology over classical production method before the deployment of AM. Part of the core characteristics of AM is that it significantly reduces the benefit of conventional economics of scales. Consequently, local manufacturing would become profitable. Over the last five years, 3D printers' price has decreased which leads to the growth in the installed base of the machinery of approximately 300–500 percent annually [8]. The result of an extensive Delphi survey on the future of AM presented by Jiang et al. [40] focused on the future economical and societal impacts in 2030. In their study, they emphasized that managers and company owners particularly in the manufacturing industry need to be proactive in ensuring the best manufacturing approach. Similarly, in making the decision as to whether AM should be implemented, continuous experiments need to be conducted to ensure the effectiveness of AM in replacing the traditional method. In another study, Khorram et al. [41] examined the economic sustainability of the AM process and identified the drivers that increased the performance of AM compared to conventional method. The authors conducted a survey involving 105 companies from 23 countries and concluded that even though AM could significantly reduce the cost, profitability of investment is higher for conventional method. In addition, Li et al. [42] identified the best AM technology installed in printers with regard to sustainability and cost. They have conducted cost analysis and employed LCA and Eco indicator 99 to assess the environmental impacts of AM. The results indicated that PolyJet Printer parts incurred higher cost compared to FDM parts which incurred lower cost. Previous studies on the economic impact of AM are summarized in Table 2. Among the costing approaches used are activity-based costing, parametric, analytical, cost breakdown structure and process-based modelling. Several direct costs had been considered such as machine, labour and material costs.

3.3 Social Impact

Social impact assessment began in 1970s. According to Sutherland et al. [63], social impacts are direct or indirect effects experienced by stakeholders in manufacturing companies. In 2016, a sustainability reporting framework was presented by the Global Reporting Initiative in which social element is the one that has the most indicator involving employment, labour and also safety. There is a methodology that can be used to assess social impacts which is the social life cycle assessment (S-LCA). Through this methodology, social impacts of all life cycle stages from cradle-to-grave can be evaluated. Each stage could be related to different geographic locations in which more than one activity is processes [64]. Huang et al. [9] reviewed the impact of AM on society by comparing between AM and conventional method.

Table 2 Economic sustainability studies in additive manufacturing

Related work	AM process	Methodology	Cost driver
[43]	SLM	Parametric	CAD, operating, setup, labour material, machine, gas, part removal, tool
[44]	AM	Cost breakdown structure	Operating, remanufacturing, setup, material, machine, labour, depreciation, electricity, replacement, maintenance, administrative
[45]	MJF	Even-driven	CAD, operating, setup, labour, material, machine
[46]	MAM	Activity-based	CAD preparation, setup, material, machine, labour maintenance, electricity, part
[47]	AM	Analytical	CAD, production, investment, downtime, maintenance, disposal, logistic, lifecycle, break-even production
[48]	LBM	Intuitive, analogy, LCA	CAD, setup, material, machine, labour, energy, depreciation, maintenance, electricity, energy, post-processing, part removal
[49]	DMLS, EBM	Process-based cost modelling	Investment, setup, material machine, labour, tool, energy maintenance, quality control, production overhead, repair, electricity, downtime and inventory, transportation
[50]	MAM, EBM	Process-based cost-modelling	Investment, material, labour, Energy, machine, recycle, maintenance, electricity, design for AM, lifecycle
[51]	AM	Activity-based costing	CAD preparation, material, machine, labour, energy, treatment, quality control, logistic
[52]	AM	Analytical network process	Investment, setup, material, machine, labour, depreciation, part removal, post-processing, production overhead, logistic
[53]	SLM	Analytical	CAD preparation, setup, operating, material, labour, production, pricing mode, part removal, treatment, post-processing, overhead

(continued)

Table 2 (continued)

Related work	AM process	Methodology	Cost driver
[54]	AM	Analytical	CAD preparation, material, precision, pricing mode, logistic, service location
[55]	SLS	Analogy	Redesign, setup, material, machine, labour, post-processing, depreciation
[56]	SLS	Activity-based costing	Material, machine, labour, production overhead, administrative
[57]	SLA, SLS, FDM	Intuitive	Material, machine, labour
[58]	SLS	Stochastic programming model	Material, machine, labour, production, energy, investment, maintenance
[59]	AM	Activity-based costing	Material, machine, labour, maintenance, CAD
[60]	AM	Stochastic optimization	Material, labour, maintenance, investment lifecycle
[61]	SLS	Analytical	Material, machine, labour
[62]	FDM	Analogy	Material, labour, setup, CAD preparation, post- processing

They identified positive impacts of AM such as customized healthcare product to improve population health and quality of life and reduced environmental impact for manufacturing sustainability. Chen et al. [65] presented an analysis of direct digital manufacturing (DDM) in comparison to conventional manufacturing. In their study working conditions and work impact on worker's long-term health were considered in their social impacts assessment. It is noted that the social impact is important to be analyzed as it includes work safety, job losses, waste management and logistics. Kondoh et al. [66] proposed a method to evaluate the impact of AM on the society which considers the multiple interrelationships among factors that represent the behavior of stakeholders driven by societal, economic and ethical reasons. They also showed the effects of AM towards life cycle value with an example of simplified calculation. The needs for research on sustainability of AM had been proposed by [10]. From the societal perspective, it was suggested that more studies should be focusing on occupational health issues primarily related to toxicity of fine powders for metal AM and the possible risk of nano-particle emissions. Matos and Jacinto [67] mapped the social impacts of AM technology and found that social impacts are still in the exploratory phase where several social challenges will have an impact on the society. In addition, several topics such as fabrication, customization, sustainability and business model were identified as related to social impacts. Furthermore, scarcity of studies related to societal impacts is slightly due to complexity of analysis which is difficult to evaluate.

4 Discussion

Three elements of sustainability of AM had been reviewed from the literature. Environmental performance of AM commonly focuses on electrical energy consumption. Undoubtedly, it is crucial to consider all the steps which occur during the process in order to improve the environmental performance particularly for material deposition and material projection processes that mostly focusing on energy consumption. It is noted that several data such as emissions, recycling, waste flows and resource consumption are still lacking [30]. Furthermore, integrated geometric complexity should be developed in the future to produce simultaneous economic and environmental sustainability analyses in more detail. This will assist the decision making for designers and industrial practitioners to identify optimal environmental and economic routes for manufacturing [26]. From the economic perspective, many previous researchers focused on the production phase. Following these works, some of researchers still adopted the traditional costing approach such as activity-based costing to estimate manufacturing costs of the product using conventional manufacturing or AM. It is noted that, recently, several types of costs such as logistic, lifecycle and break-even production cost are being considered for cost estimation. Additionally, some of the authors compared the cost for both conventional method and AM. Lindemann et al. [46] performed an analysis on the cost for producing parts using milling and metal AM (MAM).According to Matos and Jacinto [67], lack of studies and quantified data can be found examining the social impacts on AM, creating a huge gap for more researches to be performed. To this end, it remains a challenge for researchers and manufacturers to understand and identify the scope and boundary of social impact assessment [63].

5 Conclusion

This paper presented a review on the implications of AM in terms of three dimensions of sustainability viz. environment, economic and social. The background of AM was first presented followed by a discussion on the previous studies related to sustainability implications. Based on the review, most of the research only considered one or two pillars of sustainability in their studies, mostly focusing on environment and economic impacts. Social element is often disregarded by the researchers where information regarding the social implications of AM remains scarce. It is noted that research which included all the three sustainability elements are still lacking. In addition, several authors compared AM with conventional manufacturing. From their findings, it was shown that AM can minimize energy usage by using less material and removing and shortening the steps in the production process, thereby reducing cost. Furthermore, this current study shows the need to understand the sustainability implications of AM in order to assist companies and researchers in making the right decisions on whether they should maintain the traditional method or switching to AM in order to obtain economic benefits, consequently ensuring the competitiveness of their product in the market.

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References

1. Stock T, Seliger G (2016) Opportunities of sustainable manufacturing in Industry 4.0. Procedia CIRP 40:536–541
2. US EPA 2017 Hompeage, https://www.epa.gov/sustainability/sustainable-manufacturing. Assessed on 18 Nov 2020
3. Despeisse M, Yang M, Evans S, Ford S, Minshall T (2017) Sustainable value roadmapping framework for additive manufacturing. Procedia CIRP 61:594–599
4. Ribeiro I, Matos F, Jacinto C, Salman H, Cardeal G, Carvalho H, Godina R, Peças P (2020) Framework for life cycle sustainability assessment of additive manufacturing. Sustainability 12(3)
5. Guo N, Leu MC (2013) Additive manufacturing: technology, applications and research needs. Front Mech Eng 8(3):215–243
6. Gutowski T, Jiang S, Cooper D (2017) Note on the rate and energy efficiency limits for additive manufacturing. J Ind Ecol 21:1–11
7. Gibson I, Rosen D, Stucker B (2015) Additive manufacturing technologies, 2nd edn. Springer, Berlin
8. Wohler T (2012) Wohler report. 3D printing and additive manufacturing state of the industry
9. Huang SH, Liu P, Mokasdar A (2013) Additive manufacturing and its societal impact: a literature review. Int J Adv Manuf Technol 1191–1203
10. Rejeski D, Zhao F, Huang Y (2018) Research needs and recommendations on environmental implications of additive manufacturing. Addit Manuf 19:21–28
11. Verhoef LA, Budde BW, Chockalingam C, García Nodar B, van Wijk AJM (2018) The effect of additive manufacturing on global energy demand: an assessment using a bottom-up approach. Energy Policy 112:349–360
12. Garcia FL, Moris VA, da S, Nunes AO, Silva DAL (2018) Environmental performance of additive manufacturing process-an overview. Rapid Prototyping J 24(7):1166–1177
13. Kreiger M, Pearce JM (2013) Environmental life cycle analysis of distributed three-dimensional printing and conventional manufacturing of polymer products. ACS Sustain Chem Eng 1(12):1511–1519
14. Kellens K, Renaldi R, Dewulf W, Kruth JP, Duflou JR (2014) Environmental impact modeling of selective laser sintering processes. Rapid Prototyping J 20(6):459–470
15. Baumers M, Tuck C, Hague R, Ashcroft I, Wildman R (2010) A comparative study of metallic additive manufacturing power consumption. In: 21st annual international solid freeform fabrication symposium—an additive manufacturing conference (SFF 2010), pp 278–288
16. Bekker ACM, Verlinden JC (2018) Life cycle assessment of wire + arc additive manufacturing compared to green sand casting and CNC milling in stainless steel. J Clean Prod 177:438–447
17. Bourhis FL, Kerbrat O, Dembinski L, Hascoet JY, Mognol P (2014) Predictive model for environmental assessment in additive manufacturing process. Procedia CIRP 15:26–31
18. Huang R, Riddle M, Graziano D, Warren J, Das S, Nimbalkar S, Cresko J, Masanet E (2016) Energy and emissions saving potential of additive manufacturing: the case of lightweight aircraft components. J Clean Prod 135:1559–1570

19. Ingarao G, Priarone PC, Deng Y, Paraskevas D (2018) Environmental modelling of aluminium based components manufacturing routes: additive manufacturing versus machining versus forming. J Clean Prod 176:261–275
20. Jin M, Tang R, Ji Y, Liu F, Gao L, Huisingh D (2017) Impact of advanced manufacturing on sustainability: an overview of the special volume on advanced manufacturing for sustainability and low fossil carbon emissions. J Clean Prod 161:69–74
21. Ma J, Harstvedt JD, Dunaway D, Bian L, Jaradat R (2018) An exploratory investigation of additively manufactured product life cycle sustainability assessment. J Clean Prod 192:55–70
22. Malshe H, Nagarajan H, Pan Y, Haapala K (2015) Profile of sustainability in additive manufacturing and environmental assessment of a novel stereolithography process. In: ASME international manufacturing science and engineering conference, pp 1–11
23. Paris H, Mokhtarian H, Museau M, Coatane E, Ituarte IF (2016) Manufacturing technology comparative environmental impacts of additive and subtractive manufacturing technologies. CIRP Ann 65:29–32
24. Zhang H, Nagel JK, Al-Qas A, Gibbons E, Lee JJY (2018) Additive manufacturing with bioinspired sustainable product design: a conceptual model. Procedia Manuf 26:880–891
25. Balogun VA, Kirkwood ND, Mativenga PT (2014) Direct electrical energy demand in fused deposition modelling. Procedia CIRP 15:38–43
26. Lyons R, Newell A, Ghadimi P, Papakostas N (2020) Environmental impacts of conventional and additive manufacturing for the production of Ti-6Al-4V knee implant: a life cycle approach. Int J Adv Manuf Technol
27. Hodonou C, Kerbrat O, Balazinski M, Brochu M (2020) Process selection charts based on economy and environment: subtractive or additive manufacturing to produce structural components of aircraft. Int J Interact Des Manuf 14(3):861–873
28. Tagliaferri V, Trovalusci F, Guarino S, Venettacci S (2019) Environmental and economic analysis of FDM, SLS and MJF additive manufacturing technologies. Materials 12(24)
29. Böckin D, Tillman AM (2019) Environmental assessment of additive manufacturing in the automotive industry. J Clean Prod 226:977–987
30. Yosofi M, Kerbrat O, Mognol P (2019) Additive manufacturing processes from an environmental point of view: a new methodology for combining technical, economic, and environmental predictive models. Int J Adv Manuf Technol 102(9–12):4073–4085
31. Faludi J, Van Sice CM, Shi Y, Bower J, Brooks OMK (2019) Novel materials can radically improve whole-system environmental impacts of additive manufacturing. J Clean Prod 212:1580–1590
32. Liu Z, Jiang Q, Ning F, Kim H, Cong W, Xu C, Zhang H (2018) Investigation of energy requirements and environmental performance for additive manufacturing processes. Sustainability 10(10):3606
33. Yang Y, Li L, Pan Y, Sun Z (2017) Energy consumption modeling of stereolithography-based additive manufacturing toward environmental sustainability. J Ind Ecol 21:S168–S178
34. Tang Y, Mak K, Zhao YF (2016) A framework to reduce product environmental impact through design optimization for additive manufacturing. J Clean Prod 137:1560–1572
35. Priarone PC, Pagone E, Martina F, Catalano AR, Settineri L (2020) Multi-criteria environmental and economic impact assessment of wire arc additive manufacturing. CIRP Ann 69(1):37–40
36. Ron T, Levy GK, Dolev O, Leon A, Shirizly A, Aghion E (2019) Environmental behavior of low carbon steel produced by a wire arc additive manufacturing process. Metals 9(8)
37. Priarone PC, Ingarao G, Lunetto V, Di Lorenzo R, Settineri L (2018) The role of re-design for additive manufacturing on the process environmental performance. Procedia CIRP 69:124–129
38. Faludi J, Bayley C, Bhogal S, Iribarne M (2015) Comparing environmental impacts of additive manufacturing vs traditional machining via life-cycle assessment. Rapid Prototyping J 21(1):14–33
39. Senyana L, Cormier D (2014) An environmental impact comparison of distributed and centralized manufacturing scenarios. Adv Mater Res 875–877:1449–1453
40. Jiang R, Kleer R, Piller FT (2017) Predicting the future of additive manufacturing: a Delphi study on economic and societal implications of 3D printing for 2030. Technol Forecast Soc Chang 117:84–97

41. Khorram Niaki M, Nonino F, Palombi G, Torabi SA (2019) Economic sustainability of additive manufacturing: contextual factors driving its performance in rapid prototyping. J Manuf Technol Manag 30(2):353–365
42. Li Y, Linke BS, Voet H, Falk B, Schmitt R, Lam M (2017) Cost, sustainability and surface roughness quality—a comprehensive analysis of products made with personal 3D printers. CIRP J Manuf Sci Technol 16:1–11
43. Rickenbacher L, Spierings A, Wegener K (2013) An integrated cost model for selective laser melting (SLM). Rapid Prototyping J 19(3):208–214
44. Xu F, Wong YS, Loh HT (2001) Toward generic models for comparative evaluation and process selection in rapid prototyping and manufacturing. J Manuf Syst 19(5):283–296
45. Šoškić Z, Monti GL, Montanari S, Monti M, Cardu M (2019) Production cost model of the multi-jet-fusion technology. Proc Inst Mech Eng Part C J Mech Eng Sci 1–13
46. Lindemann C, Reiher T, Jahnke U, Koch R (2015) Towards a sustainable and economic selection of part candidates for additive manufacturing. Rapid Prototyping J 21(2):216–227
47. Westerweel B, Basten RJI, van Houtum GJ (2018) Traditional or additive manufacturing? Assessing component design options through lifecycle cost analysis. Eur J Oper Res 270(2):570–585
48. Kamps T, Lutter-Guenther M, Seidel C, Gutowski T, Reinhart G (2018) Cost and energy efficient manufacture of gears by laser beam melting. CIRP J Manuf Sci Technol 21:47–60
49. Laureijs RE, Roca JB, Narra SP, Montgomery C, Beuth JL, Fuchs ERH (2017) Metal additive manufacturing: cost competitive beyond low volumes. J Manuf Sci E T ASME 139:8
50. Huang R, Ulu E, Kara LB, Whitefoot KS (2017) Cost minimization in metal additive manufacturing using concurrent structure and process optimization. In: ASME 2017 international design engineering technical conference & computers and information in engineering conference computers and information in engineering conference, pp 1–10
51. Fera M, Macchiaroli R, Fruggiero F, Lambiase A (2018) A new perspective for production process analysis using additive manufacturing-complexity vs production volume. Int J Adv Manuf Technol 95(1–4):673–685
52. Ott K, Pascher H, Sihn W (2019) Improving sustainability and cost efficiency for spare part allocation strategies by utilisation of additive manufacturing technologies. Procedia Manuf 33:123–130
53. Rudolph JP, Emmelmann C (2017) A cloud-based platform for automated order processing in additive manufacturing. Procedia CIRP 63:412–417
54. Mai J, Zhang L, Tao F, Ren L (2016) Customized production based on distributed 3D printing services in cloud manufacturing. Int J Adv Manuf Technol 84(1–4):71–83
55. Atzeni E, Salmi A (2012) Economics of additive manufacturing for end-usable metal parts. Int J Adv Manuf Technol 62(9–12):1147–1155
56. Ruffo M, Tuck C, Hague R (2006) Cost estimation for rapid manufacturing—laser sintering production for low to medium volumes. Proc Inst Mech Eng Part B J Eng Manuf 220(9):1417–1427
57. Hopkinson N, Dickens P (2003) Analysis of rapid manufacturing—using layer manufacturing processes for production. Proc Inst Mech Eng C J Mech Eng Sci 217(1):31–40
58. Emelogu A, Marufuzzaman M, Thompson SM, Shamsaei N, Bian L (2016) Additive manufacturing of biomedical implants: a feasibility assessment via supply-chain cost analysis. Addit Manuf 11:97–113
59. Lindemann C, Jahnke U, Moi M, Koch R (2012) Analyzing product lifecycle costs for a better understanding of cost drivers in additive manufacturing, pp 177–188
60. Scott A, Harrison TP (2015) Additive manufacturing in an end-to-end supply chain setting. 3D Printing Additive Manuf 2(2):65–77
61. Khajavi SH, Baumers M, Holmström J, Özcan E, Atkin J, Jackson W, Li W (2018) To kit or not to kit: analysing the value of model-based kitting for additive manufacturing. Comput Ind 98:100–117
62. Urbanic RJ, Saqib SM (2019) A manufacturing cost analysis framework to evaluate machining and fused filament fabrication additive manufacturing approaches. Int J Adv Manuf Technol 102(9–12):3091–3108

63. Sutherland JW, Richter JS, Hutchins MJ, Dornfeld D, Dzombak R, Mangold J, Robinson S, Hauschild MZ, Bonou A, Schönsleben P, Friemann F (2016) The role of manufacturing in affecting the social dimension of sustainability. CIRP Ann Manuf Technol 65(2):689–712
64. Benoît C, Mazijn B (2013) United Nations Environment Programme. CIRAIG, Interuniversity Research Centre for the Life Cycle of Products, P. and S., & Canadian Electronic Library. Guidelines for social life cycle assessment of products (2013)
65. Chen D, Heyer S, Ibbotson S, Salonitis K, Steingrímsson JG, Thiede S (2015) Direct digital manufacturing: definition, evolution, and sustainability implications. J Clean Prod 107:615–625
66. Kondoh S, Tateno T, Kishita Y, Komoto H (2017) The potential of additive manufacturing technology for realizing a sustainable society, pp 475–486
67. Matos F, Jacinto C (2018) Additive manufacturing technology: mapping social impacts. J Manuf Technol Manag 30(1):70–97

Development of User Interface (UI) and User Experience (UX) for Smart Alcohol Detection System in Public Transportation

Mohd Amzar Azizan, Amirul Rohismadi, Nurhakimah Norhashim, and Nurizzati Norizan

Abstract In 2019, Malaysia has become the third highest fatality rate from road accidents in Asia because of driving under the influence of alcohol. A person who consumed excessive amounts of alcoholic beverages, and is driving in a drunken state that causes death can be charged under penalty due to criminal action. Horrendous accidents involving drunk driving have been reported recently and the numbers keep increasing every year. Although enormous international laws have been drafted to control the alcohol influence among drivers, there are lesser numbers of readily-available methods to measure the alcohol consumption for public transport drivers. This intelligent device is aims to provide real-time monitoring of blood alcohol concentration (BAC) and transfer the data to the cloud system. The algorithm was developed by integrating the sensor and the processor unit. The device also integrates with the biometric thumbprint that will capture the heart rate of the driver. By measuring the heart rate and alcohol level, the system will interpret the data and convert it into relevant information. The command center at the control room will monitor the fitness level of the drivers before performing their duties to ensure the safeness of other drivers and passengers. This invention will have novel applications not only for public transport but also involving other major sectors such as the manufacturing industry and public health organizations.

Keywords Alcohol · MQ-3 · Internet of things · Biometric sensor · Blood alcohol concentration (BAC)

M. A. Azizan (✉) · A. Rohismadi · N. Norhashim · N. Norizan
Aero-Ergonomics Research Cluster, Universiti Kuala Lumpur-Malaysian Institute of Aviation Technology, Kuala Lumpur, Malaysia
e-mail: mohdamzar@unikl.edu.my

A. Rohismadi
e-mail: mamirul.rohismadi@s.unikl.edu.my

N. Norhashim
e-mail: nurhakimah@unikl.edu.my

N. Norizan
e-mail: nurizzati.norizan09@s.unikl.edu.my

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1 Introduction

Alcohol is an addictive drug that can disrupt signals transformation to the t] brain and body. Alcohol has an adverse effect on problem-solving skills, decision making, concentration, reaction times, and psychomotor. The utmost important factors to be highlighted is, alcohol may have adverse effects on 'fitness for work' and individual health and wellbeing. Alcohol can affect the human performance of safety-related activities, such as driving an automobile or flying an aircraft, or handling machinery for short-term effect could harm on single occasion [1]. Although an alcohol tester called a breathalyzer can provide measurement data in a relatively shorter time compared to medical tes including blood tests or urine tests [2] however, a device to measure and monitor the percentage of alcohol content is still insufficient. Alcohol consumption may not only affect a single person, but also affect the whole community including the co-workers, customers, shoppers, family, friends, and community members. If the drivers drink alcoholic drinks before performing the duty, the probability of having an accident is higher and risk of death is increased as well.

The relationship between alcohol consumption and occupational accidents has been studied extensively. Most of the experimental research on alcohol's effects on safety performance was conducted in air and ground transportation. High number of accidents related to alcohol consumption either on the road or air accidents have been reported [3]. Based on Federal Aviation Administration (FAA) reports published in October 2008, a number of 2391 pilots involved in fatal accidents received by Civil Aerospace Medical Institute (CAMI) were under toxicological investigation. Out of 215 of these pilots which indicated 9% had a documented alcohol or drug-related and 23 pilots (11%) were involved in a fatal aviation accident that had consumed ethyl alcohol.

Blood alcohol content (BAC) is an estimation of alcohol intoxication utilized for legal or clinical purposes. A BAC of 0.10 (0.10% or one-tenth of one percent) implies that there are 0.10 g of alcohol for every 100 ml of blood. If an individual has a BAC 0.02%, that person will behave like a normal person. if the BAC percentage is increased to 0.05%, a person starts to lose coordination, having a slower time for responses and causing a debilitated visual perception and considered unsafe to drive. For the road users, the maximum BAC level to drive any automobile varies according to the country. In Malaysia, the allowable BAC level to drive is 0.08%, which is quite high; therefore, the tendency to be involved in an accident caused by alcohol is very high [4]. The Malaysian Institute of Road Safety (MIROS) stated the probability of a drunk driver to cause an accident is 13 times higher compared to a sober driver [5]. From the aviation industry, the pilots are prohibited from flying or even attempting to fly an aircraft within 8 hours of alcohol intake; or if they require an alcohol concentration of 0.04% or higher.

Alcohol intoxication or alcohol poisoning is a condition where a person consumes a high intake of alcoholic beverages in a short time duration. The intoxication of alcohol is serious and could cause sudden collapse or death [6]. Alcohol intoxication symptoms are loss of body coordination, blurry vision, and decreased person's reaction time that can lead to an accident [7, 8]. The alcohol intoxication involves the breathing, pulse rate, and gag reflex and affects the human body system. Consumption of alcohol also has implications for the health and well-being of the drinkers; by implication, the implications also include the lives of the people surrounding them [9]. Over the years, research has been done and the impact of alcohol on the body system has been identified that can lead to several health problems such as psychomotor deficit, cardiovascular problem and blurred vision [10–12]. This proved that consuming alcohol can cause many negative impacts not only for our health but also the society.

2 Methodology

The development of an early alcohol detection system is used to minimize the effect of alcohol influence and to identify the fitness of the person to perform work. The system will measure the alcohol level in the blood through human breathing using an alcohol sensor. And alert the safety manager if the person is unfit to perform work. In this research, we have developed a special device to measure the Blood Alcohol Concentration level (BAC). The recorded data will be transferred to the cloud system called MySQL database. It uses the PHP programming language to interact with the MySQL. The system used a local network to send the data computed by the Arduino mega and then forward to the MySQL and stored it to the database.

The software implementation for the system is using Arduino Integrated Development Environment (IDE) which is written in functions from C and C++ language. It is used to write and upload all the programs to the Arduino mega board. In addition, the alcohol sensor is an analog sensor, the AOUT terminal of alcohol sensor generates an analogue voltage that is directly proportional with the amount of alcohol intake. If the alcohol intake is higher, the analogue voltage will show higher output. If a certain threshold is met by the analogue voltage, the DOUT digital pin is high. Once this DOUT pin is high, the Arduino mega detected t the signal that the alcohol threshold reached maximum value. All the compute data will be shown on the LCD display and sent to the database and can be accessed on the website.

2.1 Equipment

(a) Alcohol Sensor, MQ3
The MQ-3 sensor is used to detect the alcohol content which consist of sensitive material including tin (IV) oxide, that can lower clean air conductivity. This basic gas sensor works the same as s other gas sensors when the alcohol appearance is noticeable, the sensor conductivity increases and the gas concentration is high. The gas sensor MQ-3 is an alcoholic sensitivity device and is resistant

to gasoline, smoke, and vapor. Usually, it is used as part of a breathalyzer or breath tester to indicate ethanol in a human breath. the alcohol's molecules in the air interact with the electrode between alumina and the tin dioxide, ethanol brings acetic acid—which generates more heat. The more molecules of alcohol that exist, the data is more precise (Fig. 1).

(b) Fingerprint Biometric Sensor
The Biometric Fingerprint Module shown in Fig. 2 is used to interface with the Arduino board as the input as. The fingerprint algorithm is used to extract features of the fingerprint image and display the detailed information of fingerprints. All of the fingerprints are stored, comparable, and searched through operating fingerprint functionality. Everyone has different patterns of fingerprints—even identical twins have a unique fingerprint. A process to identify a person's fingerprints is known as "fingerprint scanning." A fingerprint scanner system has two basic tasks. Which are scanning the image of fingerprints, and match the fingerprint pattern with pre-scanned images. For encrypted biometric purposes, special features unique to the fingerprint of each person are screened and stored from raw photos, thus the fake fingerprint are not possible to re-engineer the algorithm.

(c) Heart Rate Sensor
Pulse sensor is an Arduino-compatible, plug-and-play heart rate sensor. The Pulse Sensor provides amplification and noise cancellation for the circuitry. It is considerably simpler and easily to receive accurate pulse readings. For

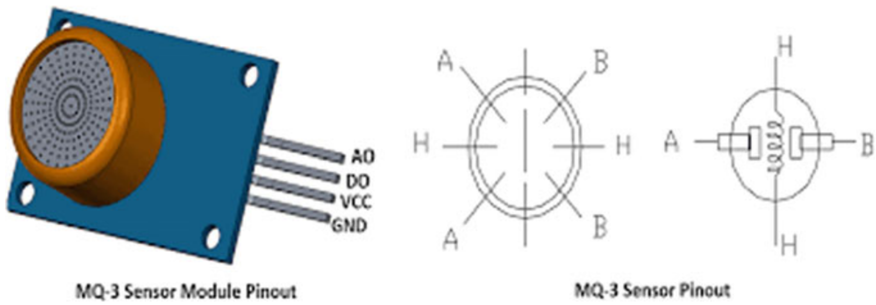


Fig. 1 MQ3 alcohol sensor

Fig. 2 Biometric sensor

either an Arduino 3V or 5V, the Amped Pulse Sensor is used 3). The module uses an infrared led (IR) and a phototransistor to track the pulse of the finger and the red led when the pulse is sensed. A phototransistor is used to remove the emitted flux and varies if the pulse is changed. (Fig. 3)

(d) LCD Module
The LCD module is used as a user interface and displays the characters or numbers which only require four pins to connect with the Arduino board (Fig. 4)

(e) Arduino Mega R3
The development board of the Arduino Mega 2560 R3 consists of 54 digital input/output pins (14 can be used as PWM outputs), 16 analog inputs, and four serial ports as shown in Fig. 5. This board consists of Arduino microcontroller core incorporated with the ATMEGA2560 that can easily connect with the computer via USB cable. This board acts as the processor that runs the system.

Fig. 3 Heart rate sensor

Fig. 4 LCD module

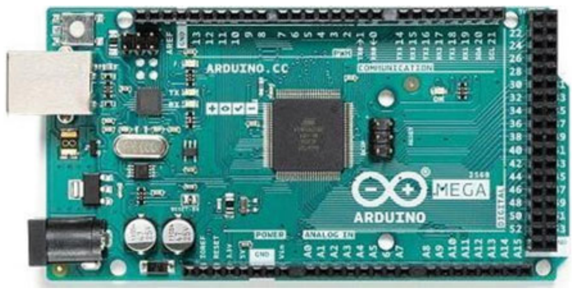


Fig. 5 Arduino mega R3

2.2 *Chemical Reaction in the Alcohol Detection System*

The alcohol level in a body can be measured by breathing into the device. The breath sample is bubbled in one vial through a mixture of sulfuric acid, potassium dichromate, silver nitrate, and water. The principle of the measurement is based on the following chemical reaction as shown in Fig. 6.

In this reaction, the sulfuric acid removes the alcohol from the air into a liquid solution. The alcohol reacts with potassium dichromate to produce: chromium sulfate, potassium sulfate acetic, acid, and water. The silver nitrate is a catalyst, a substance that reacts quickly and time consuming. The sulfuric acid, in addition to remove the alcohol from the air and providing the acidic for this reaction. The alcohol that normally found in alcoholic beverages is ethyl alcohol (ethanol). The molecular structure of ethanol is.

Where C is carbon, H is hydrogen, O is oxygen and each hyphen is a chemical bond between the atoms. For clarity, the bonds of the three hydrogen atoms to the left carbon atom are not shown. The OH (O–H) group on the molecule is an alcohol. There are four types of bonds in this molecule:

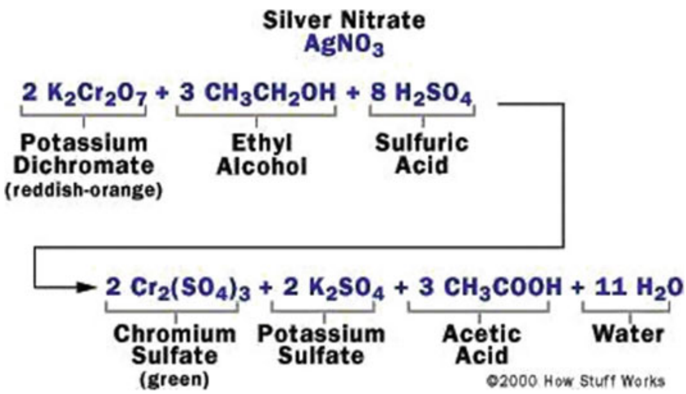


Fig. 6 Chemical reaction

carbon–carbon (C–C).
carbon-hydrogen (C–H).
carbon–oxygen (C–O).
oxygen-hydrogen (O–H).

The chemical bonds between the atoms sharing the pairs of electrons. Chemical bonds can be bent and stretched. These properties are important in detecting ethanol in a sample by infrared (IR) spectroscopy. When the user exhales into a breathalyzer, any ethanol present in the breath is oxidized to acetic acid at the anode:

$$CH_3CH_2OH(g) + H_2O(l) \rightarrow CH_3CO_2H(l) + 4H^+(aq) + 4e^- \quad (1)$$

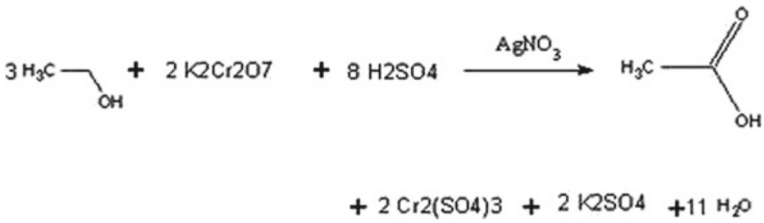
At the cathode, atmospheric oxygen is reduced:

$$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O \quad (2)$$

the overall reaction is the oxidation of ethanol to acetic acid and water.

$$CH_3CH_2OH(l) + O_2(g) \rightarrow CH_3COOH(aq) + H_2O \quad (3)$$

The electric current produced by the reaction is measured using microcontroller, and displayed as an approximation of overall blood alcohol content (BAC).



Using Beer's law, the spectrophotometer can measure concentration to absorbance levels of the chromium ion. The amount of alcohol present is proportional to the stoichiometric coefficients. An actual breathalyzer only needs to detect 25 μg of ethanol to give a reading 0.10 Blood Alcohol Level.

3 Analysis and Discussion

Figure 7 below shows the flow process of the alcohol detection module. There are three phases which are input, protocol and output. The block diagram shows that the alcohol sensor, the heart rate sensor and the fingerprint module have three inputs. The user has to place his finger on the fingerprint module to recognize the registration number and blow the breath through the alcohol sensor. The heart rhythm can be

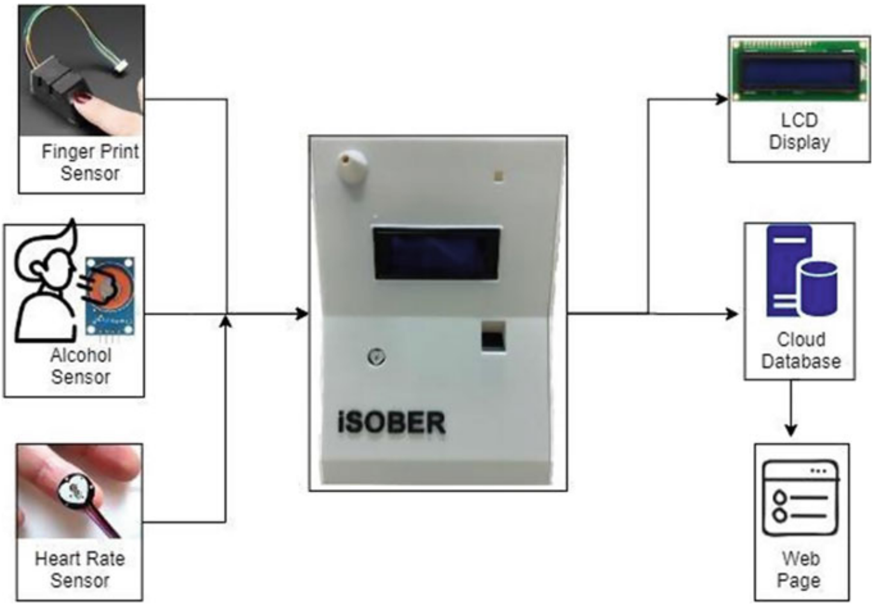


Fig. 7 The schematic diagram of how the alcohol detection system work

measured by, placing the index finger on the heart rate sensor. Arduino Mega is powered using batteries and displays the data on the LCD screen. Arduino Mega is the control unit for the processing point that performs the signal input and output of the device. With the assistance of the ESP8266 module, system output depends on the interface between Arduino Mega and the cloud database. On the web server page, the user monitoring the data collected using computer.

(a) The Sensing Device

The sensing device is where the information is being processed by the input microprocessor to the output of the system. The system starts when the Arduino Mega microcontroller is powered up by the computer via the USB connection. Firstly, the user must scan the thumb to the biometric sensor to match the ID number from the system registered (Fig. 8)

Fig. 8 The LCD displays the ID for the user

Fig. 9 The Blood alcohol level (BAC) will be displayed on LCD to show the alcohol status of the user

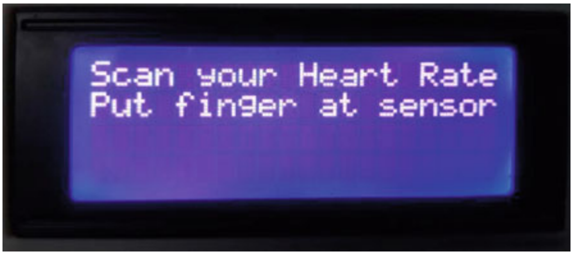


Fig. 10 The LCD displays the heart rate reading

Then, the user is required to blow breath into the alcohol sensor for 10 s.

Once the scanning is done within 10 s, the system will show the test result The "BAC" stands for Blood Alcohol Concentration in milligram/liter unit. The status will also show a "NORMAL" or "DRUNK" sign. If the BAC level is below 0.4 mg/L, the status will show a "NORMAL" sign, and if higher than 0.4 mg/L, the status will show "DRUNK" status. Once done, the system will continue + to the heart rate scanning (Fig. 9)

The system will show the heart rate of the user in beats per minute. Finally, all the data is calculated using the detector and then transferred to the cloud server to be monitored by user's device (Fig. 10).

(b) Software Implementation

Showing the process of adopting and integrating a software application into a workflow.

(i) User Registration

The website helps the user to log their details in the database. the user may access the device by inserting the user ID number, name, age, and phone number as shown in Fig. 11.

(ii) Result Data

The result page shows all the data collection by the input and output of the hardware. The time and date will be shown respectively as an input from the Arduino (Fig. 12).

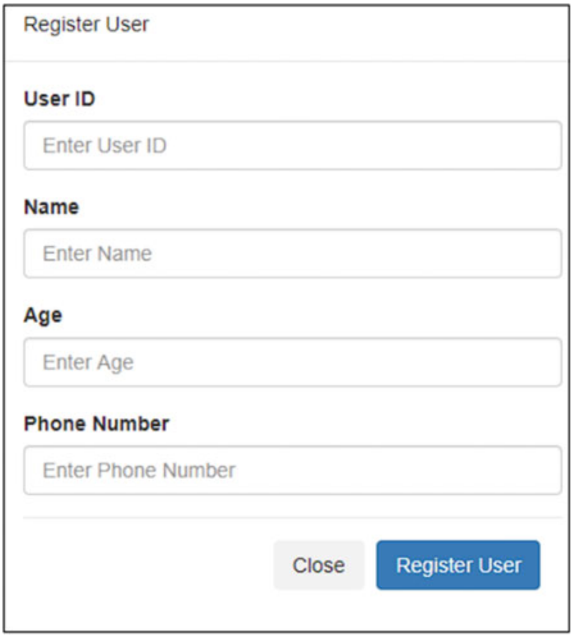
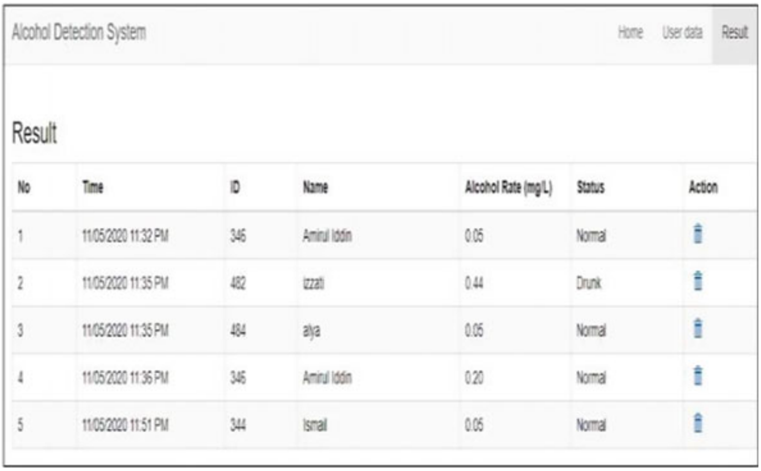


Fig. 11 User registration page



No	Time	ID	Name	Alcohol Rate (mg/L)	Status	Action
1	11/05/2020 11:32 PM	346	Amirul Iddin	0.05	Normal	
2	11/05/2020 11:35 PM	482	Izzati	0.44	Drunk	
3	11/05/2020 11:35 PM	484	alya	0.05	Normal	
4	11/05/2020 11:36 PM	346	Amirul Iddin	0.20	Normal	
5	11/05/2020 11:51 PM	344	Ismail	0.05	Normal	

Fig. 12 The alcohol status will be displayed on the user data page

4 Discussion

Alcohol consumption has poor consequences for health and well-being and this research aims to develop a device to measure and monitor the user's alcohol level. This research provides a much-advanced concept that can be implemented in the construction site, factory, office, and also public transport and to minimize alcohol-related accidents and improve the safety of workplaces. The drawbacks of this research are the sensitivity of the MQ-3 alcohol sensor to breathing pattern. If the user's mouth is in a closed position, it could result in higher concentrations of ethyl alcohol. Holding the breath before higher ethyl alcohol levels will also can cause an error. Second, if the variance in readings may not be too high, any decimal position is counted, therefore it may be enough to put you beyond the legal limit. The recommendation is to clean the mouth before blowing and wait for the recommended time duration is between 15 and 30 min. The other limitation is to do multiple tests to acquire high consistency as the accuracy variation is 12%. In addition, surrounding environments such as temperature and humidity also give effect to accuracy of the sensor indirectly. Overall, the outcome from this research will have significant impact on creating a safe and healthy community.

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References

1. Sarah J (2013) Breathalyzer technologies and sensors—advanced safety devices (2013)
2. Laurensius Davin RP, Primary M, Putra YJ, Susanto R (2011) Detection of alcohol levels. J Computer Eng 19:123–131
3. Win DT (2006) Breath alcohol testers—prevents road accidents. Au J.T 10(2):75–80
4. Madd. Statistics., http://www.madd.org/statistics/. Last accessed 20 April 2018
5. Miros M (2017) General road accident data in Malaysia (1997–2016)
6. Freeman PM, Freeman M, Parry C (2017) Alcohol use literature review, Africa, pp 1–39
7. Lampard F (2005) Alcohol intoxication: acute, symptoms, treatments, signs, and more
8. Solomon P (2018) Drunk driving is a top cause of auto accidents
9. Xiaorong Z et al (2016) The drunk driving automatic detection system based on internet of things. Int J Control Autom 9(2)
10. Cheah YK, Rasiah R (2000) Health risks and benefits of alcohol consumption. Alcohol Res Health 24(1):5–1
11. Rehm J (2011) The risks associated with alcohol use and alcoholism. Alcohol Res Health J Nat Inst Alcohol Abuse Alcohol 34(2):135–143
12. Naumanen P (2006) Opinions of ageing workers on relative importance of health promotion. Int J Nurs Pract 12(6):352–358. https://doi.org/10.1111/j.1440-172X.2006.00594.x

IoT Green-Bin: The Development of a Self-sorting Recycle Bin System

Muhammad Aiman Ismail and Aimi Shazwani Ghazali

Abstract Recycling is a huge responsibility in preserving ecosystems. However, lack of motivation besides complexity in sorting and choosing a right-colored recycle bins in dumping the trashes have hindered many from recycling. To encounter these issues, the paper proposes to develop a smart, self-sorting recycle bin system that automatically segregate the trashes based on its materials. The segregation process will take place using one light sensor and one vibration sensor to differentiate the recyclable materials based on its opaqueness and vibrational characteristics. Based on the identification of the materials, a mechanical subsystem of the bin will automatically separate the waste into designated compartments. Using IoT, the information about the level of capacity of each compartment that contained the trashes in the recycle bin will be transferred to a database and a notification will be sent to authorities when the bin needs to be emptied. Results showed that the system able to segregate trashes made from plastic, glass, paper, and aluminum up to 83% correctly. Future research might include a persuasive subsystem that motivates people to recycle by introducing point-to-voucher concept based on the amount of trashes and frequency in using the bin.

Keywords Self-sorting recycle bin · IoT · Opaqueness · Vibration

1 Introduction

Recycling is a process of collecting recyclable materials before processing them into new items [1]. There are many advantages of recycling. Firstly, it reduces the number of natural resources that will be needed when producing new products for example in the industry production line. Indirectly, the recycling activity will preserve the geometry and beauty of earth for tourist spots that can be beneficial in terms of the economy. Moreover, recycling can decrease the energy of producing new materials or

M. A. Ismail · A. S. Ghazali (✉)
Department of Mechatronics Engineering, International Islamic University Malaysia, Jln. Gombak, 53100 Kuala Lumpur, Malaysia
e-mail: aimighazali@iium.edu.my

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products. The process of making materials from scratch requires more energy rather than recycling the materials. This is because of the more energy needed to filter out some of the unwanted elements from the raw material. Whereas for recycled items, it is already undergone the filtering process and no need to re-filter the material again. As such, the recyclable materials require undergoing other processes, for example, the melting process to reshape and reuse them again, in case the material is aluminum [2, 3]. Plastic is one of the useful materials that is widely used due to its durability and long-lasting lifetime. However, the process of making plastic is very harmful in many ways. The emission that it produces through the process is dangerous that can affect the ecosystem and health [4]. Due to the long ageing in plastic, it is very damaging in case people dispose the plastic freely as plastic will emit toxic gas that can be harmful to humans, animals, and the environment. In contrast, recycling plastic can reduce the amount of gas emission produced and lower the amount of plastic production. Nowadays, most of the recyclable items could be found in technology components such as computers, smartphones, laptops that acquired valuable metals such as aluminum, copper, gold, and platinum [1].

Unlike in European countries like Netherlands and Belgium, only a few Malaysian prefer to recycle their trash. One of the issues with recycling is that many people are still confused with the type of litter they have at hand and which colored bins they need to dispose the trash in. Also, in terms of spacing, the existing recycle bins occupied a large space, in which, three different bins needed to separate at least three types of materials. Furthermore, there is no alarm or notification system implemented onto the bins in case the bins are full. The trash collector only come and empty the bin periodically. This may cause overflow of trashes inside the bins which later leads to unpleasant scenery and smell. An earlier work [5] highlights the crucial factors that may persuade people to change their behaviour or attitude towards recycling. It can be concluded from [5] that motivation, information, and knowledge, besides beliefs/perception of recycling consequences are the crucial factors that may change people's perception towards recycling. Although characteristics of the bin only contributes to 2 % of determination to recycle, it is believed that this factor has a high correlation with the motivation to recycle. In other words, a user-friendly, easy-to-use bin might boost people's motivation to put their trash inside a recycle bin, instead of a normal bin.

To solve these issues, the project aims to (i) identify the type of recyclable materials (ii) develop a mechanical subsystem for a dustbin in separating the trashes based on identified materials (iii) notify the trash collector when the capacity of the bin is near-to-full using IoT.

There are several sensors can be used to differentiate the types of materials for recycling purpose. For metal, earlier studies [6, 7] showed that inductive sensors capable to identify trashes made by metal. The sensor will generate certain amount of currents induced by magnetic fields, and in case there is a metal near the field, the value of currents will change. Meanwhile, other researches [8, 9] used capacitive sensors to detect metal. Working principle for capacitive sensor is that when there is an external conductor such as metal placed near the sensor, the increment of electric field will be sensed by the sensor. Meanwhile for glass and paper, an earlier study

[8, 9] employed photoelectric sensor to identify the material of the trashes, in which the sensor used transmitter and receiver concept. In case the surface of the material is transparent like glass, the light produced by transmitter will not be reflected to the receiver. However, in case the surface is non-transparent like paper, some amount of light will be reflected to the receiver. Some studies [6–8] utilized Light Dependent Resistor (LDR) sensors to detect plastic and paper. Due to difference of transparency of plastic and paper, the amount of light pass through the material will be measured by LDR sensors through its receiver. Other study [9] used inductive sensor to segregate between plastic and paper (non-metallic materials) and metal.

For separating the trashes based on identified materials, earlier researches [6, 7] highlighted the use of servo motors to rotate the bin's compartment and tilt the base of the trashes before dropping down the trash into respective compartment. Others like [9] used DC motors as an actuator for a recycle bin system. Using the first motor to rotate the lid of the bin to be aligned with the respective compartment, the second DC motor was used to turn and push the trashes into the compartment. Differently in [8], a servo motor will be attached with a board to slide down the trashes based on its materials. The board will be tilt only if the materials detected are either glass, paper, or plastic. Meanwhile in case the material is made by metal, the board will not tilt as the trash will be dropped straight down to the middle compartment. In terms of notification for trashes collection, many researches [10–12] measured the level of recyclable items inside the bins to avoid overflow of trashes. Most of the studies [12] used an ultrasonic sensor in measuring the distance between the level of trashes and the lid of the bin. The developed system also will give an alert to the users in case the bin has almost reached a certain threshold. Also, an earlier research [13] employed image processing technique to the amount of trashes inside the trash bin. An image will be captured from the top of the bin before it being compared with a reference image that showed a nearly full bin stored in a database.

Overall, the IoT Green-Bin study will improve the traditional trash bin that existed by reducing the whole size that required to place the bin. Additionally, this study can simplify the traditional method in segregating the trash manually by using several sensors in detecting the type of trash automatically. Combining the automatic detection in segregating the trashes using Arduino, this study also proposes to add an alert notification system to the bin that will inform the capacity of the trash from time to time automatically using Blynk software. Importantly, this study aims to promote the good health and well-being of people for a cleaner environment through recycling (in line with SDG 3).

2 System Design

The design of IoT Green-Bin is inspired by the design of "Trashbot", an automated recycling system that equipped with several sensors and cameras.[1] For a clearer

[1] https://youtu.be/eAmRMahLmxk.

overview on how the bin operates, Fig. 1 demonstrates the flow of the designed bin. Firstly, the system will detect the location of the bin using internet technology. Using IR sensor, the system will detect either the bin is empty or not. In case the bin is full, authorities will be notified using IoT technology, and the alarm system consists of buzzer and LED will be on. If not, then the lid of the bin will be opened. After the trash is detected inside the bin (using the infrared sensor), an LDR sensor will be activated before the lid is closed, the grip between the vibration motor and a servo motor is tightened and activated. In case the reading from the LDR sensor shows the value of opaqueness of the trash is less than 10, the trash might be made from aluminum or paper (case 1). Otherwise, the trash is made from glass or plastic (case 2); depending on the value shown by the vibration sensor. For case 1, the trash will be categorized as paper only if the peak vibration value is less than 750. If not, then the trash is made from aluminum. Similarly for case 2, the trash will be categorized as glass only if the peak vibration value is more than 100. If not, then the trash is made from plastic.

For the software design, two software are utilized in this project namely Arduino IDE and Blynk. Arduino IDE is needed to program the controller (the Arduino UNO) and for the system's set ups generally. Differently, Blynk is programmed as a Graphical User Interface (GUI) for the users in monitoring the level of trash inside the IoT Green-Bin as shown in Fig. 2.

For the hardware design, An Arduino Uno is used as the controller for the whole system, a WeMOS D1 R1 for IoT system, and an Arduino motor shield for controlling the speed and direction of the servo motor. For actuator, a vibration motor is used to supply a constant vibration in identifying the type of trash, a servo motor as a holder for the trash during identification of its materials (in which the trash will be placed in between a vibration motor and a servo motor), and a DC geared motor for rotating the upper base of the IoT Green-Bin so that the segregation process can be done automatically. Additionally, for the sensors, LDR is used for categorizing the trash based on its opaqueness, a piezo vibration sensor for differentiating the vibration property of the trash, and infrared sensor for an alarm system (buzzer and LED) inside the IoT Green-Bin and IR sensor in measuring the level of trash. Figure 3 shows (a) the top view of the IoT Green-Bin and (b) the final design of the bin based on the listed hardware. For electrical connection, Fig. 4 illustrates the connection of hardware used to develop the system including the sensors, actuators, controller and motor shield, WeMOS D1 R1 besides LED of the system.

3 Results and Discussion

3.1 Segregation of the Trash

There are two sensors that will be used to segregate the trash, which is a light sensor and a vibration sensor. The light sensor will evaluate the opaqueness of trash

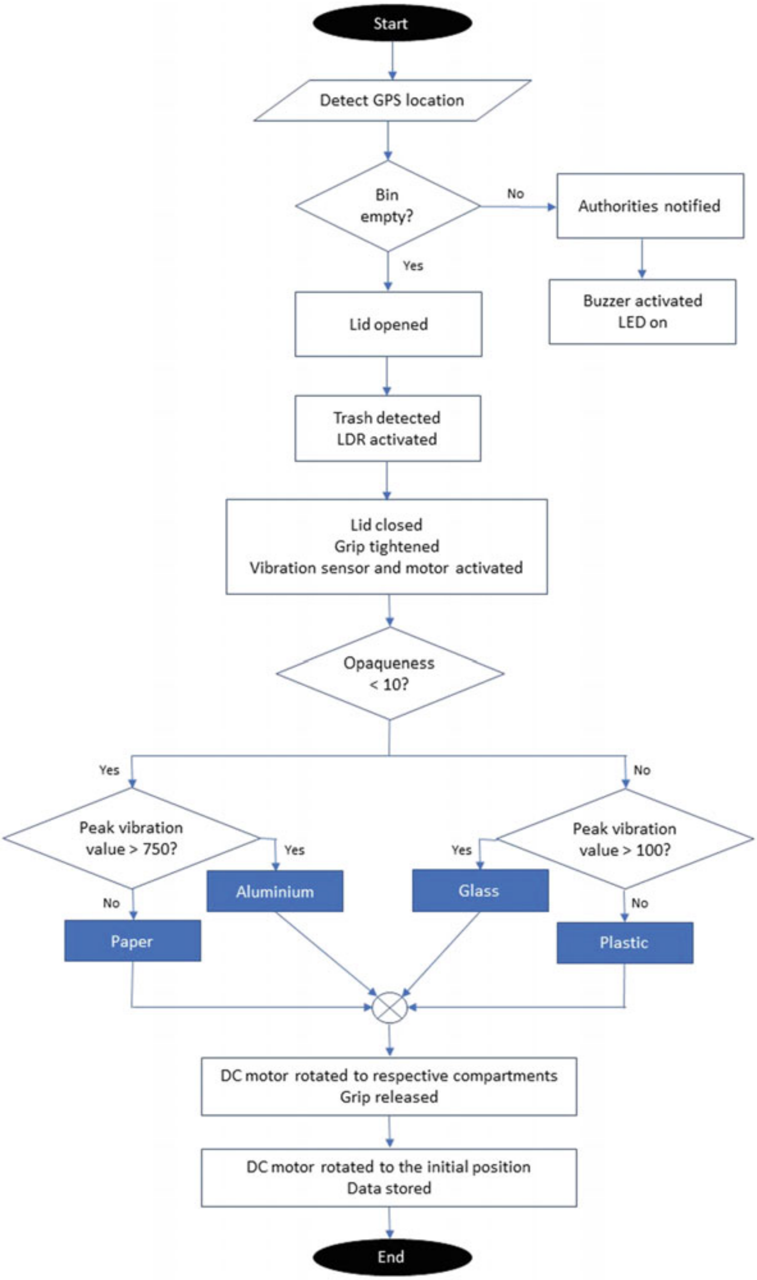


Fig. 1 Flowchart of the IoT Green-Bin's operation

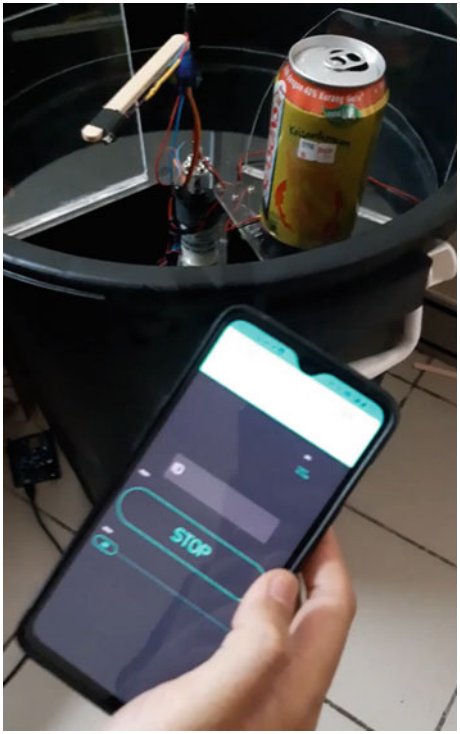
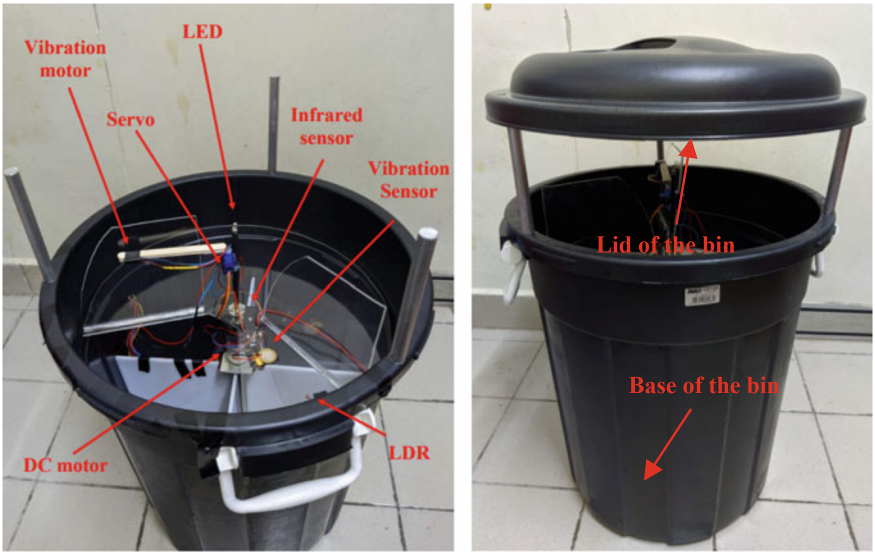


Fig. 2 Blynk interface for IoT Green-Bin

while vibration value of trash will be evaluated using a vibration sensor. Measuring the opaqueness of materials is vital in this project as it will divide the trash into two categories, which are opaque and non-opaque (transparent/translucent). The trash from aluminum and paper will be categorized under the opaque group, while glass and plastic will be considered in the transparent group. Instead of solely using vibration property, dividing the trash based on opaqueness property reduces the error in segregating the trash. After completing the opaqueness test, vibration test will be done so that the trash's frequencies can be measured. Table 1 shows the results of opaqueness and vibration properties of each material.

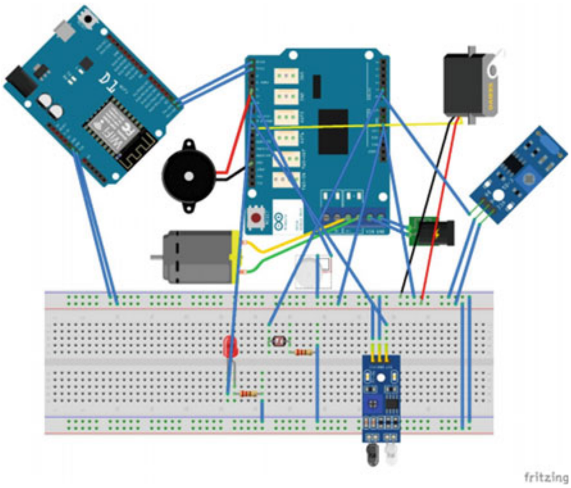
Figure 5 demonstrates the vibration values of the trash based on its materials. From this figure, it can be concluded that plastic and paper have similar values of peak. The same characteristic goes for aluminum and glass. Essentially using LDR sensor, those materials (plastic and paper) and (aluminum and glass) can be differentiated based on opaqueness property.



(a) (b)

Fig. 3 **a** Top view of IoT Green-Bin by specifying the location of a vibration sensor, LDR sensor, infrared sensor, LED, servo motor, and DC motor, **b** Final design of IoT Green-Bin

Fig. 4 Circuit connection for IoT Green-Bin



3.2 *Management of the Trash*

When the trash has been identified based on the materials used, the IoT Green-Bin will automatically sort the trash into its respective compartment using a motor. The

Table 1 Opaqueness and vibration values of the trash

Materials	Opaqueness		Peak value (mV)
	mV	Group	
Aluminum	1.75	Opaque	700–875
Plastic	25	Transparent	15–50
Paper	0.25	Opaque	30–50
Glass	23	Transparent	100–300

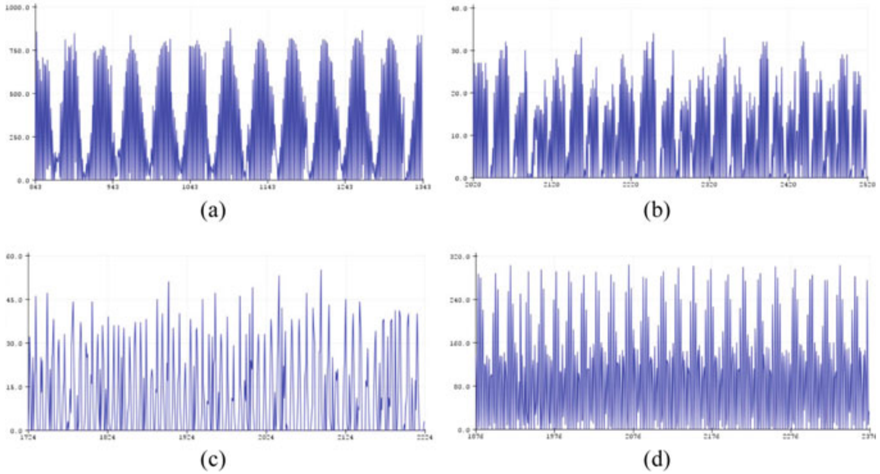


Fig. 5 Vibration properties of the trash based on materials **a** aluminum, **b** plastic, **c** paper, **d** glass

bin has been divided into four sections, which are aluminum, plastic, glass, and paper. In case the trash is made from aluminum, a specific degree of rotation will be made by the motor. For the trash to fall into the designated compartment, time (delay function in coding) is the key to the automatic segregation. This can be done by varying the period of motor activation, which means that the motor will be off when it reaches the designated trash compartment (in our example the aluminum) and leave a gap for the trash to fall. To investigate the accuracy of this method, several experiments have been conducted and the results can be observed in Table 2.

Table 2 Frequency of trash dump into its designated compartments

Materials	Trials					
	1	2	3	4	5	6
Aluminum	✔	✔	✔	✖	✔	✔
Plastic	✔	✔	✔	✔	✔	✔
Paper	✔	✔	✔	✔	✔	✔
Glass	✔	✖	✔	✔	✖	✖

Based on the table above, glass shows the lowest number of right trials that manages to dump the trash made from glass into the correct compartment. For aluminum, only once the system fails to dump the trash into its designated compartment. Significantly, the IoT Green-Bin never fails to classify and dump the trash made from plastic and paper into the right compartment. Based on observation, the bin misses dumping the glass into its compartment due to the inertia. As glass is a heavy object, higher inertia is needed to rotate the motor compares to other test materials.

3.3 Capacity of the IoT Green-Bin

An IR sensor is used to detect the volume of the trash. IR sensor is capable to detect an object near to it. For this project, when the trash has reached its maximum volume (define by the trash's height), the sensor will send a high-triggered signal to the microprocessor. Combining with the Wi-Fi module for IoT system, the microprocessor then manages to send the data to the cloud instantly. As mentioned earlier, Blynk has been used as a platform to notify the authorities in case the capacity of trash has reached its maximum.

4 Conclusion

Based on the objectives of the project, the IoT Green-Bin system successfully identifies the type of trash based on the recyclable materials using several combinations of sensors. Also, we manage to develop a mechanical subsystem for a dustbin in separating the trashes based on identified materials using motors and notify the trash collector when the capacity of the bin is near-to-full using IoT technology. However, this project is limited due to the design of the bin's lid, which has only a small covering area of the bin. As such, this bin can be used for indoor purposes only. Additionally, we observe that in some cases when we use glass (heavy trash), the bin tends to tip. Future works might tackle these issues by changing the design of the bin's lead for a bigger covering area to be used outdoor. Also, a stable bin-base and high-force gripper are required for stability purposes in classifying and segregating the trash.

References

1. Asmatulu R, Asmatulu E (2011) Importance of recycling education: a curriculum development at WSU. J Mater Cycles Waste Manage 13(2):131

2. Bolanos JE, Reeve KF, Reeve SA, Sidener TM, Jennings AM, Ostrosky BD (2020) Using Stimulus Equivalence-Based Instruction to Teach Young Children to Sort Recycling, Trash, and Compost Items.
3. Sormunen P, Kärki T (2019) Recycled construction and demolition waste as a possible source of materials for composite manufacturing. J Build Eng 24:100742
4. Healey K (2019) 9 benefits of recycling: How it helps more than just the environment, https://www.wftv.com/news/local/9-benefits-of-recycling-how-it-helps-more-than-just-the-environment/961325998/
5. Varotto A, Spagnolli A (2017) Psychological strategies to promote household recycling. A systematic review with meta-analysis of validated field interventions. J Environ Psychol 51:168–188
6. Ismail INb, Jayakumar P, Eqwan M, Zuhdi AWM, Mohamad D, Isa MR, Zahari NM, Zawawi MH, Mohamed H, Ramli MZ (2018) Design and development of smart sorting recycle bin prototype. In: AIP conference proceedings, vol 1. AIP Publishing LLC, p 020202
7. Hassan H, Saad F, Raklan MSM (2018) A low-cost automated sorting recycle bin powered by Arduino microcontroller. In: 2018 IEEE conference on systems, process and control (ICSPC). IEEE, pp 182–186
8. Russel MH, Chowdhury MH, Uddin MSN, Newaz A, Talukder MMM (2013) Development of automatic smart waste sorter machine. Res Gate
9. Norhafiza S, Masiri K, Faezah AN, Nadiah AN, Aslila A (2018) The Effectiveness of Segregation recyclable materials by automated motorized bin. J Adv Manuf Technol (JAMT) 12(1 (1)):409–420
10. Zavare S, Parashare R, Patil S, Rathod P, Babanne V (2017) Smart City waste management system using GSM. Int J Comput Sci Trends Technol 5(3):74–78
11. Al-Sanjary OI, Vasuthevan S, Omer HK, Mohammed M, Abdullah MI (2019) An intelligent recycling bin using wireless sensor network technology. In: 2019 IEEE International conference on automatic control and intelligent systems (I2CACIS). IEEE, pp 30–33
12. Salah N, Hagem RM (2018) Smart Recycle Bin System based on Wi-Fi and IoT. Int J Computer Appl 181(4):34–37
13. Arebey M, Hannan M, Basri H, Begum R, Abdullah H (2010) RFID and integrated technologies for solid waste bin monitoring system. In: Proceedings of the World Congress on Engineering, pp 316–332

"Return-To-Work": Application of New Materials to Develop the Durable and Low Cost of Solid Ankle Cushion Heel (SACH) Prosthetic Foot

Wan Syahira Wan Ramli, Mohd Isyraf Irfan Mat Zin, Mohd Shaiful Zaidi Mat Desa, and Azizan Ramli

Abstract This paper presents the conceptual design and development of an ergonomic and polymeric prosthetic foot. This study was done in two phases the prototype design and the selection of materials with fabrication. During the design stage, the inputs from the Certified Prosthetists and Orthotists (CPO) and literature review were discussed amongst four interested parties (UMP-ADTEC Jerantu-JasaMedik Enterprise-Hospital Pulau Pinang). In addition, the design was also developed based on the knowledge gathered during industrial training period with a prosthetic company, in which the company provides prosthetic and orthotic services. A series of discussions has been organized and in consensus with all interested parties, the prototype design was successfully developed. This design then simulates using Solidworks software to determine its stress, strain and displacement. The result show the von-mises stress for Solid Ankle Cushion Heel (SACH) foot was higher. In addition, the selection and analysis on material development has been carried out in one go. Finally, the prototype prosthetic foot known as Solid Ankle Cushion Heel (SACH) has been fabricated and the field test is to be carried out at a rehabilitation center. From this analysis, the prosthetic foot uses new materials which are polyurethane and neoprene, 99.4 and 0.6% because it gives good tensile strength and also young modulus for the designing process until the casting process. It also best production method that can be used.

Keywords Prosthetic foot · Ergonomic · Polymeric · Polyurethane · Neoprene

A. Ramli (✉)
Faculty of Industrial Sciences and Technology, College of Computing and Applied Sciences, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
e-mail: azizanramli@ump.edu.my

W. S. Wan Ramli · M. I. I. Mat Zin · M. S. Z. Mat Desa
Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

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1 Introduction

Occupational Safety and Health (OSH) is a main aspect that enable the organization to manage the safety and health of employees in the workplace systematically [1]. Many accident cases happen especially at the high-risk workplaces such as construction sites, chemical plants and other economics sectors. Occupational health and safety hazards occur in variety sector and expose workers to accidents. The existence of hazardous condition and hazardous working environment, if not managed and controlled systematically, can cause serious injury such as loss limbs (leg and hand). For example, loss of leg can occur because of an accident at work. In the case of loss of leg, the amputee will need to undergo a recovery process and they will be given treatment to use a prosthetic leg. Prosthetic leg system mainly involves three main part which is the foot, socket and pylon worn by the patient to enable patient to walk. The design of the prosthetic foot must follow ergonomically design to ensure the user's comfort when using it. The function of a prosthetic foot is to assist the amputee getting back to their normal life by offering the artificial foot. However, to produce the durable and low-cost prosthetic foot is not easy. Consideration on the ergonomic design, formulation and development of the suitable material is of paramount important. This will become the main challenge to designers and manufacturers.

Ergonomic is the analysis of the relationship between individuals and machines where the interaction is influenced by a factor [2]. This can also be taken from how to adjust the machine for human use, and by operating the machine, this tool can minimize discomfort. Ergonomics has been used in many products and the consumers must always take it into consideration. If the design is ergonomically complied, the user will feel less stressed and be more efficient during walking [3]. By studying the posture, repetitive motion, and workspace design [4], it is important to get a clear understanding of ergonomics so that a high-quality product can be produced [5]. Finally, bionic feet, which at some point of walking generate autonomous type movement, which movement at some degrees of liberty [6].

The durability of the product is one of the many problems with respect to the development of the prosthetic foot. Thus, the aim of this research is to design an effective foot with high durability and economically suitable for patients. This product will not only be long-lasting, but it will also be comfortable for the patient to use. In addition, almost all prosthetic foot available in Malaysia are imported, mostly from Taiwan and Germany. The imported products might not especially be suited to our climate or weather [7]. Moreover, the available prosthetic foot can sometimes become easy to crack, short-lasting and expensive. It has been reported that most of the current SACH foot can only withstand less than a year and the user need to look for a new one. This will be burdening for the user especially those who are from a low-income family.

2 Materials and Methods

2.1 *Prosthetic Foot Design*

The Solidworks software is used to design the foot. Solidworks software is mechanical design automation that gives a designer a platform to create a design and produce a detailed drawing. The conceptual design of the foot is rooted to the inputs and advises from the Certified Prosthetists and Orthotists (CPO) as well as theoretical and desktop analysis done by the team. The team involved in this project comprises the CPO (JasaMedik Enterprise), medical doctors (Hospital Pulau Pinang), technical designer (Advanced Technology Training Center or ADTEC Jerantut), and lecturers/students (Universiti Malaysia Pahang). Basically, the configuration of this artificial foot consists of the Solid Ankle Cushion Heel (SACH) foot (focal item), adjustable pylon prothesis and cast socket (customized) Fig. 1. The front support point is positioned according to the human foot. Heel area produce as strong as human heels. High stress at the heel area will affect the rear rib then the adjustable pylon creates to build lower prosthesis until it can fit lower amputees.

Fig. 1 The making of customized socket and installation of prosthetic leg (courtesy of JasaMedik Enterprise)

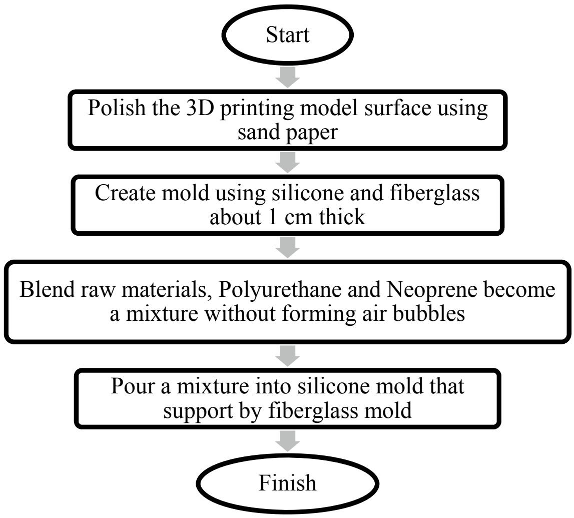

Fig. 2 The flowchart of fabrication SACH foot

2.2 Fabrication of SACH Foot

See Fig. 2.

3 Result and Discussion

3.1 Prosthetic Foot Design

To design a good-quality prosthetic leg is the most critical process in order to fulfill the needs of the user or customer: comfortability, user-friendly, low-cost and durability. When we want to design the prosthetic foot, we must design all parts of the prosthetic legs. In prosthetic legs, there are 3 main parts that need to be considered, which are socket, pylon and foot. These parts will be connected to each other and form a good quality prosthetic leg. To form the full leg, the socket will be connected to the pylon and the pylon will be connected to the foot. The criteria that had to be considered was material for pylon, as it needs to be strong because it will have to withstand force from the human weight. Figures 3 and 4 show the design of the prosthetic leg and its parts. The design was proposed based on a blended idea amongst four interested parties.

Moreover, the simulation on the ergonomic design also being carried out as shown in Fig. 5. Based on the result shown in Fig. 5a, the Von Mises stress is distributed across the pylon and it yield strength is 27.57 MPa. The maximum value of Von Mises experience by the pylon is 4.702 MPa and the minimum value is 1.716×10^{-9} MPa. We can see that most of the part experience stress between 1.716×10^{-9} MPa and

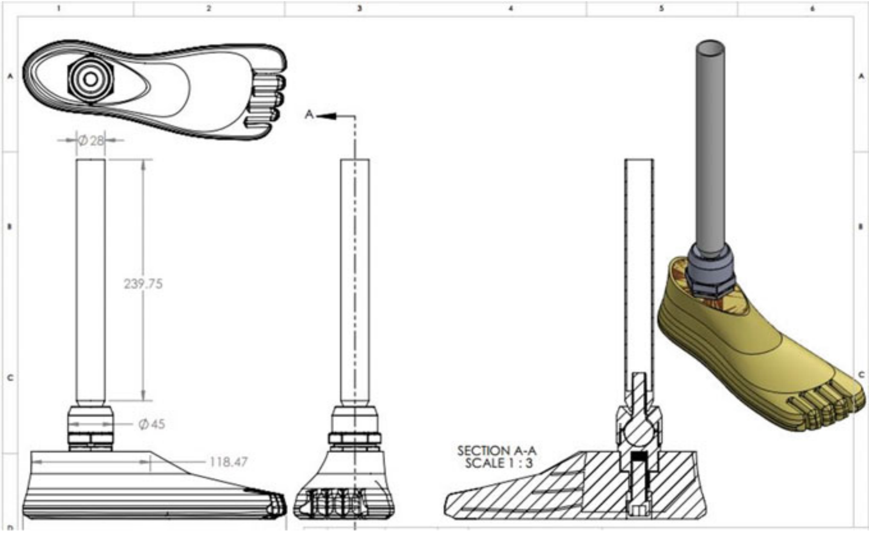

Fig. 3 Pylon and Prosthetic foot design

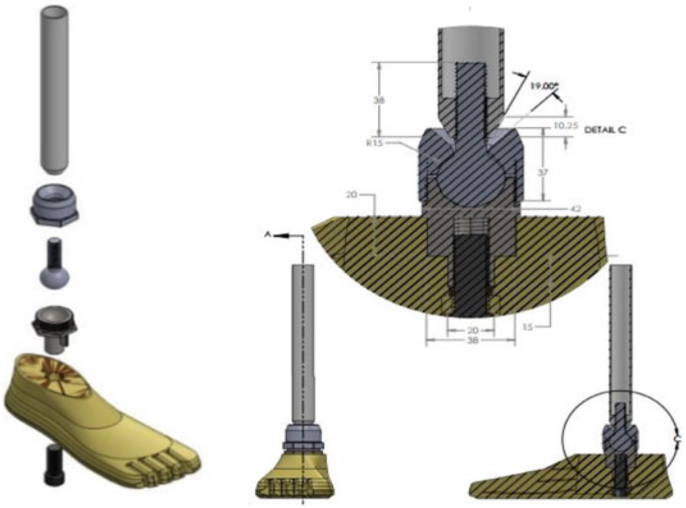

Fig. 4 Full design of prosthetic legs

1.176 MPa. Figure 5b show the static simulation for another main part of prosthetic legs which is prosthetic foot. We applied force at top of the foot to indicate the load came from human weight. The yield strength for this foot is $9.237 \times 10^6\ \frac{\mathrm{N}}{\mathrm{m}^2}$ and it also show the von-Mises stress result. The minimum stress occurred is $2.520 \times 10^{-1}\ \frac{\mathrm{N}}{\mathrm{m}^2}$ and maximum stress is at $3.797 \times 10^5\ \frac{\mathrm{N}}{\mathrm{m}^2}$.

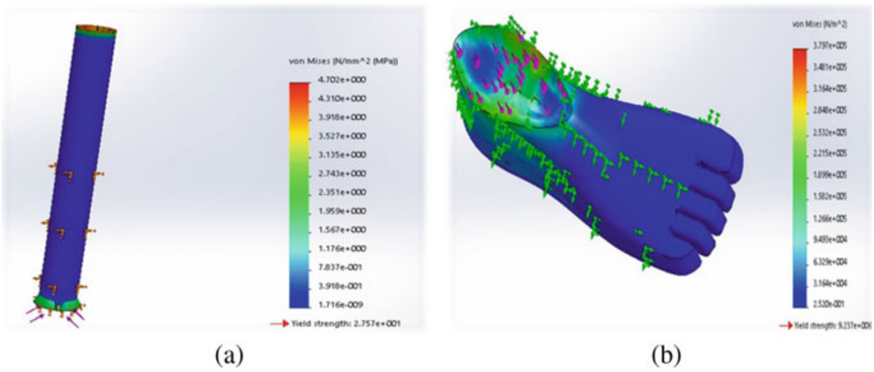

Fig. 5 Von-mises stress for the design of pylon (**a**) and SACH foot (**b**)

3.2 Fabrication of SACH Foot

The fabrication of SACH foot is an important part to form a good quality prosthesis. Based on this analysis, the process of fabricating a prosthetic foot looks simple but it is very meticulous. It is because of the 3D model's surface and the ambient temperature that can influence it.

Based on Fig. 6, the 3D model of the foot was already polished. To analyze the polish effect in a different part of the mold, the polishing process can be revealed with VT-460 Putty Filler to fill cracks and holes on the 3D model foot surface. After VT-460 Putty Filler was applied and dried, the sandpaper was used on the surface of the 3D model foot to ensure the surface does not leave marks and blemishes.

Fig. 6 The 3D model of SACH foot

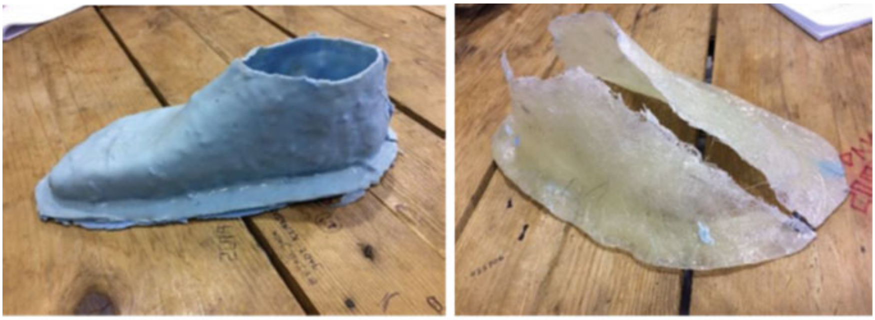
(a) (b)

Fig. 7 The mold of SACH foot **a** using silicone, **b** using fiber glass

In this part of the design analysis, forming the SACH foot mold is quite difficult as it affects the final result of the SACH foot. Silicone is used because of its superior thermal stability. This means the silicone can withstand temperature up to 180°C with no melting or creeping [8]. Other than that, silicone also low-temperature flexibility which means at low temperature [9], it becomes harder and more brittle until it eventually cracks. 1 kg of silicone (A + B) was prepared in the beaker and stirred, and was degassed in a vacuum chamber to remove an air bubble in the mixture [10]. Air bubbles in the mixture affect the mold as shown in Fig. 7a. When the concentration of mixture becomes concentrated, apply it on the 3D model of foot and mold will be formed. Next, apply about 1 m of fiber glass on the surface using resin with 1 cm thickness. The molding using fiber glass as shown in Fig. 7b purpose to support and maintain the mold of silicone. This is because the thickness of the silicone's mold is thin that can affect the final result.

The final process is forming SACH foot by using the new materials, polyurethane and neoprene. With these materials combined, it will provide the durability and toughness like metals but with the elasticity of rubber, making them suitable for the replacement of metals, plastics and rubber in some engineered products [11]. The polyurethane and neoprene were blended with a respective specific percentage of 99.4 and 0.6% because the increase of neoprene composition has resulted in enhanced thermal stability of polyurethane blend [12]. Polyurethane also have good share rate when higher viscosity [13] while neoprene also indicates that it can increase the flow resistance and reduce the processability in the blends [14]. Polyurethane and neoprene were blended about 1 L each and were stirred and degassed in a vacuum chamber to remove the any air bubbles in the mixture [10]. Inside the silicone mold, the keel was placed where it will support the performance of SACH foot. The mixture was poured into the silicone mold that is supported by fiber glass and after that, the full SACH foot was formed.

4 Conclusion

In conclusion, ergonomic prosthetic legs have been successfully designed, with help and advice from CPO and technical designer from ADTEC Jerantut. Both the pylon and foot design were applicable to be used because the higher yield strength. For the second part of the analysis which was polymeric analysis for the polyurethane and neoprene blend, 99.4 and 0.6% were chosen because it gives good tensile strength and also young modulus, and this composition will be used to produce a prosthetic foot.

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References

1. Thatshayini P, Rajini PAD (2018) Occupational safety and health hazards of apparel sector: perspective of Northern Province employees of Sri Lanka. J Bus Studies 5(1):26. https://doi.org/10.4038/jbs.v5i1.23
2. Hassan Z, Hayati N, Mohd H (2015) Ergonomic problems and stress among workers in a manufacturing company. Int J Manage Stud
3. IEA (2017) Definition and domains of ergonomics. IEA Website. https://doi.org/10.1109/TGRS.2006.872327
4. Ianuzzi A, Mkandawire C (2016) Applications of UHMWPE in total ankle replacements. In: UHMWPE Biomaterials handbook: ultra high molecular weight polyethylene in total joint replacement and medical devices, 3rd edn, pp 197–216. https://doi.org/10.1016/B978-0-323-35401-1.00013-2
5. Childers WL, Takahashi KZ (2018) Increasing prosthetic foot energy return affects whole-body mechanics during walking on level ground and slopes. Sci Rep 8(1). https://doi.org/10.1038/s41598-018-23705-8
6. Hernández Martin JA, Parra Piñero L, Pinzón Pinzón C, Bejarano Peña O, Romero Gutiérrez J, García Benavides P (2018) Analysis and construction of a prosthetic foot. I+D Tecnológico 14(1):76–82. https://doi.org/10.33412/idt.v14.1.1805
7. Design and Production of Parts. (n.d.). Retrieved 28 Jan 2021, from https://www.dinf.ne.jp/doc/english/intl/z15/z15001p1/z1500105.html
8. Shit SC, Shah P (2013) A review on silicone rubber. Nat Acad Sci Lett. https://doi.org/10.1007/s40009-013-0150-2
9. Silicones. (2014) Handbook of thermoset plastics. Retrieved from https://doi.org/10.1016/B978-1-4557-3107-7.00014-2
10. He Y, Xue GH, Fu JZ (2014) Fabrication of low cost soft tissue prostheses with the desktop 3D printer. Sci Rep. Retrieved from https://doi.org/10.1038/srep06973
11. Akindoyo JO, Beg MDH, Ghazali S, Islam MR, Jeyaratnam N, Yuvaraj AR (2016) Polyurethane types, synthesis and applications-a review. RSC Adv. Retrieved from https://doi.org/10.1039/c6ra14525f
12. Mohd Zulkifli MN, Mohamad Anas MA, Mohd Shaiful Zaidi MD, Mohd Bijarimi MP, Azizan R (2020) The thermal properties of polyurethane/neoprene blends on prosthetic foot. Mater Sci Forum. Retrieved from https://doi.org/10.4028/www.scientific.net

13. Lechner MD (2018) Polymers. Springer handbooks. https://doi.org/10.1007/978-3-319-69743-7_18
17. Salleh SZ, Ahmad MZ, Ismail H (2016) Properties of natural rubber/recycled chloroprene rubber blend: effects of blend ratio and matrix. Procedia Chem 19:346–350. https://doi.org/10.1016/j.proche.2016.03.022

Holding, Grasping and Sensing of Prosthetic Robot Arm Like a Real Human Hand, a Journey Beyond Limits: An Extensive Review

Devin Babu, Abdul Nasir, A. S. Jamaludin, and Muhammad Hisyam Rosle

Abstract This paper provides a comprehensive survey on the current state of prosthetic robotic arm; focusing on grasping strategy, sensing technologies, and control system. Numerous studies have been carried on prosthetic robotic arm field in improving its functionality. Mechanical/ prosthetic robotic arm is built to function as real—human-hand like for various fields like medical and industrial purposes. Starting from the design to details of every single compartment of the arm, up to providing the most needed function according to the purpose of the prosthetic robotic arm was built. The implementation method and system control/architecture used are with proven experimental results that indicate each study's outcome is the primary concern. Although each developed prosthetic robotic arm differed between each other based on their purpose and technology used, aiming for the optimal design similar to human's hand proves challenging for researchers, especially when it comes to the issue of practicality in whether it can be used to accomplish regular tasks a standard arm are able to.

Keywords Prosthetic robotic arm · Force actuators · Neural network

1 Introduction

Hand loss can severely affect a patient's life by limiting the ability to perform different physical movements and affecting its independence in the long run. It is estimated that nearly 3.10 million people have been living with upper limb disability since 2016 [1]. Prosthetic care, economical and affordable devices can improve the quality

D. Babu · A. Nasir (✉) · A. S. Jamaludin
Faculty of Electrical and Electronic Engineering Technology, University Malaysia Pahang, 26600 Pekan Campus, Pekan, Pahang, Malaysia
e-mail: abdnasir@ump.edu.my

M. H. Rosle
Department of Robotics, College of Science and Engineering, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu 525-8577, Shiga, Japan
e-mail: hisyam@fc.ritsumei.ac.jp

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of life for disabled patients. However, nearly 38 million patients in developed countries lack access to affordable prosthetic devices. Unfortunately, the rate of limb loss is significantly higher in developing countries, including 2.40 million patients with upper limb amputations. Undeveloped health care systems have worsened the situation for patients where it is estimated that nearly 2.7 million people in developing countries have partial hand amputations due to traumatic labour injuries and diseases [2].

The weighted prevalence of having any disability in the United States is shown in Fig. 1, showing their citizen's higher prevalence of disability. Amputations are performed as a lifesaving surgical procedure to decrease long term complications after upper body extremity injuries like a neuroma and wound complications. Nearly 1.7 million people in the United States are living with limb loss. It is estimated that, yearly there are 50,000 to 100,000 amputations in the United States [2]. Amputations can significantly impact personal quality of life and functionality in daily life activities. Length preservation in the upper extremity has supreme importance. An extended lever-arm permits more massive force generation, which can further be utilized to energise prosthetics with a small force on underlying soft tissues. Therefore, it is essential to consider optimal treatment after analysing the remaining body part [3].

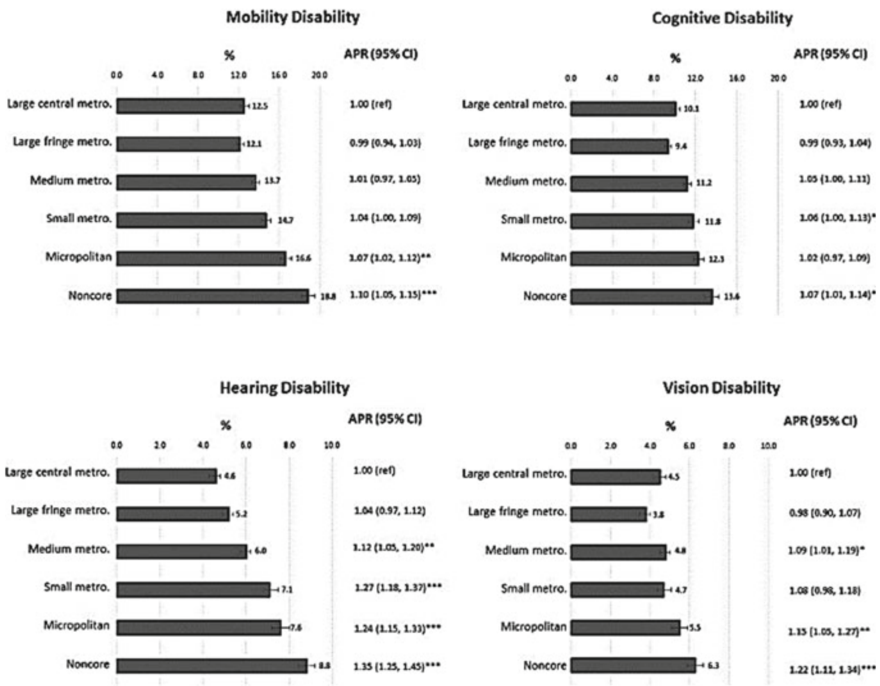

Fig. 1 Overview of disability in the United States [2]

Partial hand amputation, shoulder disarticulation, transhumeral and transracial are included in main types of upper limb amputations. Upper limb Prosthetic devices can help amputees perform daily activities [4]. Two main types of upper limb prosthetics, including passive prosthetic, functional and active prosthetics, are externally powered or body-empowered devices. A practical prosthetic robotic arm can only ease specific movement in achieving tasks. Besides that, the strength of the hand grip is a significant concern in each prosthetic robotic arm. The amount of force for each individual differs from one to another. A study conducted by Fredriksen measures the handgrip strength of children aged six to twelve years old using Jamar Dynamometer [5]. A study by Mathiowetz showed the individual's strength from age six to nineteen [6] and the results of the study are as in Table 1. The study proved that the firm grip of individual increases with chronological age [6]. Thus, this study will focus on the grip of prosthetic and robotic hand in various fields.

There are body empowered prosthetic robotic arms that are controlled by cables attached to the limbs of an amputee, however a primary level of energy is needed for this prosthetic robotic arm to function. Externally powered prosthetic robotic arms can source its power from a battery pack, electromyography (EMG) signals [7] and other available external sources to control movements of prosthetics [8]. Prosthetic hands can be largely divided into two groups: passive and active prosthetic arm. The passive arms commonly cannot be controlled by the user, and often mimic the shape of human hand. On the other hand, active arms could be controlled by the user with the help of advanced control system, communication tools, and sensing technology. In

Table 1 Average performance of normal subjects on grip strength [6]

Age	Hand	Male			Female		
		Mean	SD	Range	Mean	SD	Range
6–7	R	32.5	4.8	21–42	28.6	4.4	20–39
	L	30.7	5.4	18–58	27.1	4.4	16–36
8–9	R	41.9	7.4	27–61	35.3	8.3	18–55
	L	39.0	9.3	19–63	33.0	6.9	16–49
10–11	R	33.9	9.7	35–79	49.7	8.1	37–82
	L	48.4	10.8	26–73	45.2	6.8	32–59
12–13	R	58.7	15.5	33–98	56.8	10.6	39–79
	L	55.4	16.9	22–107	50.9	11.9	25–76
14–15	R	77.3	15.4	49–108	58.1	12.3	30–93
	L	61.4	14.9	41–94	49.3	11.9	26–73
16–17	R	94.0	19.4	64–149	67.3	16.5	23–126
	L	78.5	19.1	41–123	56.9	14.0	23–87
18–19	R	108.0	24.6	61–172	71.6	12.3	46–90
	L	93.0	27.8	53–149	61.7	12.5	41–86

this paper, the advanced design of control system, sensing functionality, and machine learning of active prosthetic robotic arm will be discussed.

2 Review

2.1 Simple Mechanical Based Prosthetic Robotic Arm

There are many mechanical arms in the field being studied for better performance and user friendliness. Ye et al. present a prosthetic robotic arm with a simple moving mechanism that is suitable for children as shown in Fig. 2. The Servo Motor A's shaft is connected to the thumb's joint axis in a concentric manner by fixing the A servo motor pole in the thumb. The Servo B engine shaft is attached to the metacarpals (M.P) concentric joint axis by improving the servo motor B's pole's position in the index finger. All fingers other than the thumb are sharing the joint axis of the M.P. So, the joint M.P.'s torque and the thumb joint are proportional to the torque of these two servo motors [9]. The results show that the proposed wire-driven mechanism had increased the pinch force of the hand without increasing the weight and size.

Researchers, Fourie and Stopforth, discussed the concept and development of a modular mechanical prosthetic robotic arm design that can be upgraded from a purely mechanical device to a mechatronic system as in Fig. 3, based on the amputee's needs [10]. The experiments were carried out on the functionality of the prosthetic robotic arm and it was decided to actuate the finger by tendons (cable actuation) or linkages. The Touch Hand 2 was created at University of KwaZulu in 2015 and cables were used for actuation. The study shows that the proposed hand was successful in manipulating most everyday's objects with multiple grip mechanism.

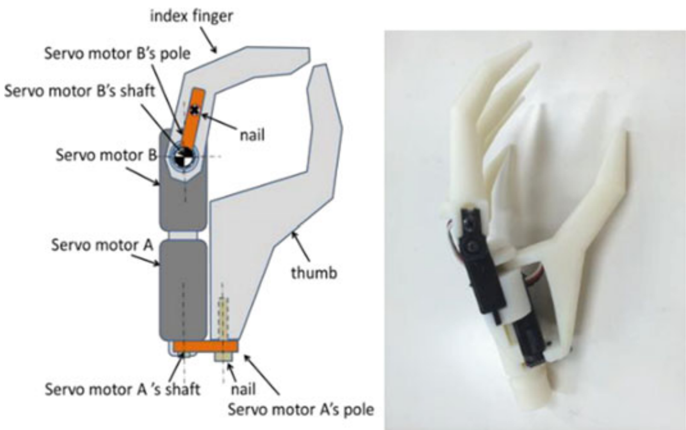

Fig. 2 Schematic diagram and photo of the EMG prosthetic robotic arm with direct drive [9]

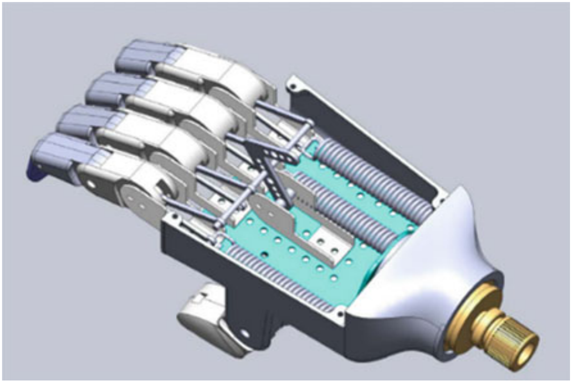

Fig. 3 CAD design of mechanical hand [10]

Wattanasiri et al. introduced the concept of a five-fingered prosthetic robotic arm as in Fig. 4 that has several grip patterns using only one actuator to execute critical everyday tasks and derive substantial grip power from the actuator's enormous scale. Different movement patterns are carried out using several sets of rigid four-bar connections, which have different fingers and thumb movements [11]. The established terminal unit consists of four identical fingers, made of a modern linkage system capable of flexion and extension. The kinematic analysis was undertaken

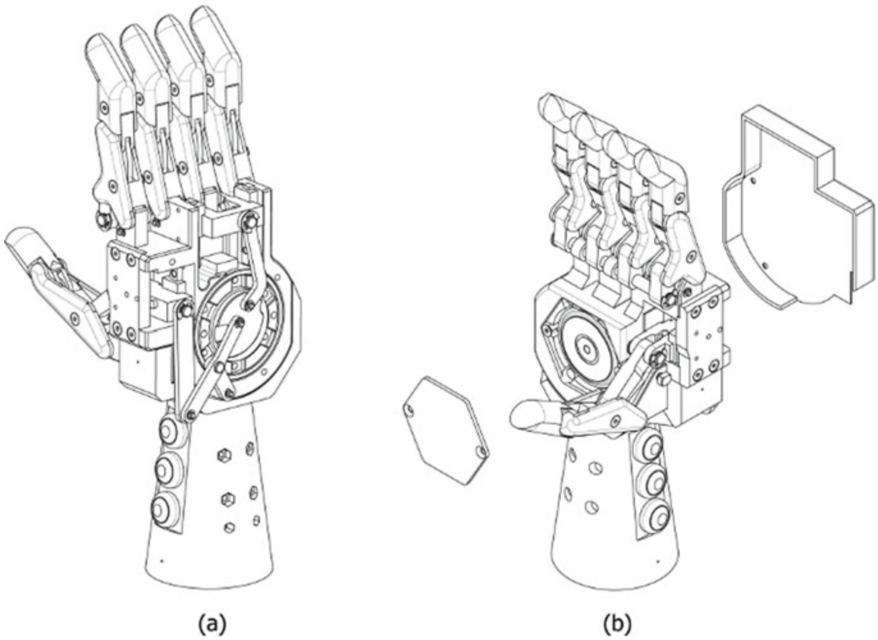

Fig. 4 Prosthetic robotic arm design in open hand position. **a** Back of the hand with mechanism, **b** the hand with front and back cover [11]

to verify the mechanism's efficacy. Moreover, motion simulation has proven that the machine can produce enough finger movements to obtain cylindrical and spherical power grips. Proposed finger job envelopes were decided and experimentally checked using the finger's 3D-printed edition. A new linkage system proposed to accomplish the necessary finger motions with sufficient forces consists of eleven separate connections [12].

2.2 Sensor Technology in Prosthetic Robotic Arm

Gundogdu et al. developed a prosthetic robotic arm controlled by a voice control system for use in medical systems. Voice control system was applied to their four-jointed revolute-revolute-revolute-revolute (RRRR) robot arm. The voice control system was developed by mathematical model systems and tested in the robot arm. The robot arm was tested with several voice commands to determine and calculate the efficiency. The study results showed that the double-defined voice control system is more efficient by 90% than the existing robot with single-defined [13]. Sahar et al. have also used voice control to develop six-degree of freedom (DOF) prosthetic robotic arm for patients with shoulder disarticulation. The prosthetic robotic arm was integrated with virtual reality (V.R.) to get instructions from the user, then connected with Arduino to perform the desired movement. The results show that the motor speed decrease over time due to friction and the V.R. module performs better in the environment with noises compared to without noise [14].

Hinwood et al. introduced a grasp deformable material through a novel robotic gripper design. The robot arm was based on lateral grasp. The gripper was stepper motor connected to linear rail for the prismatic actuator and three hobbyist servo motors. The effector successfully picked on 89 out of 90 trials equivalent to 98.88% success rate. The study can be validated for other grasping motions besides lateral grasp [16]. Ramlee et al. developed a rehabilitation robot for physiotherapist to train grasping process. The robot is equipped with a master–slave mechanism that operates based on a healthy hand controlling a weak hand. The system is made up of a motion sensor that functions as the input for the system with exoskeleton as the output. A gyroscope is utilised to determine the finger position placed on the exoskeleton [17]. The exoskeleton was constructed using a 3D printer from ABS material. The robot arm successfully showed the finger's extension with grasp strength as the flex sensor attached on the exoskeleton gripped bends. However, the exoskeleton is limited in design and not suitable in the medical field as the design needs a better improvement in material, such as aluminium, to be used in future works.

Liu et al. proposed a theoretical gradient-based iterative algorithm to plan a reach-to-grasp task for a synergy-controlled robotic arm. The synergy-based hand as six DOF and Pseudo-Distance Formulation was used in predicting grasp and reach for objects to hold. The algorithm successfully managed grabbing the object by justifying the best distance to grasp the object. However, the system was not suitable for use in real-functioning arm [18]. Besides, it classifies a specific object from the reference dataset, thereby encouraging better grasp preparation. The accuracy was 92%, i.e. 92 times out of 100 tries; and the input of the natural language returned to the correct object form. The failed eight times were for a different object being paired. The causes of uncertainty have been revealed following the investigation. Chin et al. proposed a gripper with three gripping modes: suction, parallel jaw, and delicate fingers. Using complaint handed auxetic shearing actuators as the base, this gripper can manipulate multiplex by producing special primitive grasping by permutating these grasping techniques. This gripper can grasp 88% of tested objects, of which 14% can only be grasped using a combination of grasping modes [20]. The gripper can also re-orientate flat items in-hand without the need for pre-grasp manipulation. In particular, the grip can be improvised. The stiffness and the gripping force were increased to give this model even more leverage in the finger position.

Wang et al. presents the design, study and experimentation of a passively adaptive five-finger underacted dexterous hand (UADH). The UADH can forcefully grasp items of various shapes and sizes using link-slider and rack-pinion mechanisms. UADH has 15 ground breaking joints. However, since the four-finger metacarpophalangeal (M.P.s) and distal phalanges (D.P.s) are coupled, the UADH has 11 DOFs (6 active and 5 passive). Results show that the established UADH has good dexterity, adaptability and powerful fingertip capability. The results also confirm the model of static contact power [22]. Cortez et al. inform that a Tactile-based blind grasping results in realistic robotic grasping. The hand only has access to proprioceptive and tactile sensors. The robotic arm has no prior information of the object's grasping variables, such as object weight, inertia, and shape [23]. Sainul et al. present a paper implementing the best computing system for an underactuated robotic gripper based on a novel slicing object process. Using item slicing technique, the proposed approach seeks contacts quickly, using grasp accuracy test to determine the right grasp from a grasp pool. Twenty-four household items and toys were experimented upon using a two-finger robot gripper in virtual environment to verify the operation. Using a 3D scanning system, the predetermined planner would be applied to the actual object data collected [24].

Jie et al. introduced a three-fingered reconfigurable underactuated dexterous hand that can be adjusted to various targeted shapes. The mapping relationship between the five-finger data gloves and the three-index hand is needed in dealing with dexterous hands. There is a significant difference between a human hand and a dexterous hand in actual implementations, so a motion mapping relationship is needed [25]. A 3D predictive modelling model of the universal robot (UR5) robotic arm and three-finger manipulator was proven by implementing augmented reality technologies. Therefore, the experiment used three forms of objects: disc, cylinder, and cuboid. Li et al. proposed a novel grasping method for dexterous prosthesis based on eye-tracking. The study was conducted on an interactive experiment platform as in Fig. 5. Then data was fed back to the operator during prosthetic robotic arm performing real reach and grasp task. An anthropomorphic is prosthetic robotic arm with five fingers actuated by six motors, Myo armband for opening/closing the arm with left and right waving is mapped and Kinect camera for eye-tracking were used in the experiment [26].

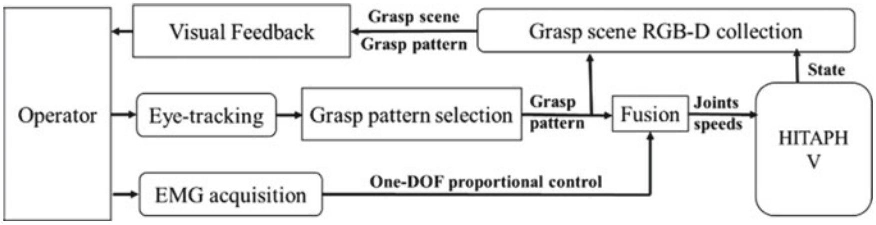

Fig. 5 The system workflow [26]

The interface has various grasping types that the operator can choose. As the operator moves the red cursor by eye movement, the corresponding grasping type was triggered. The eye-tracking and gazes are recorded in less than 0.3 s. Although the system has better response time, the system is still inflexible as the experiment requires a complex step up.

2.3 Implementation of Advanced Control System in Prosthetic Robotic Arm

Huang and Lan presented a remote-controlled prosthetic robotic arm to scan 3D printed human body parts. The six degrees of the freely moving robot arm were attached with ultrasound probe; remotely controlled through human skin to scan and measure the system's efficiency. The robot arm is controlled using a joystick integrated through interned connect to the prosthetic robot arm in the operation room. The American University of Middle East developed electroencephalogram (EEG) mind-controlled smart prosthetic robotic arm. The arm is controlled using brain signals, where the user conveys the command by thinking and being transmitted to the arm by the attached EEG headset [27].

Li et al. investigated a grasp planning method for dexterous hand grasping on different objects. The research used the maximum internal tangent sphere principle and conduct as stable grasp planning based on the minimum force to avoid object deformation. The experiment resulted in an average 95.63% grasping rate. Although the object has external factor like object weight pulled by gravitational force, the gripper manages to grip with minimum force [28].

He et al. developed vision-based myoelectric prosthetic robotic arm. The three-DOF arm is equipped with a camera to analyse, locate and estimate the target object size to be grasped. The system uses electromyography (EMG) and graphics processing unit (GPU) server to analyse the received data and respond to the motor in real-time. The developed system has high accuracy for every frame by classifying object class probability which almost all would detect an object with 100% accuracy [29]. Ibrahim et al. proposed developing a prosthetic robotic arm controlled by wireless flex sensor on their explosive ordnance disposal (EOD) robot. The robot has 2 to 3 fingers which function as gripper of explosive items. The prosthetic robotic arm is made of polylactic acid (PLA) embedded with Xbee wireless module to transmit and receive signals from the gloves equipped with flex sensors. The user is free to move their fingers and observes the prosthetic robotic arm's movement on the screen [30]. Aly et al. introduced a hybrid BCI model that integrates EMG and EEG signals to learn about upper limb prosthetic in improving its accuracy and performance using 64 channels EEG signal combined with 32 channels of surface EMG signal; analysing five motions of wrist and hand. The system resulted in 98.8% accuracy of the prosthetic using 6th-order auto-regression (A.R.) coefficient model, suitable for the daily tasks [31]. Ruhunage et al. presented a hybrid method with EEG and EMG signals. A six DOF prosthetic robotic arm known as UOMPro with one DOF elbow joint is connected with EEG motor motion that receives signals from a user by neural network (N.N.) in selecting an object's grasping pattern. The experiment was conducted on five healthy 24 years old subject. The offline EEG accuracy results are 79.8, 87.7, 92.2, 89.3 and 85.9% while the real-time accuracy in left/right hand movement is 63% [32].

Ghazali et al. combined two types of Fuzzy controllers and proportional-integral-derivative (PID) in a prosthetic robotic arm to improve transient response and steady-state error. The root-mean-square (RMS) value of the combined Fuzzy-PID resulted in 0.4073. Simultaneously, Fuzzy and PID's RMS values are 1.4660 and 0.7206, respectively, which clearly showed that the combined controller has better response and steady-state error [33]. Researcher Liu et al. implemented an impedance controller on the robotic arm. The control parameters are based on a biomechanical model arm. The relationship between sEMG and grasp force were experimented. The impedance of joints was calculated using a series of dynamic vibration test. For human hand, multisensory information acquisition platform was built. CyberGlove, which consists of a force sensor, is used to measure the data acquisition with sEMG sensor to be sampled [34].

2.4 Visual Relaying Prosthetic Robotic Arm

Wu et al. introduced mechanism that improves the rate of grasp in clutter. The system uses red–green–blue (RGB) camera image as input. The image data was processed to obtain position map, and attention map as this framework circumvents continuous motor until the same depth of an image is produced. The system resulted in a 92% real-world grasp success rate with different degrees of flexibility. There was some limitation in the grasping process when the clutter was tightly grasped causing deformation [35]. Rosenberger carried out a study on independent human to robot handovers using real-time vision. The research targets general applicability with a generic object detector and quick grasp selection algorithm. Franka-Emika Panda prosthetic robotic arm with seven degrees of freedom mounted with RGB-D (digital) camera mounted at the robot arm's end-effector was used in this research [36]. For internode messaging and interfacing between the camera and robot, robot operating system (ROS) is utilised. The approach has six modules structured into one input and three processing layers. To reduce the time between arm movement and image capturing, all the modules are events driven and instantly processed inputs (the image data) become immediately available. YOLO v3 object detector is used to detect the object that needs to be grasped and pre-train using the standard objects in context (COCO) dataset.

Liu et al. developed a novel camera fusion method for a real-time robotic grasping. The robotic grasping was utilised using hybrid eye-in-hand (EIH)/eye-to-hand (ETH) configuration cameras. The camera position was altered according to the manipulator's motion with the field of view (FOV) dynamic. The system has automatic switching from monocular to multi-camera pose estimation. The robot manipulator determines the most correct positioning and increases the total visual scope of grasping an object. The grasp success rate was 95.7%, 134 over 140 grasping attempts [37]. However, the system was only tested with two number of grippers. However, the multi number of grippers can be an attempt to be tested in the future. Omarali et al. proposed a V.R. based robot teleoperation framework for human–robot and human-scene interaction gestures. The RGB-D camera was installed at the end-effector of Frank Emika's Panda robot. The camera's image data was combined with OctoMap for image mapping with an overview of the remote environment. The OctoMap provided a remote overview scene with lower communication bandwidth cost. However, the system implementation was limited for virtual end-effector [38]. Rakhimkul et al. present an autonomous objection and grasping using deep learning with visual detecting. In principle, RGB-D data sensor was installed on Kinova Jaco 6*DOF assistive prosthetic robotic arm. YOLO algorithm was used to determine the object that needs to be grasped by the arm. The arm successfully detects and grasped the object placed on the desk [39]. However, the system is only limited to Kinova Jaco assistive arm.

Wang et al. used vision hybrid frame-event to grasp and pose detection of objects. RealSense D435 RGB module was used for the frame-based sensor in object detection with neural network architecture to process the image data. The experiment resulted in 77.29% accuracy of grasp and pose prediction [40]. However, the system was not tested on a real operating arm. Jin et al. presented a human–robot interaction using visual sensing for object grasping. The researchers used RGB-D camera and inertial measurement unit (IMU) for object targeting and pose detection. Digital video input–output (DVIO) was used to combine the 6-DOF device pose estimation with camera's depth and IMU data in a graph for the optimisation process. The experiment out-performs existing state-of-art virtual-input–output (VIO) method in both positioning and orientation estimation [41]. However, the system was not tested with a real subject to evaluate overall system performance. Mitash et al. used RGB camera for constrained placement of unknown object for the robot arm to grasp. The robot arm was programmed to pick and place an object with collisions and minimise the time to complete the task. The system's proposed pipeline architecture achieves more than a 95% success rate and speedier execution time over multiple experiments [42]. The research was limited as the picked grasp study did not focus on details since it only observed on general grasping.

2.5 Implementation of Neural Network in Prosthetic Robotic Arm

Farag et al. researched on a method of increasing the impact of computer vision implementation on selective compliant assembly robot arm (SCARA) using deep convolutional neural network (DCNN). The study resulted in 100% precise object detection, accurate robot positioning and real-time grasping in a range of 0.38 s [43]. Gabellieri et al. proposed a method for grasping unknown objects with robotic arm based on human movement. The robotic arm was trained using Decision Tree Regressor (DTR) to generate optimal hand pose to grasp an object (available box). The system architecture was installed in Pisa/IIT Soft Hand. The experiment on the method resulted in 86.7% successful grasp rate [44]. However, the amount of force acting on the grasped object was not considered.

Joshi et al. used a double deep Q-learning framework (DQN) with a novel Grasp-Q-Network to perform the output of grasp probabilities to maximise grasp pick success as in Fig. 6. In contrast, a DCNN is used in deciding the motion to grip with the most effective grasp on the object [45]. The results showed that the DQN algorithm performs better than Q-learning algorithm with higher completion and success rate.

Lambeta et al. introduced a design for a low-cost, compact high-resolution tactile sensor. The research objective was to overcome the limitation of precise sensing

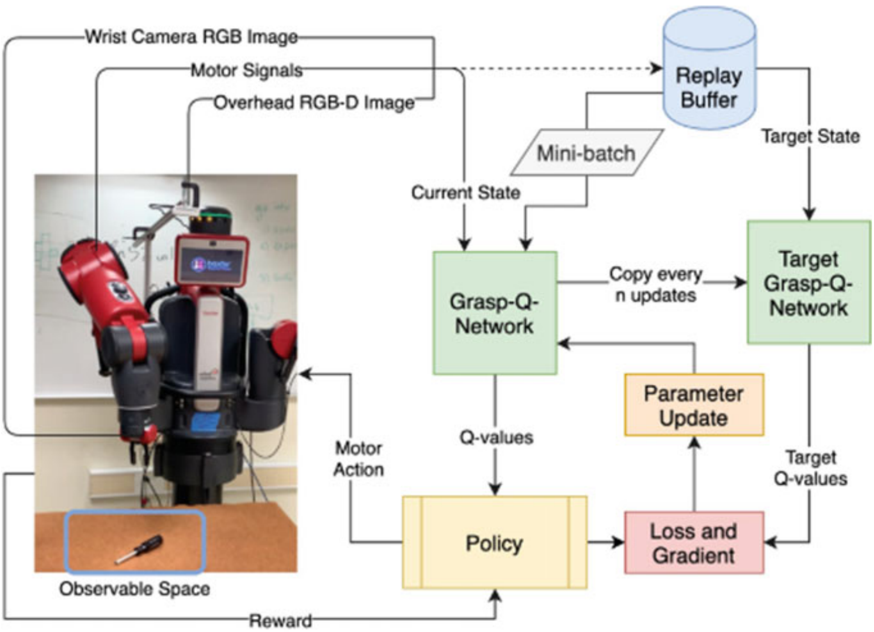

Fig. 6 The proposed system of deep reinforcement learning [45]

contact force-sensing and reasoning about contact force. The DIGIT is designed to be physically compact to fit an array at end effectors or multi-finger robot arms. The DIGIT's gel is easily interchangeable compared to the earlier design, which resulted in a rugged sensor. For learning the dynamic model, 4800 tries of which 950 were for validation, the marbles are picked with pincer grip, between thumb and another finger. The arm is programmed to roll fingers precariously over the marble to manipulate it into the desired configuration. Structural variational recurrent neural network (VRNN) architecture is used where researcher trained an autoencoder that learns to detect critical points on the object with the variation in the input data [46]. However, there was a lack of control on the number of marbles drop during training due to the proportional (P) controller performance. In the medical field, the da Vinci Research Kit (dVRK) was equipped with an optical tracker system (NDI Polaris Vicra) to improve existing teleoperated equipment. Image data processing with optical tracking operation was carried out to compute the coordinate transformation between endoscopic and optical tracking operation. The patient side manipulator (PSM) were exploited between coordinate transformation and PSM based frame and optical marker. The end-effector was pointed out through the camera—the whole robot system is controlled by a desktop computer using ROS interface [47]. As the robot arm is tested, it performs a needle grasp of 39 over 45 sets of experiments.

Chen et al. experimented using colour distribution and deformation of the fingernail and its surrounding skin to estimate torque, fingertip force and contact surface curvatures for various grasping objects as in Fig. 7. Four algorithms were tested in the research are Gaussian process, convolutional neural network (CNN), neural networks with fast dropout and recurrent neural networks for models' images mapping to the corresponding parameters. The fingernail image was transferred from RGB to hue-saturation-value (HSV) back to RGB to have a background colour close to skin colour.

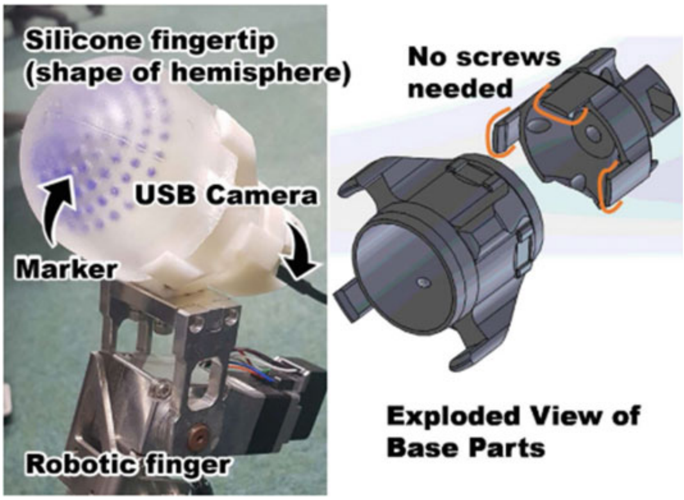

Fig. 7 Visual-tactile sensor and the exploded view of base parts [48]

The experiment showed that the Gaussian process and CNN performed better than the other two algorithm methods [48]. The image data processing ran at about 30 Hz. It can be speeded up and improved by reducing the image resolution in the future.

Gardner et al. conducted a part of the study on camera-based visual information for autonomous object recognition integration on upper-limb robotic prostheses. In the study, a low-cost Logitech C525 HD camera was installed on the robot with a standard vulnerability scoring system (CVSS) to process the camera's image data. The camera detects the edge of objects placed to be grasped. As objects edge detection were being trained, an object template was created for real-time grasping. During real-time grasping, as the camera detects the object's edge, k-nearest neighbours (KNN) classifier was used to identify the nearest object; comparing the features in order to set a most suitable grasping pattern from the pre-defined system using general-purpose simulation system (GPSS) [49]. The experiment was tested in identifying a correct object and predicting the intended grasp resulted in 84.55% for a bottle, 70.91% for lid objects and 38.18% for box objects. Researcher Sun and Lin proposed an eye-in-hand (EIH) in the prosthetic robotic arm for object recognition and grasping purpose. Objects that need to be grasped were identified using RGB-D camera, and convolutional neural network (CNN) is utilised, for instance, to facilitate segmentation of image data from the camera.

The camera was fitted in Hiwin RA 605 robot arm. A calibration board was used to calibrate the camera coordinates. The robot coordinates and applies the kinematics through the robot arm for grasping. The experiment resulted in 80 and 95% for bottle stacking and non-stacking compared to other grasped objects like aluminium cans and retort pouches [50]. The proposed system can be implanted into the prosthetic robotic arm for daily needs. Researcher He et al. proposed vision-based assistance for myoelectric hand control. RGB-D sensor is used to identify the shape of the object that need to be grasped. Deep CNN algorithm is used to detect the object image captured by the camera. The experiment successfully estimates the target object following the user's intention [51].

Further study can be done using artificial neural network (ANN) to extract the exact input value from the user muscle activity. Arapi et al. tackled the difficulty in predicting soft-handed grip failures before they occur. It combines deep learning with an inertial measurement unit-focused sensing technique. The network obtained 100 per cent precision in experimental validation. The network uses a multidimensional continuum stream of raw signals from inertial measurement units as input. The Predictor detects 100% of the two-handed errors. Detection occurs 1.96 s before the typical real failure occurs [52].

2.6 Implementation of YOLO in Robotic and Prosthetic Robotic Arm

A grasp manipulation using evolutionary computing by Shukla and Nandi used learning-based technique in correctly placing the robot arm on the object that needs to be grasped. A Kinect-V2 camera is used and placed on both arms and head of the collaborative robots (COBOT) robot. The robot has two sets of gripper, electrical and vacuum grippers. Infrared range sensor is also placed in both arms. You-only-look-once (YOLO) algorithm is used for object detection as the algorithm is efficient in real-time prediction. Image data from the Kinect-V2 camera is mapped using an evolutionary algorithm (G.A.), Regression left–right (L.R.) and mathematical approach proportional integral (P.I.). The GA is used for optimal mapping matrix, while L.R. for observation of images in a 2D plane and P.I. for inversing a non-square matrix of G.A. and L.R. Once the grasp position is mapped, the infrared sensor provides the length/depth for the robot to grasp the object. An external parameter called safe distance (S.D.) using the infrared sensor is taken in the count to avoid damaging the gripper or the grasped object. As the three errors converge, a technique was compared according to the experiment results. G.A. performed better than L.R. and P.R. with an error of 0.00189. Data collection for the train could also be robotised for future use in sufficient real grasping data [53]. Researcher Hernandez proposed a method to decode visual representations of an object using brain data towards improving robot arm grasping configurations. A Kinect camera is used to acquire data from 25 body joints of experiment assistants who presented the object to the robot arm.

YOLO algorithm is used to detect the object label. A deep convolutional autoencoder that trained noise-free standard manifold is used to combine the brain encoder's image data as only half image is provided. The image reconstruction involved data preparation and deep convolutional autoencoder construction. For data collection, photoshop data file (PSD) and region of interest (ROI) are used for each try. In-depth convolutional image processing critical discourse analysis (CDA) is trained to combine the PSD matrix and ROI into a new matrix. The research resulted in 76.5% accuracy on Inception Score Test. However, the research is limited in use on particular subjects [54]. Researcher Ruan et al. proposed a novel surface contact model to study the contacts between the target object and robot arm. A grasp detector was attached on both sides of the parallel gripper. The image classification was done using PointNetGPD and grasp pose detection (GPD). The experiment resulted in 89.53% accuracy as the robot gripper grasps an object. The object and gripper's contact area based on the shape of the object was concluded [55].

3 Humanizing the Prosthetic Robot Arm

Developing a practical prosthetic robotic arm will encounter continuous challenges as in Fig. 8 and is a main determination among researches. One of the main concerns is whether the cost is affordable for end users. Discussing about cost, type of materials used to fabricate prosthetic robotic arm, to execute the functions and mechanism and the electronic components equipped will affect the production cost. Basically, the price ranges from $500 up to a cost equivalent to the latest car model price in market [56]. In fact, an expensive prosthetic robotic arm can provide better quality in terms of functionality, light weight, robustness than the low-cost prosthetic robotic arm that might be not achieving basic functions as a normal hand area are able to do. Usually, these kinds of low-cost prosthetic robot arm are mechanical string/ pulley-based prototype that has certain limitations such as minimum generated grasping force [57]. Most will require a prosthetic robotic arm with a feedback system to rehabilitate and regain the sense of real-human-hand while picking, holding and grasping the object that even a slippage might occur. In addition, different background of end users such as kids, adults, regular working people or athletes will also affect the whole design. Therefore, ready to market developed prosthetic robot arm should be affordable by the specific end user, and at the same time can fulfil each minimum necessity and expectations.

In addition, the prosthetic robotic arm should be user-friendly because it can vary for multiple applications. The user-friendly design must have less complicated construction and easy in maintenance when it comes to execute early setup, troubleshoot or mechanical and electronics parts replacements. Also, are able to adopt the concept of 'plug and play' [58]. These ideal concepts play important roles to expand the usage of prosthetic robot arm among various end users, eliminating taboo for users like elder groups, as it approaches the concept of 'plug and play', similar to any regular daily used electrical/electronic devices [59].

Then, a prosthetic robotic arm must be readily accessible to perform multiple tasks. For the user's regular activities of daily living (ADL), the arm must be accessible as

Fig. 8 Major challenges related to practical prosthetic robot arm

it functions almost like a real-human hand where the feedback system of prosthetic robotic arm will perform as one. In order to detect the feedback to the user on real hand feel, the feedback system must consist of various parameters such as weight, temperature, friction and sense of irregular objects [60]. This gives the user more trust and faith physically and mentally in doing ADL using a prosthetic robotic arm.

4 Conclusion

The works on the prosthetic robot arm were reviewed focusing on research trends of how to execute grasping mechanism, beginning with using simple mechanical based design, implementing actuators and sensors and even applying the element of artificial intelligence. The purpose of this review is to serve as a guiding reference for researchers in developing prosthetic robotic arm with better design, systems and practicality. A general overview shows that implementing various sensors may increase the performance of the prosthetic robot arm especially in executing grasping tasks based on simple mechanical prosthetic robotic arm, sensor technology in prosthetic robotic arm, implementation of advanced control system in prosthetic robotic arm, visual relaying prosthetic robotic arm, implementation of neural network in prosthetic robotic arm, and implementation of YOLO in robotic and prosthetic robotic arm. For future works, researcher in this field should consider the challenges of affordability for targeted end user, multi-environment feedback and user friendliness in humanizing the prosthetic robot arm.

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References

1. Micera S (2016) Staying in touch: toward the restoration of sensory feedback in hand prostheses using peripheral neural stimulation. IEEE Pulse 7(3):16–19. https://doi.org/10.1109/MPUL.2016.2539760
2. Alturkistani R et al (2020) Affordable passive 3D-printed prosthesis for persons with partial hand amputation. Prosthet Orthot Int 44(2):92–98. https://doi.org/10.1177/0309364620905220
3. Mitchelson AJ, Maender CW (2020) Hand amputation. StatPearls Publishing
4. Yong X, Jing X, Wu X, Jiang Y, Yokoi H (2019) Design and implementation of arch function for adaptive multi-finger prosthetic hand. Sensors (Switzerland) 19(16). https://doi.org/10.3390/s19163539
5. Fredriksen PM, Mamen A, Hjelle OP, Lindberg M (2018) Handgrip strength in 6–12-year-old children: the health oriented pedagogical project (HOPP). Scand J Public Health 46(21_suppl):54–60. https://doi.org/10.1177/1403494818769851
6. Mathiowetz V, Vizenor L, Melander D (2000) Comparison of baseline instruments to the Jamar dynamometer and the B&L engineering pinch gauge. Occup Ther J Res 20(3):147–162. https://doi.org/10.1177/153944920002000301

7. Bicchi A (2000) Hands for dexterous manipulation and robust grasping: a difficult road toward simplicity. IEEE Trans Robot Autom 16(6):652–662. https://doi.org/10.1109/70.897777
8. Cordella F et al (2016) Literature review on needs of upper limb prosthesis users. Front Neurosci 10. https://doi.org/10.3389/fnins.2016.00209
9. Ye H, Sakoda S, Jiang Y, Morishita S, Yokoi H (2015) Pinch-force-magnification mechanism of low degree of freedom EMG prosthetic hand for children. In: Proceedings Annual International Conference on IEEE Engineering in Medicine and Biology Society (EMBS), vol. 2015, pp 2466–2469. https://doi.org/10.1109/EMBC.2015.7318893
10. Fourie R, Stopforth R (2018) The mechanical design of a biologically inspired prosthetic hand, the touch hand 3. In: 2017 Pattern Recognition Association of South Africa and Robotics and Mechatronics International Conference (PRASA-RobMech 2017), vol 2018, pp 38–43. https://doi.org/10.1109/RoboMech.2017.8261120
11. Wattanasiri P, Tangpornprasert P, Virulsri C (2018) Design of multi-grip patterns prosthetic hand with single actuator. IEEE Trans Neural Syst Rehabil Eng 26(6):1188–1198. https://doi.org/10.1109/TNSRE.2018.2829152
12. Herath HMCM, Gopura RARC, Lalitharatne TD (2017) Prosthetic hand with a linkage finger mechanism for power grasping applications. 2017 IEEE Life science conference (LSC 2017), vol 2018, pp 304–307. https://doi.org/10.1109/LSC.2017.8268203
13. Gundogdu K, Bayrakdar S, Yucedag I (2018) Developing and modeling of voice control system for prosthetic robot arm in medical systems. J King Saud Univ Comput Inf Sci 30(2):198–205. https://doi.org/10.1016/j.jksuci.2017.04.005
14. Sahar SG et al (2019) Voice controlled 6-DoF prosthetic robotic arm for the patients with shoulder disarticulation. In: 2018 IEEE EMBS Conference on Biomedical Engineering Science (IECBES 2018), pp 233–238. https://doi.org/10.1109/IECBES.2018.8626613
15. Zhu L, Wang Y, Mei D, Jiang C (2020) Development of fully flexible tactile pressure sensor with bilayer interlaced bumps for robotic grasping applications. Micromachines 11(8). https://doi.org/10.3390/MI11080770
16. Hinwood D, Herath D, Goecke R (2020) Towards the design of a human-inspired gripper for textile manipulation. In: IEEE International conference on automation science and engineering, vol 2020, pp 913–920. https://doi.org/10.1109/CASE48305.2020.9216964
17. Bin Ramlee MRH, Yusof HM, Sidek SNI (2019) Development of gripping assistive device for training system. In: 2019 7th International conference on mechatronics and engineering (ICOM 2019), pp 6–10. https://doi.org/10.1109/ICOM47790.2019.8952065
18. Liu Z, Chen Y, Zhu X, Xu K (2020) Reach to Grasp Planning for a synergy-controlled robotic hand based on pesudo-distance formulation. Int J Humanoid Robot 17(5):1–20. https://doi.org/10.1142/S0219843620500152
19. Rao AB, Li H, He H (2019) Object recall from natural-language descriptions for autonomous robotic grasping. In: IEEE International conference on robotics and biomimetics (ROBIO 2019), pp 1368–1373. https://doi.org/10.1109/ROBIO49542.2019.8961482
20. Chin L, Barscevicius F, Lipton F, Rus D (2020) Multiplexed manipulation: versatile multimodal grasping via a hybrid soft gripper. In: IEEE International conference on robotics and automation, pp 8949–8955. https://doi.org/10.1109/ICRA40945.2020.9196626
21. Yajima S, Shimono T, Mizoguchi T, Ohnishi K (2020) Automatic grasping position adjustment for robotic hand by estimating center of gravity using disturbance observer. IEEE/ASME International conference on advanced intelligent mechatronics (AIM), vol 2020, pp 595–600. https://doi.org/10.1109/AIM43001.2020.9159000
22. Wang D, Xiong Y, Zi B, Qian S, Wang Z, Zhu W (2021) Design, analysis and experiment of a passively adaptive underactuated robotic hand with linkage-slider and rack-pinion mechanisms. Mech Mach Theory 155:104092. https://doi.org/10.1016/j.mechmachtheory.2020.104092
23. Shaw-Cortez W, Oetomo D, Manzie C, Choong P (2019) Robust object manipulation for tactile-based blind grasping. Control Eng Pract 92:104136. https://doi.org/10.1016/j.conengprac.2019.104136

24. Sainul IA, Deb S, Deb AK (2019) A novel object slicing based grasp planner for 3D object grasping using underactuated robot gripper. arXiv, pp 585–590
25. Jie D, Yu H, Li C, Wu H, Ni F (2020) Research of teleoperation grasping control method based on three-fingered dexterous hand. In: 2020 39th Chinese Control Conference (CCC), July 2020, vol 2020, pp 3812–3816. https://doi.org/10.23919/CCC50068.2020.9189552
26. Li J, Shi C, Yang D, Liu H (2019) A novel grasping control method for dexterous prosthesis based on eye-tracking. IEEE International conference on robotics and biomimetics (ROBIO 2019), Dec 2019, pp 2293–2297. https://doi.org/10.1109/ROBIO49542.2019.8961380
27. Huang Q, Lan J (2019) Remote control of a robotic prosthesis arm with six-degree-of-freedom for ultrasonic scanning and three-dimensional imaging. Biomed Signal Process Control 54:101606. https://doi.org/10.1016/j.bspc.2019.101606
28. Li Y, Cong M, Liu D, Du Y, Xu X (2020) Stable grasp planning based on minimum force for dexterous hands. Intell Serv Robot 13(2):251–262. https://doi.org/10.1007/s11370-019-00305-7
29. He Y, Shima R, Fukuda O, Bu N, Yamaguchi N, Okumura H (2019) Development of distributed control system for vision-based myoelectric prosthetic hand. IEEE Access 7:54542–54549. https://doi.org/10.1109/ACCESS.2019.2911968
30. Ibrahim F, Usman J, Mohktar MS, Ahmad MY (2015) International conference for innovation in biomedical engineering and life sciences (ICIBEL2015), Putrajaya, Malaysia, 6–8 Dec 2015, IFMBE Proceedings, vol 56, pp 3–4. https://doi.org/10.1007/978-981-10-0266-3
31. Aly HI, Youssef S, Fathy C (2018) Hybrid brain computer interface for movement control of upper limb prostheses. In: 2018 International conference on biomedical engineering and application (ICBEA 2018), pp 1–6. https://doi.org/10.1109/ICBEA.2018.8471729
32. Ruhunage I, Mallikarachchi S, Chinthaka D, Sandaruwan J, Lalitharatne TD (2019) Hybrid EEG-EMG signals based approach for control of hand motions of a transhumeral prosthesis. In: 2019 IEEE 1st Global conference on life science and technology (LifeTech 2019), pp 50–53. https://doi.org/10.1109/LifeTech.2019.8883865
33. Ghazali R, Saad MZ, Hussien SYS, Jali MH, Zohedi FN, Izzuddin TA (2017) Intelligent controller design for multifunctional prosthetics hand. Int J Mech Eng Robot Res 6(6):495–501. https://doi.org/10.18178/ijmerr.6.6.495-501
34. Liu B, Jiang L, Fan S, Li C (2020) A biomimetic impedance controller for robotic hand variable stiffness grasping. In: 2020 IEEE International Conference on Mechatronics and Automation (ICMA 2020), pp 407–412. https://doi.org/10.1109/ICMA49215.2020.9233685
35. Wu B et al (2020) Generative attention learning: a 'GenerAL' framework for high-performance multi-fingered grasping in clutter. Auton Robots 44(6):971–990. https://doi.org/10.1007/s10514-020-09907-y
36. Rosenberger P et al. Object-independent human-to-robot handovers using real time robotic vision. arXiv, vol 6(1), pp 17–23
37. Liu W, Hu J, Wang W (2020) A novel camera fusion method based on switching scheme and occlusion-aware object detection for real-time robotic grasping. J Intell Robot Syst Theory Appl 791–808. https://doi.org/10.1007/s10846-020-01236-7
38. Omarali B, Denoun B, Althoefer K, Jamone L, Valle M, Farkhatdinov I (2020) Virtual reality based telerobotics framework with depth cameras. In: 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN 2020), pp 1217–1222. https://doi.org/10.1109/RO-MAN47096.2020.9223445
39. Rakhimkul S, Kim A, Pazylbekov A, Shintemirov A (2019) Autonomous object detection and grasping using deep learning for design of an intelligent assistive robot manipulation system. In: International conference on system man and cybernetics, vol 2019, pp 3962–3968. https://doi.org/10.1109/SMC.2019.8914465
40. Wang K, Yang S, Kumar D, Thakor N (2020) Hybrid frame-event solution for vision-based grasp and pose detection of objects. In: IEEE International conference on automation science and engineering, vol 2020, pp 1383–1388. https://doi.org/10.1109/CASE48305.2020.9216970

41. Jin L, Zhang H, Shen Y, Ye C (2020) Human-robot interaction for assisted object grasping by a wearable robotic object manipulation aid for the blind. In: Proceedings of 2020 IEEE Int. Conference on Human-Machine Systems (ICHMS 2020), pp 2–7. https://doi.org/10.1109/ICHMS49158.2020.9209377
42. Mitash C, Shome R, Wen B, Boularias A, Bekris K (2020) Task-driven perception and manipulation for constrained placement of unknown objects. arXiv, vol 5(4), pp 5605–5612
43. Farag M, Ghafar ANA, Alsibai MH (2019) Real-time robotic grasping and localization using deep learning-based object detection technique. In: 2019 IEEE International conference on automatic control and intelligent system (I2CACIS 2019), pp 139–144. https://doi.org/10.1109/I2CACIS.2019.8825093
44. Gabellieri C et al (2020) Grasp it like a pro: grasp of unknown objects with robotic hands based on skilled human expertise. IEEE Robot Autom Lett 5(2):2808–2815. https://doi.org/10.1109/LRA.2020.2974391
45. Joshi S, Kumra S, Sahin F (2020) Robotic grasping using deep reinforcement learning. arXiv, pp 1461–1466
46. Lambeta M et al (2020) "DIGIT: a novel design for a low-cost compact high-resolution tactile sensor with application to in-hand manipulation. arXiv, vol 5, no. 3, pp 3838–3845
47. Ozguner O et al (2020) Camera-robot calibration for the da Vinci robotic surgery system. IEEE Trans Autom Sci Eng 17(4):2154–2161. https://doi.org/10.1109/TASE.2020.2986503
48. Chen N, Westling G, Edin BB, Van Der Smagt P (2020) Estimating fingertip forces, torques, and local curvatures from fingernail images. Robotica 38(7):1242–1262. https://doi.org/10.1017/S0263574719001383
49. Gardner M et al (2020) A multimodal intention detection sensor suite for shared autonomy of upper-limb robotic prostheses. Sensors (Switzerland) 20(21):1–20. https://doi.org/10.3390/s20216097
50. Sun GJ, Lin HY (2020) Robotic grasping using semantic segmentation and primitive geometric model based 3D pose estimation. In: Proceedings of 2020 IEEE/SICE International symposium on system integration (SII 2020), pp 337–342. https://doi.org/10.1109/SII46433.2020.9026297
51. He Y, Kubozono R, Fukuda O, Yamaguchi N, Okumura H (2020) Vision-based assistance for myoelectric hand control. IEEE Access 8:201956–201965. https://doi.org/10.1109/ACCESS.2020.3036115
52. Arapi V et al (2020) To grasp or not to grasp: an end-to-end deep-learning approach for predicting grasping failures in soft hands. In: 2020 3rd IEEE International conference on soft robotics (RoboSoft 2020), pp 653–660. https://doi.org/10.1109/RoboSoft48309.2020.9116041
53. Shukla P, Nandi GC (2019) Robotized grasp: grasp manipulation using evolutionary computing. In: Proceedings of 2019 international conference on electrical, electronics and computer engineering (UPCON 2019), pp 1–6. https://doi.org/10.1109/UPCON47278.2019.8980144
54. Hernandez-Carmona D, Penaloza CI (2019) Deep learning based image reconstruction from brain data during object-grasping task with a BMI. In: Proceedings of IEEE workshop on advanced robotics and its social impacts (ARSO), vol 2019, pp 335–339. https://doi.org/10.1109/ARSO46408.2019.8948782
55. Ruan J, Liu H, Xue A, Wang X, Liang B (2020) Grasp quality evaluation network for surface-to-surface contacts in point clouds. In: IEEE International conference on automation science and engineering, vol 2020, pp 1467–1472. https://doi.org/10.1109/CASE48305.2020.9216808
56. Brown TJ, Chen C (2016) A new low-cost bionic hand. ASEE annual conference and exposition, conference and proceedings, vol 2016. https://doi.org/10.18260/p.26378
57. Schweitzer W, Thali MJ, Egger D (2018) Case-study of a user-driven prosthetic robotic arm design: Bionic hand versus customized body-powered technology in a highly demanding work environment. J Neuroeng Rehabil 15(1):1–27. https://doi.org/10.1186/s12984-017-0340-0
58. Chu X, Roddelkopf T, Fleischer H, Stoll N, Klos M, Thurow K (2016) Flexible robot platform for sample preparation automation with a user-friendly interface. In: 2016 IEEE international conference on robotics and biomimetics (ROBIO 2016), pp 2033–2038. https://doi.org/10.1109/ROBIO.2016.7866628

59. Lourens T, Barakova E (2011) User-friendly robot environment for creation of social scenarios. In: Lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics), vol 6686. LNCS, no. PART 1, pp 212–221. https://doi.org/10.1007/978-3-642-21344-1_23
60. Tadeusz M, Janusz M, Lukasz R, Adam D, Lukasz K, MichaŁ M (2013) Multipurpose mobile robot. Appl Mech Mater 282:152–157. https://doi.org/10.4028/www.scientific.net/AMM.282.152

Container Fluid Detection Design in Generator Set

Y. Arnas, Rb. Budi Kartika, T. M. Raja Nasution, W. Hendro, Ika Endrawijaya, and Irsyadi Yani

Abstract A vessel's liquid detector design is designed to keep fluid in a vessel. This design uses an ultrasonic sensor and is equipped with a warning indicator when there is a high, medium, and low level of liquid in the vessel. The ultrasonic sensor works here to measure the volume of the vessel's liquid. The microcontroller is also used as the main component in this design to give orders and process ultrasonic sensor input data. This simulation tool design works to determine the fluid availability in the vessel. When the liquid in the vessel is at a predetermined level, the tool simulation design is also equipped with a warning indicator. That is, a high level with a green indicator of L.E.D., a medium level with a yellow indicator of L.E.D., a low level with a red indicator of L.E.D. A buzzer is used as the warning indicator used in the design of this simulation tool. The tool is expected to maintain the availability of fluid in the vessel with this simulation design. So that it will surely exist when the liquid in the vessel is to be used.

Keywords ATmega 8535 · Microcontroller · Bascom AVR

1 Introduction

The development of the fluid detection system is currently increasing rapidly; even system detection is no longer an extended object that stands still and performs routines according to the manufacturer's program. There are more and more advantages to the existence of the detection system. A detection system is no longer seen as a science that is evolving in the context of physical technology [1]. Nevertheless, there are more and more issues associated with the human environment that need attention.

Y. Arnas · Rb. Budi Kartika · T. M. Raja Nasution · W. Hendro · I. Endrawijaya
Indonesia Aviation Polytechnic, Curug, Indonesia

I. Yani (✉)
Faculty of Engineering, University of Sriwijaya, Sriwijaya, Indonesia
e-mail: irsyadiyani@ft.unsri.ac.id

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The development of the fluid detection system begins with applications at the airport in an environmental structure that is more regionally conditioned, so that more systems are designed in relatively distinctive shapes according to airport needs, such as manipulators, and most of them are not mobile and autonomous. The presence of the system, however, in a more flexible environment, such as hospitals, households, offices, forest exploration, and the development of hazardous areas that cannot be reached by humans, such as nuclear reactive areas, chemical areas and many more. Humans also have to rearrange a detection system's definition, construction and function.

From here, a fluid detection system based on functions or practical advantages must be developed to help humans do a task that is complex, hazardous and requires a high level of accuracy/precision. It is impossible to sacrifice a life like a fire extinguisher in a building that is prone to collapse, where a job to be done by humans takes enough time, and for something dangerous.

2 Literature Review

Fluid detection has components that are slightly different in development from other basic or applied sciences. Usually, basic science evolves from a principle or hypothesis that is then methodically examined. After the underlying sciences are well developed, applied science is developed. In the meantime, robotics often develops initially through a practical approach [2]. There are a few types of sensors have been used for the purpose of measuring fluid level, such as ultrasonic and pressure sensor [3]. Then theoretical research is developed by observing the behavior of living things or objects/machines/other moving equipment. The robot evolved to be more sophisticated from theory back to practice, and from here [4, 5].

Figure 1 illustrates this in order to find out what themes can be examined for fluid detection. The connection between all component sub-domains within the scope of research in the field of the system was explained in Fig. 1. System research can be carried out by selecting 4 phase themes based on the plot, namely classification, research objects, research focus and research objectives. The structure of the system, and block clarification, can be defined by the group.

3 Methods

This research was conducted in the form of literature review. The tools were theoretically designed, and the tools were made to obtain data from the results of the test. This research calculates the performance with this information and compares the tool's actual and theoretical capabilities.

Budiarto Airport is critical to the provision of aviation services, as it involves the safety of air transport services users. There is a generator set (generator set)

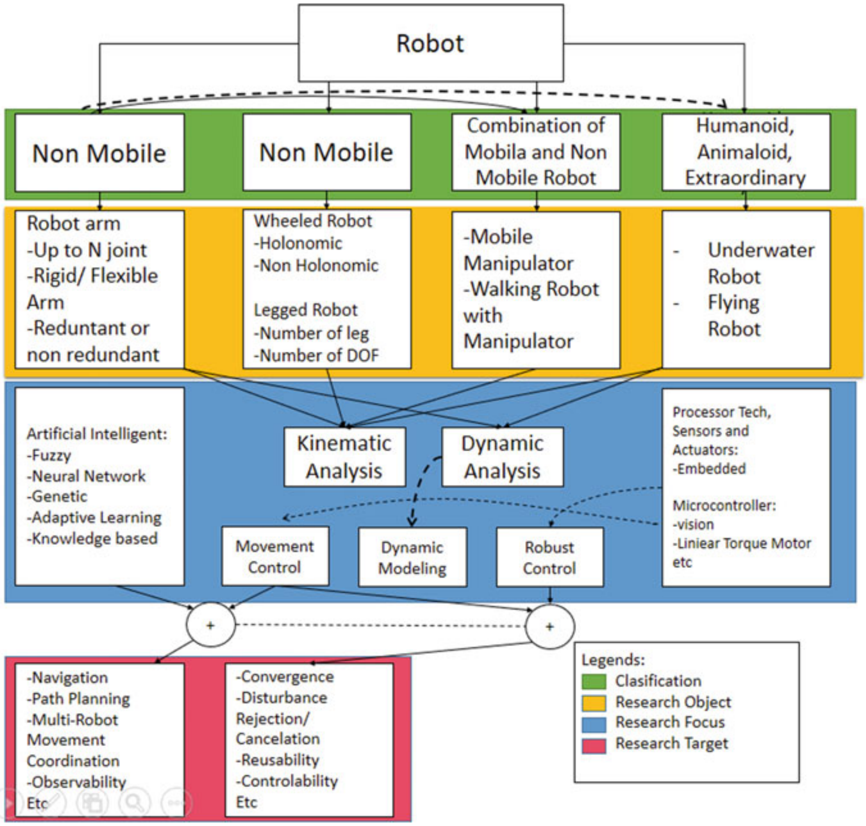

Fig. 1 Research illustration in the domain of robotics

at Budiarto Airport that acts as a backup power plant for the voltage and current sources of all electrical equipment which is used at the airport. There is a Cummins generator set with a 250 KVA capacity at Budiarto Airport. The ability to monitor the availability of generator fuel is the goal in this case so that it can automatically operate/run properly.

In order to determine the availability of fuel generators in the daily fuel tank, only the indicator hose that shows the amount of fuel in the daily fuel tank which is examined by the technicians. However, due to its useful life, the indicator hose is extended, the technician cannot know for sure how much fuel left in the tank every day.

If the main power supply from the power plant industry goes out, the generator set will operate automatically so that the fuel will be used. Supposedly the technician is not aware of how much fuel left in the tank every day. In that case, probably, because the generator fuel tank is empty, the generator will not be able run.

Arduino Uno microcontroller, Ultrasonic Sensor, LCD, Buzzer, L.E.D., Push Button and Adapter are the main components required to create this tool's simulation design. Ultrasonic sensors are used in this design to detect changes of the liquid's volume in the vessel, using the Arduino Uno microcontroller as a control or data processing unit. This Ultrasonic Sensor will continue to monitor fluid volume changes, and then input data from the Ultrasonic Sensor to the processing microcontroller. After that, the data is processed by the microcontroller and it will then be shown on the LCD. A buzzer and indicator which are L.E.D.s, also fitted with the tool simulation design to provide warnings when the volume of liquid in the vessel is at a predetermined limit. The buzzer works with a yellow L.E.D. when the liquid level is at a medium level. The buzzer works again when the liquid level with a red L.E.D. indicator is at a low level. The push button is manually operated as a button to turn off the functioning buzzer. The voltage source in this tool's simulation design is obtained from the 9 VDC adapter. A simulation design for a liquid detection device in the vessel was made based on these thoughts.

Using the CAD structural design program to analyze the parts of the structure while using the CAD structure analysis program when designing this detection system. This program was selected because it has a high degree of precision, full features, full 3D and easy to operate (Fig. 2).

The desired conditions in the simulation design of a liquid detection device in a vessel can be explained as follows, as shown in Fig. 3. If a 9-V power supply is given to the tool simulation design through an adapter that goes into the microcontroller, the simulation design of this tool will operate. In order to detect the distance and height of the liquid within the vessel, the ultrasonic sensor works. The data obtained from the ultrasonic sensor will be delivered into the microcontroller and displayed on the LCD. The ultrasonic sensor will continue to work to detect the surface height of the liquid in the vessel when there is liquid use/reduction in the vessel, and the results are always displayed on the LCD.

The green L.E.D. The indicator is ON if the liquid level in the vessel is > 7 cm. The liquid is at a high level in this case. When the liquid level in the vessel is about 7 cm to > 3 cm, the yellow L.E.D. will ON. This condition is the medium-level liquid in the vessel. The buzzer will be ON with a set time delay between ON and OFF when the liquid level is at the mean level. In this case, to turn off the buzzer that is working, the push button can be manually operated.

When the level is low, the red L.E.D. will be ON, the condition of the quantity of liquid in the vessel is cm3cm in height, and the buzzer will be ON. If the liquid is filled into the vessel, the condition that occurs is that the liquid exceeds the level of liquid specified. Since this condition is liquid filling, because it has been determined by programming on the Arduino Uno microcontroller, the buzzer does not work. It is anticipated that the design of the simulation tool, if applied to the field, will be able to assist electrical engineers in carrying out their operational tasks in the field of maintenance and maintenance of generator sets.

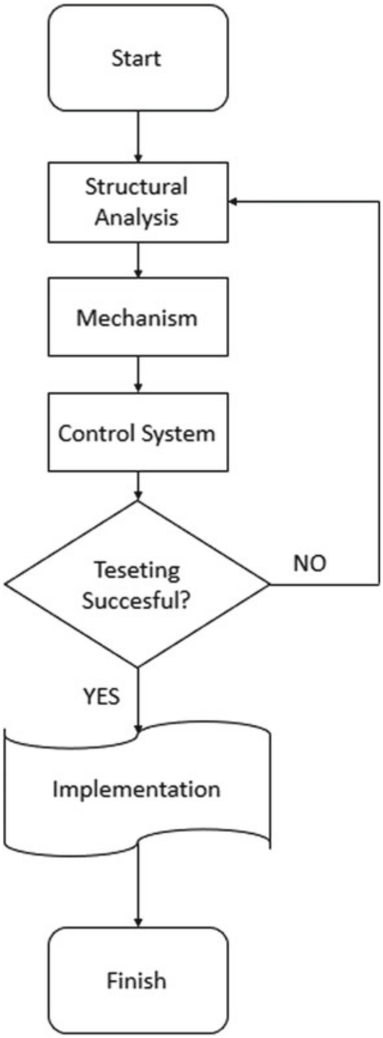

Fig. 2 Flow chart of design methodology

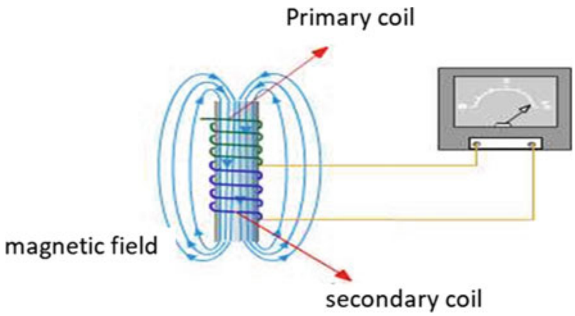

Fig. 3 Transformer schematic

4 Result and Discussion

Ultrasonic sensors' working principle is as follows:

1. The signal is emitted by an ultrasonic transmitter with a frequency above 20 kHz, which is used to measure the distance of objects at 40 kHz. The signal is generated by an ultrasonic transmitter circuit.
2. The emitted signal is then propagated with a sound velocity ranging from 340 m/s as a signal/sound wave. The signal will then be reflected and the ultrasonic receiver will receive it again.

After the signal reaches the ultrasonic receiver, it is processed to calculate the distance of the signal. The distance is determined in accordance with the formula (Fig. 4):

$$S = 340 \times t/2 \quad (1)$$

In the ultrasonic sensor circuit consists of 2 parts, named ultrasonic transmitter (ultrasonic transmitter) and ultrasonic receiver (ultrasonic receiver). Ultrasonic Transmitter Circuit (Transmitter) Transmitter is a device that functions as an ultrasonic wave transmitter with a particular frequency. In the ultrasonic transmitter

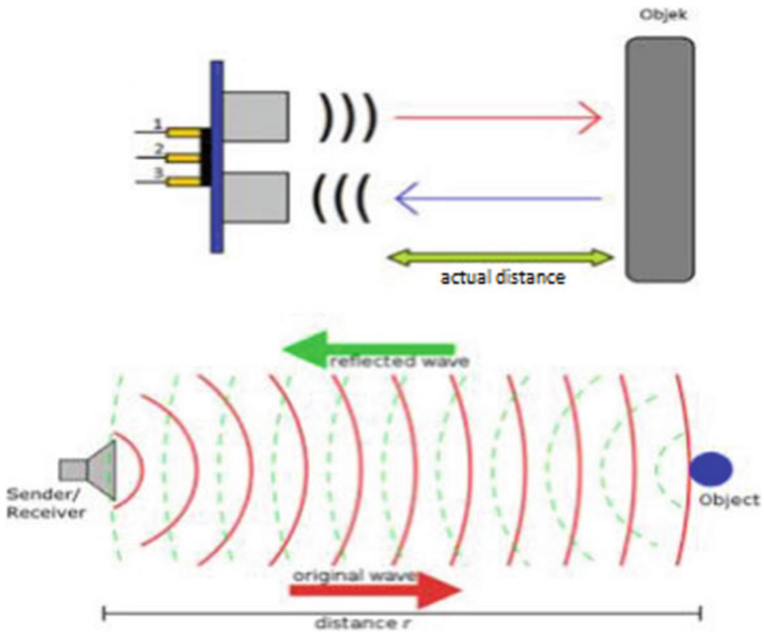

Fig. 4 Working ultrasonic sensors

circuit, there is a signal generator section. The function of the signal generator is to produce digital waves with a frequency of 40 kHz.

The signal generator circuit is a stable multivibrator with LM555 IC. On foot 4, the IC LM555 is connected to pin 5 foot of the microcontroller, which serves to give the signal emit command. The ultrasonic transmitter circuit IC 555 works at a voltage of 5–12 V D.C. The IC 555 ultrasonic transmitter circuit works in the 40 kHz frequency range determined by the IC NE555 a stable multivibrator circuit. The magnitude of the positive and negative peak levels on the pulses is used to drive the ultrasonic transducer, which can be adjusted using R3 and R4 potentiometers.

Potentiometer R3 functions to regulate the magnitude of the period of the "HIGH" side pulse and the R4 potentiometer functions to regulate the period of the "LOW" side pulse. Setting the period of the HIGH and LOW sides must be kept in mind so that the pulse frequency stays in the range of 40 kHz (Fig. 5).

The reflected signal captured by the receiving transducer is amplified using a two-transistor amplifier circuit. For the support of this ultrasonic receiver circuit consists of an amplifier with two transistors and a voltage multiplier. The following is a picture of the ultrasonic receiver circuit:

This ultrasonic receiver will receive ultrasonic signals emitted by ultrasonic transmitters with appropriate frequency characteristics. Then the output signal will be amplified and passed to the comparator circuit (comparator) determined based on the amplifier output voltage when the distance between the sensor and the barrier/wall reaches the minimum distance to bounce/reverse direction. This situation can be considered a comparator output with high conditions. At the same time,

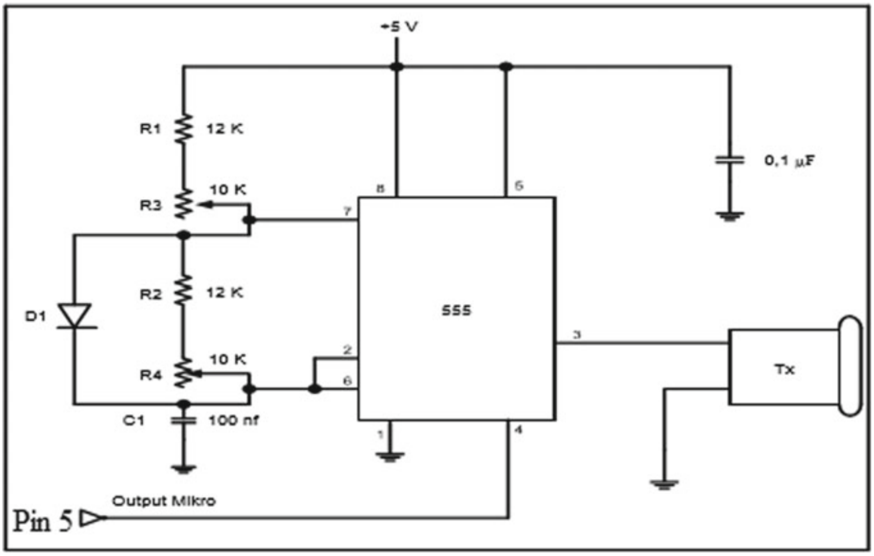

Fig. 5 Generator circuit schematic

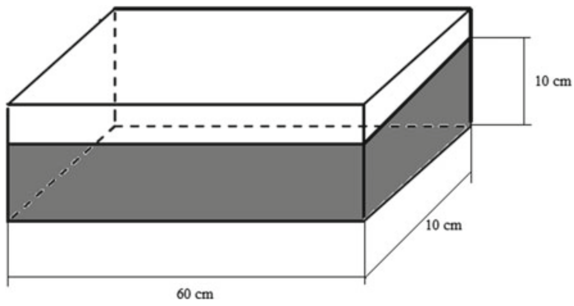

Fig. 6 The vessel contains a liquid as high as 10 cm

Table 1 Liquid level criteria in vessels

No	Fluid level	Buzzer	L.E.D	Information
1	10 cm	OFF	Green	Level high, buzzer OFF and the green led indicator is ON
2	> 7 cm	OFF	Green	Level *high*, *buzzer* OFF and the green led indicator is ON
3	≤ 7 cm - > 3 cm	ON	Yellow	Level *Medium*, *buzzer* ON, with a fixed delay time between ON and OFF
4	≤ 3 cm	ON	RED	Low level, buzzer ON, with a set delay time between ON and OFF. The red led indicator is ON

the longer distance is low. These logics are then passed on to the controller circuit (microcontroller).

In liquid volume calculating the in a vessel, there are several criteria for the amount of liquid in the vessel. Here follows the calculation of the volume of liquid in the vessel with the height of the liquid in the vessel that is 10, 7, 5, 3 cm. If the liquid height in the vessel is 10 cm, the volume can be calculated with the following calculation (Fig. 6; Table 1).

5 Conclusion

Based on the results of the discussion, it is concluded that the overall tool design as contained in Appendix 1 can detect the liquid in the vessel by producing the amount of liquid available in the vessel. Reduced. The microcontroller working system as a control system is to regulate the entry and exit of the current, which is translated into signals and will then be responded to regulate the work of the manipulator and actuator.

References

1. Jignesh Patoliya HP, Mehta H (2016) Arduino controlled war field spy robot using night vision wireless camera and android application Arduino controlled war field spy robot using night vision wireless camera and android application. In: 2015 5th Nirma University of International Conference on Engineering Arduino, pp 1–6, Nov 2015
2. Snyder Wesley E (2005) Industrial robots: computer interfacing and control. Prentice-Hall
3. Manashti M, Azimi MA (2013) Water level measurement using image processing. In: The second international conference on agriculture and natural, vol 2(2), pp 393–395
4. Tood DJ (1986) Fundamental of robot technology: introduction to industrial robot, teleoperators and robot vehicles. Kogan Page Ltd., London
5. Fu KS, Gonzales RC, Lee CSG (1987) Robotics: control, sensing, vision, and intelligence. McGraw Hill Publishing Company, New York

Simulating the Cycle Time Based on a Manpower Performance Through a System Dynamics Model: A Case Company in the Automotive Sector

Ahmad Afif Ahmarofi, Norhaslinda Zainal Abidin, and Nurul Husna Mahadzir

Abstract The uncertainty of cycle time due to manpower performance could affect the efficiency of completion time at a production line. Ultimately, the challenges of manpower performance contribute to tardiness, which is the delay of a job's due date from its completion time. Hence, the cycle time of a specific task must coordinate efficiently to ensure the smoothness of production operation. In this regards, a company facing the issue of uncertain cycle time due to manpower factor in producing an audio system for the automotive sector was considered. This study aims to determine the best-so-far cycle time to produce the audio system at a production based on manpower performance. To mimic a production line, a simulation model was developed based on a system dynamics (SD) approach. Subsequently, what-if analysis is conducted by adjusting the cycle time to observe the effect of schedule pressure and manpower fatigue on productivity. As a result, 5 s is the best cycle time to produce the product at the production of the selected company. Consequently, a policy on setting the cycle time at the production was proposed for the best completion time without tardiness.

Keywords Manpower performance · Cycle time · Simulation · System dynamics · Automotive dector

1 Introduction

A rapid transformation is progressively carried out by the Malaysia government in strengthening the manufacturing sector to cope with the challenges of the Industrial Revolution 4.0 (IR 4.0) [1]. Even though 49 percent of manufacturers in Malaysia

A. A. Ahmarofi (✉) · N. H. Mahadzir
Department of Computer Science, Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, 08400 Merbok, Kedah, Malaysia

N. Zainal Abidin
School of Quantitative Sciences, College of Arts and Sciences, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

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still depend on the semiautomatic production line, the transformation of the manufacturing sector into a smart operation is deemed crucial [2]. Consequently, a shorter completion time for the production of products is vital to remain competitive in the marketplace.

In determining completion time with on-time delivery, the cycle time becomes a big problem for the management [3]. Cycle time is the time required by manpower to complete a specific task [4]. Several studies found out that the completion time of a product always deviated which caused by the uncertain cycle time [5–7]. Hence, the cycle time appears as a frequent problem and considered a crucial factor in completion time.

Moreover, the expected cycle time is uncertain at the production line due to unforeseen performance of manpower [8, 9]. This issue has occurred since human being experiences fatigue and stress during production [10, 11]. In this regards, a problem based on a real company situation was considered. The company is a global business manufacturer for audio products in the automotive sector for both the local and international markets. However, the company was facing an issue with an uncertain cycle time of the new audio products based on manpower performance. Consequently, the completion time of the new product was affected which contributed to tardiness.

Based on the problem, it is vital to evaluate the expected cycle time using various strategies through a risk-free experiment, i.e., a technique that can mimic the production operation without any interruption on the real system. Besides, the technique should have a capability in evaluating manpower fatigue, schedule pressure and production workload during production operation to avoid an unhealthy working environment. In this regards, the objective of this study is to determine the best-so-far cycle time to produce the audio system at a production based on manpower performance through the development of a simulation model. The following section elaborated further on the research methodology. Subsequently, the results are discussed deeper while conclusion and recommendation are included in the final section.

2 Research Methodology

Due to the complexity and risk of production operation, the mathematical programming technique is incompatible to tackle the evaluation of production operation [8, 12, 13]. However, simulation technique which is a process of designing a model that resembles a real system in a graphical appearance [14, 15], provides risk-free experimentation without any interruption on the actual system [16, 17].

Based on the literature review, the system dynamics (SD) technique which is a thinking system over time function model [13, 16, 18] can understand the complexity of a production environment. Moreover, it is superior to improve the production operation policy by integrating the relevant cause-effect relationships of various factors in a dynamics behaviour [17, 19]. Hence, the SD is potentially useful to implement in the modelling of production operation for evaluating cycle time and manpower fatigue.

The purpose of modelling in SD is to improve decision making in solving a problem based on a hypothesis or working theory [19]. As illustrated in Fig. 1, there are five stages in the modelling process of SD which are problem articulation, model conceptualization, model formulation, model testing and finally, model evaluation and policy improvement [14, 17, 19].

In the SD modelling process, the iteration may happen continually until the structure and behaviour of the model mimic the real system [14]. In this study, the problem of determining the cycle time with manpower was identified at the selected company in the automotive sector.

In the second stage, a model related to the problem is conceptualized based on the interview session with the production planner to capture the related causes and effects on the cycle time problem. Subsequently, for the model formulation, the formulated stock, flow and auxiliary variables are structured. At this stage, the parameters for manpower, cycle time and other related variables were embedded in the SD model. The parameters for the variables are set as indicated in Table 1 as follows.

Fig. 1 The development of system dynamics modelling process

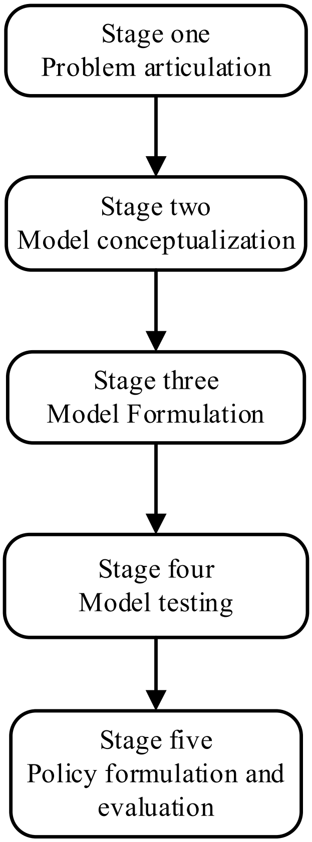

Table 1 The parameter values for the related auxiliary variables in the developed SFD

Auxiliary variable	Parameter value	Unit
Number of manpower	30	Number of workers
Material preparation time	1	Hour
Machine breakdown rate	0.0013	1 Per pieces
Cycle time	5	Second per pieces
Target completion hour	1	Hour
The standard working hour in second	3600	Second
Standard working hour	1	Hour
Attendance rate	1	Dimensionless
Time per task	0.41667	Person × hour per pieces
Delivery rate	1	Hour
Material usage per unit	7	Dimensionless
The desired production start rate	5040	Pieces
Material reject rate	0	Dimensionless
Supplier lead time delivery	1	Hour

After that, the simulation model to determine the production completion time was developed based on the stock flow diagram (SFD) as presented in Fig. 2.

Subsequently, the related variables were connected in the SD model for simulating cycle time as illustrated in Fig. 3.

In stage four, i.e., model testing, the SFD model with the inclusion of related variables are validated in terms of structure and behaviour assessments. Finally, for policy improvement and model evaluation, what-if analysis was carried out to evaluate the completion time.

What-if analysis is an intervention strategy to observe model responsiveness towards uncertainty incidents. In this study, the parameter for cycle time is reduced to 4 s since the management of the selected company would like to evaluate the effect of accelerating the production conveyor on production output. However, the conveyor decelerating, i.e., increasing the cycle time more than 5 s is not tested since

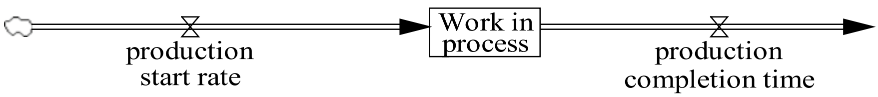

Fig. 2 The developed stock flow diagram for production completion time

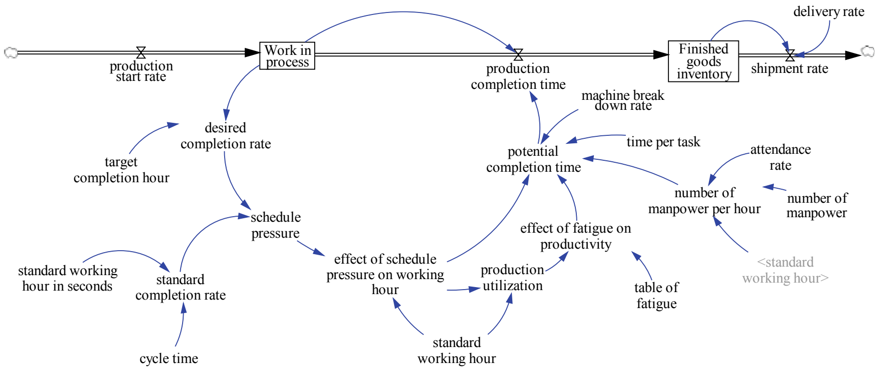

Fig. 3 The developed system dynamics model to simulate cycle time

Table 2 The scenario for a what-if analysis of the developed system dynamics model

Description of the scenario	The parameter for the base run	Observation of performance output
Cycle time is reduced to 4 s	5 s	(i) production completion time (ii) schedule pressure (iii) effect of fatigue on productivity

the management had found that the manpower has less work at the production line. Hence, the cycle time of 4 and 5 s are considered as uncertain parameters when it involves a lot of manpower, i.e., almost 30 manpower at the production line as it will give negative effects on the overall completion time. Furthermore, the results of schedule pressure and the effect of fatigue on productivity were measured to avoid overproduction workload and extreme manpower fatigue, respectively, as shown in Table 2.

Based on Table 2, the management of the selected company would like to evaluate the effect of adjusting the production conveyor, i.e., between 4 and 5 s on completion time, schedule pressure, and the effect of manpower fatigue. Subsequently, the results of what-if analysis are discussed further in the following section.

3 Results and Discussion

The scenario was conducted through what-if analysis by reducing the cycle time to 4 s. The scenario performances were observed on production completion time, schedule pressure and the effect of fatigue on productivity as illustrated by Figs. 4, 5 and 6, respectively.

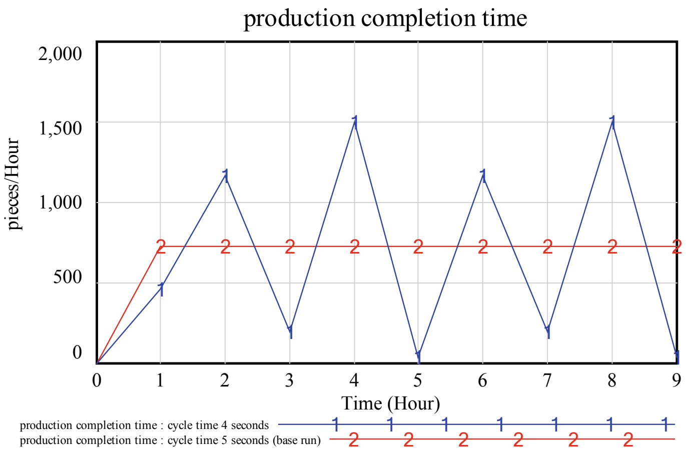

Fig. 4 Performancse of production completion time on different cycle time

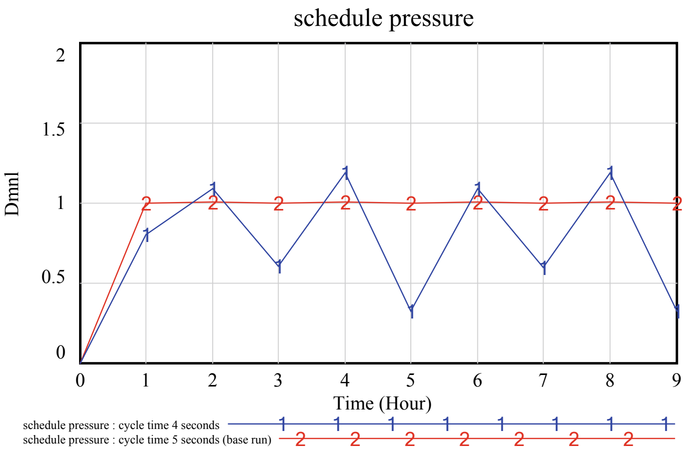

Fig. 5 The fluctuation of schedule pressure at a different cycle time

Referring to Fig. 4, the production completion time of the new audio product is unstable if the cycle time is decreased to 4 s. The cycle time of 4 s is considered as sensitive parameter especially when it involves 30 manpower at production line since it affects the overall completion time as mention in Sect. 2. Consequently, the behaviour of production completion time based on 4 s has fluctuated.

Table 3 shows the production completion time of the new audio product based on variations of cycle time during the working period from initial time, $t_{init} = 0$ until the current time, $t_{cur} = 9$ h at the semiautomatic production line.

According to Table 3, a time of 4 s was insufficient for the manpower to complete specific tasks during the production process as compared to 5 s. As a result, schedule

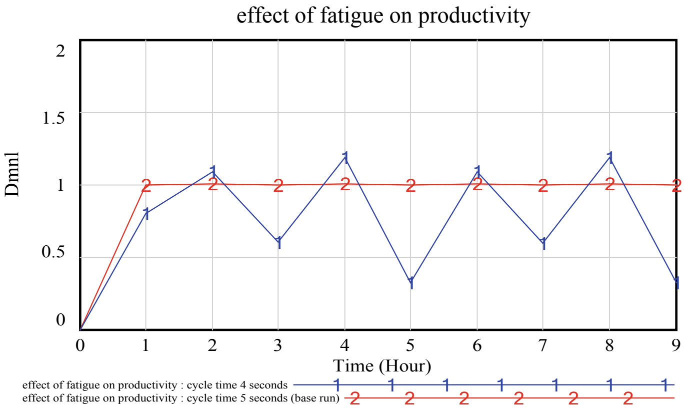

Fig. 6 Effect of fatigue at different cycle time

pressure is recorded higher than 1 during t_{cur} = 2, 4, 6 and 8 of working time as indicated by Fig. 5, which indicates production is over-utilized.

However, $t_{cur} = 1, 3, 5, 7$ and 9 show lower schedule pressure, i.e., below than scale 1 which indicates poor production utilization. Consequently, the effect of fatigue on productivity as presented in Fig. 6 shows a scale higher than 1 which indicates that the situation is unhealthy for manpower performance since more task is done at the production line. The unit for schedule pressure (see Fig. 5) and effect of fatigue on productivity (see Fig. 6) are dimensionless, i.e., Dmnl, due to both variables have no physical units which resulted from the ratio quantities. Moreover, both variables have the same pattern due to schedule pressure has direct influences on the effect of fatigue on productivity (see Fig. 3).

From the performance of different cycle time, there is no requirement of adjusting the production conveyor by decreasing the cycle time to 4 s. A cycle time of 4 s creates an unstable production utilization that led to high schedule pressure, thus manpower experience extreme fatigue to complete their task. Hence, the result indicates that the ideal cycle time is 5 s since the production completion time, schedule pressure and effect of fatigue on productivity are stable.

4 Conclusion

Based on the results of what-if analysis, it was found that the ideal cycle time is 5 s to consistently produce 720 pieces of the new audio products for every one hour. Moreover, the ideal number of manpower at the production line to produce 6480 pieces of the product within 9 h is 30 persons. The acceleration and deceleration of the cycle time must be carefully observed as it significantly influences the effect of

Table 3 Description of production completion time at a different cycle time

Cycle time	Production completion time for the new audio product from initial time, $t_{init} = 0$ to the current time, $t_{cur} = 9$ h										Total of the new audio product (pieces)
	0	1	2	3	4	5	6	7	8	9	
4 s	0	461	1159	194	1494	31	1166	189	1495	30	6219
5 s (base run)	0	720	720	720	720	720	720	720	720	720	6480

manpower fatigue on productivity and schedule pressure. With the policy improvement on completion time for producing the new audio products at the semiautomatic production line, the occurrence of manpower fatigue and tardiness may be avoided, hence manpower performance is improved and customer orders are met on-time.

References

1. Ooi KB, Lee VH, Tan GWH, Hew TS, Hew JJ (2018) Cloud computing in manufacturing: the next industrial revolution in Malaysia? Expert Syst Appl 93:376–394
2. Ahmarofi AA (2019) An integrated ANN and SD models with momentum rate to estimate completion time at a semiautomatic production line (unpublished thesis). Universiti Utara Malaysia, Sintok
3. Bülbül K, Şen H (2017) An exact extended formulation for the unrelated parallel machine total weighted completion time problem. J Sched 20(4):373–389
4. Schäfer R, Chankov S, Bendul J (2016) What is really "on-time"? a comparison of due date performance indicators in production. Procedia CIRP 52:124–129
5. Lembang LA (2015) Factors related to intention to stay among Gen Y in Malaysian manufacturing companies (Unpublished dissertation). Universiti Utara Malaysia, Sintok
6. Gyulai D, Pfeiffer A, Monostori L (2017) Robust production planning and control for multi-stage systems with flexible final assembly lines. Int J Prod Res 55(13):3657–3673
7. Ahmarofi AA, Ramli R, Abidin NZ, Jamil JM, Shaharanee IN (2020) Variations on the number of hidden nodes through multilayer perceptron networks to predict the cycle time. J Inform Commun Technol 19(1):1–19
8. Russell RS, Taylor BW (2011) Operations management. Wiley, Alaska
9. Ahmarofi AA, Abidin NZ, Ramli R (2017) Effect of manpower factor on semiautomatic production line completion time: a system dynamics approach. J of Mech Eng Sci 11(2):2567–2580
10. Mehrjerdi YZ, Aliheidary T (2014) System dynamics and artificial neural networks integration: a tool to evaluate the level of job satisfaction in services. Int J Ind Eng Prod Res 25(1):13–26
11. Ahmarofi AA, Ramli R, Zainal Abidin N (2017) Predicting completion time for production line in a supply chain system through artificial neural networks. Int J Supply Chain Manage 6(3):82–90
12. Sumari S, Roliana I, Zakaria NH, Hamid AHA (2013) Comparing three simulation model using taxonomy: system dynamic simulation, discrete event simulation and agent based simulation. Int J Manage Excell 1(3):54–59
13. Inam A, Adamowski J, Halbe J, Prasher S (2015) Using causal loop diagrams for the initialization of stakeholder engagement in soil salinity management in agricultural watersheds in developing countries: a case study in the Rechna Doab watershed, Pakistan. J Environ Manage 152:251–267
14. Sterman DJ (2000) Business dynamics. Irwin McGraw-Hill, Boston
15. Chen SH (2016) The influencing factors of enterprise sustainable innovation: an empirical study. Sustainability 8(5):425
16. Aslam T (2013) Analysis of manufacturing supply chains using system dynamics and multi-objective optimization (unpublished doctoral thesis). University of Skovde, Skovde
17. Garcia JM (2016) Theory and practical exercises of system dynamics. Juan Martin Garcia, Barcelona
18. Mussa YM (2009) A system dynamics model for operations management improvement in multi-plant enterprise (unpublished doctoral thesis). Delft University of Technology, Delft
19. Sapiri H, Zulkepli J, Ahmad N, Abidin NZ, Hawari NZ (2017) Introduction to system dynamics modelling and vensim software. UUM Press, Sintok

Design and Implementation of Adaptive Cyanosis Baby Manikin for Medical Training Application

Nur Fatihah Azmi and Loe Feijs

Abstract This paper explores the design principles for an adaptive cyanosis colour changing baby manikin by assembling all previous pieces of knowledge of cyanosis baby manikin. We attained the cyanosis colouration in an experimental setup during the previous study using a three-dimensional (3D) printed baby's head in a black box with the Philips Hue bulb as an actuator. This paper's motivation is to develop a working prototype of an adaptive cyanosis baby manikin, which aims to change colour from cyanosis to non-cyanosis with the real colouration, within the correct timing to be used for cyanosis recognition in medical training application. To attain this goal, we introduce the design and development of adaptive cyanosis colour changing baby manikin by employing smart lighting control, together with the Philips Hue LED bulb attached to the 3D printed baby's head. In this paper, the cyanosis colour changing in a 3D printed baby's head was simulated by controlling the Philips Hue bulb using the Processing software and IoT-based mechanism. The LDRs were embedded into the adaptive cyanosis baby manikin by monitoring the lux values of the room's lighting condition. The colour change of the cyanosis can be visualised and verified both on the 3D printed baby's head and in the trainer's laptop in Processing software. We believe that the proposed adaptive cyanosis baby manikin will pave the way for a future practical cyanosis simulator to be used in real training.

Keywords Cyanosis · Blue baby · IoT · Baby manikin · Philips hue · Smart lighting · 3D printing · Colour changing actuator · Adaptive colouration · LDR

N. F. Azmi (✉)
Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
e-mail: fatihah@utem.edu.my

L. Feijs
Future Everyday, Department of Industrial Design, Eindhoven University of Technology, Eindhoven, The Netherlands

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1 Introduction

Cyanosis is derived from the Greek word, κυανεος meaning a dark blue. It refers to the blue purplish discolouration normally seen in mucous membranes, for example, around the lips, fingers, and toes [1, 2]. After birth, cyanosis is a common clinical finding in newborn infants and is caused by reduced arterial oxygen saturation. Newborn infants normally have cyanosis several minutes after birth and become pink when the oxygen saturation rises above 85%. However, persistent central cyanosis is pathological and should be evaluated and treated promptly [3]. When the blood contains a lack of oxygen, the skin changes from bright red to a darker bluish colour. These changes can make the skin and lips appear to be blue. Central cyanosis is often visually recognized by dark-blue or purple discolouration of the tongue, mucous membranes and the mouth's linings.

To date, in order to evaluate a cyanosis's colouration efficacy, physicians or new medical trainees utilize a standard colour-assessment scoring system known as the Apgar scoring method [4]. However, when the instrumental measurement is inaccessible, unreliable, or not reproducible, a skin colour evaluation in training sessions is needed. Consequently, the training in assessing cyanosis colouration is important in newborn's simulation research. Many uncontrollable factors interfere and influence a clinician's evaluation, mainly due to lighting conditions in the delivery room, the coloured objects near the baby, and the observer. In assessing the newborn baby's condition, colour is very important, and we must be aware of the subjectivity of human visual perception. In a review of educational literature, no accurate-colour-baby simulation manikin was found that focused on a reversible colour change from cyanosis to non-cyanosis for the new medical trainee.

The idea of using the Philips Hue LED as a smart lighting control together with the 3D printed head is attractive as with can be turned into a practical cyanosis simulator. In this study, we adopt the following design principles: first, the use of off-the-shelf components such as the Arduino and Philips Hue Bulb as an actuator. Secondly, the use of open platforms for software architecture from Philips Hue app Developer, Processing and C++ in Arduino. Thirdly, the deployment of all the knowledge gathered in part three and four of the thesis into this design chapter. Fourthly, the adaptivity principle was used to simulate the environment light with indirect control of Philips Hue lighting by users. Lastly, as for the adaptivity, we have a baby's head simulator in the Processing to simulate the colour changing time and the colour values of a baby manikin.

2 Design Principle

In Industrial Design Department, Eindhoven University of Technology, students are exposed to various concept generation or known as the ideation phase, in order to develop a more creative design that has innovation potential. Compared with traditional product design, industrial design emphasized creating and developing interactive systems, products, and services that incorporate the physical and digital worlds [5]. Three conventional concept generation methods are:

1. Brainstorming which refers to gathering ideas phase [6].
2. Synectics is referring to the ideas reviving method phase [7].
3. TRIZ refers to untangle the ideas disagreement phase of the design [8].

However, in this paper, we utilize 'Design Heuristics,' which referring to a design task that leads us to solve and explore more and more ideas [9]. There are seventy-seven (77) Heuristics design approaches gathered in the article. We implemented some of them, which are animate, apply existing mechanisms in a new way, convert 2D to 3D, create a system, incorporate with environment and user input, and use multiple components for one function. To summarise the above-chosen method, we divided our cyanosis manikin's design development into several phases of the design principle in the next paragraph.

The first design principle applied off-the-shelf components such as the Arduino and Philips Hue bulbs as an actuator. Secondly, the use of open platforms for software architecture from Philips Hue app Developer, Processing, and C++ in Arduino. The first and second design principle's motivation is to provide an inexpensive and the uses of reliable and commonly available components and employed an open-source system, which is the Internet of Things (IoT). Thirdly, the deployment of all the knowledge gathered in [10] and [11] of the thesis into this design study. In particular, a colour correction results from [10] presented in CIELAB colour space and the colourimetry analysis based on real cyanosis and non-cyanosis colour changes on a 3D printed baby's head presented in previous publication in [11]. The measured colour values with the combined effects of the subtractive and additive colour mixing, which occur when adding an observation lamp will simulate central cyanosis in a baby. Fourthly, the adaptive principle was explained to simulate the environment light with indirect control of Philips Hue lighting by users. Our proposed adaptive system can perform an IoT-based system for real-time and remote continuous simulating a colour change and the environment's lux value. Lastly, as for the data-driven, we have a baby's head simulator exhibits in the Processing to simulate the colour changing time and displaying the colour values of a baby manikin. By changing some settings and numbers in the code, the same baby simulator can be rebuilt in another set. Figure 1 shows how we categorize the element of Heuristic in our adaptive cyanosis manikin design principles.

This study proposes a solution that comprises hardware, software, and communication integrated into a solution that aims to optimize cyanosis baby manikin's design and implementation through an adaptive lighting approach. The colour changing actuator generated a real-time colouration that contributes to an accurate cyanosis recognition in medical training. We extend our previous work from engineering to industrial design working principle to develop a new design solution. In terms of research methodology, we divided the system's architecture into three main phases, as in Fig. 2.

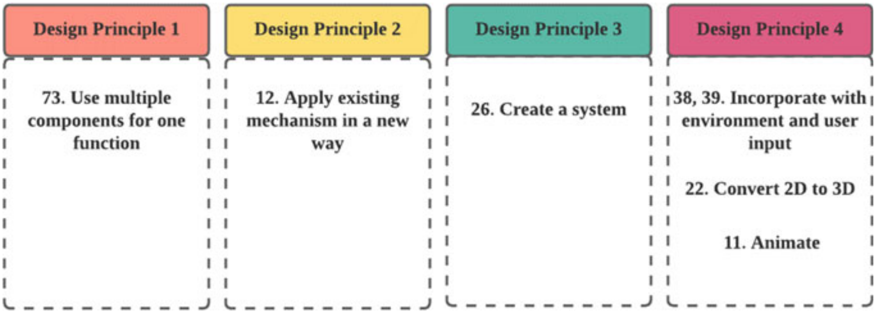


Fig. 1 Implementation of heuristic design in adaptive cyanosis manikin design principles. The number in the figure is adapted from [9]

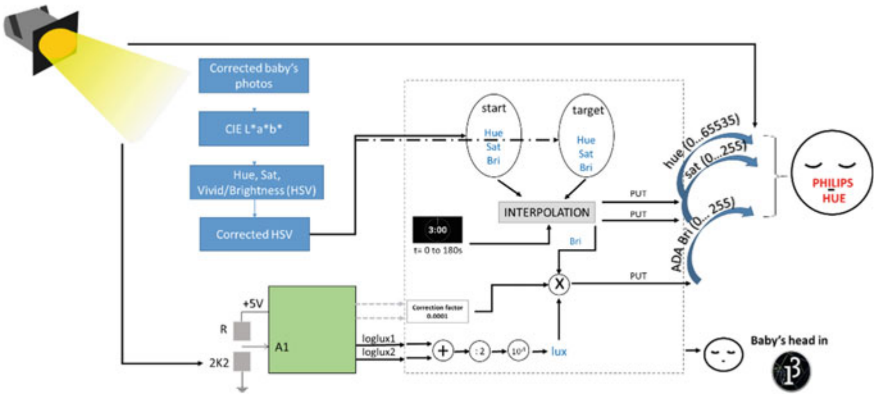


Fig. 2 The architecture design for the adaptive cyanosis baby manikin

The first phase of the system follows an approach based on baby images' color corrected values from [10] and [11]. Moreover, in this phase, the environment light and the room's lighting condition will be sensed by the Light Dependence Resistors (LDRs), and light adaptation will occur. The collected data will be sent to the next phase. The second phase consists of the interpolation of the input data coming from Phase 1. The correction factor of 0.0001 is applied to ensure the natural appearance of the baby manikin. In the last phase of the system, Phase 3, the interpolated data integration was sent to the Philips Hue Application Programming Interface (API) and Philips Hue Software Development Kits (SDK) through the Processing platform. The cyanosis simulated baby's head with correct colouration and correct timing is demonstrated both in 3D printed baby's head and in the Processing visualization.

3 Prototype of Cyanosis Baby Manikin

Initially, the baby manikin will show the colouration change from cyanosis colour to non-cyanosis colour. The colour changing can be perceived in the 3D printed baby's head, as depicted in Fig. 3. Figure 3a is a real prototype of the baby under a blanket and a snuggle. We utilized the same 3D printed baby's head in [11] with the same size, dimension, and types of material used. Figure 3b illustrates the baby manikin's full formation under a blanket and a snuggle. The Arduino with the embedded Light Dependent Resistors (LDRs) and resistors were hidden under the blanket. Two small holes were made to give room for the two LDRs to detect and measure the environment's light.

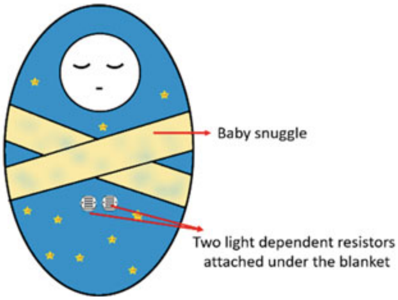
3.1 Interconnections

The works in this paper utilized the use of off-the-shelf components (Arduino, LDRs, and resistors) and the open APIs of Philips Hue bulbs, which is based on the Internet of Things (IoT) [12]. In connecting the hardware components, two interconnections are considered. The two interconnections are shown in Fig. 4.

In the first interconnection, the Philips Hue bulb connects wirelessly to the Hue bridge. The Bridge needs to be plugged into the router via Ethernet cable and works as a central controller to accept commands from the user's app or use the HTTP commands to communicate to the bulb. Upon the proper authorizations, users can wirelessly control the colour changing bulb and visualize the data acquired on any IoT platform.

In the second interconnection, the Arduino board is connected to the laptop with installed Arduino IDE using a USB cable. The LDRs embedded on the Arduino

(a) Real baby prototype



(b) Illustration of the front-view of the adaptive baby manikin

Fig. 3 The real baby prototype and the illustration of the cyanosis baby manikin

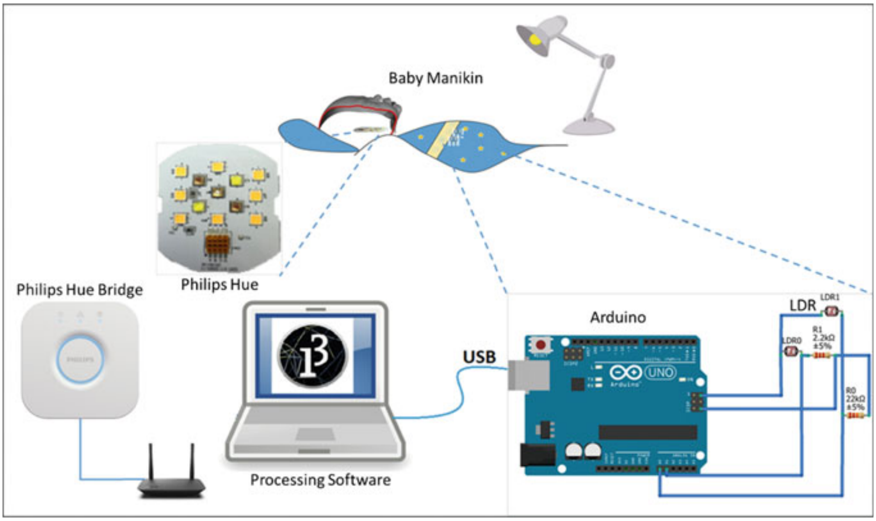


Fig. 4 The interconnections of architecture design for the adaptive cyanosis baby manikin control system

board senses and measure the lux input from the environment. The Arduino programming language (C++) was used to program a microcontroller on the board using the Arduino development environment. Arduino and Processing are frequently used in combination. The black circle with the stencil font ‘P’ and the number ‘3’ in the laptop in Fig. 4 represents the Processing software version 3.0 [13]. Processing is an open-source language or a development tool for writing programs on computers. It is suitable for artists and designers for example, students in the industrial design [14] as it provides visual and computer graphics [15]. Researchers in the Industrial Design Department, Eindhoven University of Technology, developed a mini-tool using Processing for tessellations. They interactively manipulated edges of the basic figure using one of the variations of spline theory [16]. Previously, they succeeded in creating the tessellations of vector graphics representations to apply in creative programming and laser cutting [17]. Both Arduino and Processing programs can ‘talk’ or communicate with each other by using the Arduino library for Processing as below.

In Processing, below codes needed for Processing to select the serial port used by Arduino:

```
import processing.serial.*;
```

and to find the correct port in the array, below’s code is running in Processing.

```
myport = new Serial(this, Serial.list[1], 9600);
```

3.2 Components of the Adaptive Cyanosis Baby Manikin Simulator

The baby manikin with a cyanosis control system proposed in this work comprises the Philip Hue bulb, Philip Hue Bridge, Light Dependent Resistor (LDR) for data acquisition, and Arduino microcontroller. The respective components are described in details below:

Arduino Uno Board The Arduino is a well-known platform to construct and programming electronics. It comprises a hardware part called Arduino Uno circuit board and a software part called Arduino IDE (Integrated Development Environment) [18] with simplified C++ to program the board. Arduino is an open-source platform [19] used for constructing and programming electronics.

Light Dependent Resistance (LDR) LDRs are frequently used in physics lessons in various schools as they are cheap and easy to operate [20]. LDR sensor measures the light intensity falling over the sensor. The Arduino microcontroller employs these sensors by indirectly calculating and storing the collected data through the Arduino's I/O serial monitor. This paper promotes the multitasking of LDRs and Arduino in measuring and adapting the environment's lighting condition or can be simplified as an Arduino-based lux meter. This study's circuit operation is based on the LDR circuit in [17], as illustrates in Fig. 5.

The LDR system consists of two voltage dividers with one LDR each, but with different resistors. Pin A here is referring to the analog pin value, in the range of 0–1023. First LDR, LDR0 is connected to the 22 [kΩ] resistor at pin A0 of the Arduino board. While the second LDR, LDR1 is connected to the 2.2 [kΩ] resistor

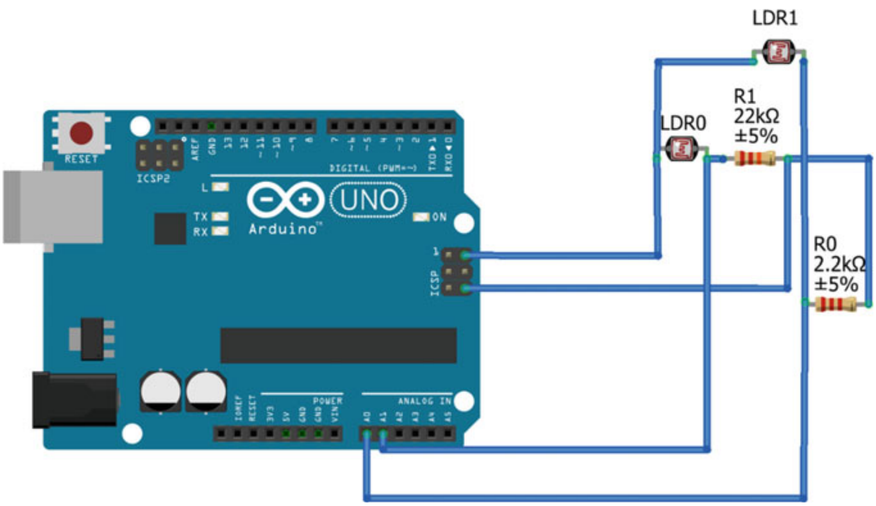


Fig. 5 Circuit diagram of the adaptive cyanosis baby manikin control system

at pin A1. The 5 [V] input voltage is supplied to the circuit. Then, it is divided into both pins with the resistors connect to the ground. Therefore, we can calculate the resistance-values for each pin as follows:

At pin A0, V_{A0} is the voltage divider with 22 [kΩ]. So,

$$V_{A0} = \frac{(R_{LDR0} \times 5[\mathrm{V}])}{1023} \times 22\,[\mathrm{k}\Omega] \tag{1}$$

Similarly, at pin A1, we find:

$$V_{A1} = \frac{(R_{LDR1} \times 5[\mathrm{V}])}{1023} \times 2.2\,[\mathrm{k}\Omega] \tag{2}$$

As for the Arduino code for lux reading by the LDRs at pin A0 and A1, the `analog Read()` are employed as follows:

```
LDRValue1 = analogRead (LDRpinA0) ;
LDRValue2 = analogRead (LDRpinA1) ;
```

Philips Hue Kit

Philips Hue bulb. Previously, the colour change actuator based on Philips Hue Kit (Bridge and bulb) was introduced and applied to our cyanosis baby manikin in [11]. The colour changing of the Philips bulb in this study was controlled remotely via an app in a mobile smart device or through a Philips developer web browser [12]. This study extends the use of the Internet of Things (IoT) device, the Philip Hue intelligent lighting system, which will bridge our cyanosis baby manikin's physical and virtual worlds. Figure 6 depicts the Philips Hue kit employed in this study. The box contains three bulbs and a bridge. However, in this study, we only used one of

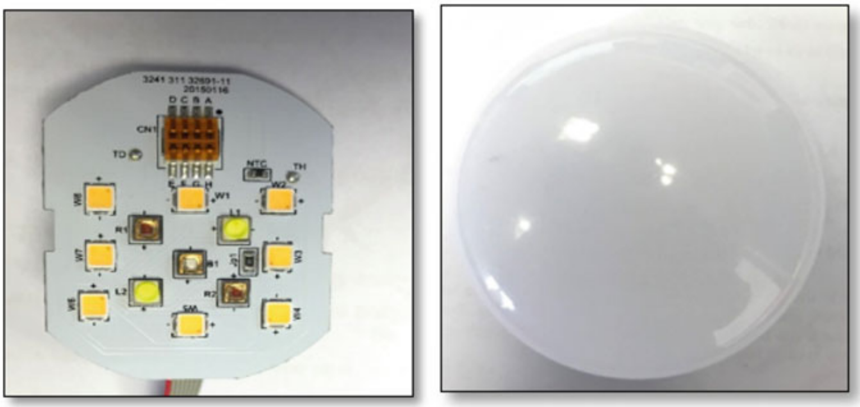


Fig. 6 Left: the inside of Philips Hue LED bulb. Right: the bulb's cover is removed from the bulb

the bulbs and removed the bulb's cover as in Fig. 6 (Right) and the inside of the bulb is as in Fig. 6 (Left).

Philips Hue SDKs. In [11], we controlled and illuminated the Philips Hue bulb by manually following the steps described in the Philips Developer website. However, in this study, we develop an automated connection between the bulb and the Processing software to design a colour-changing cyanosis actuator for cyanosis recognition training in the near future. The Philips Hue bulb now is controlled by code, not manually.

The below codes are the example of the coupling of Processing codes and the HTTP protocol. The Bridge offers the set of APIs in brackets. These allow users to control lights' setting. These APIs are accessible only from the same local networks. The string light here refers to the specific light used in the system.

```
String apiKey = "WCVbwc2fz7c3AbuyRmB7IXfLC4B9xJQTSKpZo-zU" ;
// change according to your API key
String light = " 6 " ; // change according to your Hue Light
String ip = " 192.168.1.112 " ; // change according to your IP address
```

3.3 Software and System Development

The goal of the Processing software is to bring the simulator to life. It will make the manikin behave like a real baby, which recovers from cyanosis to non-cyanosis in 3 min (other scenarios can be played as well. Here, we choose 3 min). Figure 7 indicates the full overview of the software architecture of the system. In Fig. 7, we see two plots to show that the baby travels in x, y space, and at the same time, the Y value increases from t = 0 to t = 180 s.

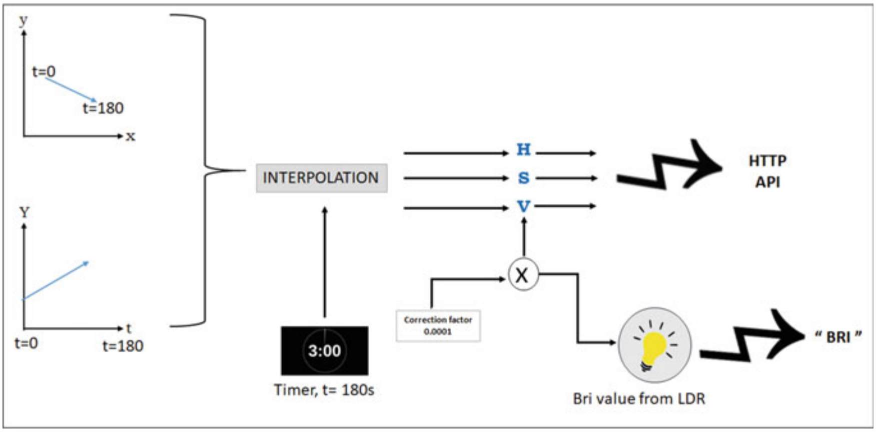


Fig. 7 The software architecture design for the adaptive cyanosis baby manikin control system

Fig. 8 A baby manikin in the baby's snuggle placed on the table with cyanosis observation light

Referring to Fig. 8, in Phase 1, we take the colour data of baby one ([11]) as a reference, taking the initial colour and the final colour of that baby. In Processing, the initial values of Y, x, y and H, S, V are denoted as startY, startx, starty, and startH, startS, startV, respectively. For the final colour values, we represented them as targetY, targetx, targety, and targetH, targetS, targetV, respectively.

```
float startY = 7.61;
float startH = 15.84;
float startx = 0.4214;
float startS = 49.14;
float starty = 0.3617;
float startV = 41.63;
float targetY = 23.26;
float targetH = 16.75;
float targetx = 0.4599;
float targetS = 58.0;
float targety = 0.3702;
float targetV = 75.2;
```

Processing needs to provide a timer value which runs from 0 to 180. Next, to convert the timer into an interpolation factor, which runs from 0 to 1, we employ the linear interpolation, called lerp. The interpolation factor here is called amt, for the amount.

```
counter++;
float time = float (counter) / frameRate ;
float amt = time / 180.0;
if (amt >1)
```

```
amt = 1;
```

Then we interpolate linearly. To do the interpolation in colour space, we apply lerp to each of the colour coordinates separately.

```
float hue = lerp (starthue, targethue, amt);
float sat = lerp (startsat, targetsat, amt);
```

The brightness is more complicated because we apply interpolation and multiply with the brightness obtained from the LDRs. We use a correction factor, which is determined experimentally in the lab, to make the brightness appear natural (note that Y coordinate of colour is scaled from 0 to 100, not coupled to Lux values).

```
float LogLux = (LogLux1 + LogLux2) /2.0;
float lux = pow(10, LogLux ) ;
final float correctionfactor = 0.0001;
float bri = lerp(startbri, targetbri, amt) ;
```

Finally, the values have to be sent to the Hue by writing a small Java interface to help us work with the HUE. The coupling of Processing and the HTTP protocol was tricky, by encoding and decoding JSON (JavaScript Object Notation) using Java. We acknowledge the help of Peter Peters and Henk Apeldoorn. The code for using the HTTP is given next:

```
PostRequest post = new PostRequest (" http: //"+ip+"/api/"+ apiKey
+"/lights/" + light + "/state") ;
post.method( "PUT" ) ;
post.addJson ("{\ "on " : true} ") ;
post.send ( );
```

Lastly, we send the JSON to Philips Hue coding:

```
public void addJson ( String json ) {
addHeader (HttpHeaders.CONTENT_TYPE, " application /json" ) ;
this. json = json ;
```

4 The Actuation

To see the system works, both in colour change actuation in a 3D printed baby's head and a Processing graphic visualization, the experimental booth is set up at the Department of Industrial Design, Eindhoven University of Technology (TU/e), The Netherlands. Figure 4 shows a baby manikin in the baby's snuggle placed on the table where the cyanosis observation light is installed.

The working place is in an open space with natural light coming from the open windows. The same setting was established in the Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka, Malaysia. The hardware must be corrected individually due to factors like the different layout of blankets

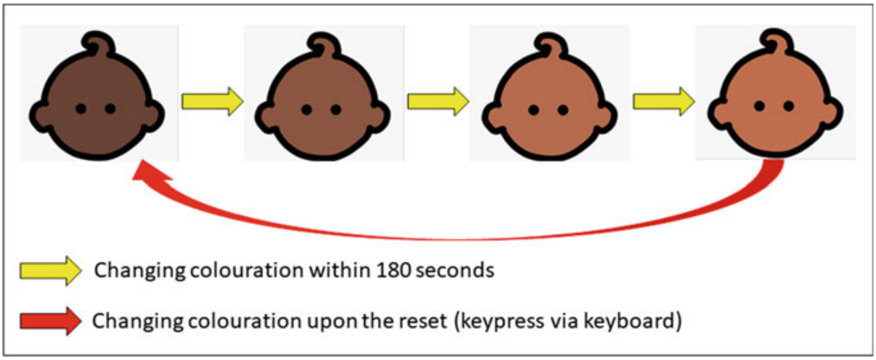


Fig. 9 Colour changing actuator visualized in processing

and the LDRs. As depicted in Fig. 5, for a screen baby, the visualization can be noticed by the graphic on the operator's laptop in the Processing platform.

The leftmost of Fig. 5 represents the initial colouration of the screen baby or known as cyanosis, and after 180 s or within three minutes, it will be transformed to right most of Fig. 5. The time range is set to 3 min to imitate the colour changing time from cyanosis to non-cyanosis [11, 21]. Upon clicking any keyboard or reset key, the baby on the screen will switch back to the original colour.

The baby model in Fig. 9 is inspired from the Digital craftsmanship course taught in the Industrial Design Department, in TU/e. By using Processing and mathematical concepts (Catmull-Rom splines), I acknowledge Prof. Loe Feijs in generating a baby's head patterns based on the codes below:

```
void babyEllipse ( float xc, float yc, float dx, float dy) {
float scale = 0.004* (dx + dy ) ;
int offsetx = -115;
int offsety = -25;
pushStyle ( );
smooth ( );
stroke (0) ; / / black contour
strokeWeight (scale * 25) ;
beginShape ( ) ;
curveVertex ( xc + (-82+ offsetx ) * scale , yc + (30+ offsety)*
scale) ;
curveVertex ( xc + (-82+ offsetx ) * scale , yc + (30+ offsety)*
scale) ;
curveVertex ( xc + (-86+ offsetx ) * scale , yc + (21+ offsety)*
scale) ;
. .
. .
endShape ( ) ;
```

5 Conclusion

This study shows the implementation of IoT-based cyanosis colouration in a 3D printed baby's head using the Philips Hue bulb and Processing software. The integration of several approaches to this study is promising. For example, the technical setup using the LDRs integrated into the adaptive cyanosis system monitored the lux values of the room's lighting condition and exhibited it on the 3D printed baby's head. Simultaneously, the changing of cyanosis colouration can be seen in the trainer's laptop.

Moreover, the idea of implementing various data from several previous studies seemed to function too. In particular, we utilized the colour values from cyanosis baby images, measured the colour values from the 3D printer cyanosis baby's head colouration (by the Philips Hue). Finally, in this study, we adopt a correction factor to compensate for the additional colour mixing.

A small user study was carried out among test subjects (with a technical background) in the Industrial Design Department lab in TU/e. From the participants' subjective experiences, it has been figured out that the overall cyanosis colouration observed from the 3D printed baby's head is not realistic enough. The distinct colour differences are challenging to recognize.

Looking back, we have been focusing on absolute colour, but in this study, the users seemed not to notice that. This relates to another imperfection of the present design, which is, we only have one colour (no separated lips). Perhaps the small colour differences would be visible as a face-lips contrast, but now they are hard to see as an absolute value. As an option for future work, it would be interesting to have a setup with two Philips Hue lamps (requiring further miniaturization).

References

1. Tuteur PG (1990) Cyanosis. In: Walker HK, Hall WD (eds) The history, physical, and laboratory examinations, ch 46, 3rd edn. Butterworths, Boston
2. Morgan E, Brown A (1935) Cyanosis of the new-born. J Am Med Assoc 105(14):1085–1088
3. Lees MH (1970) Cyanosis of the newborn infant: recognition and clinical evaluation. J Pediatr 77(3):484–498
4. Frommelt PC, Frommelt MA (2004) Cyanosis. In: Practical strategies in pediatric diagnosis and therapy, ch. 10, 1st edn. W.B. Saunders, USA, pp 166–180
5. Bachelor-industrial design (2020). https://www.tue.nl/en/education/bachelorcollege/bachelorindustrial-design
6. Osborn A (2012) Applied imagination-principles and procedures of creative writing. Read Books Ltd
7. Gordon WJ (1961) Synectics: the development of creative capacity
8. Altshuller GS (1984) Creativity as an exact science: the theory of the solution of inventive problems. Gordon and Breach
9. Yilmaz S, Daly SR, Seifert C, Gonzalez R (2013) Comparison of design approaches between engineers and industrial designers. In: DS 76: Proceedings of E&PDE 2013, the 15th international conference on engineering and product design education, Dublin, Ireland, 05.06.09

10. Azmi NF, Delbressine F, Feijs L, Bambang Oetomo S (2018) Color correction of baby images for cyanosis detection. In: Annual conference on medical image understanding and analysis. Springer, Berlin, pp 354–370
11. Azmi NF, Delbressine F, Feijs L (2020) Dynamically colour changing actuator for cyanosis baby manikin application with the Philips hue led kit. In: Proceedings of the 2020 10th international conference on bioscience, biochemistry and bioinformatics, pp 145–152
12. Philips hue. http://www.meethue.com
13. Reas C, Fry B (2007) Processing: a programming handbook for visual designers
14. Reas C, Fry B (2004) Processing.org: programming for artists and designers. In: ACM SIGGRAPH 2004 web graphics, p 3
15. Schweitzer D, Boleng J, Graham P (2010) Teaching introductory computer graphics with the processing language. J Comput Sci Coll 26(2):73–79
16. Feijs L, Hu J, Funk M, Goevaerts M, Keusters T, Van Kessel C et al (2017) Constructing mini-tools for tessellations. In: Bridges 2017 conference proceedings. Tessellations Publishing, pp 395–398
17. Feijs LM, Hu J et al (2013) Turtles for tessellations. In: Proceedings of bridges, pp 241–248
18. Boxall J (2013) Arduino workshop: a hands-on introduction with 65 projects. No Starch Press, USA
19. Arduino L (2015) Arduino introduction. http://arduino.cc/en/guide/introduction
20. Kinchin J (2020) Using an arduino in physics teaching: Ldr as a simple light sensor. Phys Educ 55(5):053005
21. Campbell M, Hills T (1950) Angiocardiography in cyanotic congenital heart disease. Br Heart J 12(1):65

Ergonomics

Investigation on Ergonomics Risk Factors at an Electronic Component Company

Nur Yasmin Suhaimi and Ahmad Nasser Mohd Rose

Abstract This study was conducted at a selected production line in an electronic company. Most of the processes were performed manually by the workers. Hence, they were exposed to risk factors of musculoskeletal disorders (MSDs) like repetitive motion and awkward postures while sitting for a long time while doing the job. The purpose of this study is to identify risk level related MSDs at each of the processes. This study used Body Discomfort Survey (BDS) and Rapid Upper Limb Assessment (RULA) for investigation. The assessment was analysed based on the actual working posture at each of the processes. Besides that, the evaluation also used recorded video and photos as secondary assessment. The preliminary result shows that winding and stripping (flat wire) scored at medium risk, needing further investigation and change soon. Similarly, BDS results show both processes winding and stripping were felt most discomfort by the workers. Then, existing process was simulated by using DELMIA software for analysing the suggestion option of human body postures. The analysis controlled the angular movement of the body parts and allowed the manikin to bend at a minimum angle of their body. These alternatives were able to reduce the final RULA score into an acceptable score. The outcome of this evaluation has given a message to the management to conduct further research for correct working posture.

Keywords MSDs · Body discomfort survey · Delmia simulation software

1 Introduction

Based on Malaysia's Social Security Organizations (SOCSO) report, the number of occupational diseases has increased from 194 cases in 2005 to 3002 cases in 2014. Similarly, musculoskeletal disorders (MSDs) was recorded 10 cases in 2005 has increased to 675 in 2014 [1]. Thus, the productivity and profitability will be affected due to high absenteeism from unhealthy worker who took medical or sick leaves.

N. Y. Suhaimi · A. N. Mohd Rose (✉)
College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
e-mail: nasser@ump.edu.my

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Besides, the National Institute of Occupational Safety and Health (NIOSH) defined ergonomics as the science or art of fitting workplace conditions and job demands to the workers' capabilities. Any company did not follow ergonomics principles might leads to inefficiency and musculoskeletal disorders (MSDs) to the workers [2]. Therefore, this study aims to determine the risk level of MSDs and suggest some improvement of the workers' body postures in the electronic component company.

The selected company produces various electronic components models for automotive industry. However, most of the processes in the production line are operated manually by the workers. Thus, they are exposed to have MSDs risk factors such as repetitive motion, sitting for a long time while working, awkward postures, and forceful exertion. Although the company has Environmental, Health and Safety department that strives to improve workers' safety and health, ergonomics issues like MSDs are inevitable in the manual production line. The symptoms of MSDs occur when the worker felt discomfort and pain in the body parts [2]. The ergonomics approach is to ensure the workers are comfortable with the tasks, safe, healthy and conducive to perform work. Apart from that, the organisation needs understand the workers behaviour on potential risk at their workplace and able to make improvement for better performance. As the goals of ergonomic are to reduce risk, increase productivity and satisfaction level of workers.

2 Literature

Ergonomics is the process of designing a product or workplace according to the suitability of the human body. The easiness and comfortability of using a product or a tool could increase productivity and reduce injuries while working. Most of the companies are still applying manual material handling at their workplace. Based on an ergonomics point of view, manual material handling could cause spinal injuries. All manual handling using force when lifting, pressing and pushing parts or tools. Most manual handling involves handling heavy objects, forceful arm and shoulder exertions, extensive bending and working in awkward postures [3]. The repetitive job on the same process will cause MSDs. MSDs are injuries or pain in the human musculoskeletal system including the joints, ligaments, muscles, nerves, tendons, neck and back. It is caused by unexpected or continual exposure to repetitive motion, force exertion, vibration and awkward postures. MSDs are widespread throughout the world and are the second most common cause of disability in work-setting. The continuous MSD could influence to the reduction of productivity [4]. Therefore, all companies have to ensure their workers are in good health in order to perform at optimum productivity. A few of past studies were studied on the effects of poor ergonomic to company performance. The awkward posture by bending has caused low productivity in one of the food companies due to the workers are a frequent stop for stretching [5]. Any abnormal movement could cause pain in the nerves and muscles [6]. There were many attempts done by researchers and ergonomists to reduce the level of discomfort, musculoskeletal disorder risk level and optimize the productivity during the past years by using ergonomic approach [5, 7]. Body discomfort survey (BDS) and Rapid Upper Limb Assessment Method (RULA) can be used for evaluation of body discomfort and risk level of working postures. BDS examines how often the workers experienced discomfort or pain, how uncomfortable they are and lastly is how much it interferes with the workers' ability to work [8]. Then, the musculoskeletal disorder impact score is calculated by the survey's scoring guidelines to determine the level of discomfort felt by workers [2]. However, RULA is used to assess the working posture, repetitive motion and force exertion on the musculoskeletal system. It was sensitive towards the upper limb body parts and suitable for sedentary works [9]. The RULA worksheet's scoring system generates an action level, which indicates the urgency of an indication required to reduce the risk of MSDs experienced by the workers [10]. At the same time, digital human modelling is considered an effective tool for analysis compared to the manual method. Therefore, it is easier to analyse the worker performance and safety condition through 3D virtual model [11] carried a simulation for the man–machine operation of the cylinder production plant using Delmia software to evaluate the ergonomics analysis. The study improved the unreasonable area for the improvement of ergonomics to reduce the risk level of work-related musculoskeletal disorders and eventually improve production efficiency. Digital Enterprise Lean Manufacturing Interactive Application (DELMIA) provides tools to connect computer modelling and simulation with the real world of operations. In DELMIA, the author performed ergonomics design and analysis with human builder, human measurement editor and human activity analysis.

3 Methodology

This study was conducted in one of the electronics companies in Pekan, Pahang. This company produces a various model of electronic parts such as inductors, magnet systems and transformers. Each model had almost the same processes as winding, looping, tinning, coating, stripping and testing. The study focused on winding, stripping (flat wire), and the looping process recommended by the Safety Manager. It was due to high injuries at these processes compared to others. All observations on workers at these processes were recorded for evaluation. It was noticed that workers were exposed to repetitive works, awkward postures, and prolonged sitting while working. Apart from that, the interviews were also conducted to the Safety manager and six workers from winding, stripping and looping. The workers were also asked to fill up the survey form as to know the level of body discomfort while working. This form was adapted from Cornell. Then, the last analysis used RULA to measure the risk assessment on the musculoskeletal within upper limbs and neck. This assessment is considered easy and quick to use for everybody [10].

The observations were done by observing workers' behaviour and body position. It was noticed that workers were exposed to repetitive works, awkward postures, and prolonged sitting while working. Next, from the interview with the Head of EHS department, it was reported that some injuries occurred in the winding, stripping (flat wire) and looping process. The summary of the injuries is shown in Table 1.

Besides, some photos (as shown in Figs. 1, 2 and 3) and video recordings of the workers doing their manual jobs were taken during winding, stripping (flat wire) and looping processes. This is important to understand how the workers perform the tasks and easy to analyse the body postures later on.

A set of questionnaires based on modified Body Discomfort Survey [3] was used for quantitative analysis. It was distributed to the respective workers to acquire the MSDs risk factor identification. Prior to answering the question, the respondents were explained clearly on the study's purpose and risk assessment. There were six respondents for each winding, stripping (flat wire) and looping process. The questionnaire contents consist of demography data and body evaluation on ten points i.e. neck, shoulder, upper back, lower back, upper arm, forearm, wrist, hip, knee, and lower leg. MSD Impact Score can be obtained from this survey by counting the number of symptoms and summing the rating values for each person. Table 2 is weighting scores for identification of the highest problem. Then, the total MSD Impact Score was calculated by using formula;

Table 1 Summary of injuries

Process	Types of injuries	Frequency
Winding	Musculoskeletal Disorders (MSD)	3
Stripping (flat wire)	Musculoskeletal Disorders (MSD)	1
Looping	Carpal Tunnel Syndrome (CTS)	1

Fig. 1 Winding

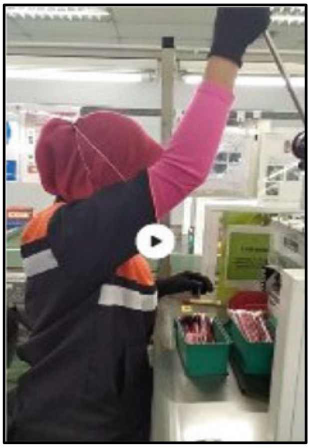

Fig. 2 Stripping

Fig. 3 Looping

Table 2 Weighting scores

Frequency weighting score	Severity weighting score	Productivity weighting score
1–2 times/week = 1.5 3–4 times/week = 3.5 Every day = 5 Several times every day = 10	Slightly uncomfortable = 1 Moderate uncomfortable = 2 Very uncomfortable = 3	Slightly interfere = 2 Substantially interfere = 3

Table 3 RULA action level

Score	Risk level of MSD
1–2	Negligible risk, no action required
3–4	Low risk, change may be needed
5–6	Medium risk, further investigation, change soon
6+	Very high risk, implement change now

Total MSD Impact Score = Total weighted frequency × Total Weighted Severity × Total Weighted Productivity [2].

RULA is performed by using a single worksheet. It consists of two sections—A (arm and wrist analysis) and B (neck, trunk and leg analysis). There is a posture scoring scale for each body parts and some additional adjustments that should be considered when the evaluation is made. After that, all the scores are calculated and used to compile the risk factor variables, producing a final RULA score representing the risk level of MSDs as shown in Table 3.

Then the suggestion for improvement was performed and analysed by using Delmia software. The outcomes of the Delmia result were presented to this company for their consideration on the improvement.

4 Results and Discussion

Based on body discomfort survey, it was discovered that the most discomfort process is winding with MSD impact scores (13,115.5), followed by stripping flat wire process (11,457.67) and looping process (3711.92). The highest score shows the process is highly uncomfortable compared with lower scores. As shown in Table 4, each process had six workers who answered the survey. P1–P18 represented workers. However, age and working experience factors did not affect the MSDs impact scores for all processes. Furthermore, according to the mean MSDs impact scores, we can conclude that most of the workers felt discomfort at the winding process (13,115.5), followed by stripping flat wire process (11,457.67) and looping process (3711.92).

Table 5 shows the results of final RULA scores. From the assessments, both winding and stripping (flat wire) processes have the same score of five, indicating the worker works at a medium risk towards MSD and changing body posture is needed. Similarly, both processes had the highest score for the upper arm position. It is believed that, this discomfortness was mainly involving inadequate postures and repetitive handling with high force. Meanwhile, the final RULA score in the looping process had a score of four which indicates the worker works at a low risk towards MSD and changing of body posture may be needed. Also, for this process, the upper arm and wrist position had the highest score, followed by the other body parts.

DELMIA software is used to evaluate suggestion for body posture improvement. The analysis will allow the worker or manikin to bend at a minimum angle of their body to be fit with the task, along with the correct way of sitting and adjusted height

Table 4 Result of body discomfort survey

Person	Process	Age	Experiences	MSD impact	Mean MSD impact
P1	Winding	44	9 years	45,066	13,115.5
P2	Winding	20	11 months	14,091	
P3	Winding	19	5 months	9072	
P4	Winding	22	4 years	7722	
P5	Winding	24	1 year	2322	
P6	Winding	25	1 year	420	
P7	Stripping	20	1 year	41,800	11,457.67
P8	Stripping	22	1 year	13,230	
P9	Stripping	26	2 years	8550	
P10	Stripping	35	15 years	4620	
P11	Stripping	28	2 months	539	
P12	Stripping	32	2 years	7	
P13	Looping	22	3 years	12,960	3711.92
P14	Looping	19	4 months	7104	
P15	Looping	55	28 years	740	
P16	Looping	41	20 years	577.5	
P17	Looping	35	18 years	530	
P18	Looping	39	15 years	360	

Table 5 Result of RULA worksheet

Process/body parts	Winding	Stripping (flat wire)	Looping
Upper arm	4	5	3
Forearm	2	2	2
Wrist	1	1	3
Wrist twist	1	1	1
Posture A	4	5	4
Muscle	2	1	1
Force/load	0	0	0
Wrist and arm	5	6	5
Neck	3	2	2
Trunk	2	2	2
Leg	1	1	1
Posture B	3	2	2
Neck, trunk and leg	4	3	3
Final score	5	5	4

of workstation. All of these actions will make the worker more comfortable while doing their manual work and reduce the risk level of MSD and improve the worker's work performance. Innitially, the workers complaining that the sitting position is uncomfortable due to unproper seatback.

As shown in Fig. 4, the winding process's final RULA score reduced from five to two after improvement simulated in DELMIA software. This score indicates an acceptable and safe body posture for the worker. Apart from changing the angle for body parts, the intermittent posture and the arm were analysed with arm support. The implementation of armrest is subject to top management approval due to it is involved with safety and productivity.

Similarly, as shown in Fig. 5, the final RULA score in the stripping (flat wire) process also lowered from five to two after improvement in the analysis of DELMIA software. Thus, the score indicates that the worker's body posture is acceptable and could reduce the risk level of MSD. Also, the company could implement some changes to satisfy the scores in DELMIA software. For instance, they could provide arms support for the worker to restrict or limit the arm's angular movement. Besides, the company could change or redesign the stripping machine's crank handle to avoid excessive reaching and awkward posture.

Furthermore, as shown in Fig. 6, the RULA score after improvement in the looping process also reduced from four to two, indicating that the body posture is acceptable. Besides, to satisfy the scores in DELMIA, the company could change or redesign the workstation to suit the worker's height. This action could prevent the worker from straining the neck and allow the worker to work comfortably. Also, they could provide arms support so that the worker could limit the angular movement while doing the task and reduce the risk of MSD.

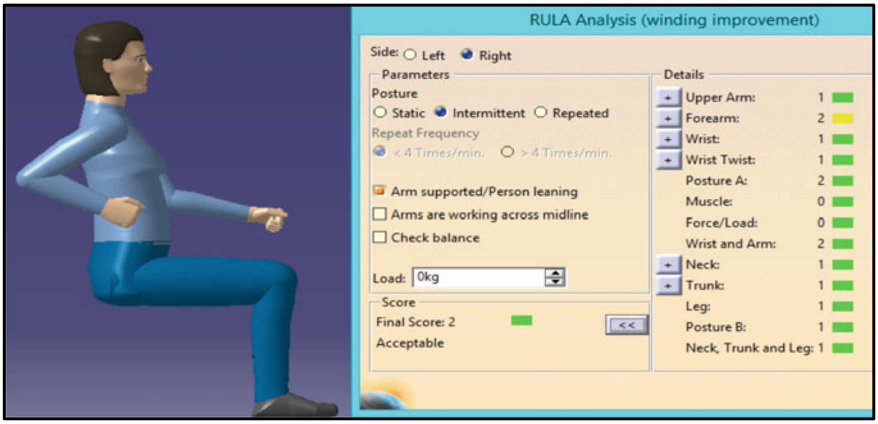

Fig. 4 Winding after improvement

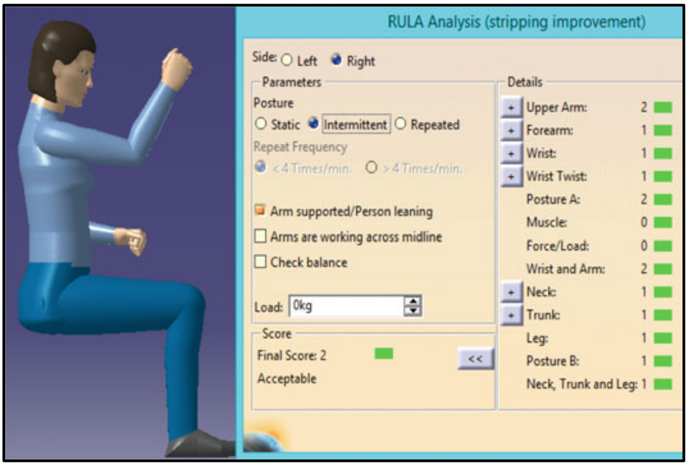

Fig. 5 Stripping flat wire after improvement

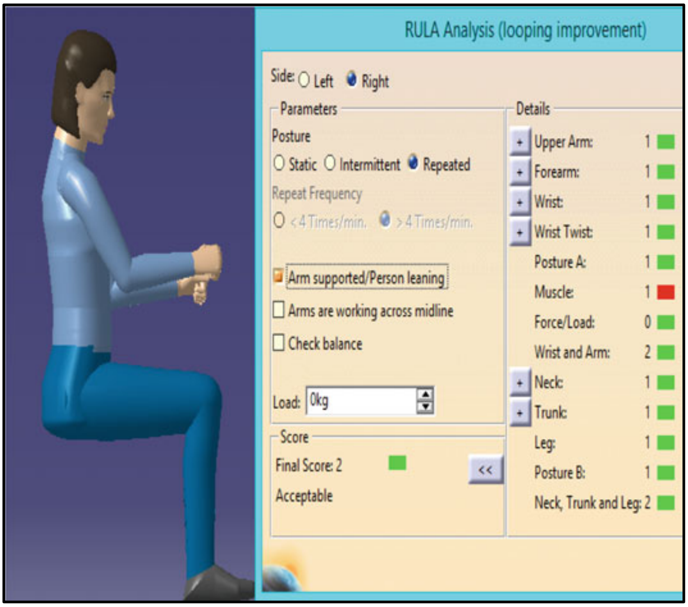

Fig. 6 Looping after improvement

5 Conclusion

The analysis shows that two processes were categorised at medium risk. It is subjected to the potential of MSD. These awkward postures could affect productivity because the worker had to stop for a while and stretch the body. Both evaluations i.e. body discomfort and RULA shows these two processes were at risk. Therefore, the manager in this company has to think provided solution through this study. Among the suggestion are improve body posture by ensuring the worker bend with a small angle while do a winding process and also provide arm rest as to restrict the angular movement. As long-term improvement, the company need redesign the workstation to suit the height of the worker. This action could prevent the worker from straining the neck and allow the worker to work comfortably. In addition, the company also needs to consider redesigning the crank handle of the stripping machine to avoid excessive reaching and awkward posture while working. It is believed that, these improvements could increase the worker productivity. The body simulation based on suggested improvement could reduce RULA score assessment from 5 to 2. Therefore, it is good if this company could consider these improvements for the betterment of their process.

References

1. Abdullah NH, Wahab E, Shamsuddin A, Hamid NAA, Kamaruddin NK (2016) Workplace ergonomics and employees' health: a case study at automotive. In: Proceedings of the 2016 international conference on industrial engineering and operations management
2. Çakıt E (2019) Ergonomic risk assessment using cornell musculoskeletal discomfort questionnaire in a grocery store. Ergon Int J 3(6):000222
3. Suryoputro MR, Wildani K, Sari AD (2018) Analysis of manual material handling activity to increase work productivity (case study: manufacturing company). MATEC Web Conf 154(2):01085
4. Daneshmandi H, Choobineh A, Ghaem H, Fakherpour A (2017) The effect of musculoskeletal problems on fatigue and productivity of office personnel: a cross-sectional study. J Prev Med Hyg 58(3):E252–E258
5. Mohd Rose AN, Ab Rashid MFF, Nik Mohamed NMZ, Jubri MAS (2019) The implementation of lean manufacturing and ergonomics in small medium enterprise—case study. IOP Conf Ser Mater Sci Eng 702:012057
6. Muslimah E, Pratiwi I, Rafsanjani F (2006) Manual material handling analysis using NIOSH equation (analisis manual material handling Menggunakan NIOSH equation). J Ilmiah Teknik Ind 5(2):53–60
7. Fazi HM, Nik Mohamed NMZ, Ab Rashid MFF, Mohd Rose AN (2017) Ergonomics study for workers at food production industry. MATEC Web Conf 90:01003
8. Hedge A, Morimoto S, McCrobie D (1999) Effects of keyboard tray geometry on upper body posture and comfort. Ergonomics 42(10):1333–1349
9. Bowden S (2018) Rapid upper limb assessment tool (RULA)—a step by step guide. Accessed by 10 Jan 2021
10. Mcatamney L, Corlett EN (1993) RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon 24(2):91–99
11. Liang D, Sun GZ, Wu S (2016) The ergonomics analysis in the process of reversed loader cylinder virtual assembly based on CATIA and DELMIA. MATEC Web Conf 44:02020

A Review on Ergonomic Assessment Tool at Small and Medium Enterprise (SME) Industries

Zayyinul Hayati Zen, Mirta Widia, and Ezrin Hani Sukadarin

Abstract An ergonomic assessment is a foundation for designing a comfortable workplace, which is safer and healthier with less injuries, optimized well-being, and improved overall workplace performance. Previous studies showed that most of the ergonomic assessment tools assess physical risk factors related to Musculoskeletal Disorder (MSD). It is interesting to investigate other ergonomic risk factors that are important to include in an ergonomic assessment tool that is related to workers' productivity in SME industries. This study set out to review the ergonomic assessment tools that have been widely used in Small and Medium (SME) Industries. To achieve the study objective, the review was conducted by searching the Google Scholar and Science Direct database. About 83 articles were identified in the first process. However, only 25 articles are included in this study after the screening process. The review found that there is lacking assessment on other ergonomic risk factors, such as psychosocial and cognitive risk factors that would also contribute to workers' productivity. Many ergonomic assessment tools that have been used in Small and Medium (SME) Industries only focused on assessing the physical risk factors that affect MSD. The knowledge and understanding of various ergonomic assessment tools will help the researchers plan the next step to improve the tool that will assess the significant ergonomic risk factors that affect worker's productivity. It might help to establish a common set of ergonomic assessment tools that are more effective, efficient, and user-friendly.

Keywords Ergonomic assessment tool · Productivity · Risk factor

Z. H. Zen · M. Widia (✉) · E. H. Sukadarin
Occupational Safety and Health Program, Faculty of Science and Technology Industry, Universiti Malaysia Pahang, Pekan, Malaysia
e-mail: mirta@ump.edu.my

Z. H. Zen
Industrial Engineering Department, Faculty of Engineering, Muhammadiyah University of Riau, Pekanbaru, Indonesia

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1 Introduction

Recently, Malaysia's economic development comes mostly from Small and Medium Enterprises (SMEs). Microenterprises also included a significant contribution to Malaysia's economic transformation process. It seems that SMEs have an important role in job creation and the growth of income in the country (National SME Development Council 2012). Data showed that 38.3% of the GDP have been contributed by Malaysia's SME sector that provides in creating a job for the large number of people (over seven million people). The government has regulated a system to ensure the sustainability of SMEs by establishing an ecosystem that simplifies the link to public and private societies [1]

SME Corp. Malaysia has been conducting surveys on SMEs to gauge their performance as well as to identify the issues and challenges faced. The feedback gathered through these surveys serve as a useful reference for policy formulation and the development of capacity building programs for SMEs. The recent strategies will develop on existing initiatives to reinforce SMEs by increasing the level of productivity of SMEs [1]. Consideration of the ergonomic aspects may be a solution to increase productivity in the SME industry.

Ergonomics is described as creating products, facilities of work, and workplaces to improve the performance, safety, and health of workers [2]. Some of the main benefits of ergonomics include safer jobs and fewer injuries, better productivity and efficiency, and improved quality. The aspect of a particular job that imposes effects on the worker is considered as ergonomic risk factors. The most common ergonomic risks are repetition, awkward body posture, cold/hot temperature, contact stress, illumination, force, static postures, and vibration [3]. All types of industries, from small to big scale industries and household businesses, need a very ergonomic workplace. It is found to be as a vital importance to improve the productivity of industries [4].

An ergonomic risk factor is known as any characteristic and attribute or exposure that contribute to musculoskeletal disorders. Mostly, the increased risk of disorders happen when two or more risk factors come out at one time [5]. Previous studies have shown that the principal causes of worker's MSDs are the condition of work, as well as the high physical demands with activities, such as lifting heavy loads, repetitive motion, and awkward postures (e.g., activities of bending, twisting, kneeling, and activities using the arms above shoulder). Various tools are used for analyzing the MSD risk factors.

In the subsequent section, risk and risk factors are two common concepts used in applied ergonomic literature and work safety. Several statements showed that risk is the number of accidents that delivered an exposure. The risk of a worker's accident can be shown as the lowest probability but with high effect, such as multiple fatalities. It also appears to have higher probability; however, with less effect. An example is a worker slipping or tripping in the workplace [6].

Ergonomic Risk Assessment is defined as a systematic scheme that is used as an objective approach to identify, assess, and control ergonomic risk factors linked by work roles and actions in the workplace. The purpose of conducting an ergonomic risk assessment is to identify ergonomic risk factors that may cause injury to workers, assign possibilities that may result from the effect of the ergonomic risk factors and suggest the right action control for decreasing the risk [7].

The assessment depends on the types of ergonomic risk factors identified. The exposure duration of each work posture may differ depending on the professional judgment of the trained person. There are several ergonomic assessment tools which was proven by previous studies that could be used to identify, assess, and evaluate the risk factors. Most of the ergonomic risk assessment tools that have been developed were assessments on the physical risk factors related to Musculoskeletal Disorder (MSD). Hence, this study set out to review current ergonomic assessment tools and to investigate other ergonomic risk factors that are important to be included in an ergonomic assessment tool that is related to workers' productivity in the Small and Medium (SME) Industries.

2 Method

2.1 Literature Selection

The first step is literature selection. This study used an electronic database for the selection of literature. The database included Google Scholar, Science Direct, and Scopus. The searches were materials collected from 2015 to 2020. The process used a set of terms related to ergonomic assessment tools in Small and Medium (SME) Industries using "AND" and "OR". The terms that were chosen were risk factors, risk system, risk assessment tools, risk assessment method, ergonomic assessment, ergonomic method, and ergonomic assessment tools in SMEs. In addition, there was also selection of "related articles" of the main reference. There were 83 journals, articles, and review reports characterized by the title, abstract, and the relevant articles to ergonomic risk factors.

2.2 Evaluation Criteria Development

The evaluation criteria used for these review methods are based on the exposure to ergonomic risk factors (awkward posture, forceful and sustained exertions, repetitive motion, static and sustained posture, vibration, contact stress, and environmental), the objectives and the methods used in Small and Medium (SME) Industries.

2.3 Evaluation Process

The evaluation process compared the current tools from previous case studies related to ergonomic risk assessment tools in Small and Medium (SME) Industries. The objective of the evaluation process was to identify the advantages and limitations of the tools that have been widely used.

3 Result

Table 1 shows the distribution of risk factors in Small and Medium (SME) Industries in the previous paper. Seven risk factors have been included in the analysis. The risk factors are awkward posture (AW), force (F), repetitive (R), static and sustained posture (SP), vibration (V), contact stress (C), and environmental (E). Among the fourteen studies, contact stress was only found in two studies as the risk factor. The first round of studies revealed that the risk factors found are awkward posture, repetitive, static and sustained posture, and vibration [7]. The second round of studies found awkward posture, force, repetitive, and environmental risk factors in workstations [8].

Ergonomic risk assessment methods are crucial to specify the risk factors and evaluate the risk level of ergonomics that exist for workers/workstations. Table 2 shows the Ergonomic Risk Assessment Method in Small and Medium (SME) Industries. Most of the previous papers assessed workers/workstations. There are 3 types of methods: Questionnaire Method, Observational Method, and Digital Method. The Questionnaire method has many tools, usually using the checklist form, such as the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) [20], Standard Nordic Questionnaire (SNQ) [21], and others.

The Observational Method usually use a worksheet, such as the Ergonomic Risk Assessment (ERA) [5], Rapid Upper Limb Assessment (RULA) [19], Rapid Entire Body Assessment (REBA) [14, 22], The Ovako Working Posture Analysing System (OWAS) [9, 23], Quick Exposure Check (QEC) [7, 24], Workplace Ergonomic Risk Assessment (WERA) [4, 9, 25], Occupational repetitive action index (OCRA) [26], and Hazard Identification, Risk Analysis and Risk Control (HIRARC) worksheet [10]. The digital method which is the developed tool from both the methods above is usually built as a digital application/software.

Some studies found that in Malaysia the Ergonomic Risk Assessment (ERA) is used as a tool to solve problems [7, 17]. This assessment follows the Guidelines on Ergonomic Risk Assessment at Workplace, 2017 by the Department of Occupational Safety and Health. Other ergonomic risk assessment tools mostly used in SME industries are RULA and REBA. Both RULA and REBA tools were used for assessing the risk of workers. One of the studies measured the ergonomic risk factors for WMSDs among adult male manual meat cutters working in Jabalpur, India [19]. Several studies have developed some tools in the observational method

Table 1 Distribution of risk factor in SME industries

Author	Risk factor						
	AW	F	R	SP	V	C	E
Sanmugum et al.[7]	✔		✔	✔	✔		
Ajayeoba [8]	✔	✔	✔				✔
Mufti et al. [4]		✔	✔	✔	✔	✔	✔
Pratiwi et al. [9]		✔	✔	✔	✔	✔	
Yen Siong et al. [10]							✔
Boulila et al. [11]	✔	✔	✔	✔			✔
Özkaya et al. [12]		✔		✔			✔
Yadi et al. [13]	✔	✔	✔				
Tee et al. [14]	✔	✔	✔	✔			
Peres et al. [15]	✔	✔	✔	✔			
Lasota et al. [16]		✔		✔			✔
Deros et al. [17]	✔	✔	✔	✔			
Barros et al. [18]		✔		✔			✔
Mukhopadhyay et al. [19]			✔	✔			

[a] Awkward Posture (*AW*), Force (*F*), Repetitive (*R*), Static and Sustained Posture (*SP*), Vibration (*V*), Contact Stress (*C*), Environmental (*E*)

Table 2 Previous studies on ergonomic risk factor in small and medium (SME) industries

Tool	Author	Method	Risk factor	Object
RULA	[19]	Observational method	F, R, SP	Workers
REBA	[14, 22]	Observational method	F, R, SP	Workers
ERA	[5]	Observational method	AW, R, SP, V	Workers
QEC	[7, 24]	Observational method	AW, R, SP, V	Workers
OWAS	[9, 23]	Observational method	F, R, SP, V, C	Workstation
WERA	[4, 9, 25]	Observational method	E	Workstation
HIRARC	[10]	Questionnaires method	E	Workstation
SEAT	[15]	Digital method	AW, F, R, SP	Workers
OCRA	[26]	Observational method	R, SP	Workers

[a] Awkward Posture (*AW*), Force (*F*), Repetitive (*R*), Static and Sustained Posture (*SP*), Vibration (*V*), Contact Stress (*C*), Environmental (*E*)

(RULA and REBA) connected to software, such as CATIA [11, 13]. Meanwhile, the digital method still develops, e.g., Self-report Ergonomic Assessment Tool (SEAT). SEAT was developed for risk assessment using the design of software interaction and facilitate risk mitigation [15]. Each ergonomic risk assessment tool has its usage and it is better to use these methods together to complement each other.

4 Conclusion

In conclusion, these studies show that there are various methods and devices applied in an ergonomic assessment. The review has demonstrated the excess and lack of the methods and devices which will be beneficial as a recommendation for a new policy at the workplace. It was observed that many ergonomic assessment tools that have been used in the Small and Medium (SME) Industries were mostly focused on assessing the physical risk factors that affect MSD. We also know of other ergonomic risk factors, such as vibration and contact stress. It might give an effect on the workers' productivity. A digital assessment tool is worth developing for the future as there are more and more workplaces.

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References

1. SME Corporation Malaysia (2019) SME annual report 2018/2019: entrepreneurship driving SMEs
2. Wignjosoebroto S (2007) Indonesia ergonomics roadmap: where we are going? J Hum Ergol (Tokyo) 36(2):91–98. https://doi.org/10.11183/jhe1972.36.2_91
3. Shamsan A, Qasem AG (2020) Development of a scoring methodology for ergonomic risk assessment in the workplace
4. Mufti D, Ikhsan A, Putri TM (2019) Workplace ergonomic risk assessment toward small-scale household business. IOP Conf Ser Mater Sci Eng 528(1). https://doi.org/10.1088/1757-899X/528/1/012013 (Chapter 6)
5. Manap IMFBA, Amat HBC et al (2017) Guidelines on ergonomics risk assessment at workplace 2017_July Edited Rev.002.pdf, p 155 [Online]. Available: www.dosh.gov.my
6. Jaffar N, Abdul-Tharim AH, Mohd-Kamar IF, Lop NS (2011) A literature review of ergonomics risk factors in construction industry. Proc Eng 20:89–97. https://doi.org/10.1016/j.proeng.2011.11.142
7. Sanmugum S, Karuppiah K, Sivasankar (2020) Ergonomic risk assessment on selected hot-work workers at company XXX. Malays J Publ Health Med. 20(1):176–185. https://doi.org/10.37268/MJPHM/VOL.20/NO.SPECIAL1/ART.688 (Chapter 14)
8. Ajayeoba AO (2019) Risk, postural and physical strain assessment of sawmill workers in Nigeria. Int J Eng Res Africa 45(2016):74–88. https://doi.org/10.4028/www.scientific.net/JERA.45.74 (Chapter 4)
9. Pratiwi I, Munfi'ah, Fitriadi R, Sufa MF (2019) Evaluation of work posture in sohun noodles workers using OWAS and WERA method. Int J Innov Technol Explor Eng 8(11):1788–1793. https://doi.org/10.35940/ijitee.K1767.0981119 (Chapter 11)
10. Yen Siong V, Azlis-Sani J, Nor NHM, Yunos MNAM, Boudeville JA, Ismail S (2018) Ergonomic assessment in small and medium enterprises (SMEs). J Phys Conf Ser 1049(1). https://doi.org/10.1088/1742-6596/1049/1/012065 (Chapter 1)
11. Boulila A, Ayadi M, Mrabet K (2018) Ergonomics study and analysis of workstations in Tunisian mechanical manufacturing. Hum Fact Ergon Manuf 28(4):166–185. https://doi.org/10.1002/hfm.20732 (Chapter 3)
12. Özkaya K, Polat O, Kalinkara V (2018) Physical workload assessment of furniture industry workers by using Owas method. Ergon Open J 11(1):11–19. https://doi.org/10.2174/1875934301811010011 (Chapter 7)
13. Yadi YH, Kurniawidjaja LM, Susilowati IH (2018) Ergonomics intervention study of the RULA/REBA method in chemical industries for MSDs' risk assessment. KnE Life Sci 4(5):181. https://doi.org/10.18502/kls.v4i5.2551 (Chapter 9)
14. Tee KS et al (2017) A study on the ergonomic assessment in the workplace. AIP Conf Proc 1883. https://doi.org/10.1063/1.5002052 (Chapter 2)
15. Peres SC, Mehta RK, Ritchey P (2017) 8. Assessing ergonomic risks of software: development of the SEAT. Appl Ergon 59:377–386. https://doi.org/10.1016/j.apergo.2016.09.014 (Chapter 8)
16. Lasota AM, Hankiewicz K (2017) The conceptual framework for physical risk assessment in multi-purpose workplaces. MATEC Web Conf 137. https://doi.org/10.1051/matecconf/201713703007 (Chapter 12)
17. Deros BM, Ali MH, Mohamad D, Daruis DDI (2016) Ergonomic risk assessment on oil palm industry workers. Iran J Publ Health 45(March):44–51 (Chapter 13)
18. Barros RQ, Marçal MA, Soares MM (2015) Ergonomic analysis of the job of assembly and maintenance in an electronic equipment company. Proc Manuf 3(Ahfe):6542–6549. https://doi.org/10.1016/j.promfg.2015.07.953 (Chapter 5)
19. Mukhopadhyay P, Khan A (2015) The evaluation of ergonomic risk factors among meat cutters working in Jabalpur, India. Int J Occup Environ Health 21(3):192–198. https://doi.org/10.1179/2049396714Y.0000000064 (Chapter 10)

20. Kreuzfeld S, Seibt R, Kumar M, Rieger A, Stoll R (2016) German version of the Cornell musculoskeletal discomfort questionnaire (CMDQ): translation and validation. J Occup Med Toxicol 11(1):1–12. https://doi.org/10.1186/s12995-016-0100-2
21. López-Aragón L, López-Liria R, Callejón-Ferre ÁJ, Gómez-Galán M (2017) Applications of the standardized nordic questionnaire: a review. Sustainability 9(9):1–42. https://doi.org/10.3390/su9091514
22. McAtamney L, Hignett S (2004) Rapid entire body assessment. In: Handbook of human factors and ergonomics methods, vol 31, pp 8-1–8-11. https://doi.org/10.1201/9780203489925.ch8
23. Scott GB, Lambe NR (1996) Working practices in a perchery system, using the OVAKO working posture analysing system (OWAS). Appl Ergon 27(4):281–284. https://doi.org/10.1016/0003-6870(96)00009-9
24. David G, Woods V, Li G, Buckle P (2008) The development of the quick exposure check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. Appl Ergon 39(1):57–69. https://doi.org/10.1016/j.apergo.2007.03.002
25. Abd Rahman MN, Abdul Rani MR, Rohani JM (2011) WERA: an observational tool develop to investigate the physical risk factor associated with WMSDs. J Hum Ergol (Tokyo) 40(1–2):19–36. https://doi.org/10.11183/jhe.40.19
26. Occhipinti E, Colombini D, Don F, Onlus G (2009) Ocra method: a new procedure for analysing multiple repetitive tasks. In: Proceedings of the 17th world congress on ergonomics

A Short Review on Heat Stress and Heat Strain in Construction Industry: The Effect on Worker Performance, Associated Health Effect, It's Measurement and Control Mechanism

Che Mohammad Nizam, Ahmad Rasdan Ismail, Ezrin Hani Sukadrin, Nor Kamilah Mokhtar, Arham Abdullah, Norfadzilah Jusoh, and Norlini Husshin

Abstract Prolonged exposure to hot and humid environments increases the probability of heat load that may cause harm to an individual. It is estimated that 35% of individuals working in heat stress condition experience occupational heat strain and 30% experience productivity loss. Worker's start to experience heat stress when Web Bulb Globe Temperature (WBGT) is over 22 °C for intense work and WBGT over 25 °C for non-intense work. Furthermore, working at a temperature above 32.2 °C in a hot-humid environment and 33 °C in a hot-dry climate have shown to have an

C. M. Nizam (✉)
Department of Occupational Safety and Health, Johor Bahru, Johor, Malaysia
e-mail: chenizam@mohr.gov.my

C. M. Nizam · A. R. Ismail
Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, Pengkalan Chepa, Malaysia
e-mail: rasdan@umk.edu.my

E. H. Sukadrin
Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang, Gambang, Pahang, Malaysia
e-mail: ezrin@ump.edu.my

N. K. Mokhtar
Department of Educational Planning and Research, Institute of Teacher Education, Kota Bharu, Kelantan, Malaysia

A. Abdullah
Deputy Research and Innovation Office, Universiti Malaysia Kelantan, Pengkalan Chepa, Malaysia

N. Jusoh
Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia
e-mail: fadzilah.j@utm.edu.my

N. Husshin
Department of Mechanical Engineering, Polytechnic of Ibrahim Sultan, Pasir Gudang, Johor, Malaysia

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impact on workers mental performance. This include reduce in workers speed of response, reasoning ability, visual perception, associative learning, and mental alertness. Therefore, objective of this study is to identify heat stress and strain control mechanism that have been developed in order to maintain construction workers safety and health. The review was done by analyzing past journal and article related with heat stress control mechanism for construction workers. Preventive safeguard measures from heat stress includes providing drinking water or sports drinks, rescheduling non-essential work, work break cycles and providing shades. Furthermore, Middle East countries implement regulation that ban working from 12 noon to 3 p.m. In addition, employer need to be proactive by monitoring worker condition on site and promote 'drink water' culture. In conclusion, there are numerous heat stress control and mechanism implemented to protect construction worker safety and health. The control mechanisms reduce heat stress by hydrating the worker through drinking water or reducing worker contact with sunlight.

Keywords Heat stress · Heat strain · Heat control mechanism

1 Introduction

The side effect of environment heat stress to worker body is called occupational heat strain, which harms workers health and works productivity. Rowlinson et al. [1] mentioned six factors that established environmental heat stress from scientific perspective; humidity, radiant heat, air temperature, wind speed, metabolic heat generated by physical activities and "clothing effect", which is the exchange of heat between the environment and worker's body.

1.1 *Heat Stress and Heat Strain in Construction: Effect on Workers Performance*

Temperatures in the range of 24–26 °C is linked with reduction of labour productivities by International Labour Organisation (ILO). When the temperature rise to 29°C, workers thermal comfort starts to drop [2] and at 33–34 °C, workers productivities will be cut in half at moderate work intensity level [3]. As the temperature increase to 39 °C, the productivity will diminish significantly and have the potential to cause fatalities. For example, steel industry workers experience maximum WBGT of 41.7 °C while working and they experience adverse heat-related health symptoms periodically.

Flouris [4]assessment finds out 35% workers exposed to heat stress environment will feel occupational heat strain, while 30% workers lost productivities. Worker's start to experience heat stress when WBGT goes beyond 22 °C for work with intense load and WBGT over 25 °C for non-intense workload. The worker will feel a significant toll of the heat stress at the end of their work shift. Besides that, Rowlinson experimental study for National Electrical Contractors Association (NECA) claimed that worker productivities are at full efficiencies level when temperatures are in the range of 40–70 °F (4.5–21 °C) with relative humidity below 80%. Performance drop is noticeable when the temperature rises above 70 °F threshold.

Yi and Chan [5] study findings reflect that exposure to prolonged and intense heat has a significant influence on construction workers concentration and dedication. The scorching heat made the workers irritated, thus, increase Non-productive time (NPT) where the workers stop doing their work to rest. Lowest direct work time (DWT) level was reported at 13:00–14:00, which is around 55.96%. During this hour, the WBGT is at the peak level with reading of 25.91–35.46 °C. Li et al. [6] studies on rebar workers productivities in China also shown negative correlation between high temperatures and productivities. Findings shown rebar workers DWT drop 0.57% for each 1 °C increase in WBGT. On the other hands, NPT reported to increase by 0.74% for each 1 °C increase in WBGT. Sett and Sehu [7] mention that there is a linear decline in Indian female brick worker productivities when the air temperature is increase beyond 34.9 °C. Furthermore, working in hot-humid or hot-dry climate when temperature is 32.2 °C or 33 °C respectively, have shown to have an impact on workers mental performance. Major side effect reported includes reduction in worker response time, decision making, visual perception ability, learning, and most importantly, mental alertness to surrounding which likely led to causality [8].

Zander et al. [9] assess the impact of heat stress on Australia workers productivities from the perspective of presenteeism and absenteeism. The worker mentioned loss of productivities up to 35% when they experience heat stress. This indicate presenteeism, and it is estimated that each person loss productivities of US$932 per year. On the other hands, minority (7%) of workers in the study said they prefer to be absent compared to working during peak temperature days. The loss due to this absenteeism is reported to be US$845 for each person per year. Overall, the total loss of productivities due to presenteeism and absenteeism was reported to be around US$6.2 billion for Australia in 2014. The loss is significant since it amounts to 0.33–0.47% of Australia's 2014 GDP.

Dunne et al. [10] physiological models' assessment estimate that global labour capacities will be reduced up to 80% in 2050 due to heat exposure. The most impacted region will be hot climate region such as South East Asia, which is estimated to loss 11–27% productivities. Altinsoy and Yildirim [11] study in Turkey reveals that agriculture and construction sector productivities are expected to diminish up to 52% due to the scorching weather. The study focuses on manual labour and outdoor work in particular, thus give a clear picture of the impact of heat stress on worker performances.

1.2 Identify Measurement Parameters for Heat Stress and Heat Strain Index

Construction labour productivity or also known as (CLP) is usually influenced by numerous factors in the construction sites. Yi and Chan mentioned CLP was associated with hot environments through an experiment conducted by Grimm and Wagner in 1974 in field environment setting. The study explores the association between CLP and thermal environmental factors, such as relative humidity and air temperature. Grimm and Wagner study findings indicate humidity as critical environment factor for CLP either for low or high temperature. Moreover, work quality shown significant decline when temperatures is very high.

Nonetheless, these measurements are too simplistic since it ignores other existing environment factors, which might have influenced workers heat strain. Therefore, Wet Bulb Globe Temperature was developed, which measured three specific temperatures, namely; dry bulb temperature (DB), wet bulb temperature (WB) and globe temperature (GT) [12]. WBGT measurement has been improved further with the increased heat stress studies. Srinavin and Mohammad [13] research in Thailand include factors such as air velocity and workers clothing. Li et al. expand WBGT measurement by adding demographic variables into the equation, such as age and body fat.

Altinsoy and Yildirim study measure environmental readings through Regional Climate Model (RegCM3) which calculate data extracted from the ENSEMBLES Project. RegCM3 is still actively being used to calculate WBGT reading on Western Turkey region.

Another heat stress index relevant to construction industry is the Thermal Work Limit (TWL), a commonly used measure in occupational settings that incorporates environmental parameters into the single index as the equivalent metabolic rate. In general, TWL calculates the maximum metabolic rate, in watts of metabolic heat per square meter of body surface area.

2 Heat Stress and Heat Strain Impact on Workers Health

Prolonged exposure to hot and humid environments increases the probability of heat load that may cause harm to an individual, and this is known as heat stress. There are several acute health status associated with heat-stress work environment. Rowlinson survey results indicate construction workers which is over-exposure to heat could induce disorders such as heat rash, heat cramps, heat syncope or fainting, heat exhaustion, or heatstroke in the long run.

Nonetheless, construction sites have a different type of heat risk throughout the project lifecycle. For instance, a road construction project is profoundly affected by sunray since the construction sites are in open fields with little to no natural shades. On the other hands, building sites have a different source of shades, such as trees and other closed buildings. On the other hands, building sites are more prone to high humidity and poor ventilation. Li et al. study points out construction worker heart rate tempo reach 109.37 ± 1.23, when WBGT is at peak. Sett and Sehu study support this finding with their study in India, where the female brick workers cardiac parameters (peak heart rate (HRp), net cardiac cost (NCC), relative cardiac cost (RCC), and recovery heart rates (RHR) were significantly higher on hotter days.

Besides that, Miliaria rubra cases was found on miner ankle and knee after prolonged heat exposure [14, 15]. Moreover, individual with BMI over the median of 29.6 have higher chance to experience heat exposure and muscular cramp. Vandetorren et al. [16] mentioned that individual with cardiovascular and heart-disease are more vulnerable and would be under higher risk of heat-related illness due to global warming. In addition, Vandetorren said aging also reduce workers ability to maintain homeostasis in a heat stress environment.

Gubernot et al. [17] state that United States construction workers are more likely to die from heat-related illness (HRI) compared to other industry workers. Gubernot estimate that the likelihood of fatalities is 13 fold higher for construction workers such as roofers and road constructions. Furthermore, labourer which exposed to temperature above 39.5 °C are highly susceptible to experience Exertional Heat-stroke, which could cause confusion, irrational behaviour, low coordination, fainting, vomiting, convulsions, and loss of consciousness [18]. In addition, Tawatsupa et al. [19] research in Thailand identify male workers that is directly exposed to sunlight have 10% more case of occupational injury compared to those that are not exposed.

In Italy, workers are faced with significant heat stress risk during summer, where the temperature can go up to 33.5 °C [20]. Days with an average daytime Apparent Temperature (AT) value ranged between 24.8 and 27.5 °C were at the highest risk of work-related accidents compared to days with extreme AT of 31 °C and above. According to Xiang [21] study in South Australia, every increase in daily maximum temperature (°C) above the point of 37.7 °C will lead to increase 0.2% increase in daily injury claims. Xiang study finding points out that young male workers (below 24 years old) have higher accident ratio compared to other age range and gender.

Besides that, occupational heat strain is also associated with dehydration, excessive sweating, headaches, nausea, dizziness, and fatigue [22]. In fact, workers which is frequently exposed with heat stress combined with dehydration can develop kidney injury which would transform into permanent kidney damage [23]. Flouris analyses show that people who worked a single shift in heat stress conditions had an increase of 14.5% in urine specific gravity (indicate dehydration) compared with those who worked a change in thermoneutral conditions. In addition, the reading for serum creatinine concentration is over 1.2 mg/dL, which indicate acute kidney injury.

3 Heat Stress and Heat Strain Control Mechanism

Occupational Safety and Health Administration [24] heat index guideline categorizes heat risk into four groups: Lower; Moderate; High; and Very High/Extreme. OSHA recommends preventive measure such as providing rest, shade and water; training; acclimatization; developing a monitor system for HRI signs; limiting physical tasks; rescheduling non-essential work; and closely monitoring workers' vital signs and strictly enforcing work/rest cycles to reduce the side effect of heat stress.

Hong Kong Special Administrative Region [25] suggest to safeguard construction workers from heat stress by providing drinking water or sports drinks, with the inclusion of work-break cycles, work arrangement, and cool down facilities. Even when the employer provides water and breaks, workers shown to drink less water than what they sweat out. Hence, employer should take initiative to promote drinking during working through monitoring and supervision.

Besides that, a strict work-rest regimen should be implemented during the summer for construction work. The aim is to reduce workers heart rate and body temperature to a comfortable level, so they do not become irritated and uncomfortable, which are the cause for poor productivity. Moreover, Dutta [26] emphasize the need for revision on work practices, which include increasing protective measures, and possible development of indigenous work safety standards for heat exposure.

In additions, Rowlinson suggest that contractors reduce work pace during summer even though it will reduce project productivity output. Workers that work in slower pace during heat stress environment will have less chance to get heat stress in the long run, and this will reduce the possibility of presenteeism and absenteeism which would lead to more significant reductions in project productivity.

Morabito study participants said they start to adapt preventive safety measure themselves, such as working in the shade, drinking more water and begin working activity earlier in the morning when AT start to rise more than 27.5 °C, to reduce the risk of work accidents. Tamm et al. [27] explain individual will react to heat stress more proactively with the scorching environment, due to them being highly uncomfortable and feeling fatigued at the same time.

This finding is aligned with Xiang et al. study, which said workers halt or stop their work when the temperature is too extreme, in this case, it is reported to be above 37.7 °C. Hence reducing the possibility for injury or accident to occur. Middle East countries, including Qatar and the United Arab Emirates, reduce the risk of heat stress by limiting construction site work hours in summer between 11:30 a.m. and 3:00 p.m [4]. However, the enforcement is not fully effective since the temperature can spike outside of the restricted hours. For example, Al-Bouwarthan [28] study indicate that high level of heat stress (WBGT 31–33 °C) occur for both moderate and heavy workloads starting from 7 a.m. until noon in Saudi Arabia. The early peak of WBGT in the morning have invalidated Saudi Arabia legislation work ban from 12 noon to 3 p.m., which is aimed to reduce worker heat stress.

On the other hands, legislation and regulation could also be used to protect workers from heat stress. For example, Costa Rica requires an employer to provide shades, water, rest breaks, and protective clothing to workers that affected by heat stress [29]. Another example is the state of California which requires employers to provide rest, shade and portable water to workers when temperatures exceed 35 °C.

4 Conclusion

Countries all over the world have implemented numerous preventive measures, engineering control and regulation in order to manage heat stress impact on worker productivities, safety and health. Nonetheless, lack of implementation, monitoring and proactive engagement by the employer have made the effort less effective. On top of that, the rise in global average temperature due to climate change indicate that heat stress environment will only become worse for the construction industry in the future. Henceforth, future study should focuses on developing control mechanism which is easy to be implemented and monitored by the employer, in order to increase its effectiveness.

References

1. Rowlinson S, Jia A, Li B, Ju Ch (2014) Management of climatic heat stress risk in construction: a review of practices, methodologies, and future research. Accid Anal Prev 66:187–198
2. Ismail AR, Jusoh N, Bakar RA, Makhtar NK, Ismail S (2015) An analysis in the implication of thermal energy distribution towards human comfort in an office space. Int J Creative Future Heritage (TENIAT) 3(1):15–30
3. International Labour Organisation (2019) Working on a warmer planet: the impact of heat stress on labour productivity and decent work. Preface. Available online: https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_711919.pdf. Accessed on 27 Mar 2020
4. Flouris AD, Dinas PC, Ioannou LG, Nybo L, Havenith G, Kenny GP, Kjellstrom T (2018) Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. Lancet Planet Health 2(12):521–531
5. Yi W, Chan A (2017) Effects of heat stress on construction labor productivity in Hong Kong: a case study of rebar workers. Int J Environ Res Public Health 14(9):1055–1057
6. Li X, Chow KH, Zhu Y, Lin Y (2016) Evaluating the impacts of high-temperature outdoor working environments on construction labor productivity in China: a case study of rebar workers. Build Environ 95:42–52
7. Sett M, Sahu S (2014) Effects of occupational heat exposure on female brick workers in West Bengal, India. Glob Health Action 7:21923. https://doi.org/10.3402/gha.v7.21923
8. Chia C-F, Changa T-C, Ting H-I (2005) Accident patterns and prevention measures for fatal occupational falls in the construction industry. Appl Ergon 36:391–400
9. Zander K, Oppermann E, Kjellstrom T, Garnett S (2015) Heat stress causes substantial labour productivity loss in Australia. Nat Clim Chang 5:647–651
10. Dunne JP, Stouffer RJ, John JG (2013) Reductions in labour capacity from heat stress under climate warming. Nat Clim Change 3(6):563–566
11. Altinsoy H, Yildirim HA (2015) Labor productivity losses over western Turkey in the twenty-first century as a result of alteration in WBGT. Int J Biometeorol 59(4):463–471
12. Hancher DE, Abd-Elkhalek HA (1998) The effect of hot weather on construction labor productivity and costs. Cost Eng 40:32–36
13. Srinavin K, Mohamed S (2003) Thermal environment and construction workers' productivity: some evidence from Thailand. Build Environ 38:339–345
14. Donoghue A, Sinclair M (2000) Miliaria rubra of the lower limbs in underground miners. Occup Med 50(6):430–433. https://doi.org/10.1136/oem.57.3.165
15. Donoghue A, Sinclair M, Bates G (2000) Heat exhaustion in a deep underground metalliferous mine. Occup Environ Med 57(3):165–174. https://doi.org/10.1136/oem.57.3.165

16. Vandentorren S, Bretin P, Zeghnoun A, Mandereau-Bruno L, Croisier A, Cochet C, Ribéron J, Siberan I, Declercq B, Ledrans M (2006) Heat wave in France: risk factors for death of elderly people living at home. Eur J Public Health 16(6):583–591
17. Gubernot DM, Anderson GB, Hunting KL (2015) Characterizing occupational heat-related mortality in the United States, 2000–2010: an analysis using the census of fatal occupational injuries database. Am J Ind Med 58:203–211
18. Shapiro Y, Seidman D (1990) Field and clinical observations of exertional heat stroke patients. Med Sci Sport Exerc 22(1):6–14
19. Tawatsupa B, Yieng-Sbirakos Y, Vasoontara M, Kjellstrom T, Berecki-Gisolf J, Seubsman S, Sleigh A (2013) Association between heat stress and occupational injury among Thai workers: findings of the Thai cohort study. Ind Health 51:34–46
20. Morabito M, Cecchi L, Crisci A, Modesti P, Orlandini S (2006) Relationship between work-related accidents and hot weather conditions in Tuscany (Central Italy). Ind Health 44:458–464
21. Xiang J, Bi P, Pisaniello D, Hansen A, Sullivan T (2014) Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010. Occup Environ Med 71:246–252
22. Glazer J (2005) Management of heatstroke and heat exhaustion. Am Fam Physician 71(11):2133–2140
23. Nerbass FB, Pecoits-Filho R, Clark WF, Sontrop JM, McIntyre CW, Moist L (2017) Occupational heat stress and kidney health: from farms to factories. Kidney Int Rep 2(6):998–1008. https://doi.org/10.1016/j.ekir.2017.08.012
24. OSHA (Occupational Safety and Health Administration) (2011) Using the heat index: a guide for employers. Available online: https://www.osha.gov/SLTC/heatillness/heat_index/pdfs/all_in_one.pdf. Accessed on 10 Mar 2020
25. Hong Kong Special Administrative Region (2010) Employers and employees should take precautions against heat stroke. Available online: https://www.info.gov.hk/gia/general/201906/05/P2019060500612.htm. Accessed on 27 Mar 2020
26. Dutta P, Rajiva A, Andhare D, Azhar G, Tiwari A, Sheffield P, Ahmedabad Heat and Climate Study Group (2015) Perceived heat stress and health effects on construction workers. Ind J Occup Environ Med 19(3). https://doi.org/10.4103/0019-5278.174002
27. Tamm M, Jakobson A, Havik M, Burk A, Saima T, Allik J, Ööpik V, Kreegipuu K (2013) The compression of perceived time in a hot environment depends on physiological and psychological factors. Quart J Exp Psychol 67:1-6
28. Al-Bouwarthan M, Quinn MM, Kriebel D, Wegman DH (2019) Assessment of heat stress exposure among construction workers in the hot desert climate of Saudi Arabia. Ann Work Expo Health 63(5):505–520
29. Chavkin S (2015) Reform in Costa Rica signals new strategy against lethal epidemic. Available online: https://www.publicintegrity.org/2015/07/29/17716/reform-costa-rica-signals-new-strategy-against-lethal-epidemic. Accessed on 27 Mar 2020

Ergonomics and Manual Handling Workplace Improvement: A Case Study of Firefighter at Pagoh

Salwa Mahmood, Siti Hana Nasir, Norashid Mamat, Ismail Abdul Rahman, and Noorul Azreen Azis

Abstract Firefighter are constantly at risk since they are directly exposed to various physical factors, harmful chemicals and mental stress during rescue and fire-fighting. In fire extinguishing, unstable posture is one of the possible hazardous factors and contribute to high ergonomic risk factor. Due to manual handling and lack of proper standard operation procedure, firefighter are at risk of developing musculoskeletal disorders problem such as awkward postures. This paper identify ergonomics risk factor that may cause harm to firefighter during rolling of fire hose. This study was conducted in Pagoh fire station. In order to achieve those aims, observational method was used by applying Ergonomic Risk Assessment (ERA).The Failure Mode and Effect Analysis (FMEA) method is used by calculating the severity, occurrence and failure detection which has rating score from one (1) to ten (10). Then, the risk priority number (RPN) was calculated to get the highest priority number which led to identification of ergonomic risk factor. A set of questionnaire was distributed to 20 firefighter located at Pagoh fire station for analyzing the ergonomic risk factor and compared to the FMEA result. The result of the analysis shows 56% of the respondent experienced awkward posture during handling of fire hose. The result of the questionnaire was compared to the highest RPN value from FMEA to obtain the solution on ergonomic workplace improvement at Pagoh fire station. In addition, a new tool that is expected to improve the ergonomic and manual handling of firefighter was proposed.

Keywords Ergonomic risk factors · Manual material handling · Firefighter hose handling

S. Mahmood (✉) · S. H. Nasir
Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, KM 1 Jalan Panchor, 84600 Pagoh, Muar, Johor, Malaysia
e-mail: msalwa@uthm.edu.my

N. Mamat
Balai Bomba Dan Penyelamat Pagoh, Jalan Muar–Labis, 84600 Muar, Johor, Malaysia

I. Abdul Rahman · N. A. Azis
Ergonomics Excellence Centre, National Institute of Occupational Safety and Health (NIOSH), No. 10, Jalan Persiaran Teknologi, Taman Teknologi Johor, 81400 Senai, Johor, Malaysia

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1 Introduction

1.1 Background of the Study

The cases of work-related musculoskeletal disorders (WMSDs) in Malaysia are increasing every year, and the total compensation for WMSDs cases was found to be higher than other occupational disease cases. The increase in trend was the result of increased awareness among Malaysian employers and workers. The chairman of the National Institute of Occupational Safety and Health (NIOSH) Malaysia quoted as saying that for one out of four cases reported to the Social Security Organization (SOCSO) in 2013 was related to MSDS [1]. MSDs are a condition in which the muscles are under stress due to muscles being exposed to static and repetitive motions over prolonged periods of time. The action causes damage to the ligaments, tendons, and joints [2].

Tasks that require awkward postures and/or excessive efforts may cause fatigue and discomfort to the employees. Furthermore, this may lead to damage of the muscles, tendons, nerves, and blood vessels [3]. Over the last decades, industrial practitioners and academicians have paid a lot of attention to manual material handling (MMH) as it is known as one of the most causes of back injury which impacts on work efficiency [4]. MMH can be defined as any activity requiring the utilization of force exerted by someone either lifting, lowering, pushing, carrying and holding of an object. It will delineate as moving something by victimization of human energy [5].

An operation involved with the lifting of a load is considered as one of the MMH activities. It involves the factors of imbalance that are encountered in industries like warehousing and maintenance [5]. Ohnishi et al. [6] revealed that inappropriate design of a mechanical aid will result in postures change and leading to higher muscular loads during pushing activity. One of the strategies to improve efficiency in MMH activities is to introduce assistive devices that can reduce exertion requirements and poor working postures [4].

Fire department is one of the toughest industries which provide services to people who need help. Fire department is one of the most hazardous, physically demanding and psychologically stressful occupations [7]. 86% of American career firefighter reported a history of lower back pain and 55% reported current lower back pain [8]. Roh and Kim [9] reported in their study that 41.5% of firefighter experienced work-related lower back pain within a year and 12.3% of firefighter had chronic lower back pain.

Thus, it gives a high ergonomic risk factor towards firefighter who are doing the most high risk work. In Malaysia, the fire department still demands manual handling when doing their work and currently there is no standard operation procedure. This leads to various WMSDs problems and one of them is awkward posture. The objective of this paper is to identify and assess the risk of WMSDs to firefighter at Pagoh fire station due to unnatural or awkward postures. This paper also proposed a new tool to improve the ergonomic and manual handling of firefighter.

1.2 Ergonomics and Manual Material Handling

Ergonomics is known as human factors which engineering science involved with the understanding of interactions among humans and alternative components of a system. Therefore, the profession that applies theory, principles and data to optimize human well-being and overall performance [10]. The ergonomics consist of three domain as shown in Fig. 1. Physical ergonomics is expounded to the target of activity Safety and Health Act 1994 (OSHA 1994), that is to market activity environment for person at work that related to their physiological.

Ergonomics is that the study of the connection between the employees and the operating atmosphere. It is important for the employees to concern and realizes the potential engineering risk factors around them [11]. Ergonomic assessment is one of the techniques to determine the ergonomic risk factor. Ergonomic assessment is importance in industry nowadays especially on a technical work. Therefore, it is necessary to adapt it and applicable to a technical work in industry [12].

Awkward posture is known as positions of the human body whereas work activities that deviate considerably from the neutral position. Samples of awkward postures are twisting, bending, operating with neck or back bent quite thirty degrees with no support and over reaching [13]. Due to awkward posture, muscles and tendons must work harder and can be stressed. An outside range of motion, joint of body bents could led to awkward posture. It is related to associate magnified risk of injury. It is typically considered that a lot of joint deviates from the natural position, the bigger chance to have an injury [13].

Manual handling is known as one of the most causes of back injury. It can be outlined as any activity requiring the utilization of force exerted by someone either lifting, lowering, pushing, carrying or holding of an object. It will delineate as moving something by victimization of human energy [5]. An operation involved with the lifting of a load is considered as one of the manual handling activities. It involve the factors of imbalance that encountered in industries like warehousing and maintenance [5]. Besides, pushing and pulling also one of the manual handling activities. In

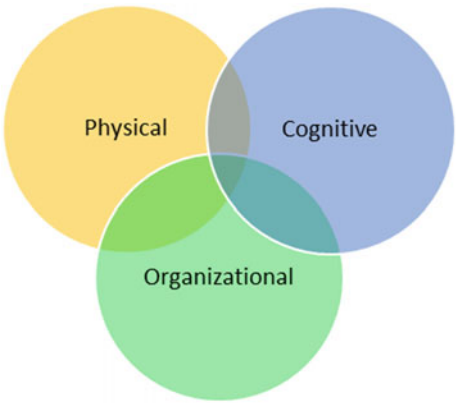


Fig. 1 Domains in ergonomics

industry, various techniques of pushing and pulling is used by workers to avoid manual handling activities since those actions contribute to injuries in industries.

2 Literature Review

2.1 ERA and FMEA

Method used to identify the most ergonomic risk factors that cause harm to employees. There are several step involved in an ERA. Hierarchical task analysis is one of the step to analyze the ergonomic risk factor and it is a recommended method for mapping all performed task by workers [14]. In ERA, the mapped performed task will be ranked by it levels of severity.

Next, FMEA is a systematic designing tool that is used to see the probable potential failures which might occur in an industries [15]. FMEA is an engineering technique used to outline the potential failures on system, design, process, or services before it reach client. FMEA used to mistreatment previous experiences or technology and coming up with new development for those failures to not occur [15]. FMEA is a technique practiced by firms that adopted the philosophy of total quality management (TQM). This method can result in an improvement of product for client satisfaction. This method was used for hazard analysis control point (HACCP) for the Apollo Space Program and later at the food industry in general [16]. In the late 1970s, the Ford Motor Company introduced the FMEA to the automotive industry for safety and regulatory consideration. It was applied by them as the same approach on process failure mode and effect analysis (PFMEA) to consider potential process induced failures prior to launched production [16].

FMEA is consist of three main type which is FMEA system, FMEA design and FMEA process. FMEA system is the highest level of analysis which focused on system related to deficiencies [17]. FMEA design focused on product design, typically at the subsystem or component level. Related deficiencies is focused in this system with emphasis on improving the design and ensuring product operation is safe and reliable. The product that will be manufactured according to specifications usually will be assumed by FMEA design [17]. FMEA process is focused on the manufacturing or assembly process, emphasizing how the manufacturing process can be improved to ensure the product is built in safe manner. This type of FMEA focused on potential failures modes of the process that caused by manufacturing process. This way, engineer can see which uses of the system are desirable and which are not.

Table 1 Previous research using ERA and FMEA

Author, Year	Method	Findings
[18]	FMEA	• Higher RPN value obtained for stripping process • Proper care and maintenance should be given to stripping unit • Misalignment of robotic axis could effect on the sheet delivering process
[19]	FMEA and Grey Relation Analysis (GRA)	• **Problem**: sharp corners of the step caused cuts in the seal • **Solution**: Magnetic protectors were made • **Problem**: noisy window glass from hole position • **Solution**: position of rivet hole was moved to 3 mm lower position
[20]	FMEA	• **Potential failure**: size outer diameter plus/minus • **Potential cause**: dept of cut • **Potential effect**: displacement during operation.
[21]	ERA	• Respondents are still lack of awareness on the importance of MSDs management

2.2 *Previous Research Work on ERA and FMEA*

Table 1 shows the previous research work that using ERA and FMEA on different type of industry.

2.3 *Principle of Motion Economy*

Motion economy is known as making and refining plans for a certain group of simple task in industries. A motion economy is used to generate plan, which is related to fundamental of hand motions and it is economic from the view of motion economy expertise. Manual operation is categorized as one of scope of motion economy task which required the use of arms limited time for completion [22]. Motion economy help to reduce the cumulative trauma as a result to repetitive work done by workers. It is used to prevent from unnecessary motion so that it is avoided [23].

Hence, reduce the fatigue cumulative trauma. The motion economy used as a guideline to examine and design a workstation. The principle of motion economy are based on the combination of ergonomic principles so that it what are the basis for developing the principle. In principle of motion economy, there are three categories which is use of human body, arrangement of workplace and design of tools and

Table 2 Recommendation and description of design of tool and equipment [23]

No.	Recommendation	Description
1	Hands should be relieved of all work of holding	Tool should be as simple to operate as possible
2	Two or more tools should be combined wherever possible	Easier to perform a task without changing tool and too many movements
3	Tools and material should be pre-positioned	The load should distributed in accordance with the inherent capabilities of the finger

equipment. Design of tool and equipment helps to minimize the distance of workers must move in the workstation. The recommendation of design of tool is shown in Table 2.

3 Methodology

The observational method is used on manual handling observation towards firefighter. This observation is commonly to observe the working posture and determine the risk factor of MSDs. ERA and FMEA was then used to analyze the most risk factor occur by conducting a survey. The assessment of FMEA is done using FMEA form.

3.1 ERA

An ERA is done using a questionnaire that distributed to 30 firefighters as respondent at Pagoh fire station. The criteria of the questionnaire is shown in Table 3.

Table 3 Example of questionnaire

Ergonomic assessment checklist	Answer (tick one only)	
	Yes	No
1. Have any workers been previously diagnosed with any of the following disease: Carpal tunnel, Tendonitis, Tenosynovitis, Trigger Finger or Back ailments?		
2. Have there been any worker complaints concerning ergonomic issues?		
3. Do the employees perform high repetition task?		
4. Do the employees routine task require repeated heavy lifting?		
5. Are employees using awkwardly designed tools?		

Fig. 2 Firefighter carrying a hose

Fig. 3 Setting up the hose

3.2 Observational Method

Based on observational method, several pictures were snapped during the observation at Pagoh fire station. The observation of firefighter doing manual handling is shown in Figs. 2, 3, 4 and 5.

3.3 FMEA

The first step of FMEA method is to analyze functional requirements and their effects to identify all failure mode. List all failure modes per function in technical terms,

Fig. 4 Setting up the hose nozzle

Fig. 5 Warm up session

considering the ultimate effects of each failure mode and noting the effects. This method is done by determine the severity (s), occurrence (o), failure detection (d) by referring its own categories of rating value. It is then multiplied to get the highest risk priority number (RPN) so that the most ergonomic risk factor detected.

Severity It is the seriousness of failure consequences of failure effects [23]. Usual practice rates failure effect severity (s) on a scale of one (1) to ten (10) where one (1) is the lowest severity and ten (10) is highest. Rate of the severity and its meanings is shown in Table 4.

Occurrence Examine the cause of each failure on how often it occurred. Look at similar processes or products and their documented failure modes. Failure mode are assigned an occurrence ranking (o) from one (1) to ten (10) as shown in Table 5.

Failure Detection These step enable researcher to determine the likelihood of identifying failures. Then each combination from steps one and two is assigned a detection

Table 4 Severity rating and meanings [18]

Rating	Meaning
1	No effect, no danger
2	Very minor—usually noticed only by discriminating or very observant users
3	Minor—only minor part of the system affected. Noticed by average users
4–6	Moderate—most users are inconvenienced and/or annoyed
7–8	High—loss of primary function. Users are dissatisfied
9–10	Very high—hazardous. Product becomes inoperative, customer angered. Failure constitutes a safety hazard and can cause injury or death

Table 5 Occurrence rating and meanings [18]

Rating	Meaning
1	No documented failures on similar product or process
2–3	Low—relatively few failures
4–6	Moderate—some occasional failure
7–8	High—repeated failures
9–10	Very high—failure is almost certain
9–10	Very high—hazardous

value (d), which indicated how likely it is that failures was detected. The higher the value of (d), the more likely the failure not detected. Failure detection rating is shown in Table 6.

Risk Priority Number (RPN) RPN value is calculated from the value of severity (s), occurrence (o) and failure detection (d) shows in Eq. (1).

$$\mathrm{RPN} = \mathrm{S} \times \mathrm{O} \times \mathrm{D} \tag{1}$$

RPN is calculated for the entire design or process and documented in the FMEA form. Result will shows the most problematic areas with the highest RPN value that should get highest priority for corrective measures. The corrected measures then

Table 6 Failure detection rating and meanings [18]

Rating	Meaning
1	Fault is certain to be caught by testing
2	Fault almost certain to be caught by testing
3	High probability that tests will catch fault
4–6	Moderate probability that tests will catch fault
7–8	Low probability that tests will catch fault
9–10	Fault will be passed undetected to user

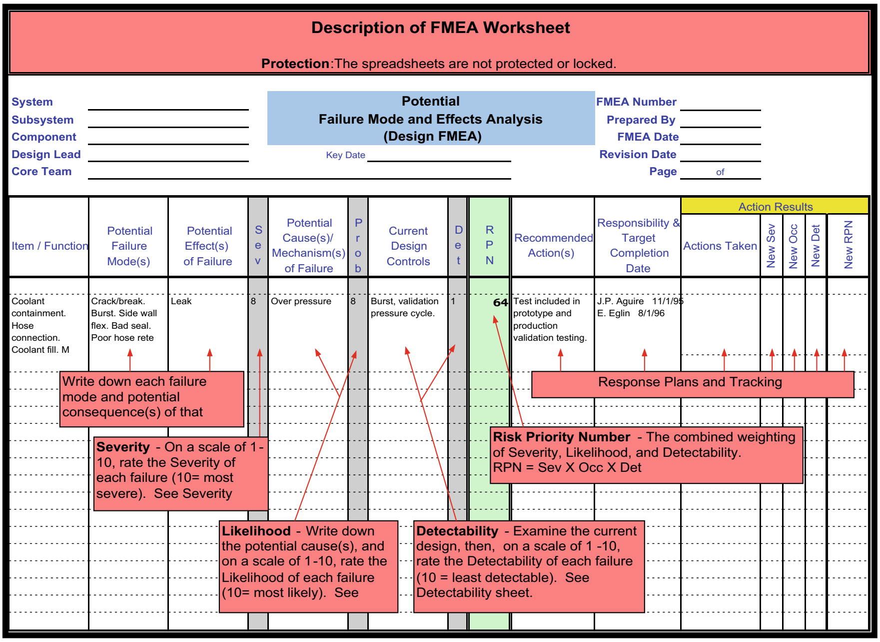


Fig. 6 FMEA form sheet

calculated again on the RPN value and documented in the FMEA form. An FMEA form sheet is shown in Fig. 6.

4 Result and Discussions

4.1 Questionnaire Analysis

Awkward Posture. It is generally acknowledged that awkward posture is a posture not suitable or not proper for certain working activities. The awkward posture analysis result is consisting of few questions concerned on awkward posture. The question that the firefighter answered between "Yes" and "No" on concerned of awkward posture is shown in Fig. 7. It shows that 56% of respondents agreed that manual handling that firefighter done related and concern with awkward posture. However, 44% does not agree because of several firefighters are not involved in works that concerned with awkward posture. The potential cause of awkward is shown in Fig. 8.

The result shows the equipment obtained the largest section with 53% of the respondent agreed that equipment contribute to awkward posture. Awkward posture analysis followed by body part affected by awkward posture work. The result of

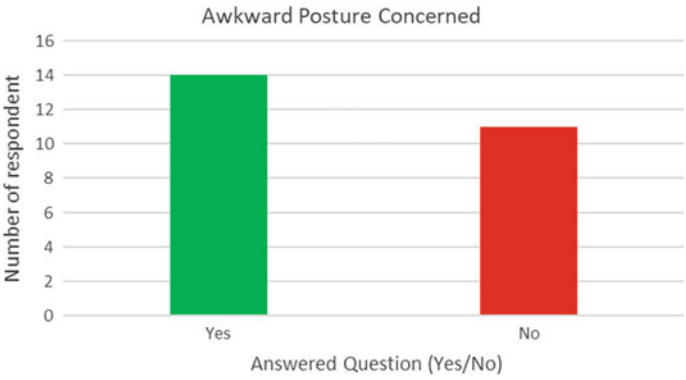
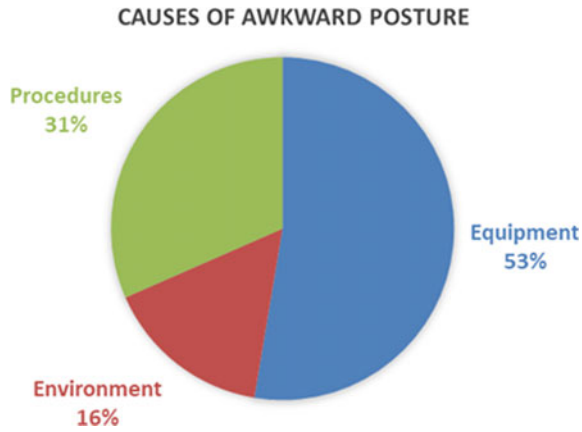


Fig. 7 Frequency of awkward posture

Fig. 8 Potential causes of awkward posture

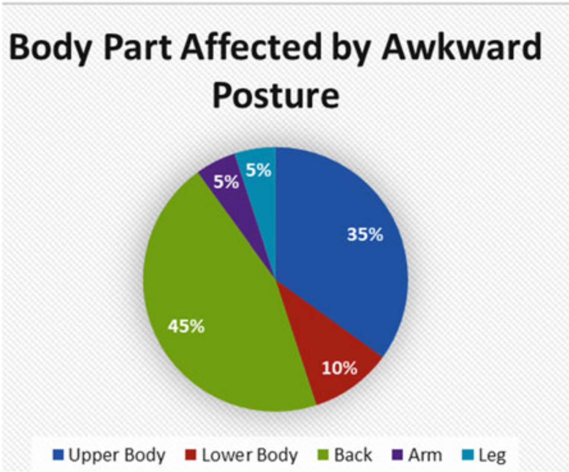


body part affected is shown in Fig. 9. The most affected body part is back part with score of 45% of the respondent experienced it. It followed by second highest, which is upper body with score of 35%, 10% of lower body and both 5% for arm and leg.

Repetitive Motion. Part B is the question related to repetitive motion applied during working among firefighter at Pagoh fire station. The result of repetitive motion analysis is shown in Fig. 10. It shows that the repetitive motion is not too concerned with manual handling among firefighter at Pagoh fire station which is the highest score goes to "No" answer. This is because 56% of respondent choose "No" answer that shows several firefighter does not involved with repetitive motion.

Vibration. Part C is a question regarding on vibration that could be an ergonomic risk. The result of vibration concern is shown in Fig. 11. The result shows 40% of respondent agree that vibration contributed to ergonomic risk factor. However, 60% of respondent does not agree that vibration contributed towards ergonomic risk factor.

Fig. 9 Body part affected by awkward posture



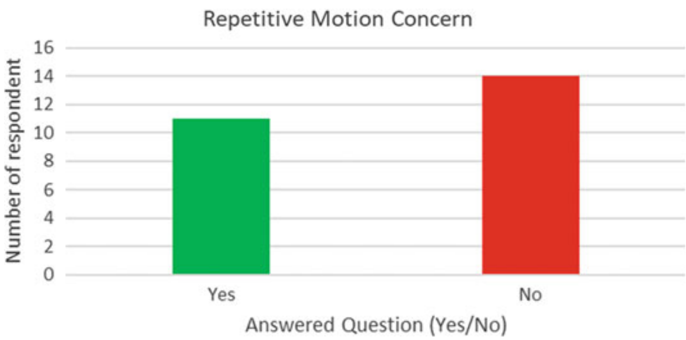


Fig. 10 Frequency of repetitive motion

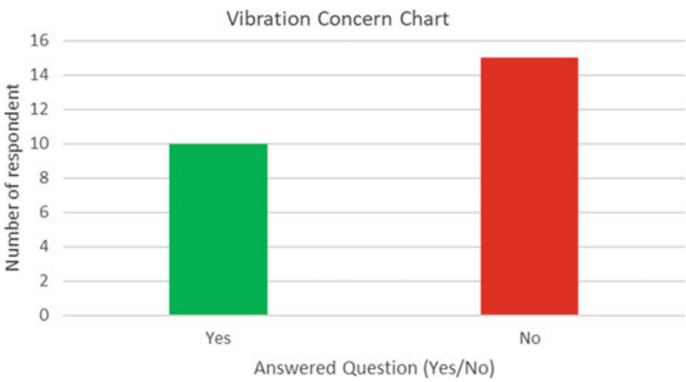
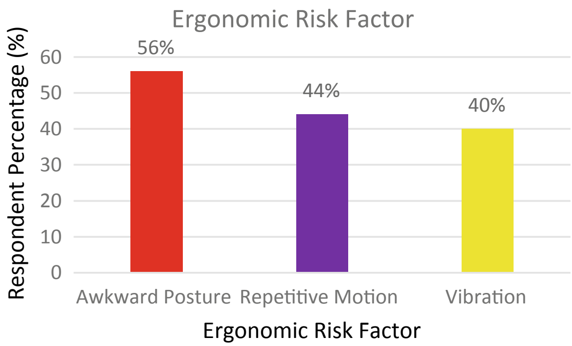


Fig. 11 Frequency of vibration motion

Fig. 12 Overall result



This is because majority of firefighter does not doing their work that concerned with equipment that related to vibration.

Overall Result. Overall, based on those result of awkward posture, repetitive motion and vibration analysis, the overall result is concluded in Fig. 12. For overall result of the questionnaire analysis, it shows that the awkward posture risk factor obtained the highest result with 56% of respondent experienced the awkward posture ergonomic risk factor. It followed by 44% of respondent on repetitive motion analysis that experienced it lesser than awkward posture. Lastly, the vibration analysis obtained a result of only 40% of respondents does the work related to vibration. It can be concluded that the awkward posture is the most ergonomic risk factor that has been determined for the project.

4.2 FMEA Result

This assessment is based on the observation towards firefighter doing the hose rolling work. From the analysis, the result obtained shows which work give the most ergonomic risk effect towards firefighter. The data collected using FMEA form to detect the injury that occurred during the hose roll process. The FMEA form result is shown in Table 7. The FMEA result shows that the highest RPN value goes to potential failure of injury on back part of body that related to awkward posture. It is then compared to the result of questionnaire and ERA to find the best solution for workplace improvement at Pagoh fire station.

4.3 Proposed Design of Ergonomic Tool for Firefighter

As seen from the result of all ERA and FMEA analysis, it is recommended to propose a design of ergonomic tool for firefighter. The proposed ergonomic tool should be

Table 7 Result of FMEA analysis

System ______ Subsystem ______ Component ______ Design Lead ______ Core Team ______

Potential
Failure Mode and Effects Analysis
(Design FMEA)

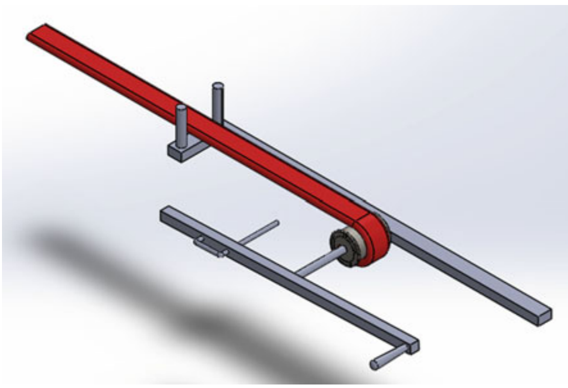
Key Date ______

FMEA Number ______ Prepared By ______ FMEA Date ______ Revision Date ______ Page ______

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occ	Current Design Controls	Det	RPN	Recommended Action(s)
Hose									
Hose rolling	Injury to hand	Delay of operation	2	Fast roll work during operation	4	Manually roll	3	**24**	Develop SOP for hose rolling
	injury of leg	couldn't roll the hose completely	2	repeatedly doing the same task	5	repeatedly train for the same task	4	**40**	Tool development
	injury on back part of body	couldn't proceed for operation	7	Awkward posture during task working	6	Random posture during task completion	5	**210**	Suitable posture applied
Carrying a hose	Injury of shoulder	Couldn't carry the hose	5	Improper of carrying a hose	1	Manually carry by firemens	5	**25**	Proper way of carrying the hose

able to provide support for firefighter when rolling the hose during operation. This proposed design of tool aims to reduce the firefighter movement. It is also use the concept of the use of human body. This concept is under principle of motion economy that used to reinforce the effectiveness of work. The concept also can lead to smooth and automatically performance of any operation. The proposed design of tool is shown in Fig. 13.

Fig. 13 Proposed design tool



5 Conclusion

The aim of the study is to identify most ergonomic risk factors that may cause harm to firefighter. The aim is achieved by applying the ERA to identify ergonomic risk factor (ERF) among firefighter. The ERF is applied by an observation towards firefighter doing their manual handling at Pagoh fire station. Awkward posture is the most ergonomic risk factor identified compare to other factors (repetitive motion and vibration). The second aim of the research to improve ergonomic at workplace is achieved by proposing a new tool that control the ergonomic risk factor experienced by firefighter. However, the proposed tool need further investigation especially on the design, strength, functionality, portability and suitability for firefighter. The proposed design tool will be discussed detailed for further research.

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References

1. Yazuli ZA, Karuppiah K, Kumar E, Md Tamrin SB, Sambasivam S (2019) Discomfort, fatigue and work-related musculoskeletal disorders associated with prolonged standing among Malaysian manufacturing workers: a mini review. Songklanakarin J Sci Technol 41(2):271–275. https://rdo.psu.ac.th/sjstweb/journal/41-2/4.pdf
2. Sholihah Q, Hanafi AS, Bachri AA, Fauzia R (2016) Ergonomics awareness as efforts to increase knowledge and prevention of musculoskeletal disorders on fishermen. Aquat Proc 7:187–194. https://doi.org/10.1016/j.aqpro.2016.07.026
3. Aqlan F, Lam SS, Ramakrishnan S, Testani M (2014) An ergonomic study for 6s workplace improvement. In: IIE annual conference. Proceedings. Norcross, pp 3063–3068
4. Radin Umar RZ, Ahmad N, Halim I, Poh YL, Hamid M (2019) Design and development of an ergonomic trolley-lifter for sheet metal handling task: a preliminary study. Saf Health Work 10(3):327–335. ISSN 2093-7911. https://doi.org/10.1016/j.shaw.2019.06.006
5. DOSH Malaysia (2018) Guidelines for manual handling at workplace 2018, pp 1–90
6. Ohnishi A, Takanokura M, Sugama A (2016) Evaluation of interhandle distance during pushing and pulling of a four-caster cart for upper Limb exertion. Saf Health 7(3):237–243
7. Kim MG, Seo JI, Kim K, Ahn YS (2017) Nationwide firefighter survey: the prevalence of lower back pain and its related psychological factors among Korean firefighters. Int J Occup Saf Ergon 23(4):447–456
8. Karter M Jr, Molis J (2008) U.S. firefighter injuries-2007. National Fire Protection Association, Quincy, MA
9. Roh SG, Kim JH (2013) Work related diseases in Korean fire fighters. J Digital Converg 11(10):571–576
10. DOSH Malaysia (2017) Guidelines on ergonomics risk assessment at workplace 2017. Department of Occupational Safety and Health, p 155
11. Tee KS et al (2017) A study on the ergonomic assessment in the workplace. AIP Conf Proc 1883, Aug 2017
12. Jithin V (2016) Ergonomic assessment and implement controls in automobile closed room testing by using risk assessment methodology. Int Res J Eng Technol 3(5):2737–2742

13. Jaffar N, Abdul-Tharim AH, Mohd-Kamar IF, Lop NS (2011) A literature review of ergonomics risk factors in construction industry. Proc Eng 20:80–88
14. Wilhelmus GJA, Johanssons E (2018) Observational methods for assessing ergonomic risks for work-related musculoskeletal disorders. A scoping review. Rev Cienc Salud 16(special issue):8–38
15. Hamdi (2008) Graduate school of natural and applied sciences. Program, p 508
16. Prajapati DR (2012) Implementation of failure mode and effect analysis: a literature review. Int J Project Manage 2(7):264–292
17. Carlson CS (2015) Understanding and applying the fundamentals of FMEAs summary. In: 2015 annual reliability and maintainability symposium. ReliaSoft Corporation, USA
18. Rakesh R, Jos BC, Mathew G (2013) FMEA analysis for reducing breakdowns of a sub system in the life care product manufacturing industry. Int J Eng Sci Innov Technol 2(2):218–225
19. Baynal K, Sari T, Akpinar B (2018) Risk management in automotive manufacturing process based on FMEA and grey relational analysis: a case study. Adv Prod Eng Manag 13(1):69–80
20. Shinde RR, Shrivastava R, Morey RB (2015) Failure mode effect analysis-case study for bush manufacturing process. Int J Sci Eng Appl Sci 1(4):2395–3470
21. Adnan NH, Ressang A (2014) Ergonomics awareness on construction site. Engineering UTM. Available at: http://civil.utm.my/wp-content/uploads/2016/12/Ergonomics-Awareness-on-Construction-Site.pdf. Accessed on Jan 2019
22. Abide A (2013) Applications of principles of motion economy. Bahirdar University Institute of Technology, pp 7–19
23. OSHA (2007) Ergonomic assessment checklist. vol 1, pp 1–2

Development of a Survey Instrument for Measuring Workers Satisfaction on Usability of Manual Handling Equipments at the Warehouse: A Pilot Study

Ismail Abdul Rahman, Noorul Azreen Azis, Salwa Mahmood, Jafri Mohd Rohani, Nor Amira Farhana Zaidi, Suhaimi Mohd Sukri, and Mohd Arif Afzan Mohd Zain

Abstract Scientific evidence show that manual handling devices are one of the effectives controls that can lower the physical demands of manual material handling (MMH) activities. Incidence and severity of the musculoskeletal injuries might happen to workers while company's productivity, product quality, and overall business competitiveness also will be affected. However, few studies had been done regarding on manual handling devices provided in the industries especially in term of user satisfaction on the usability of the devices when performing their job and task. The aim of this study is to develop a survey instrument for the evaluation of worker satisfaction on usability of manual handling device among warehouse worker in manufacturing industry. A set of questionnaires was developed which consist of three sections; demographic profile of respondent, work nature and discomfort survey and worker satisfaction on the usability of the manual handling devices. The content of the questionnaire was derived through extend literature reviews and expert's opinions. A pilot study was conducted at four manufacturing companies in their warehouse's operation. The reliability and validity of the instrument were determined through Cronbach's Alpha, face validity and content validity. Cronbach's Alpha values for each section of the questionnaire range from 0.937 and 0.961 while the value for Cronbach's Alpha for all 35 standardized items is 0.921. The finding shows that the survey instrument has face and content validity at acceptable level. In conclusion, finding indicated that this instrument had acceptable and adequate reliability and

I. Abdul Rahman (✉) · N. A. Azis · N. A. F. Zaidi · S. Mohd Sukri · M. A. A. Mohd Zain
Ergonomics Excellence Centre, National Institute of Occupational Safety and Health (NIOSH), No. 10, Jalan Persiaran Teknologi, Taman Teknologi Johor, 81400 Senai, Johor, Malaysia

I. Abdul Rahman · S. Mahmood
Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, KM 1 Jalan Panchor, 84600 Pagoh, Muar, Johor, Malaysia

J. Mohd Rohani
School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

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validity to meet its objectives. The survey instrument now ready to be distributed in larger data sets.

Keywords Manual material handling · Instruments development · Warehouse · Pilot study · Manufacturing

1 Introduction

Manual material handling (MMH) tasks have been identified as one of the major sources of work-related musculoskeletal disorders (WMSDs), which is one of the big concerns in manufacturing industry [1, 2]. MMH consist of activities that utilizing human capability to perform frequent lifting, lowering, carrying, pulling and usually associated with several ergonomics risk factors. It is including awkward posture, excessive force, repetitive task, tools or material mobilization from one point to another point. Despite the widespread use automation system such as of robots, mechanisation and work-related interventions in industry, several tasks are still performed manually by workers especially in warehouse operation. Several jobs are necessary to be perform manually, when requiring observation and decision-making, also in other instances tasks benefit from human precision, skill and movement capabilities [1, 3, 4]. Hence, despite increased automation, many jobs still require workers to perform task manually.

In warehouse operation, poor working conditions such as repetitive back bending while lifting objects, twisting and pulling or pushing of heavy objects, are all kinds of poor posture conditions can lead to a significant impact on performance as well as postural stresses. A research found that heavy physical demand and improper posture while performing a task can cause musculoskeletal disorders [5–9]. For example, tasks that need lifting activity and pulling or pushing tasks in various sectors such as manufacturing and warehouses [5]. The excessive physical demands placed on the human operator under these working conditions on continuous basis have shown to be a major contributor to WMSD [6, 7]. Previously two epidemiological studies, which is each conducted among more than 31,000 American workers in warehouse superstores, show a consequence between MMH activities with the development of back pain [8, 9]. The study was conducted involving a total of 92 warehouse workers for evaluating the musculoskeletal disorders. The study found that ergonomics risk factor related to manual handling task in warehouse was identified, which the result showed that the task highly significantly impacted low back pain among all participants [5].

In this day, industry revolution (IR-4.0) happens to be the present and future of the manufacturing sector especially using artificial intelligence with the synchronization of automation system. Incorporating internet technology advances to optimize automated system in production industry, where logistics system is one of the core activities, could end up being more flawless and self-decision making [10]. Flexible and modular material handling system facilitates easier configuration to meet ever changing market demands and new product launch. In order to prevent back disorders related to high-risk manual handling activities, attempts to control these disorders should focus on assessing and redesigning the tasks of manual material handling and equipment used [11, 12]. One of the strategies to improve efficiency in MMH activities in warehouse operation is to introduce assistive devices that can reduce exertion requirements and poor working postures. To make the large item handling activities more efficient and safer, mechanical aids are usually used to assist workers. The planning and choice of right material handling equipment rely on materials to be handled, quantities and distances to be moved, routing and workplaces facilities dan layout. Based on the study by Wurzelbacher et al. [13], additional research that examines the effectiveness of ergonomic engineering interventions need to be conducted.

The main objective of this paper is to describe the development and validation of survey instrument for measuring workers satisfaction on usability of manual handling devices. The devices such as trolley, hydraulic pallet lifter, conveyor system and vacuum assist device will be considered at manufacturing's warehouse operation. For the future, this study target to evaluate workers satisfaction on manual handling devices at warehouse operation because most of the high significant task related to ergonomics exist at warehouse and few studies show that warehouse personnel experienced body discomfort and pain [14, 15], despite some prior research that indicates ergonomic material handling equipment can reduce biomechanical risk factors for musculoskeletal disorders [7, 13, 16, 17].

2 Methodology

A structured approach for the development of the survey instrument was adopted based on a guideline in designing research questionnaire, research paradigm and theory in a survey-based research [18]. In developing the survey instruments that are valid and reliable, several sequential steps involved must consist the construction of survey instrument, validation and verification of the instruments, ethical approval and pilot study. All steps are depending on fine tuning and testing. Previous step must be completed before next step is taken. Figure 1 shows the development step of the survey questionnaire used in this study.

2.1 Construction of Survey Instrument

In this study the first step is construction of survey instrument. The goal and objectives, research questions and hypothesis of the set of questionnaires for the proposed research was examined and discussed in order to come out with the content and structure of the research questionnaire. Part of this process is deciding the target respondent, respondent background as well as their demographic profiles. This is because questionnaire should not only suit with the research and the researcher but

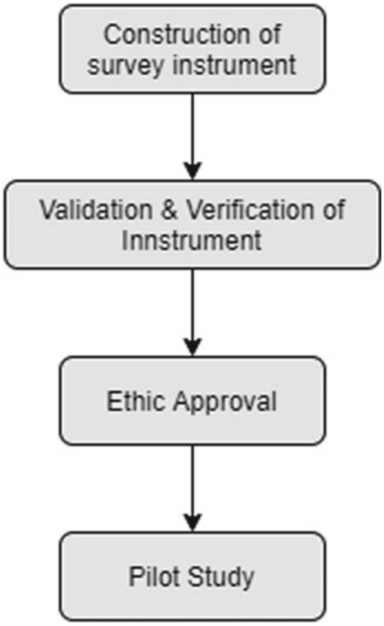

Fig. 1 Development of survey questionnaire

also to respondents [19, 20]. Then, the content of the questionnaire needs to be constructed after an understanding through theoretical framework from an extensive literature review and transformed into structures of the questions being developed.

The questionnaire consisted of 61 standardized items with four main sections consist of: (A) demographic profile of respondents, (B1) nature of jobs and tasks of respondent, (B2) history of body discomfort and pain, and (C) workers satisfaction on usability of manual handling devices. The question in section A is a demographic profile of the respondents such as gender, race, age, citizenship, work designation, workstation area, working experience, working duration, job activities and involvement with manual material handling devices. For section B1 the question is more about the performance of workers with job task and the evaluations of sub-capabilities related to the increased workforce. The question in section B2 is related to history of body discomfort and pain for specific body region is based on a modified Nordic discomfort assessment tool [21]. Meanwhile, for section C, a scale questionnaire is constructed and modified from a design requirements and user satisfaction for the ergonomic design of a hand tool [22] to evaluate the agreement of the respondent to the factors found on the manual handling devices that are being used. The factor consists of energy expenditures, effectiveness, efficiency, productivity, design, user friendliness, safety and comfortability when using manual handling devices. A closed ended questionnaire has been used in all section to reduce the amount of thinking and effort required by respondent in answering the question.

Table 1 List of experts for face and content validation

Panel	Expertise	Experience (years)
1	Health and safety, warehouse operation	20
2	Warehouse management, production engineering	7
3	Health and safety, auditing, industrial operation	9
4	Statistical data analysis, ergonomics, education	11
5	Education, R&D, ergonomics, industrial hygiene	10
6	Ergonomics, education, R&D, consultation	7
7	Ergonomics, risk assessment, safety and health	17
8	Industrial hygiene, ergonomics, industrial inspection	10

2.2 Validation and Verification

Next for ensuring the consistency and high confidence level of the survey result, validation and verification of the questionnaire were conducted. Face and content validity is the common methodology to establishing the validity of an instrument or survey questionnaires [23]. In this study, face and content validity are secured and reviewed by panel of experts which are three persons from industrial representatives, three persons from academics' representatives and two persons from ergonomics practitioners as per Table 1. The survey's appearance, relevance and representativeness of its elements were judged the panel of experts. Following these reviews, some items that are irrelevance were removed from the questionnaire, other items were added and rephrase for enhanced precision and clarity.

2.3 Ethic Approval

Ethical approval for all relevant aspects of the development process was received from the National Institute of Occupational Safety and Health Malaysia Ethics Committee. This ethic was applied under "The Study on Ergonomics Intervention Control for Manual Material Handling in Manufacturing Sector (Reference number: NIOSH/03/JEP/2020(8))".

2.4 Pilot Study

After the survey instruments were approved by the ethics committee, a pilot study was conducted by targeting about ten percent (10%) of the required sample size. Statistical data from Department of Statistic Malaysia (DOSM) shows that the number of workers in Malaysia manufacturing industry as in September 2019 are about

1,087,179 persons [24]. Using Krojchie and Morgan table (1970), the sampling size should be considered is 384 for the sampling population size over 100,000 population [25]. The unit of analysis for this study is worker. So, a total of 50 warehouse workers were chosen randomly from various manufacturing sub sector to participate in the pilot study. Then, reliability of the questionnaire was assessed by using Cronbach's alpha (α) considering minimum value of 0.6 [26].

3 Results and Discussion

3.1 Instrument Administration and Respondent Profiles

The pilot study was conducted at four (4) manufacturing company in southern region of peninsular Malaysia with a different type manufacturing sector. A total of 50 respondents from warehouse operation were chosen randomly to participate in the survey. A face-to-face interviews session were conducted between the respondents and researchers in order to fill in the questionnaire. The majority of the respondents are general worker which is involve directly with the manual handling activities in warehouse storing area and frequently using manual handling devices when performing the task as in Table 2. The demographic profiles of the respondent in this study were summarize in Table 2.

3.2 Analysis of the Validity and Reliability of Questionnaire

The result for the validity of the questionnaire based on the expert judgement for all 61 items was found to be good as the questionnaire can be measure and evaluate the worker satisfaction toward the manual handling devices that are used in warehouse operation. Face and content validity by the panel of experts consist of several criteria which include such questions understanding, clarity and language, content and suitability as well as questionnaire template, style and responses time. Summary of the comment were summarized in Table 3. Minor modification and adjustment of the questionnaire have been revised accordingly based on experts' comments to enhance the content of the questionnaire.

Result for reliability of the questionnaire shows that the Cronbach's alpha value ranged from 0.610 for the nature of jobs and tasks of respondent (section B1), 0.961 for the history of body discomfort and pain (section B2) and 0.937 for the workers satisfaction on usability of manual handling devices (section C) as per Table 4. Total Cronbach's alpha (α) for all three section (B1, B2 and C) with 35 standards items is 0.921. The value of Cronbach's alpha was calculated using IBM SPSS statistics for windows version 21.0. Armonk, NY: IBM Corp. The α reliability coefficient of the Cronbach usually is between 0 and 1. As per the rule of thumb, the reliability

Table 2 Table demographic profile of the warehouse workers involved in the pilot study

Profile		Frequency	Percentage (%)
Gender	Male	38	76
	Female	12	24
Citizen	Malaysia	21	42
	Non-Malaysia	29	58
Sector	Transportation	0	0
	Electrical equipment/electronics	27	54
	Petroleum, coal, chemicals, plastics and rubber	15	30
	Wood, paper, printing	0	0
	Primary metal/metal fabrication/machinery	0	0
	Food/beverage/tobacco	0	0
	Textiles, leather/apparel	0	0
	Furniture and fixture	0	0
	Others	8	16
Age	<20 years	0	0
	20–29 years	26	52
	30–39 years	16	32
	40–49 years	5	10
	>50 years	3	6
Designation	General workers	42	84
	Supervisor	6	12
	Others	2	4
Workstation area	Incoming/receiving	10	20
	Storing	23	46
	Order picking/kitting	7	14
	Packaging/delivery/outgoing	7	14
	Others	3	6
Working experience	<1 year	3	6
	1–5 years	28	56
	5–10 years	11	22
	>10 years	8	16
Working duration	≤8 h	1	2
	8–12 h	31	62
	>12 h	18	36
Work schedule	Shift	7	14
	Normal working hour	43	86

Table 3 Experts comments for validation of questionnaire

Panel	Comment
1, 2, 3, 4, 5, 6, 7, 8	Format acceptable
5, 6, 8	Grammar and typing error
6	Unclear wording
3	Additional others box for sector, designation and workstation area
4, 5	Need to do correction in sentences structure
7	Divide left/right side for body symptom survey
1, 8	Suggest to have multilanguage
2	Suggest to have a simple word for criteria for satisfaction
4	Might consider to have semi-quantitative scale

Table 4 Cronbach's alpha value for each section of the questionnaire

Section	No of items	Cronbach's alpha	Cronbach's alpha based on standardized items
Section B1			
• Work natures	6	0.610	0.609
Section B2			
• History of discomfort • Body symptom survey	21	0.961	0.959
Section C			
• Workers satisfaction on usability of control measures	8	0.937	0.941
Section B1, B2 and C	35	0.921	0.917

coefficient of 0.6 is considered to be sufficient. If the value of the Cronbach alpha is less than 0.6, it is recommended to rewrite/rephrase questions and modify their questionnaire items. The rule of thumb for Cronbach's alpha are 0.9—Incredible, 0.8—Nice, 0.7—Acceptable, 0.6—Controversial, 0.5—Bad, and 0.5—Unacceptable [27].

4 Conclusion

In this research, a reliable, accurate, empirically validated instrument was established based on the analysis of pilot test samples. In general, an outstanding Cronbach alpha was obtained. Further study may be needed to validate the findings of these pilot tests from larger data sets. The outcomes from the proper larger data set of the study might be useful in supporting and designing manual handling device for manual material handling activities in manufacturing warehouse operation based on user criteria and agreements.

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References

1. Zurada J (2012) Classifying the risk of work related low back disorders due to manual material handling tasks. Expert Syst Appl 39:11125–11134
2. Collins JD, O'Sullivan LW (2015) Musculoskeletal disorder prevalence and psychosocial risk exposures by age and gender in a cohort of office based employees in two academic institutions. Int J Ind Ergon 46:85–97
3. De Looze MP, Bosch T, Krause F, Stadler KS, O'Sullivan LW (2016) Exoskeletons for industrial application and their potential effects on physical work load. Ergonomics 59(5):671–681
4. Bos J, Kuijer PPM, Frings-Dresen MHW (2014) Definition and assessment of specific occupational demands concerning lifting, pushing and pulling based on a systematic literature search. Occup Environ Med 59:800–806
5. Basahel AM (2015) Investigation of work-related musculoskeletal disorders (MSDs) in warehouse workers in Saudi Arabia. Proc Manufact 3(Ahfe):4643–4649
6. Ferguson SA, Marras WS, Allread WG, Knapik GG, Splittstoesser RE (2012) Musculoskeletal disorder risk during automotive assembly: current vs. seated. Appl Ergon 43:671–678
7. Marras WS, Granata KP, Davis KG, Allread WG, Jorgensen MJ (1999) Effects of box features on spine loading during warehouse order selecting. Ergonomics 42(7):980–996
8. Gardner LI, Landsittel DP, Nelson NA (1999) Risk factors for back injury in 31,076 retail merchandise store workers. Am J Epidemiol 150(8):825–833
9. Kraus JF, Schaffer KB, McArthur DL, Peek-Asa C (1997) Epidemiology of acute low back injury in employees of a large home improvement retail company. Am J Epidemiol 146(8):637–645
10. Mehami J, Nawi M, Zhong RY (2018) Smart automated guided vehicles for manufacturing in the context of Industry 4.0. In: 46th SME North American manufacturing research conference, NAMRC, vol 46, Elsevier B. V., Texas, USA, pp 1077–1086
11. Patrick GD (1999) Utilizing criteria for assessing multiple-task manual materials handling jobs. Int J Ind Ergon 24:405–416
12. St-Vincent M, Denis D, Imbeau D, Laberge M (2005) Work factors affecting manual materials handling in a warehouse superstore. Int J Ind Ergon 35:33–46
13. Lowe BD, Albers J, Hayden M, Lampl MP, Naber S, Wurzelbacher SJ (2020) Review of construction employer case studies of safety and health equipment interventions. J Construct Eng Manag 146(4):1–11
14. Menzel NN (2001) Manual handling workload and musculoskeletal discomfort among warehouse personnel. ProQuest dissertations and theses, Dec 2001, pp 212–n/a
15. Snook SH, Webster BS (2007) The cost of disability. Clin Orthop 221:77–84
16. Mirka GA, Smith C, Shivers C, Taylor J (2002) Ergonomic interventions for the furniture manufacturing industry, part I. Int J Ind Ergon 29(5):263–273
17. Bongers PM, Luijsterburg P, Van den Heuvel F, De Vroome E, Miedema MC, Douwes M (2001) Evaluation of new working methods for a team of bricklayers: heightened bricklaying and mechanisation of transport. Hoofddorp: Nederlandse Organisatie Voor Toegepast-Natuurkundig Onderzoek (TNO)

18. Rahi S, Alnaser FMI, Ghani MA (2019) Designing survey research: recommendation for questionnaire development, calculating sample size and selecting research paradigms, Feb 2019, pp 14–15
19. Rahi S (2017) Research design and methods: a systematic review of research paradigms, sampling issues and instruments development. Int J Econ Manag Sci 6(2):1–5
20. Rowley J (2014) Designing and using research questionnaires. Manag Res Rev 37(3):308–330
21. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, BieringSorensen F, Andersson S, Jorgensen K (1987) Standardized Nordic questionnaires for the analysis of muscuIoskeletal symptoms. Appl Ergon 18(3):233–237
22. Lee C (2005) Ergonomic design and evaluation using a multidisciplinary approach: application to hand tools. ProQuest dissertations and theses, Aug 2005, p 274
23. Burton LJ, Mazerolla SM (2011) Survey instrument validity part 1: principles of survey instrument development and validation in athletic training education research. Athl Train Educ J 6(1):27–35
24. Department of Statistics Malaysia DOSM (2019) Monthly manufacturing statistics Malaysia, Dec 2019. Retrieved from: https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=90&bul_id=UTN0cmkyMTV0SzV1ck12NXQ4UXRZZz09&menu_id=SjgwNXdiM0JlT3Q2TDBlWXdKdUVldz09
25. Krejcie RV, Morgan D (1970) Small-samlpe techniques. NEA Res Bull 30:607–610
26. Nunnally JC (1979) Psychometric theory. In: Applied Psychological Measurement, vol 3, 2nd edn, pp 279–280
27. George D, Mallery P (2003) Using SPSS for windows step by step: a simple guide and reference, 4th edn. Pearson Education, London

Does Human Factor Contribute to Mining Accidents? A Systematic Literature Review Approach

Siti Noraishah Ismail and Azizan Ramli

Abstract Human factor always has been debated as the key factor contributes to industrial accidents such as manufacturing, construction and many more. However, there are lack of studies globally within this research to review and prove the human factor is a primary cause of accidents at mining industry. The objective of this systematic literature review (SLR) study is to investigate the dominant factor contributes to mining accidents by applying a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. Three main themes and fifteen subthemes have been developed based on 25 selected articles from Scopus database. The findings showed the organizational factor is the most dominant contributor to mining accidents (53%) followed by human factor (27%) and situational factor (20%). In conclusion, this finding hopefully could facilitate mine owners to improve organizational safety concern and provide a healthy safety culture in reducing mining accidents in future.

Keywords Systematic literature review · Mining industry · Mining accidents · Organizational factor · Preferred reporting items for systematic reviews and meta-analyses

1 Introduction

Various researches have claimed human factor has a great influence on industrial accidents in construction industry [1, 2], manufacturing industry [3, 4] and many more. Mining industry is the most hazardous industry and many mining accidents have been reported such as coal mine accident in China [5], USA [6] and Turkey

S. N. Ismail · A. Ramli (✉)
Faculty of Industrial Sciences and Technology, College of Computing and Applied Sciences, Universiti Malaysia Pahang, Pahang Kuantan, Malaysia
e-mail: azizanramli@ump.edu.my

S. N. Ismail
Faculty of Chemical and Process Engineering Technology, College of Engineering Technology, Universiti Malaysia Pahang, Pahang Kuantan, Malaysia

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[7]. However, there is a lack of study in reviewing the factors contributes to mining accidents. Therefore, the objective of this systematic literature review (SLR) study is to investigate the dominant factor contributes to mining accidents in year 2015–2019.

2 SLR Methodology on Mining Accidents

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) [8] was used to establish the SLR on factor contributes to mining accident. Scopus indexed database was used for this review to ensure the quality of the articles reviewed in this paper. Figure 1. shows the steps of SLR including;

i. Identification using search string: *TITLE-ABS-KEY* ("*mine accidents*" *OR* "*mining accidents*" *OR* "*mine accident*" *OR* "*underground mine accident*" *OR* "*surface mine accident*" *OR* "*mine disasters*" *OR* "*mining disasters*" *OR* "*mine hazard*" *OR* "*mine casualty*").
ii. Screening process include the articles published between years of 2015–2019 (5 years period of time) and journals in English language only on mining accidents.
iii. Eligibility refers to the process that includes or excludes articles manually according to the authors 'specific criteria.
iv. Data abstraction and analysis include evaluate, reviewed, and analyzed manually throughout the full text of articles (in-depth).

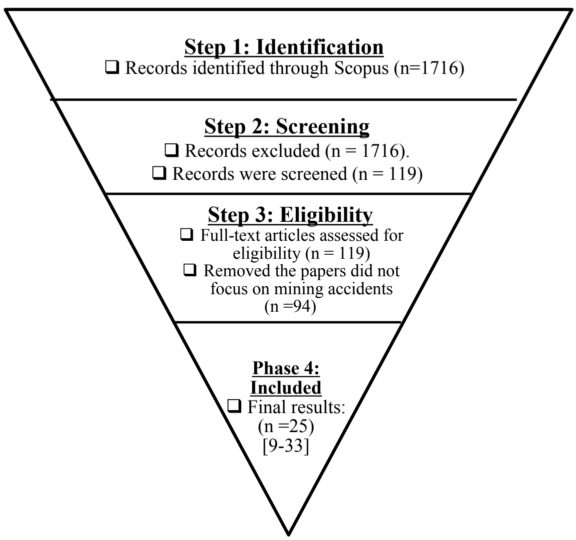

Fig. 1 The process of SLR study. Adapted from [8]

3 Main Finding

The review managed to obtain 25 selected articles from China, Ghana, Spain, New Zealand, Brazil, South Africa, Iran, and United States of America in year 2015–2019. China was a leading country for published articles with 15 articles (studies) related to mining accidents followed by South Africa (3 studies), Iran (2 studies). One paper from Brazil, USA, Ghana, Spain and New Zealand respectively. 18 coal mine accidents were reported followed by iron ore mine accidents (3 accidents), platinum mine (2 studies) and gold mine (2 accidents). Three main themes and fifteen sub-themes were developed using thematic analysis with the assisted of PRISM approach as shown in Table 1.

4 Discussion

Based on SLR study, the most dominant factor contribute to mining accidents was organizational factor which resulted 53% (8 sub-themes) followed by human factor (4 sub-themes) and situational factor (3 sub-themes) were resulted 27% and 20% respectively. The findings have proven the dominant factor caused mining accident was organizational factor and the least contributor was situational factor. Based on SLR study, poor organizational portrays the lack of safety concern such as poor safety management, poor leadership by supervisor, lack of safety training, lack of safety education, poor safety culture, poor safety awareness, lack of rules and regulations. Human factor such as human error, unsafe act, unsafe behavior, and inexperience were reported as the second factor contributes to mine accident. This factor could lead to mine disaster if the necessary precaution is neglected. Therefore, the adequate training to mine worker and safety education are important as reported in China by [9, 20]. Another important factor is situational factor such as geologic factor, poor workplace environment and mechanical failure contribute to mining accidents.

The mining organization or mining industry should come out with the new strategy to minimize the mining accidents. One of promising solution is implementing a healthy and positive safety culture in mining industry. Various industries around the world industry already realized the potential of promoting a healthy safety culture in organization to reduce large-scale disasters and accidents [34]. Safety culture focuses on the root causes of accidents; not symptoms of accidents, leading to more effective accident prevention strategy. To promote a good safety culture, safety knowledge must be strengthened first such as knowledge on production and production equipment, machine handling, safety awareness, knowledge on skills and competencies and safety training [35]. Moreover, to foster a safety culture, it is important for the mine owner to provide a safer working environment to mine workers.

Table 1 Main themes and sub-themes

Theme	Subtheme	Type of mine accidents			
		Coal	Gold	Iron	Platinum
Human factor	Human error	China [9–12], USA [13]		Iran [14]	South Africa [15]
	Unsafe behaviour	China [9, 12, 16, 17], USA [13], Spain [18]		Iran [14, 19]	South Africa [15]
	Unsafe act	China [20, 17]		Iran [14, 19]	South Africa [15]
	Inexperience worker	China [9, 12]		Iran [19]	South Africa [15]
Situational factor	Poor workplace environment	China [9, 21, 10], USA [13], Spain [18]		Iran [14]	South Africa [15]
	Geological factor	China [22–25]			
	Mechanical failure	China [22, 23, 26, 22–24, 26–28], New Zealand [29], Spain [18]	Ghana [21], South Africa [30]	Brazil [31]	
Organization factor	Leadership behaviour of supervisor	China [10, 11, 16], USA [13], New Zealand [29]		Iran [14]	South Africa [15]
	Organizational deficiencies	China [10, 11, 16], USA [13], New Zealand [29], Spain [18]		Iran [14]	South Africa [15]
	Lack of rules and regulations	China [9]			South Africa [15]
	Poor safety culture	China [17]			
	Poor safety awareness	China [9, 11, 12, 17]		Iran [14]	
	Lack of safety training	China [32, 10, 17], USA [13], Spain [18]		Iran [19]	South Africa [15]
	Lack of safety education	China [9, 20, 11], Spain [18]			

(continued)

Table 1 (continued)

Theme	Subtheme	Type of mine accidents			
		Coal	Gold	Iron	Platinum
	Poor safety management	China [9–11, 11, 17], USA [13], South Africa [33], Spain [18], New Zealand [29]		Iran [14]	South Africa [33]

5 Conclusion

In conclusion, organizational factor (53%) is the most dominant contributor to mining accidents based on SLR findings. A healthy and positive safety culture seems possible to be applied if mine owner has a high commitment to promote it among mine workers and hopefully the mine accident can be minimized in future.

References

1. Kim S, Lee J, Kang C (2021) Analysis of industrial accidents causing through jamming or crushing accidental deaths in the manufacturing industry in South Korea: focus on non-routine work on machinery. Saf Sci 133:104998. https://doi.org/10.1016/j.ssci.2020.104998
2. Wang Y, Ding Y, Chen G, Jin S (2019) Human reliability analysis and optimization of manufacturing systems through Bayesian networks and human factors experiments: a case study in a flexible intermediate bulk container manufacturing plant. Int J Ind Ergon 72:241–251. https://doi.org/10.1016/j.ergon.2019.05.001
3. Zhou C, Chen R, Jiang S, Zhou Y, Ding L, Skibniewski MJ, Lin X (2019) Human dynamics in near-miss accidents resulting from unsafe behavior of construction workers. Phys A Stat Mech Appl 530:121495. https://doi.org/10.1016/j.physa.2019.121495
4. Guo S, Zhou X, Tang B, Gong P (2020) Exploring the behavioral risk chains of accidents using complex network theory in the construction industry. Phys A Stat Mech Appl 560:125012. https://doi.org/10.1016/j.physa.2020.125012
5. Morisson CD, Neumann R, Ramalho A, Evangelista H, Heilbron M, Cristine C, Neto A, Paravidini G, Souza D (2019) Applied Geochemistry Sm–Nd and Sr isotope fingerprinting of iron mining tailing deposits spilled from the failed SAMARCO Fundão dam 2015 accident at Mariana, SE-Brazil. Appl Geochem 106:34–44. https://doi.org/10.1016/j.apgeochem.2019.04.021
6. Düzgün HS, Leveson N (2018) Analysis of soma mine disaster using causal analysis based on systems theory (CAST). Saf Sci 110:37–57. https://doi.org/10.1016/j.ssci.2018.07.028
7. Spada M, Burgherr P (2016) An aftermath analysis of the 2014 coal mine accident in Soma, Turkey: use of risk performance indicators based on historical experience. Accid Anal Prev 87:134–140. https://doi.org/10.1016/j.aap.2015.11.020
8. Shaffril HAM, Abu Samah A, Samsuddin SF, Ali Z (2019) Mirror-mirror on the wall, what climate change adaptation strategies are practiced by the Asian's fishermen of all? J Clean Prod 232:104–117
9. Zhu Y, He G, Zhu X, Qiao G, Zhang G (2015) Research on factors affecting employees' security behavior based on structural equation model. Int J Secur Appl 9(8):375–384. https://doi.org/10.14257/ijsia.2015.9.8.33

10. Xiang C, Zhou E, Hong R, Liu H, Xu X (2019) Brittleness risk evaluation of mine safety based on brittle relational entropy
11. Li Y, Wu X, Luo X, Gao J, Yin W (2019) Impact of safety attitude on the safety behavior of coal miners in China. Sustain (Switz) 11(22):1–21. https://doi.org/10.3390/su11226382
12. Chen Z, Qiao G, Zeng J (2019) Study on the relationship between worker states and unsafe behaviours in coal mine accidents based on a Bayesian networks model. Sustainability 11:5021. https://doi.org/10.3390/su11185021
13. Bonsu J, Van Dyk W, Franzidis J, Petersen F, Isafiade A (2016) A systems approach to mining safety: an application of the Swiss cheese model. J South Afr Inst Min Metall 16:777–784. https://doi.org/10.17159/2411-9717/2016/v116n8a10
14. Aliabadi MM, Aghaei H, Kalatpour O, Soltanian AR, Seyedtabib M (2018) Effects of human and organizational deficiencies on workers' safety behavior at a mining site in Iran. Epidemiol Health 40:1–9. Article ID: e2018019. https://doi.org/10.4178/epih.e2018019
15. Bonsu J, Van Dyk W, Franzidis J, Petersen F, Isafiade A (2017) A systemic study of mining accident causality: an analysis of 91 mining accidents from a platinum mine in South Africa, 59–66
16. Nie B, Huang X, Sun X, Li A (2016) Experimental study on physiological changes of people trapped in coal mine accidents. Saf Sci 88:33–43. https://doi.org/10.1016/j.ssci.2016.04.020
17. Fu G, Zhao Z, Hao C, Wu Q (2019) The accident path of coal mine gas explosion based on 24 model: a case study of the Ruizhiyuan gas explosion accident. Processes 7:73. https://doi.org/10.3390/pr7020073
18. Sanmiquel-Pera L, Bascompta M (2019) Analysis of a historical accident in a Spanish coal mine. Int J Env Res Publ Health 16:3615. https://doi.org/10.3390/ijerph16193615
19. Aliabadi MM, Aghaei H, Kalatpuor O, Soltanian AR, Nikravesh A (2019) Analysis of the severity of occupational injuries in the mining industry using a Bayesian network. Epidemiol Health 41:7. Article ID: e2019017. https://doi.org/10.4178/epih.e2019017
20. Jiang W, Zhu ZM, Xiang YC (2017) Study on the unsafe acts and education function in coal mine accidents caused by rescue. EURASIA J Math Sci Technol Educ 8223(11):6203–6209. ISSN: 1305-8223 (online) 1305-8215 (print) 2017 13(9):6203-6209. https://doi.org/10.12973/eurasia.2017.01059a
21. Clarke EE (2015) Injuries among Artisanal and small-scale gold miners in Ghana. 10886–10896. Int J Env Res Publ Health 12:10886–10896. https://doi.org/10.3390/ijerph120910886
22. Tianwei L, Hongwei Z, Sheng L, Jun H, Weihua S, Batugin AC, Guoshui T (2015) Numerical study on 4–1 coal seam of Xiaoming mine in ascending mining. Sci World J 2015:4. Article ID 516095. https://doi.org/10.1155/2015/516095
23. Yu Q, Yin K, Ma J, Shimada H (2018) Vertical shaft support improvement studies by Strata grouting at aquifer zone. Hindawi Adv Civ Eng 2018:10. Article ID 5365987. https://doi.org/10.1155/2018/5365987
24. Wang J, Zhang J (2019) Research on high-power and high-speed hydraulic impact testing machine for mine anti-impact support equipment. Shock Vib 2019:12. Article ID 6545980. https://doi.org/10.1155/2019/6545980
25. Shao L (2019) Geological disaster prevention and control and resource protection in mineral resource exploitation region. Int J Low Carbon Technol 14:142–146. https://doi.org/10.1093/ijlct/ctz003. Hindawi Adv Civ Eng 2019:10. Article ID 1269537. https://doi.org/10.1155/2019/1269537
26. Shi L, Wang J, Zhang G, Cheng X, Zhao X (2017) A risk assessment method to quantitatively investigate the methane explosion in underground coal mine. Proc Saf Environ Prot 107:317–333. https://doi.org/10.1016/j.psep.2017.02.023
27. Qin Z, Li T, Li Q, Chen G, Cao B (2019) Combined early warning method for rock burst and its engineering application
28. Xiao W, Xu J, Lv X (2019) Establishing a georeferenced spatio-temporal database for Chinese coal mining accidents between 2000 and 2015. Geomat Nat Haz Risk 10(1):242–270. https://doi.org/10.1080/19475705.2018.1521476

29. Pons DJ (2016) Pike river mine disaster:systems-engineering and organisational contributions. Safety 2:21. https://doi.org/10.3390/safety2040021
30. Find TO, Persons M, Mine AA (2018) Towards safer mining: the role of modelling software to find missing persons after a mine collapse. Min Miner Depos 12(2):13–28. ISSN 2415-3443 (Online) ISSN 2415-3435 (Print). https://doi.org/10.15407/mining12.02.013
31. Grande C, Science S (2017) Brazil's worst mining disaster: corporations must be compelled to pay the actual environmental costs. Ecol Appl 27(1):5–9. © 2016 by the Ecological Society of America. https://doi.org/10.1002/eap.1461
32. Xu Q, Xu K (2018) Mine safety assessment using gray relational analysis and bow tie model. PLoS ONE 13(3):e0193576. https://doi.org/10.1371/journal.pone.019357
33. Engelbrecht J, Thomas A (2017) Changes in stakeholder dynamics and salience during a mining disaster. S Afr J Bus Manage 48(4): 71–81
34. Cooper MD (2000) Towards a model of safety culture. Saf Sci 36:111–136
35. Lööw J, Nygren M (2019) Initiatives for increased safety in the Swedish mining industry: studying 30 years of improved accident rates. Saf Sci 117:437–446. https://doi.org/10.1016/j.ssci.2019.04.043

A Study of Occupational Stress and Risk Factors Among Palm Oil Mill Workers

Y. L. Ting, Nur Syafiqah Fauzan, and M. N. I. Md. Yusuf

Abstract Occupational stress could damage the health of worker as it may affects their emotional and physical wellbeing. The aim of the study is to determine the relationship between depression, anxiety and stress level and risk factors (physical environment, conflict at work and job requirement) among palm oil mill workers. Fifty (50) workers from palm oil mill industries were participated as respondents. Questionnaires and interviewed sessions were used to determine the level of depression, anxiety and stress, risk factors and relationship between the variables. The result obtained reveal that majority of the palm oil mill workers have a normal level of depression, anxiety and stress. Conflict at work was reported as top risk factor that affect the worker's psychological state followed by job requirement and physical condition of the workplace. Lastly, there is a significant relationship between depression level and physical environment and job requirement ($p = 0.001$, $r = -0.511$) ($p = 0.000$, $r = 0.574$). Anxiety level and job requirement also show a significant positive relationship ($p = 0.004$, $r = 0.403$). In conclusion, the result shows a positive and negative significant correlation between the variables. Besides normal and low depression, anxiety and stress level was detected among palm oil mill workers. Thus, the employer can continuously implement the control measure based on the nature of work to maintain workers' psychological state.

Keywords Depression · Stress · Anxiety · Risk factor · Palm oil mill workers

Y. L. Ting · N. S. Fauzan (✉)
Faculty of Industrial Sciences and Technology, University Malaysia Pahang, 26300 Gambang, Kuantan, Pahang, Malaysia
e-mail: syafiqah@ump.edu.my

M. N. I. Md. Yusuf
Kilang Sawit LCSB, 26300 Gambang, Pahang, Malaysia

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1 Introduction

Stress is a physical, mental and emotional components that can result in physical or mental stress due to the demands of the work environment nowadays. It is also called as occupational stress that could damage the health of worker as it affects their emotional and physical wellbeing [1]. The importance of assessing and concerning on occupational stress, depression and anxiety level have emerging every job and position. A study reported that work stress is responsible for 19% of absenteeism cost, 40% of turnover cost and 60% of injuries at work [2]. Consequently, risk factors that associated with the condition must be concerned.

Risk factors such as physical environment, conflict at work and job requirement were described as common risk factors that could affect the worker's psychological state. Owing to drastic changes in recent years as a result of globalization, competition, technical developments and economic instability, the employment climate is currently marked by a heavy workload, high job requirements and more conflict at work [2]. Several studies proved that a plethora of factors can influence the mental health of individuals including working environment, job requirement and conflict at work [3–5]. Besides, physical environment as such noise may also affect the level of stress [5].

The palm oil mill workers especially operators were believed that they were exposed to large degree of noise during the operating day, experiences excessive workload due to large production and have conflict at the workplace. However, the effect of these factors towards the workers' mental health is unknown. Therefore, this study is conduct to determine whether the level of depression, anxiety and occupational stress among palm oil mill workers will be affected by the risk factors.

2 Methodology

A combined questionnaire of NIOSH Generic Job Stress Questionnaire [6] and Depression Anxiety Stress Scales (DASS) Questionnaire [7] was used to obtain the necessary details from the respondents. The questionnaires were distributed and sent to the palm oil mill workers through online survey to collect information about demographic characteristic, risk factor, depression, anxiety and stress level.

About 50 respondents from production department in two palm oil mill industries were selected randomly to participate in the study as respondents. As workers from the production department are considered experiencing large workload, high possibility of having conflict with co-worker and highly exposed to a high level of noise due to the operating of several machines and equipment.

The data obtained were analyzed using IBM Statistical Package for the Social Science Software (SPSS) Version 23.0. Descriptive analysis was carried out to analyse the demographic of respondents and risk factors into percentage, frequency and mean. The relationship between depression, anxiety and stress level and risk factors among palm oil mill workers were determined using Spearman's correlation.

3 Results and Discussion

3.1 Background of the Respondents

Table 1 shows the frequency and percentage for the demographic details of respondents. Descriptive analysis was conducted based on the information of section A in the questionnaire to assess the background of the respondents. Respondents among operators were predominantly male which are 47 respondents (94%) and married 38 respondents (76%). Majority of them were aged 31–40 years old and 40 years old and above. Besides, most of them completed secondary level (41 respondents, 82%) and work 8–9 h (25 respondents, 50%). Among 50 respondents, 43 of them (86%) are Malaysian and 44 respondents (88%) are Malay.

Table 1 Demographic data among respondents

Demographic	Characteristic	N	(%)
Gender	Male	47	94
	Female	3	6
Age	20 years and below	3	6
	21–30 years	8	16
	31–40 years	19	38
	41 years and above	20	40
Marital status	Single	10	20
	Married	38	76
	Divorced	2	4
Working duration	8–9 h	25	50
	10–11 h	9	18
	More than 12 h	16	32
Nationality	Malaysian	43	86
	Non-Malaysian	7	14
Race	Malay	44	88
	Others	6	12
Educational level	Primary school	5	10
	Secondary school	41	82
	Tertiary	4	8
Job	Operator	50	100

N 50

Table 2 Level of depression, anxiety and stress among respondents

Variables	N (%)	Level				
		Normal	Mild	Moderate	Severe	Extremely severe
Depression	N	22	15	8	4	1
	(%)	44	30	16	8	2
Anxiety	N	28	2	9	6	5
	(%)	56	4	18	12	10
Stress	N	34	5	9	–	2
	(%)	68	10	18	–	4

N 50

3.2 Level of Depression, Anxiety and Stress

Table 2 shows the frequency and percentage for the level of depression, anxiety and stress among 50 respondents. Majority of the respondents had a normal level of depression (44%), anxiety (56%) and stress (68%).

3.3 Risk Factor (Physical Environment)

Table 3 shows the frequency and percentage for the physical environment risk factors including level of noise, level of air circulation, tidiness of work area and quality of environment. A study done by Schonfield [8] found that workers who exposed to poor environments will lead to depressive problems and decreased job satisfaction. Majority of the respondents agreed that their working area is exposed to high level of noise (74%). However, all the workers were provided and equipped with adequate personal protective equipment such as earmuffs and earplug when doing their duties.

Besides, 29 respondents (58%) denied on their overall physical workplace environment was poor. In term of level of air circulation, most of the respondents, which

Table 3 Frequency and percentage of physical environment

		Risk factors			
		High level of noise	Poor quality of environment	Good level of air circulation	Crowded work area
True	N	37	21	43	10
	(%)	74	42	86	20
False	N	13	29	7	40
	(%)	26	58	14	80

N 50

is about 43 (86%), agreed that the workplace is under good and adequate air circulation. While, there are 40 respondents (80%) denied their work area are awfully crowded.

3.4 Risk Factor (Conflict at Work)

Table 4 shows the frequency and percentage for the conflict at work risk factor. There are 18 respondents (36%) strongly agree there is harmony within their group while only 4 workers (8%) moderately disagree on this statement. Majority of respondents (13, 26%) (16, 32%) moderately agree on they have lots of bickering over the job scope and there is dissension in the group respectively. Whereas, 12 respondents (24%) were strongly disagree on both of the statement. Palm oil mill workers (24, 48%) strongly agree on the statement where there is friendliness among the members of the group and 23 respondents (46%) strongly agree there is cooperation between their group and other groups. In term of the statement on there are disputes between my group and other groups, only 5 respondents (10%) strongly agree with it but most of the respondents (15, 30%) given the option of neither agree nor disagree.

3.5 Risk Factor (Job Requirement)

Table 5 shows the percentage and frequency for job requirement risk factor. There are 13 respondents (26%) and 11 respondents (22%) felt their job rarely require them to work very fast and very hard respectively. Besides, same number of respondents, which is 14 (28%), selected the option of rarely and sometimes for statement on how often is there a marked increase in the workload. While, same number of respondents (10, 20%) chosen the option of rarely, sometimes and fairly often for statement on how often is there a marked increase in the amount of concentration required on the job.

3.6 Risk Factor

Table 6 shows the determining factors that associated with the level of depression, anxiety and stress. The top risk factor reported to affect the worker's psychological state was conflict at work (mean = 3.32 ± 1.03). Relationship between co-worker is the most determinant factor due to workers spend most of the time at the workplace and result the formation of workplace friendship [9]. The second important factor was job requirement (mean = 2.97 ± 1.42) followed by physical conditions of the workplace (mean = 1.45 ± 0.27).

Table 4 Frequency and percentage of conflict at work

Question		Conflict at Work				
		Strongly disagree	Moderately disagree	Neither agree nor disagree	Moderately agree	Strongly agree
1. There is harmony within my group	Frequency (N)	5	4	9	14	18
	Percentage (%)	10	8	18	28	36
2. In our group, we have lots of bickering over who should do what job	Frequency (N)	12	10	10	13	5
	Percentage (%)	24	20	20	26	10
3. There is dissension in my group	Frequency (N)	12	14	5	16	3
	Percentage (%)	24	28	10	32	6
4. There is friendliness among the members of my group	Frequency (N)	4	5	9	8	24
	Percentage (%)	8	‘10	18	16	48
5. There are disputes between my group and other groups	Frequency (N)	12	10	15	8	5
	Percentage (%)	24	20	30	16	10
6. There is cooperation between my group and other groups	Frequency (N)	4	6	10	7	23
	Percentage (%)	8	12	20	14	46

N 50

Palm oil mill workers feel that their job rarely requires them to work fast, work hard, increase in workload and concentration. Besides, overall quality of the physical environment is good where the air circulation is adequate and the work area does not awfully crowd. Although the workers feel that they are exposed to high level of noise, however, they were provided with personal protective equipment.

Table 5 Frequency and percentage of job requirement

Question		Job requirement				
		Rarely	Occasionally	Sometimes	Fairly often	Very often
1. How often does your job require you to work very fast?	Frequency (N)	13	4	11	12	10
	Percentage (%)	26	8	22	24	20
2. How often does your job require you to work very hard?	Frequency (N)	11	10	9	10	10
	Percentage (%)	22	20	18	20	20
3. How often is there a marked increase in the workload?	Frequency (N)	14	7	14	7	8
	Percentage (%)	28	14	28	14	16
4. How often is there a marked increase in the amount of concentration required on your job?	Frequency (N)	10	9	10	10	11
	Percentage (%)	20	18	20	20	22

N 50

Table 6 Scores on risk factors

Risk factor	Mean	Standard deviation (SD)
Conflict at work	3.32	1.03
Job requirement	2.97	1.42
Physical environment	1.45	0.27

N 50

3.7 Relationship Between the Depression Level and Risk Factors

Table 7 shows the Spearman's correlation analysis on depression level and risk factors. The result signify that the *p*-value for the physical environment and job requirement were below significant level ($\alpha = 0.05$), which are ($p = 0.001$, $r = -0.511$) and ($p = 0.000$, $r = 0.574$) respectively. This indicating that there is a significant negative correlation between the physical environment and depression level

Table 7 Relationship between depression and risk factors

Variable	Depression	
	Correlation coefficient (r value)	Sig. (2-tailed) (*p* value)
Physical environment	−0.511	0.001*
Conflict at work	−0.136	0.345
Job requirement	0.574	0.000*

N 50
*Correlation is significant at the 0.01 level (2-tailed)

while there is a significant positive correlation between job requirement and depression level. However, there is no significant correlation between conflict at work (p = 0.345, r = -0.136) and depression level.

The level of depression increases when the physical environment of the workplace deceases (negative relationship). For example, more crowded workplace, poor quality of environment, poor air circulation and high level of noise could increase the level of depression among workers. This statement have been supported by previous study which revealed that physical condition such as high level of noise result in increased level of depression [10]. It is also proved by another study where poor working conditions can be major stressors for oil palm plantation workers [11].

Besides, the level of depression increases wen the job requirement increases (positive relationship). This statement have been supported by a study which revealed that there was a significant correlation between job demand and risk of depression [12]. It is also proved by another study where the requirement to work fast will increased depression among blue-collar worker [13].

3.8 Relationship Between the Anxiety Level and Risk Factors

Table 8 shows the Spearman's correlation analysis on anxiety level and risk factors. The result signify that the p-value for the job requirement was below significant level

Table 8 Relationship between anxiety and risk factors

Variable	Anxiety	
	Correlation coefficient (r-value)	Sig. (2-tailed) (*p*-value)
Physical environment	−0.180	0.210
Conflict at work	0.007	0.960
Job requirement	0.403	0.004*

N 50
*Correlation is significant at the 0.01 level (2-tailed)

Table 9 Relationship between stress and risk factors

Variable	Stress	
	Correlation coefficient (r-value)	Sig. (2-tailed) (*p*-value)
Physical environment	−0.218	0.128
Conflict at work	−0.092	0.524
Job requirement	0.242	0.091

N 50

($\alpha = 0.05$), which is ($p = 0.004$, r = 0.403). This indicating that there is a significant positive correlation between job requirement and anxiety level. However, there is no significant correlation between anxiety level and physical environment ($p = 0.21$, r = -0.18) and anxiety level and conflict at work ($p = 0.96$, r = 0.007).

The level of anxiety increases when the job requirement increases (positive relationship). This statement are supported by a study where it revealed that job demand is significant associated with the prevalence of anxiety symptoms [14]. A chi-square test was conducted to determine the distribution differences in anxiety symptoms based on job characteristic and job demands. It is also proved by another study where the workload of nurses has a positive effect on their psychological state. For example, as workload of nurses increase, the level of anxiety also increases [15].

3.9 Relationship Between the Stress Level and Risk Factors

Table 9 shows the Spearman's correlation analysis on stress level and risk factors. The result signify that the *p*-value for all of the risk factors are above significant level ($\alpha = 0.05$). Physical environment ($p = 0.128$, r = −0.218), conflict at work ($p = 0.524$, r = −0.092) and job requirement ($p = 0.091$, r = 0.242). These results indicating that there is no significant correlation between stress level and risk factors.

4 Conclusion

The study had found that the respondents were predominantly male which are 47 respondents (83.9%) and married 43 respondents (76.8%). Majority of them were aged 31–40 years old and 40 years old and above. Besides, most of them completed secondary level (46 respondents, 82.1%) and work 8–9 h (30 respondents, 53.6%). Majority of the respondents has a normal level of depression, anxiety and stress. Conflict at work was reported as top risk factor that affect the worker's psychological state followed by job requirement and physical condition of the workplace.

The significant relationship between depression and anxiety level and risk factor among palm oil mill workers was identified in the study. Result showed a significant positive correlation between job requirement and depression and anxiety level whereas a significant negative correlation had shown between physical environment and depression level. The presented findings encourage the companies continuously implement the control measure based on the nature of work to maintain the level of depression, anxiety and stress of workers.

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References

1. Marcus M, Yasamy MT, Van Ommeren M, Chisholm D (2012) Depression, a global public health concern. WHO Department of Mental Health and Substance Abuse
2. Azagba S, Sharaf MF (2011) The effect of job stress on smoking and alcohol consumption. Health Econ Rev. https://doi.org/10.1186/2191-1991-1-15
3. Hasanati N, Winarsunu T, Karina VD (2018) The influence of interpersonal conflict on counterproductive work behaviour mediated by job stress. https://doi.org/10.2991/acpch-17.2018.17.LNCS Homepage, http://www.springer.com/lncs. Last accessed 21 Nov 2016
4. Al-Omar B (2003) Sources of work-stress among hospital-staff at the Saudi MOH. J King Abdulaziz Univ Econ Adm. https://doi.org/10.4197/Eco.17-1.1
5. Abbasi M, Yazdanirad S, Arabi S, Madvari RF, Mehri A, Poursadeghiyan M, Ebrahimi MH, Ghaljahi M (2019) Relationship among noise exposure, sensitivity, and noise annoyance with job satisfaction and job stress in a textile industry. Noise Vib Worldw 50(6):195–201. https://doi.org/10.1177/0957456519853812
6. National Institute for Occupational Safety and Health: Niosh generic job stress questionnaire. https://www.cdc.gov/niosh/topics/workorg/detail088.html, last reviewed on 14 June 2017
7. Parkitny L, McAuley J (2010) The depression anxiety stress scale (DASS). J Physiother. https://doi.org/10.1016/s1836-9553(10)70030-8
8. Schonfield IS (2000) An updated look at depressive symptoms and job satisfaction in first-year women teachers. J Occup Organ Psychol 73(3):363–371
9. Owusu B (2014) An assessment of job satisfaction and its effect on employees' performance: a case of mining companies in the [Bibiani–Anhwiaso–Bekwai District] in the Western Region, Knust
10. Aziah BD, Rusli BN, Winn T, Naing L, Tengku MAT (2004) Prevalence and associated factors of job-related depression in laboratory technicians in Hospital Universiti Sains Malaysia (HUSM) and Ministry of Health Malaysia (MOH) hospitals in Kelantan. Med J Malaysia
11. Myzabella N, Fritschi L, Merdith N, El-Zaemey S, Chih H, Reid A (2019) Occupational health and safety in the palm oil industry: a systematic review. Int J Occup Env Med. https://doi.org/10.15171/ijoem.2019.1576
12. DeSanto Iennaco J, Cullen MR, Cantley L, Slade MD, Fiellin M, Kasl SV (2010) Effects of externally rated job demand and control on depression diagnosis claims in an industrial cohort. Am J Epidemiol. https://doi.org/10.1093/aje/kwp359
13. Cohidon C, Santin G, Imbernon E, Goldberg M (2010) Working conditions and depressive symptoms in the 2003 decennial health survey: The role of the occupational category. Soc Psychiatry Psychiatr Epidemiol. https://doi.org/10.1007/s00127-009-0157-7

14. Lee KH, Chae CH, Kim YO, Son JS, Kim J, Kim CW, Park HO, Lee JH, Jung YS (2015) Anxiety symptoms and occupational stress among young Korean female manufacturing workers. Ann Occup Environ Med. https://doi.org/10.1186/s40557-015-0075-y
15. Kokoroko E, Sanda MA (2019) Effect of workload on job stress of Ghanaian OPD nurses: the role of coworker support. Saf Health Work. https://doi.org/10.1016/j.shaw.2019.04.002

Effect of Mental Workload on Heart Rate Variability and Reaction Time of Aircraft Maintenance Personnel

Abdul Ghani Abdul Samad, Mohd Amzar Azizan, Md Hafis Khairuddin, and Muhd Khudri Johari

Abstract Any employee's mental workload can be assessed in a traditional maintenance-nature workplace by recording psychophysiological elements, job performance, and self-rating questionnaires/scales. This research focuses on mental workload, which is defined as the cognitive demand of a task that was previously studied (Galy et al. in Int J Psychophysiol 83:269–275, 2012 [1]). Measuring the workload response of personnel was used to assess mental workload using the Easy ECG Monitor Model PC-80A for heart rate variability (HRV) and an online RED LIGHT–GREEN LIGHT Reaction Time Test for reaction time (RT). 20 personnel (with approved pre-checked health conditions and consents) were selected for this experiment. The results showed that mental workload significantly affects HRV as the numbers indicate increased values of the powers in Low frequency (LF) band, high frequency (HF) band, and the ratio of LF to HF; which are sensitive indicators for mental and physical stress. The reaction time was also significantly affected as the task-completion period was increased by two hours in between trials.

Keywords Mental workload · Heart rate variability · Reaction time

1 Background

1.1 Mental Workload

Mental workload is one of the many significant domains under human factors in the aviation world. According to Charles and Nixon, workloads can be imagined as inputs and outputs, both subject by users, requested by users from work and spent by users to perform tasks [2]. Marinescu et al. highlighted that terms like "mental workload" or "mental strength" have been used interchangeably to indicate their

A. G. Abdul Samad (✉) · M. A. Azizan · M. H. Khairuddin · M. K. Johari
Universiti Kuala Lumpur—Malaysian Institute of Aviation Technology, 43900 Sepang, Selangor, Malaysia
e-mail: abdulghani@unikl.edu.my

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importance as compared to physical strength in assessing physical work performance of aviation personnel—which include studies done to incorporate these elements with application of technology [3].

Poor performance occurs from overload information and there are limits on human information processing capabilities. Bevilacqua et al. [4] stated that because of human resource is limited, employees should not be burdened by assignment. To be sure on the long-term productive efficiency, comfort, safety and health of the employee is to maintain task demands so that they do not experience overloading an individual [4]. Human brains constantly process inputs from mental workload accumulated. The level of workload determines between the demand and the capacity.

Wu presented a theoretical framework that provides a systematic approach to analyzing mental workload in manufacturing [5].

Behavioral analysis pilots suffering from excessive mental workload are affected cognitively, particularly concerning actions related to short-term memory as described by Causse et al. [6]. The human operator has limited capacity usually in terms of attention or focus.

The performance measures based on high demands will lead to an increase in the task which will reduce the performance. The study of psychological and physiological human factors may aid in predicting the work performance of maintenance crews as mentioned by Wang and Chuang [7].

1.2 Issues

The human capacity to work is limited. Due to working longer periods, it will decrease the efficiency of working. However, fatigue simply defines as tiredness after working continuously.

Physical fatigue has been studied mainly in fields, such as exercise physiology. Setiawan et al. [8] stated that while they were focusing on mental fatigue, they were not able to come up with a standardized testing procedure to assess fatigue. Levin et al. [9] revealed that the subjective and complex elements of the entire domain is a considerable factor.

Wendsche et al. [10] explained that aviation workers in certain departments like air traffic control, aircraft handling and aerospace operations are all exposed to fatigue and stress. Laukkala et al. also shared the same sentiment that these workers, especially in air traffic control, aircraft handling, and aerospace operations are all exposed to fatigue and stress [11]. Most of these are 24-hour operations, where they have to be in constant situational awareness and they have the potential to become mentally overloaded.

1.3 Previous Research

Fatigue can come from various sources. Fatigue is dangerous but it is easy to prevent;

Härmä et al. had the same idea of a worker's physical health, wellbeing and conditions are crucial in determining level(s) of seriousness for fatigue [12].

This was considered to be a major deficiency in accidents and incidents in aviation companies performing internal investigations as mentioned by Göker [13] in a previous research. Fatigue is a manageable threat to transportation security that can be mitigated by a combination of science-based rules, comprehensive risk management programs, and individual responsibility. To measure fatigues, HRV and reaction time experiments are optimal options.

1.4 Heart Rate Variability (HRV)

The rate at which cardiac beats occur is known as heart rate, and it is normally expressed in beats per minute.

Thomas et al. [14] said that an electrocardiogram or sensors that detect the cardiac inter beat interval are used to assess HRV (IBI). Hoogendoorn et al. suggested that heart rate and heart rate variability were used to assess physiological measures of mental workload. Some heart rate research studies have looked into the effects of physical pressure and mental stress on HRV [15].

Normal people's electrocardiograms (ECGs) show intermittent variations in the RR interval (the time between two consecutive R-waves of the ECG) when they are at rest. Ichwana et al. [16] added that at rest, the normal heart rate is between 60 and 100 BPM.

1.5 Reaction Time (RT)

Many methods have been used to test the level of fatigue that occurs after various types of mental workload.

Most investigators use the ergograph to show the effects of mental fatigue in the regular series of voluntary muscle action, but such methods can only provide general results and not allow them to know the mental fatigue.

Russell et al. [17] said that the wide differences in the participants involved, the design of the cognitively taxing tasks used to cause mental fatigue, and the measures used to measure performance outcomes can all be due to contradictory results in the limited available literature.

While doing a lot of experiments at the time of reaction, various manifestations of fatigue in the different recordings analyzed that fatigue had lasted after some long experiments. Campbell et al. [18] mentioned that a different outcome acknowledges the ambiguous relationship between response time and respondents' choices to assess the level of fatigue by extending the response time; it is important to get an idea of the out-of-state conditions that affect reaction time. Therefore, as it can be easily understood, the main factor in the response to the reaction time is its concern.

1.6 Objective

The main objective is to evaluate whether the tasks performed in the trial experiment will have any significant effect on the personnel's heart rate variability (HRV) and reaction time (RT) by using non-intrusive methods.

In particular, studies in aircraft maintenance are mostly the studies focused on pilot mental workload as mentioned by Tanaka et al. [19] and Zhou et al. [20].

Heart rate variability was also used in the study by utilizing "Simulator-based Ship Handling" like how it was done by Kitamura et al. [21] and Sugimoto et al. [22].

2 Methodology

2.1 Experiment

Aircraft maintenance personnel and pilot incapacitation when involving fatigue have become a big issue that causes many fatal accidents. So for this study, UniKL MIAT (Universiti Kuala Lumpur—Malaysian Institute of Aviation Technology), which is an ATO Part 147 aviation training school, will be the center of an experiment measuring fatigue issues at workshop and hangar as in the real aviation industry.

Thus, the scope for this study is focusing more on sheet metal repair workshops and limited to the UniKL MIAT students only—which are the same scenario as working in an AMO Part 145 environment.

The limitation of this study is the difficulty of a base maintenance organization to approve on the survey to collect the general information and data regarding fatigue; so, having selected the respondents from UniKL MIAT students is the best solution to resolve the limitation. A combination of 20 EASA Part 66—Aircraft Maintenance Engineer License students from UniKL MIAT were chosen to base the research on. For the record, none of the participants had a sedentary lifestyle, a history of cardiovascular or musculoskeletal disorders, or were actively taking drugs that could affect heart rate. On the days of the trial, the participants were asked to refrain from any strenuous exercise as well as the intake of alcohol, nicotine, or caffeine.

The following information was gathered for the study:

i. During physical and mental workload output, heart rate (beat to beat data) was measured using a heart rate monitor. This task consisted of 360 trials with a total time of 10–13 min. as described by Luque-Casado et al. [23]

ii. Subjective workload assessments for both mental and physical activities (obtained from the measurement and estimation process).
iii. Range of reaction time measured for the participant in assessing to identify the crack skin area for surface patch repair. This task had a total of 360 trials and took between 10 and 13 min to complete.

2.2 Experiment

For the pre-test procedures, the participants were given a consent form that explained the research protocols, advantages, risks, and exclusion criteria in order to participate; they were expected to sign it. Full explanation on how to use the heart rate monitor and how the experiment would be carried out were both given in explicit verbal instructions. Participants also completed a demographics form, which included questions about their age, gender, ethnicity, and physical fitness.

For the actual procedure, on two different days, each participant repeated the experiment (example: Monday and Tuesday) by following the same steps (although the informed consent and the demographic questionnaire were conducted only on the first day). The current thesis was based on the data collected during the two sessions. The following protocols were followed:

i. The participants completed the demographics form and signed the consent form.
ii. Each participant was given verbal instructions on how to use the simple ECG monitor by an experimenter, which is a handheld portable device. It can be uploaded to be saved in personal computers after entering into the ECG viewer system. After the participant had put the display on, an experimenter visually examined it.
iii. The resting heart rate was recorded after the HR monitor was turned on. The participant was asked to sit still for the duration of this period - with no significant movements or mental disturbances.

Each individual was responsible for both tasks and the protocol outlined above was followed each time. Between each mission, a 5-min rest period was permitted.

The participants performed the mental and physical tasks on day one for 2 (two) hours; on the second day, they would perform the physical and mental tasks for 4 (four) hours.

This was done to see if there were any possible order results. If the participants' heart rates exceeded 85% of their maximum heart rate at any point during the experiment, or if they stopped at any time without penalty, the experiment would be terminated [24].

Any participant who had an abnormally higher or lower HR during the rest time was not allowed to participate in the experiment. In both sessions, participants followed the same sequence.

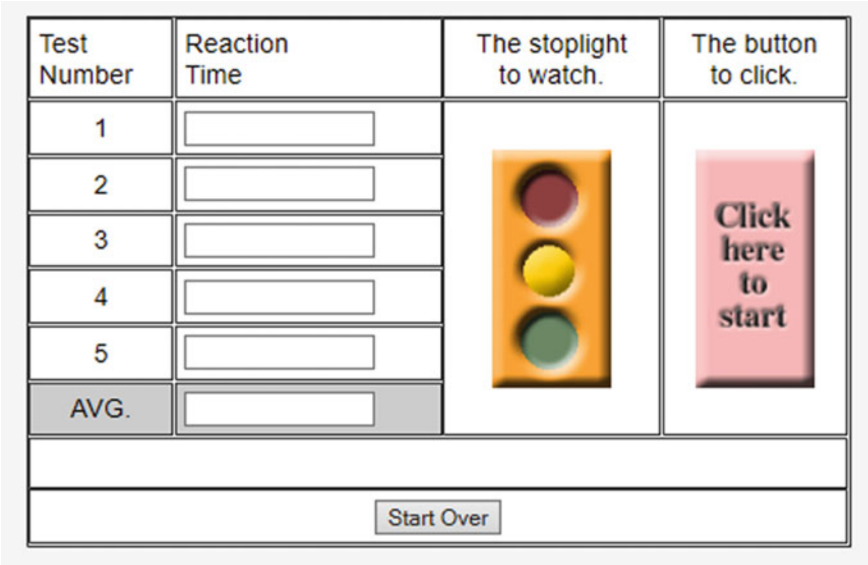

Fig. 1 Online RED LIGHT–GREEN LIGHT reaction time test [25]

2.3 Apparatus

The Easy ECG Sensor was used as a heart rate monitor. The Model PC-80A, which is a handheld portable device, uploaded all the data records of the waveform description list—the PQRST wave. It included a 3-Lead Cable, Pack of Pads, and a USB cable which can be uploaded to be saved in personal computer after entering into ECG viewer system. Beat to beat (RR) intervals, or the time between beats, were used to capture the heart rate data.

For the reaction time testing, the University of Washington's online RED LIGHT–GREEN LIGHT Reaction Time Test was utilized as shown in Fig. 1. This simple reaction time is a convenient and continuous performance test for long-term testing of awareness.

2.4 Tasks

A collective of various aircraft maintenance tasks was sequenced for every personnel; they were instructed to complete their work as quickly and accurately as possible whilst referring to the specific safety regulations, standard operating procedures, and maintenance manuals.

During the entire process, their heart rates would be recorded for five minutes and they would be tested with the RED LIGHT–GREEN LIGHT Reaction Time

Test—right after they have completed each task. The tasks involved were expected to be completed within 120 min; the details are as mentioned below:

i. Assessing the damage of a metal structure—identifying stressed/cracked skin (10 min)
ii. Making a circular patch that has uniform strength in all directions—which included calculating the rivet diameter, rivet length, edge distance, rivet pitch, rivet gage, rivet per inch, and several rivets. Verification and reference documents used were the AC 43.13-1B/2A/aircraft repair manual / Sheet Repair Manual (SRM) for the recommended shape for the patch and repair completion (50 min).
iii. Preparation of protruding head rivet holes on aircraft structures—every hole must have accepted MS20426AD3 after the patch was reinstalled on the skin and the holes have been drilled (30 min).
iv. Preparation of flush rivet holes on aircraft structures—depending on the thickness of the skin (30 min).

3 Analysis

3.1 Variables

There were 2 independent variables; task type (mental task and physical task) and trial order (it was done in two ways—physical task and mental task was done in the morning or the afternoon).

There were four categories in the dependent variables as follows:

i. The power in the LF (low frequency) and HF (high frequency) bands, as well as the ratio of LF to HF, were included in the frequency domain output for R-R intervals during both the mental and physical tasks. These components were discovered through HRV power spectral analysis.
ii. For both tasks, the time-domain output is as follows: The time domain value of interest was a root, which was defined as the square difference of successive RR intervals (RMSSD). This metric was used to see whether the RR interval data for the physical and mental tasks differed.
iii. The level of time measured and preparation after each task for the participant is identified and calculating the crack skin area.
iv. Level of fatigue on workload assessed during drilling and flush rivet.

3.2 RR Interval Data

The data for the RR interval was derived directly from the heart rate monitor. The easy ECG Monitor Model: PC-80A uploaded all the data records of the waveform description list that can be uploaded to be saved in PC after entering into the ECG Viewer System.

There are two types of HRV analysis methods: time-domain and frequency-domain. The data over some time-domain and frequency-domain analyze a mathematical function or a signal for the frequency.

3.3 Time Domain Analysis

The raw RR interval data was used to obtain the time-domain parameters. The standard deviation and mean of the RR intervals are the most common time-domain indicators.

Short-term variation is defined by the square root of the standard deviation of the differences between consecutive RR intervals (RMSSD). The RMSSD values obtained were used in this research.

3.4 Frequency Domain Analysis

The power spectral density (PSD) measurement provides details on power distribution as a function of the frequency. In this research, the RR interval time series was used. If the spectrum estimate had been made using this raw interval data, there would have been more harmonic components in the range.

The RR interval signal was interpolated before the spectral analysis to obtain an equally sampled signal from the raw data. Signal de trending was the term for this. The trend could be eliminated using the smoothness prior's method, or the first or second order linear pattern could be omitted.

The conventional non-parametric approach of using fast fourier transformation (FFT) and parametric method based on autoregressive models can both be used to estimate the PSD.

The non-parametric analysis was used in this study. The band powers were measured as powers of these components after splitting the spectrum into components. Low frequency (LF, 0.04–0.15 Hz) and high frequency (HF, 0.15–0.4 Hz) frequency bands were used [26].

The power of the LF and HF bands in absolute values, the normalized power of the LF and HF bands, and the LF to HF ratio were the frequency-domain parameters measured. The statistical analysis for this study used HF, LF, LF/HF absolute values (natural logarithm transformed), and normalized units.

4 Results

The participants did the two-hour mental and physical tasks (trial order 1) followed by the four-hour mental and physical tasks (trial order 2).

Despite the fact that the software produced standard units for each component, the absolute power values for each component were taken to represent the maximum power distribution across the spectrum. The LF and LF power components (i.e. absolute power values) were evaluated after the natural logarithmic transformation due to the measure of the probability distribution's asymmetry. Tables 1 and 2 show the complete methods and standard deviations for each dependent variable.

The statistical analysis involves all of the variables mentioned above. All of the variables were subjected to an ANOVA. Tables 3 and 4 show the ANOVA *p*-values,

Table 1 Dependent variable for standard deviations and averages (Trial 1—two hours)

Trial order 1 (2 h)				
	Mental task (L)	Mental task (H)	Physical task (L)	Physical task (H)
Ln (low frequency (LF))	3.65 (1.13)	4.89 (1.27)	6.78 (1.32)	7.12 (0.98)
Ln (high frequency (HF))	3.49 (0.86)	3.34 (1.23)	3.21 (1.12)	3.04 (1.31)
LF (n.u)	73.0 (11.4)	77.0 (14.6)	79.0 (12.5)	82.0 (7.49)
HF (n.u)	25.7 (9.3)	23.6 (12.4)	21.2 (6.7)	20.6 (11.6)
LF/HF ratio	4.21 (2.4)	5.23 (2.3)	5.46 (2.6)	5.92 (2.1)
Root means square standard deviation	19.4 (9.5)	25.0 (23.7)	29.7 (20.3)	33.8 (25.5)

Note *L* Light; *H* Heavy

Table 2 Standard deviations and averages for dependent variables (Trial 2—four hours)

Trial order 2 (4 h)				
	Mental task (L)	Mental task (H)	Physical task (L)	Physical task (H)
Ln (low frequency (LF))	3.13 (1.29)	4.13 (0.89)	5.34 (1.32)	5.99 (0.98)
Ln (high frequency (HF)	3.35 (0.86)	3.29 (1.23)	3.21 (1.12)	3.03 (1.31)
LF (n.u)	71.0 (9.3)	72.0 (12.3)	74.0 (10.4)	79.0 (8.67)
HF (n.u)	25.3 (8.4)	23.5 (10.4)	21.4 (5.3)	20.4 (9.5)
LF/HF ratio	4.31 (2.7)	4.97 (2.5)	5.43 (2.4)	5.86 (2.1)
Root means square standard deviation	18.9 (10.3)	23.6 (21.3)	27.6 (21.3)	31.3 (23.5)

Note *L* Light; *H* Heavy

Table 3 ANOVA *p*-values (trial)

Trial				
Dependent variables	Mental task (L)	Mental task (H)	Physical task (L)	Physical task (H)
Ln (low frequency (LF))	0.673	0.789	0.876	0.987
Ln (high frequency (HF))	0.245	0.678	0.923	0.875
LF/HF ratio	0.564	0.753	0.712	0.784
Root means square standard deviation	0.932	0.954	0.923	0.967

Note L Light; *H* Heavy

Table 4 ANOVA *p*-values (task)

Task		
Dependent variables	Trial 1	Trial 2
Ln (low frequency (LF))	<0.0001*	<0.0001*
Ln (high frequency (HF))	<0.0001*	<0.0001*
LF/HF ratio	0.456	0.267
Root means square standard deviation	<0.0001*	<0.0001*

with "*" indicating important *p*-values. For any of the dependent variables, trial order is not a relevant factor.

The task in this research is split into two ANOVA analyses for Trial 1 and Trial 2 as shown in Tables 3 and 4. The *p*-values for the LF and HF components are <0.0001 for the tasks of Trial 1 (two hours) and Trial 2 (four hours). Based on the significant *p*-values for both trials obtained, the results showed that task types during Trial 1 and Trial 2 affected both LF and HF components.

The *p*-values for the RMSSD are also <0.0001 for the tasks of Trial 1 (two hours) and Trial 2 (four hours). Hence, it can also be interpreted that task types during Trial 1 and Trial 2 affected the personnel's reaction time.

5 Discussion and Recommendations

5.1 Discussion

In this research, a significant effect of the task type on both HF, LF and RMSSD components was shown. A number of studies had been conducted with prolonged support and the principal findings of this research aligned with those studies. The key finding of this research is that HRV indices, such as LF, HF, and the LF/HF ratio, are sensitive measures of mental and physical stress, which is consistent with many other studies using either prolonged [27] or short-term recordings to psychosocial stressors [28].

The HF power factor and the time-domain variable RMSSD are highly correlated. The rise in RMSSD values was important for both tasks, with the mental task being the most prominent. The explanation for this may be that the respiratory sinus arrhythmia regulates the HF capacity [26]. There may have been shifts in breathing patterns as a result of the mental task's nature, reducing the HF components and suggesting an improvement in HRV.

As a result, all heart rate variables were found to be responsive to physical and mental stress. With an increase in demands, the HF component decreased. It was particularly responsive to physical demands, and during the physical task, it was reduced. The LF variable increased in response to an increase in overall stress levels and was more responsive to the mental activity. Regardless of the type of role performed, the LF/HF ratio increased as demands increased. The RMSSD component differed from the HF component in that it was a sensitive measure of physical stress.

The real tasks were designed to simulate mental and physical stress, while the laboatory tasks were designed to simulate mental and physical stress to provide as close to a productive working atmosphere as possible. However, since college students seldom do extreme work, the physical activity may not be very realistic for them. The aim was to create a general manual task handling system. In fact, those in charge of these tasks may be more accustomed to and capable of completing them.

In real time, the mental task may not be a condition. Responses to job complexity, extra work, multitasking, and scheduling breakthroughs (shift work, or any airline industry) are more realistic examples of psychological pressure.

6 Conclusion

The current research looks at only one of these responses, namely the heart's reaction to physical and mental stress induced in a lab environment. These responses, however, are of interest not only as stress markers, but also as a potential correlation between psychosocial stress and a variety of physical healthcare outcomes. Future research could look at how HR variables affect task intensity and location in different situations. Rather, it investigates the potential effects of induced physical and mental stress on cardiovascular disease (CVD). Although this study does not directly link CVD triggers to HR variability, it does so implicitly. The association between perceived workload ratings and heart rate variables will be further explored in the future.

References

1. Galy E, Cariou M, Mélan C (2012) What is the relationship between mental workload factors and cognitive load types? Int J Psychophysiol 83(3):269–275
2. Charles RL, Nixon J (2019) Measuring mental workload using physiological measures: a systematic review. Appl Ergon 74:221–232
3. Marinescu A, Sharples S, Ritchie A, Lopez T, McDowell M, Morvan H (2018) Physiological parameter response to variation of mental workload. Hum Factors 60(1):31–56
4. Bevilacqua M, Ciarapica F, Mazzuto G, Paciarotti C (2013) Visual management implementation and evaluation through mental workload analysis. In: 11th IFAC workshop on intelligent manufacturing systems. Elsevier, Sao Paulo, pp 294–299
5. Wu C (2016) The five key questions of human performance modeling. Int J Ind Ergon 63:3–6
6. Causse M, Fabre E, Giraudet L, Gonzalez M, Peysakhovich V (2015) EEG/ERP as a measure of mental workload in a simple piloting task. Proc Manuf 3:5230–5236
7. Wang T, Chuang L (2014) Psychological and physiological fatigue variation and fatigue factors in aircraft line maintenance crews. Int J Ind Ergon 44(1):107–113
8. Setiawan A, Wibawa A, Pane E, Purnomo M (2019) EEG-based mental fatigue detection using cognitive tests and RVM classification. In: 2019 international conference of artificial intelligence and information technology (ICAIIT). IEEE, Yogyakarta, pp 180–185
9. Levin E, Mendonca F, Keller J, Teo A (2019) Fatigue in collegiate aviation. Int J Aviat Aeronaut Aerosp 6(4):1–25
10. Wendsche J, Ghadiri A, Bengsch A, Wegge J (2017) Antecedents and outcomes of nurses' rest break organization: a scoping review. Int J Nurs Stud 75:65–80
11. Laukkala T, Bor R, Budowle B, Navathe P, Sajantila A, Sainio M, Vuorio A (2018) Pilot posttraumatic stress disorder and fatal aviation accidents. Aviat Psychol Appl Hum Fact 8(2):93–99
12. Härmä M, Karhula K, Ropponen A, Puttonen S, Koskinen A, Ojajärvi A, Hakola T, Pentti J, Oksanen T, Vahtera J, Kivimäki M (2018) Association of changes in work shifts and shift intensity with change in fatigue and disturbed sleep: a within-subject study. Scand J Work Environ Health 44(4):394–402
13. Göker Z (2018) Fatigue in the aviation: an overview of the measurements and countermeasures. J Aviat 2(2):185–194
14. Thomas B, Claassen N, Becker P, Viljoen M (2019) Validity of commonly used heart rate variability markers of autonomic nervous system function. Neuropsychobiology 178(1):4–26
15. Hoogendoorn R, Hoogendoorn S, Brookhuis K, Daamen W (2010) Psychological elements in car-following models: mental workload in case of incidents in the other driving lane. Proc Eng 3:87–99
16. Ichwana D, Ikhlas R, Ekariani S (2018) Heart rate monitoring system during physical exercise for fatigue warning using non-invasive wearable sensor. In: 2018 international conference on information technology systems and innovation (ICITSI). IEEE, Bandung, pp 497–502
17. Russell S, Jenkins D, Smith M, Halson S, Kelly V (2019) The application of mental fatigue research to elite team sport performance: new perspectives. J Sci Med Sports 22(6):723–728
18. Campbell D, Mørkbak M, Olsen S (2018) The link between response time and preference, variance and processing heterogeneity in stated choice experiments. J Environ Econ Manag 88:1834
19. Tanaka M, Murai K, Hayashi Y (2013) Evaluation of pilot mental workload for simulator based training using heart rate variability. In: Proceedings—2013 IEEE international conference on systems, man, and cybernetics, SMC 2013. IEEE, Manchester, pp 4601–4605
20. Zhou Y, He J, Wang Z, Fu S (2014) Study on the correlation between physiological and subjective workload measurements. In: 2014 international conference on information science, electronics and electrical engineering. IEEE, Sapporo, pp 308–312
21. Kitamura K, Murai K, Furusho M, Wang Y, Wang J, Kunieda Y (2016) Evaluation of mixed culture bridge teammates' mental workload using heart rate variability: simulator-based ship

handling. In: 2016 IEEE international conference on systems, man, and cybernetics (SMC). IEEE, Budapest
22. Sugimoto I, Kitamura K, Murai K, Wang Y, Wang J (2016) Study on relation between operator and trainee's mental workload for ship maneuvering simulator exercise using heart rate variability. In: 2016 IEEE international conference on systems, man, and cybernetics (SMC). IEEE, Budapest
23. Luque-Casado A, Zabala M, Morales E, Mateo-March M, Sanabria D (2013) Cognitive performance and heart rate variability: the influence of fitness level. PLoS ONE 8(2):e56935
24. Latorella K, Prabhu P (2000) Human error in aviation maintenance and inspection. Int J Ind Eng 26(2):133–161
25. University of Washington's online reaction time test, https://faculty.washington.edu/chudler/java/redgreen.html. Last accessed 16 Mar 2020
26. Kamath M, Fallen E (1993) Power spectral analysis of heart rate variability: a noninvasive signature of cardiac autonomic function. Crit Rev Biomed Eng 21(3):245–311
27. Collins S, Karasek R, Costas K (2005) Job strain and autonomic indices of cardiovascular disease risk. Am J Ind Med 48(3):182–193
28. Hjortskov N, Rissen D, Blansted A, Fallentin N, Lundberg U, Sogaard K (2004) The effect of mental stress on heart rate variability and blood pressure during computer work. Eur J Appl Physiol 92(1–2):84–89

A Review on the Mental Workload and Physical Workload for Aircraft Maintenance Personnel

Abdul Ghani Abdul Samad, Mohd Amzar Azizan, Md Hafis Khairuddin, and Muhd Khudri Johari

Abstract This paper reviews the nature and differences of both mental workload and physical workload that exist in the maintenance working culture. From general point of view to aviation maintenance in specifics, it can be ascertained that both workloads are equally imperative to be balanced and distributed to ensure effectiveness of work completion and safety for working personnel. While physical workload is more apparent and noticeable by many, mental workload can actually become evident from emotions conveyed and physical interactions displayed. It is hoped that industry players can focus on both mental workload and physical workload issues equally when it comes to personnel's welfare and wellbeing to ensure win–win environment for all. This review will be used as a main reference for a subsequent research focusing on the relationship of physical workload and mental workload toward aircraft maintenance personnel's reaction time and heart rate variability.

Keywords Mental workload · Physical workload · Aircraft maintenance industry

1 Fatigue

Fujita et al. [1] generally address fatigue as either physical or mental. Other definition of fatigue is loss of capacity to respond of an organism or part to function normally because of excessive workload. It is normally the results of a person who works beyond their limitation or capacity due to exertion. Based on Abdul Hamid et al. [2], fatigue is described as a temporary inability or decrease in capacity or general objection to responding to a situation as a result of previous mental, emotional, or physical overactivity. Fatigue can also affect to the worker performance decrement due to extreme mental workload. Colle and Reid [3] revealed much earlier on how mental workload's subjective nature prohibits certain levels of understanding and testing.

A. G. Abdul Samad (✉) · M. A. Azizan · M. H. Khairuddin · M. K. Johari
Universiti Kuala Lumpur—Malaysian Institute of Aviation Technology, 43900 Sepang, Selangor, Malaysia
e-mail: abdulghani@unikl.edu.my

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It has been initiated that mental workload relays to restriction of individual capability to accomplish the task given since the mental workload level cannot be directly detected. Shakouri et al. stated that many researchers prefer physiological workload measurements to subjective ones because they don't involve a direct response from the person, while subjective ones are based on the operators' emotional state and experiences during the mission [4].

Marquart et al. [5] said physiological measurements tend to be an appealing workload evaluation tool since they can be obtained without the need for subjective responses which concluded secondary performance. Most of these are 24-hour operations, where they have to be in situational awareness and they have potential to become mentally overloaded. In general, limiting work hours alone is insufficient to combat fatigue. Flynn-Evans et al. [6] detailed that fatigue caused by sleep deprivation and circadian misalignment has long been recognized as a danger in jobs that include 24-hour operations. Basically, in every airline company all over the world, passengers' safety always become their main priority that need to be emphasized every time an aircraft is flying in the sky. Morris et al. [7] estimated that fatigue plays a role in 4–8% of aircraft accidents, which can result in millions of dollars in damage and casualties in a single incident. It has also been researched by Karanikas and Nederend [8] that fatigue can dangerously cause many impacts that will lead to fatal aircraft accidents that can cause death to all the passengers and flight crew onboard the aircraft. Fatigue can also affect the pilots' critical thinking especially when it requires them to make decisions during emergency situations. Zaslona et al. [9] stated that the International Civil Aviation Organization (ICAO) demands that airline management, pilots, and support staff share responsibility for fatigue risk management. For aircraft maintenance personnel, fatigue would also give effects on them while completing their task on ground before releasing the aircraft to fly. Therefore, as fatigue cannot be eliminated, it must be managed.

Furthermore, sleepiness is another concept of exhaustion, which refers to an individual's inability to fall asleep due to a neurobiological need for sleep that triggers sleep drives. Sadeghniiat and Yazdi [10] said sleepiness also defines that fatigue is affected by the amount of sleep and the time of person awake after sleep. This underlined that sleep is one of the factors on fatigue. There are many other causes by fatigue such as stress, tiredness or drowsiness but 95% of fatigue results from inadequate amount of sleep. The problems occured could be classified as fatigue due to extended wakefulness where the workers have to stay awake for long shifts and work for a long period of time [11–14]. Tucker [15] explained that researchers can use a number of concepts and metrics to describe and measure fatigue in consideration of both physiological and psychological reactions. They also assume that if they will themselves to feel more alert or sleep-deprive themselves enough to adapt, they can learn to live with less sleep [15].

For many years, investigations had been carried out because of many accidents and in all modes of transportation where fatigue is referred to as a possible cause or contributing factor. Wu et al. [16] detailed on how human factors account for more than 76% of current aircraft incidents, with pilots' service failures due to fatigue accounting for more than 60%. Liu and Guo [17] mentioned that based on a large amount of evidence, human errors account for half of all incidents; and fatigue related failure as a component of human errors has become a major cause of accidents. Burgess et al. [18] said that accidents caused were categorized using information from the NTSB final report. It is critical to reduce fatigue related injuries, prevent workplace injury, and reduce job related fatigue [18].

Fatigue diminishes one's ability to watch, alert and observe the aircraft's handling, piloting and maintenance needs. Hanakova et al. [19] said that human factors are to blame for the majority of aviation injuries and accidents. Hobbs et al. [20] reported that fatigue is increasingly recognized as a hazard that must be managed by the transportation industry. It is, therefore, an important factor influencing human efficiency, and thus a topic of debate among aviation authorities such as the ICAO, FAA, EASA, and others.

2 Mental Workload

With the increased use of technology in the workplace, mental strength has become more important than physical strength [21]. In the real world, many tasks require mental information to be processed simultaneously with physical activity. As quoted from Basahel [22]: "Mental workload may be viewed as the difference between the capacities of the information processing system that are required for task performance to satisfy performance expectations and the capacity available at any given time."

Hart and Staveland [23] stated that working load can be defined as NASA Task Load Index developer (NASA-TLX) workload can be defined as "the cost incurred by a human operator to achieve a particular level of performance" that may have harmful health implications. The effects of mental work on health, especially the links between mental workload and cardiovascular diseases has been widely investigated. The risk of coronary heart disease is increased through work-strain (high demands of employment and/or low decision-making capacity). The reason for using this concept in this research is that the current consensus was that the high and low level of mental workload negatively impacts performance with the strong link with human performance. Reichlen [24] said that human factors, mental workload is a thoroughly investigated topic and is becoming increasingly important as new technology imposes higher cognitive needs.

Hefron et al. [25] stated that the first use of statistical machine learning to a model that enables prediction of mental workload from physiological signals is a very common method for estimating mental workload. If a worker is physically exhausted for a long period of time, the worker will also be mentally tired. At the end of the day, a human body needs to sleep to rejuvenate. A pilot, for example, is possible to instantly process a large quantity of flight information and decide on the situation. As a result, there can be a high mental workload or even excess. Cain [26] summarized that many factors, which make definite measurement difficult, can influence mental workload; and the degree to which workload affects performance is sometimes unclear. When the task has more demand and subsequently becomes more difficult, the worker will need more time to accomplish the task [26]. Durantin et al. [27] explained that the end result of extreme mental stress can be a cognitive tunnelling phenomenon that can be defined as the incapacity for the operator to convert responsiveness to another task.

Ranchet et al. [28] concluded that task output can decrease when the cognitive workload exceeds a specified cognitive resources. The word "mental workload" refers to the job requirements as an individual, external variable for which workers must cope more or less effectively. Performance deterioration has been observed during rapid, unexpected workload increases. Workload should be viewed as a dynamic response to task requirements that is dependent on the availability and utilization of resources. Mental workload attempts to measure the extent to which occupational activity matches or exceeds the worker's capability. Rusnock and Borghetti [29] described that workload refers to how much effort an operator expends when performing a task, and it is determined by both the operator's context and external factors.

Aircraft, ships, trains, trucks and buses are complex machines that require the attention of operators, maintenance personnel, and others who perform critical safety tasks. Dehais et al. [30] said that long periods of intense and prolonged cognitive activity trigger active cognitive exhaustion; which is also known as mental fatigue. Whether it is driving a commercial vehicle, transport operators, or even airline pilots and maintenance technicians; they must have enough rest to get enough sleep. Fatigue has a variety of effects on pilots and cabin crews' ability to operate; and it is one of the most important human factors affecting safety [30].

3 Physical Workload

Fatigue may be physiological or psychological. The body's need for replenishment and regeneration is reflected in physiological exhaustion. Physical workload refers to the amount of physical energy spent while performing a job, and it is influenced by the nature of the job, preparation, motivation, and external factors.

As stated by Sadeghniiat and Yazdi [10], fatigue is affected by the amount of sleep and the time of person awake after sleep. Respiration, blood pressure, metabolic effects, and work physiology parameters such as physical and psychological stress are the key factors that affect the attitude of momentary heart rate [10]. Martin et al. [31] discussed that physiological measures, rather than subjective rating scales, can provide an objective assessment of workload according to the analysis. Orlandi and Brooks [32] on the other hand, said that the physiological responses could be used to assess training changes and results in the future; and they could also be used to indirectly track levels of mental workload.

4 Aircraft Maintenance

Aircraft maintenance is a complex inter-related process, which involves diligent human interaction with aircraft systems and related machine components. Fernandez [33] described that there are two types of aircraft maintenance the line maintenance and base maintenance. Junqueira [34] added that it is important to emphasise the importance of aircraft maintenance in aviation industry. The purpose of aircraft maintenance is to deliver a predictive state of certainty in terms of aircraft reliability, operation, performance, safety, quality and airworthiness [35]. Preventive maintenance often contributes to an aircraft's airworthiness by obtaining and analyzing component reliability data to assess whether those components need to be replaced or serviced. Maintenance activities are the backbone of a successful and profitable airline company. Callewaert et al. [36] said that the airline industry relies heavily on aircraft maintenance; maintenance maintains fleet airworthiness and has a significant impact on an airline's operating costs. An aircraft on the ground, especially for service or other maintenance, cannot generate revenue. The goal is to maintain airplanes in good working order so that they are available for use as needed.

At the strategic level, airlines either set up organization units such as their own Line Maintenance Operation (LMO) unit and Base Maintenance Operation (BMO) or Maintenance Repair and Overhaul organizations (MRO) to service regular aircraft maintenance. Makrygianni [37] argued that since it consists of numerous contributing parts of the aviation industry, the aviation maintenance ecosystem is clearly defined as a complex sociotechnical structure. In the domain of an airline's day-to-day operations, all activities aimed at restoring any functionality of a product during its lifecycle are referred to as maintenance, according to Palmarini et al. [38]. Aircraft line maintenance is the last remaining interface at the end of the chain of all maintenance activities, where all aspects of maintenance must work together to achieve the desired level of safety and operation.

In aviation, aircraft maintenance works based on time to retain the airworthiness of the aircraft available for daily flights. Millions of dollars can be lost caused by the delays of flight schedules, in addition to the possibility of airlines losing their customers' trust regarding this issue. As mentioned by Ionescu and Kliewer, [39] additional, so-called reactionary costs can be incurred because of delays, cancellations, and resource reassignment. As a result, operating costs are often higher than expected. This is also intended to emphasize more on the consequences toward the line maintenance personnel; this is so they would be aware and take precaution steps as described by Abdul Samad and Omar [40]. Aviation maintenance is carried out in many different environments, but the most familiar is in commercial airlines; which include Line Maintenance Operations (LMOs) and hangar maintenance. In aviation maintenance organisations, there are two types of workshop operations. These workshops are usually parts of hangar maintenance organization. They mainly support out-of-service aircrafts, though some line maintenance assistance is provided when required.

Lee et al. [41] detailed that (i) scheduled inspections, (ii) modifications to the airframe structures by an airworthiness directive or engineering order, and (iii) special inspections ordered by the airline; these are all part of hangar maintenance. The aircraft is out of service while undertaking hangar repairs. Chiu and Hsieh [42] described how the operators had organised the work process prior to the maintenance work. The other types of maintenance shops at an airline hangar are the engines, hydraulic, avionics, pneumatic systems, structures, and other advanced equipment on aircraft; these are supported by overhaul shops. Knight [43] stated in her thesis that once an engine has been removed from the aircraft, it is shipped to an MRO facility for disassembly, inspection, repair, reassembly, and acceptance testing processes. The works done in these shops are on aircraft equipment that have been removed during line or hangar repair operations [43].

Work on a flight line can be stressful at times due to flight schedules, maintenance emergencies, inclement weather, and the ever annoying "time constraints." Korvesis et al. [44] explained that scheduled maintenance is the conventional method of repairing equipment, in which maintenance activities are planned ahead of time and carried out on a regular basis. Hangar work, on the other hand, can be less hectic because there is more time to complete each task, but there are still a time limit and other pressures. Pimapunsri and Weeranant [45] further added that the number of the unplanned activity depends on the type of check and the flight hours of the aircraft. Qin et al. [46] described that one of the most important responsibilities of a maintenance company is to create a maintenance programme that entails considerable organisational decision-making. This includes each aircraft's maintenance schedule.

Aviation maintenance, inspections and modifications of equipment are to be completed within a certain amount of time. Erkoc and Ertogral [47] proposed an overall programming model to minimize total emergence by yielding optimum time for startup revision for spin element on parallel processing line and table swap for order. These are to discourage general lack of recognition of fatigue as a workplace hazard. Jayawardena [48] outlined that human error is caused by a variety of factors, including a lack of experience, insufficient processes, and the work environment. While the larger airlines generally have appropriate fatigue management system in place for flight crew, there does not seem to be the same recognition of fatigue as a workplace hazard for maintenance personnel.

5 Conclusion of Review

A healthy relationship must be distinguished between workload and strain on the individual. Physical workloads, for example, can gradually increase the health risk of workers due to unfavorable postures or heavy lifts and carriages. Physical workload is correlated with mental workload. As the physical workload is increased, the mental workload will also be increased. With regard to physical workload, it is conceptually reasonable that a combination of working strength by work time can be used to eliminate the effect of the accumulated workload on the worker (i.e. typically fatigue).

On the other hand, the accumulated size of the workload effect may not be equivalent to the measured size of the momentary workload. Mental overload can be caused by a number of factors, including job complexity and time constraints, but it also tends to be influenced by other factors, such as alertness.

As a result, solutions aimed at reducing workplace injuries and accidents must be taken into account as both are organizational.

The compilation of this review will contribute in providing new knowledge to Malaysia's aviation industry working environment in sheet metal workshop about the risk of mental workload and fatigue. Moreover, the results can also be used to enhance the importance of managing and coping on fatigue during work. It also contributes in terms of developing awareness about fatigue among line maintenance airline worker. The effects of (i) steady-state exercises and (ii) mild, moderate, and high-intensity exercises on heart rate variability have been studied in the past. Future research may look at how power spectral components behave when a mental task and a physical task that emulate manual regular maintenance are completed. In order to better understand how physical and mental tasks influence existing stress, such as heart rate variables, the possible effects of task type and trial order have been investigated.

References

1. Fujita K, Kinoshita F, Touyama H (2018) Detection of cognitive decline due to mental fatigue using electroencephalogram. In: 2018 IEEE international conference on systems, man, and cybernetics (SMC). IEEE, Miyazaki, pp 562–567
2. Abdul Hamid S, Manap R, Ahmad Z, Md. Shariff S (2018) A review on occupational stress towards academician health and wellbeing: a systematic literature review. In: 5th international research management and innovation conference. KUIS, Putrajaya, pp 1–10
3. Colle H, Reid G (1998) Context effects in subjective mental workload ratings. Hum Factors 4:591–600
4. Shakouri M, Ikuma L, Aghazadeh F, Nahmens I (2018) Analysis of the sensitivity of heart rate variability and subjective workload measures in a driving simulator: the case of highway work zones. Int J Ind Ergon 66:136–145
5. Marquart G, Cabrall C, Winter J (2015) Review of eye-related measures of drivers' mental workload. Proc Manuf 3:2854–2861
6. Flynn-Evans E, Ahmed O, Berneking M, Collen J, Kancherla B, Peters B, Rishi MA, Sullivan SS, Upender R, Gurubhagavatula I (2019) Industrial regulation of fatigue: lessons learned from aviation. J Clin Sleep Med 15(4):537–538
7. Morris M, Wiedbusch M, Gunzelmann G (2018) Fatigue incident antecedents, consequences, and aviation operational risk management resources. Aerosp Med Hum Perform 89(8):708–716
8. Karanikas N, Nederend J (2018) Pilot fatigue and safety events: results from analysis of investigation reports. In: 33rd conference of the European association for aviation psychology: connecting people, organisations and technology in aviation. European Association for Aviation Psychology, The Netherlands, pp 390–401
9. Zaslona J, O'Keeffe K, Signal L, Gander P (2018) Shared responsibility for managing fatigue: hearing the pilots. PLoS ONE 13(5):1–11
10. Sadeghniiat-Haghighi K, Yazdi Z (2015) Fatigue management in the workplace. Ind Psychiatry J 24(1):12–17
11. Abdul Samad A, Abu Mansor N (2019) The possible factors related in failure to follow aircraft maintenance procedures. Int J Innov Technol Explor Eng 8:604–609

12. Abdul Samad A, Mat Yusoff S (2019) Enhance safety and efficiency by controlling and managing the slip and lapse made by individuals. Int J Innov Technol Explor Eng 8:708–713
13. Abdul Samad A, Mohd Yusoff N (2019) Human negligence play the largest contributing factor of airplane accidents. Int J Innov Technol Explor Eng 8:146–153
14. Abdul Samad A, Haider R, Md Hairudin K (2019) Human factors affecting avionics workshop in MRO 145. Int J Innov Technol Explor Eng 8:553–555
15. Tucker P (2010) The impact of rest breaks upon accident risk, fatigue and performance: a review. Work Stress 17(2):123–137
16. Wu E, Zhu L-M, Zhang W-M, Deng P-Y, Jia B, Chen S-D, Ren H, Zhou G-R (2019) Novel nonlinear approach for real-time fatigue EEG data: an infinitely warped model of weighted permutation entropy. IEEE Trans Intell Transp Syst 21(6):1
17. Liu L, Guo C (2016) Research on the improvement of human error in the process of production operation—taking the fatigue operation in the production as the object of study. In: 2016 international conference on logistics, informatics and service sciences (LISS). IEEE, Sydney, pp 1–6
18. Burgess S, Boyd S, Boyd D (2018) Fatal general aviation accidents in furtherance of business (1996–2015): rates, risk factors, and accident causes. J Aviat Technol Eng 8(1):11–19
19. Hanakova L, Socha V, Socha L, Lalis A, Kraus J, Malich T (2019) The influence of fatigue on psychophysiological indicators during 24 hours testing of pilots. In: 2019 IEEE 17th world symposium on applied machine intelligence and informatics (SAMI). IEEE, Herlany, pp 181–186
20. Hobbs A, Gregory K, Parke B, Pradhan S, Caddick Z, Bathurst N, Flynn-Evans E (2018) San Francisco bar pilot fatigue study. NASA, Hampton
21. Ozkan A, Ozdevecioglu M, Kaya Y, Koç F (2015) Effects of mental workloads on depression–anger symptoms and interpersonal sensitivities of accounting professionals. Rev Contab 18(2):194–199
22. Effect of physical and mental workload interactions on human attentional resources and performance. https://bura.brunel.ac.uk/handle/2438/6614. Last accessed 04 May 2020
23. Hart S, Staveland L (1988) Development of NASA-TLX (task load index): results of empirical and theoretical research. Adv Psychol 52:139–183
24. A comparison of linear and nonlinear ECG-based methods to assess pilot workload in a live-flight tactical setting. https://ir.uiowa.edu/cgi/viewcontent.cgi?article=7585&context=etd. Last accessed 03 May 2020
25. Hefron R, Borghetti B, Christensen J, Schubert Kabban C (2017) Deep long short-term memory structures model temporal dependencies improving cognitive workload estimation. Pattern Recogn Lett 94:96–104
26. Cain B (2007) A review of the mental workload literature. Defence Research and Development Canada, Toronto
27. Durantin G, Gagnon J-F, Tremblay S, Dehais F (2014) Using near infrared spectroscopy and heart rate variability to detect mental overload. Behav Brain Res 259:16–23
28. Ranchet M, Morgan J, Akinwuntan A, Devos H (2017) Cognitive workload across the spectrum of cognitive impairments: a systematic review of physiological measures. Neurosci Biobehav Rev 80:516–537
29. Rusnock C, Borghetti B (2018) Workload profiles: a continuous measure of mental workload. Int J Ind Ergon 63:49–64
30. Dehais F, Dupres A, Flumeri G, Verdiere K, Borghini G, Babiloni F, Roy R (2018) Monitoring pilot's cognitive fatigue with engagement features in simulated and actual flight conditions using a hybrid fNIRS-EEG passive BCI. In: 2018 IEEE international conference on systems, man, and cybernetics (SMC). IEEE, Miyazaki, pp 544–549
31. Martin J, Schneider F, Kowalewskij A, Jordan D, Hapfelmeier A, Kochs E, Wagner KJ, Schulz C (2016) Linear and non-linear heart rate metrics for the assessment of anaesthetists' workload during general anaesthesia. Br J Anaesth 117(5):767–774
32. Orlandi L, Brooks B (2018) Measuring mental workload and physiological reactions in marine pilots: building bridges towards redlines of performance. Appl Ergon 69:74–92

33. Base maintenance capability research Embraer 190. https://core.ac.uk/reader/161423530. Last accessed 02 May 2020
34. Junqueira V, Nagano M, Miyata H (2018) Procedure structuring for programming aircraft maintenance activities. Rev Gestão 27(1):2–20
35. Mrusek BM, Kiernan K, Clark P (2018) UAS maintenance: a critical component in maintaining airworthiness. Int J Aviat Aeronaut Aerosp 5(5):2–2
36. Callewaert P, Verhagen W, Curran R (2018) Integrating maintenance work progress monitoring into aircraft maintenance planning decision support. Transp Res Proc 29:58–69
37. Makrygianni M (2018) Aircraft accident evaluation using quality assessment tools. Aviation 22(2):67–76
38. Palmarini R, Erkoyuncu J, Roy R, Torabmostaedi H (2018) A systematic review of augmented reality applications in maintenance. Robot Comput Integr Manuf 49:215–228
39. Ionescu L, Kliewer N (2011) Increasing flexibility of airline crew schedules. Proc Soc Behav Sci 20:1019–1028
40. Abdul Samad A, Omar N (2019) Shift and schedule affecting line maintenance. Int J Innov Technol Explor Eng 8:585–589
41. Lee S, Ma Y-S, Thimm G, Verstraeten J (2008) Product lifecycle management in aviation maintenance. Comput Ind 59(2–3):296–303
42. Chiu M, Hsieh M (2015) Latent human error analysis and efficient improvement strategies by fuzzy TOPSIS in aviation maintenance tasks. Appl Ergon 54:136–147
43. Next generation commercial aircraft engine maintenance, repair, and overhaul capacity planning and gap analysis (2018). https://dspace.mit.edu/handle/1721.1/117979. Last accessed on 06 May 2020
44. Korvesis P, Besseau S, Vazirgiannis M (2018) Predictive maintenance in aviation: failure prediction from post-flight reports. In: 2018 IEEE 34th International conference on data engineering (ICDE). IEEE, Paris, pp 1414–1422
45. Pimapunsri K, Weeranant D (2018) Solving complexity and resource-constrained project scheduling problem in aircraft heavy maintenance. Int J Appl Eng Res 13(11):8998–9004
46. Qin Y, Wang Z, Chan F, Chung S, Qu T (2019) A mathematical model and algorithms for the aircraft hangar maintenance scheduling problem. Appl Math Model 67:451–509
47. Erkoc M, Ertogral K (2016) Overhaul planning and exchange scheduling for maintenance services with rotable inventory and limited processing capacity. Comput Ind Eng 98:30–39
48. Jayawardena A, Duffy D, Manahan JM (2017) Lighting matters in industrial environments: a framework linking workplace safety to lighting quality metrics. IEEE Ind Appl Mag 23(3):54–63

Significance of Aircraft Maintenance Personnel's Reaction Time During Physical Workload and Mental Workload

Abdul Ghani Abdul Samad, Mohd Amzar Azizan, Md Hafis Khairuddin, and Muhd Khudri Johari

Abstract The paper examines the significance of reaction time recorded by aircraft maintenance personnel whilst undertaking both physical and mental workload in an aircraft maintenance hangar setting. The workloads included surface patch repair, implementing corrosion prevention on mating surface, calculating various rivet dimensions, verification of patched skin, and drilling necessary holes on the intended layout of the patched skin. Their reaction time was recorded using the online RED LIGHT—GREEN LIGHT Reaction Time Test. Both mean and standard deviation were analyzed; reaction time was measured in milliseconds (ms) for all the seen tasks types given. Results have shown a significant increase in reaction time between Trial 1 (two hours) and Trial 2 (four hours). It is hoped that future studies can focus more on personnel's reaction time during work as an alternative for maintaining personnel's safety and wellbeing.

Keywords Reaction time test · Aircraft maintenance tasks · Workload

1 Background

In a working memory task, the present study discovered that task complexity and time pressure have additive effects, which explains why these variables are often listed in connection with workplace health and safety concerns. Furthermore, their combined effect on mental workload measurements was modulated by memory; indicating that rather than concentrating on individual job characteristics, it might be more beneficial to understand the overall work situation, including work schedules.

Fallahi et al. [1] suggested that as the workload of the operator rises, their mental fatigue increases, their stress levels rise, and their mental health deteriorates [1]. At low level workload, users can often be frustrated and disappointed when processing information, thus increasing reaction time. But, high level workload can also be a

A. G. Abdul Samad (✉) · M. A. Azizan · M. H. Khairuddin · M. K. Johari
Universiti Kuala Lumpur—Malaysian Institute of Aviation Technology, 43900 Sepang, Selangor, Malaysia
e-mail: abdulghani@unikl.edu.my

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problem and even dangerous as it creates confusion, reduces the performance of information processing and raises the risk of mistakes by International Civil Aviation Organization (ICAO) [2]. From the 1960s to the 2009s, several studies were conducted on the impact of time on task on vigilance or sustained attention [3].

Most of these analyses changed the task demand such as the event rate, and explained how output changed over time on task based on Trials 1 and 2. The results of reaction time have often been overlooked in more recent mental workload research. However, workload estimation via physiological measures such as eye tracking and electroencephalogram (EEG) has shown to be task dependent [4].

Serrano et al. [5] mentioned one theory that summarizes inattention causes people to ignore vital emotional signals. Secondly, in most cases, it seems that this procedure progressively decreases the time and people become capable to concentrate on the act. Kowsari et al. [6] reported that the subject would hear a warning beep, focus on the screen and respond by the left hand. Brungart et al. [7] added that in human perception, auditory localization is crucial. Hearing helps us to hear sounds coming from anywhere in the world and to easily focus our visual attention to them. Therefore, when one reacts to a specific auditory or visual stimulation, they adopt a mental attitude in front of the stimulus in order to appreciate the brief sensation of acceleration. To some degree, the sensory impression forces the motor act, which was initially of a distinctly willed nature.

Amir Kassim et al. [8] stated that the results of the reaction time tests revealed that participants were substantially slower in responding to auditory stimuli than to visual stimuli, which is possibly due to variations in how visual and auditory stimuli are processed. Cinaz et al. [9] said that one stimulus and one response are used in basic reaction time experiments [9]. This is usually found at the end of a long series of reaction time tests, when the individual involuntarily performs the normal motor act of response when a sensory stimulus appears at an unexpected time. Zhu et al. [10] added that one of the most severely impaired cognitive areas is focus. The psychomotor vigilance task is one of the most common tests of sustained attention (PVT). If concentration is the most important factor influencing the length of reaction time responses, fatigue is more than likely to have an impact by gradually decreasing the power of attention.

2 Methodology

Personnel for this study are semi-skilled students enrolled in European Aviation Safety Agency (EASA) Part 66—Aircraft Maintenance Engineer License programmer. 20 students from UniKL MIAT were chosen for this experiment, which is an aviation training school under approval training organization (ATO) Part 147. As they were taking license courses throughout the program, they could be considered as working aircraft maintenance personnel. The workloads included surface patch repair, implementing corrosion prevention on mating surface, calculating various rivet dimensions, verification of patched skin, and drilling necessary holes on the intended layout of the patched skin.

For the reaction time test, the RED LIGHT—GREEN LIGHT Reaction Time Test was utilized to record everyone's reaction time [11]. The test itself is uniquely simple and easily accessible. It has been proven to be both valid and useful; as simple as it is, it still measures reaction time efficiently without exerting significantly more mental workload or physical workload after their individual maintenance tasks. In short, by the end of the experiment, every participant will have taken this reaction time test a few times. To take the reaction time test after every completed maintenance task, the participants simply need to open the website and click the start button. By now, the short instructions and the background colour displayed on the same button will have changed and the participants will have to continue clicking button every time: (i) the red light switches to green light, (ii) when the button instructs to continue with the next round (until the 5th round), and (iii) when the button says "*Done!*".

It has been documented that every participant did not have the following conditions whilst they were taking part in this experiment: have practiced sedentary lifestyle, have had history of musculoskeletal disorders or cardiovascular, and have recently consumed medicines or drugs that may influence heart rate. They were also regularly reminded to avoid any intensive activities, alcohol, tobacco, or caffeine intake during the days of the experiment. The data collected consisted of reaction times to finish their given tasks respectively.

3 Analysis

The data were analyzed in order to get Mean (M) and Standard Deviation (SD) as shown in Table 1. The reaction times were measured in milliseconds (ms) for all tasks given during Trial 1 and 2.

The statements for the reaction times recorded in Table 1 are as follows:

*initial figure is *M*; followed by a later figure in parentheses, which is the *SD*.

Table 1 Standard deviation (SD) and mean (M) for reaction times

		Trial 1		Trial 2	
		M	SD	M	SD
1	Resting heart rate	0.368	0.023	0.352	0.031
2	Evaluation	0.256	0.031	0.267	0.023
3	Calculating and sketching	0.267	0.034	0.297	0.032
4	Cutting	0.345	0.025	0.355	0.025
5	Punching	0.334	0.029	0.352	0.023
6	Drilling	0.376	0.030	0.410	0.026
7	Riveting	0.443	0.042	0.446	0.033

Table 2 ANOVA *p*-values for task variables

Dependent variable	Trial
Resting heart rate	0.027*
Evaluation	0.016*
Calculating and sketching	< 0.0001*
Cutting	< 0.0001*
Punching	< 0.0001*
Drilling	< 0.0001*
Riveting	< 0.0001*

i. the resting heart rate Trial 1 is 0.368 (0.023) ms and Trial 2 is 0.352 (0.031) ms
ii. evaluation Trial 1 is 0.256 (0.031) ms and Trial 2 is 0.267 (0.023) ms
iii. calculating and sketching Trial 1 is 0.267 (0.034) ms and Trial 2 is 0.297 (0.032) ms
iv. cutting Trial 1 is 0.345 (0.025) ms and Trial 2 is 0.355 (0.025) ms
v. punching Trial 1 is 0.334 (0.025) ms and Trial 2 is 0.352 (0.023) ms
vi. drilling Trial 1 is 0.376 (0.030) ms and Trial 2 is 0.410 (0.026) ms
vii. and riveting Trial 1 is 0.443 (0.042) ms and Trial 2 is 0.446 (0.033) ms.

The outcomes show that there is an increased reaction time from Trial 1 (two hours) to Trial 2 (four hours). All seven task types have shown a significant increase in reaction time between Trial 1 and Trial 2. Hence, to properly estimate the operator performance based on reaction time, it is necessary to identify the task type and associated workload (visual, motor, auditory, etc.). The reaction time for evaluation, calculating and sketching, punching, drilling and riveting were increasing when comparing reaction time in Trial 2 to reaction time in Trial 1. The statistical analysis took into account all of the variables listed above. All of the variables were subjected to ANOVA. The ANOVA *p*-values are mentioned in Table 2, with "*" indicating large *p*-values. Reaction time was a significant factor for all the dependent variables. There were seven null hypotheses that had been tested in order to measure the significance of their reaction time.

The *p*-values for the variables are as followed: *resting heart rate* is 0.027; *evaluation* is 0.016; and less than 0.001 for *calculating and sketching*, *cutting*, *punching*, *drilling*, and *riveting*. In a summary, the null hypothesis were proven false and the alternative hypotheses were verified. They indicated that riveting is affected by trial order significantly. Therefore, the statistics imply that the reaction times on the resting heart rate, evaluation, calculating and sketching, cutting, punching, drilling and riveting are significantly different between Trial 1 and Trial 2.

4 Discussions

The length of time it takes for a person or system to respond to a given stimulus or event is described as reaction time. When it comes to reacting to stimuli and situations like driving, conversing, and playing sports, having a good reaction time helps us to be agile and effective. We benefit from quick response times in a number of ways, but it is critical that we properly analyze the information we obtain.

The amount of time between when we experience something and when we respond to it is referred to as reaction time or response time. It is the ability to identify, analyze, and respond to a stimulation. The following factors influence reaction time:

i. ***Perception***: To have good response time, you must be able to see, hear, or sense a sensation with certainty
ii. ***Processing***: To have a good response time, you must be focused and have a good understanding of the facts
iii. ***Response***: In order to be able to function and have a quick response time, you must have strong motor agility.

As a result of any change to one of these systems, reaction time will be impaired. In other words as an example; if athletes have a slower response time than the others, they would be at a disadvantage. Unlike processing speed, reaction time must include a motor part. This is why having strong reflexes is linked to having good reaction time.

The processes (perceive, process, and respond) are completed in milliseconds but reaction time varies depending on a variety of factors, including:

i. ***Complexity of the stimulus***: The more details that must be handled, the longer this process will take
ii. ***Familiarity, preparation, and expectations***: The response time would be shorter if you have to respond to a known stimulus that you have already reacted to. The less details you have to process, the faster you'll be able to respond.
iii. ***State of the organism***: Fatigue, concentration (being sleepy), high temperature, old age, or even consuming too much food or substances like alcohol or other medications may all impair the detection of the stimulus. Both of these factors can have an adverse impact on the identification, processing, and reaction to the stimulus.
iv. ***Stimulated sensory modality***: Since auditory stimuli need less processing than visual stimuli, reaction time is quicker when the stimulus that activates the response is auditory.
v. We may also affect the type of stimulus we process, in addition to other factors
vi. ***Simple***: A single stimulus elicits a single response
vii. ***Choice***: Different stimuli elicit different responses. If a word appears in Spanish, for example, press the right arrow key; if the word appears in another language, press the left arrow key.

viii. ***Selection***: There are many stimuli to choose from, but you only have to answer to one of them.

5 Conclusion

This is the first research that we are aware of that evaluates the response time of traditional, working aircraft maintenance staff. The average reaction time of the participants was measured in this study; and it was discovered that during Trial 2, the reaction time was higher than during Trial 1. While several factors contribute to the development of cardiovascular diseases, the current research only looked at the impact of mental and physical activity on heart response.

To different types of stress caused on the human body in general, there are numerous physiological responses such as heart rate blood pressure, cortisol secretion and catecholamine. The existing research looks at only one of these responses, namely the heart's reaction to physical and mental stress induced in a lab environment. These responses, however, are of interest not only as stress markers, but also as a potential correlation between psychosocial stress and a variety of physical health outcomes. It is possible that a confluence of variables has a stronger impact on physiological outcomes. Extending physical outcome levels to hormone levels including catecholamine and cortisol secretion may be beneficial.

As a result, future studies should look at how employer reaction time can be used to figure out what is causing different workplace issues. Another angle of perspective could also optionally focus on how reaction time or task variables behave at different intensities of the nature of work itself and personnel's different positions.

References

1. Fallahi M, Motamedzade M, Heidarimoghadam R, Soltanian A, Miyake S (2016) Effects of mental workload on physiological and subjective responses during traffic density monitoring: a field study. Appl Ergonomics 95–103
2. International Civil Aviation Organization: Doc 9966 (2016) Manual oversight of fatigue management approaches, 2nd edn. ICAO, Quebec
3. Tucha L, Tucha O, Walitza S, Sontag T, Laufkötter R, Linder M, Lange K (2009) Vigilance and sustained attention in children and adults with ADHD. J Attention Dis 410–421
4. Zhang Y, Zhang Y, Cui X, Li Z, Liu Y (2020) Assessment of mental workload using physiological measures with random forests in maritime teamwork. In: International conference on human-computer interaction (HCII 2020), pp 100–110. Springer, Cham, Copenhagen
5. Serrano V, Owens J, Hallowell B (2018) Where children with ADHD direct visual attention during emotion knowledge tasks: relationships to accuracy, response time, and ADHD symptoms. J Attention Dis 752–763
6. Kowsari E, Moosavi Z, Rahimi A, Faramarzi M, Haghighi M (2018) The effect of short-term taurine amino acid supplement on neuromuscular fatigue, serum lactate level and choice reaction time after maximal athletic performance. J Res Med Dental Sci 358–364
7. Brungart D, Kruger S, Kwiatkowski T, Heil T, Cohen J (2019) The effect of walking on auditory localization, visual discrimination, and aurally aided visual search. Hum Factors 976–991

8. Amir Kassim A, Rehman R, Price J (2018) Effects of modality and repetition in a continuous recognition memory task: repetition has no effect on auditory recognition memory. Acta Psychol 72–80
9. Cinaz B, Arnrich B, Tröster G (2012) Monitoring of scognitive functioning by measuring reaction times with wearable devices. First International Workshop on pervasive care for people with dementia and their careers. IEEE, Dublin
10. Zhu Y, Xi Y, Fei N, Liu Y, Zhang X, Liu L, Qin W (2018) Dynamics of cerebral responses to sustained attention performance during one night of sleep deprivation. J Sleep Res 184–196
11. The Online Reaction Time Test. https://faculty.washington.edu/chudler/java/redgreen.html. Last accessed on 01 June 2020

Ergonomic Risk Assessment in a Sawmill Industry

Balqis Syahirah Jamaludin, Balkis Haris Fadzilah, Ezrin Hani Sukadarin, and Mirta Widia

Abstract Previous studies have shown that sawmill workers develop an enormous amount of physical workloads, such as the actions of bending, holding, cutting, and raising limbs awkwardly, which were common contributing factors of work-related musculoskeletal disorders (WMSDs). A cross-sectional study was carried out to investigate the musculoskeletal complaints among sawmill workers. After the workers' complaints have been identified, the significant ergonomics risk factors in manual handling tasks among sawmill workers were investigated. Data collection was done using two instruments: Cornell Musculoskeletal and Hand Discomfort Questionnaire (CMDQ) and initial Ergonomic Risk Assessment (iERA). The study results show that sawmill workers are highly exposed to ergonomic risk factors, such as awkward postures. Therefore, further research concerning WMSDs is required to explore this issue. This study's findings can contribute significantly to the body of knowledge, especially in occupational safety and health in Malaysia's manufacturing industry involved with wood-based products.

Keywords Sawmill · Work-related musculoskeletal disorders · Forceful exertions

1 Introduction

The wood-based industry has emerged as one of the most important, prominent, and fastest-growing manufacturing sectors in the Malaysian economy. There is an increasing demand for wood products. The wood industry contributed 4.8% of Malaysia's Industrial Production Index in 2019 [1]. Malaysia exports RM22.5 billion worth of wood-based goods [2]. In the meantime, there are approximately 35,122 employees in the forestry sectors [3]. Despite advanced technology, most workers

B. S. Jamaludin · B. Haris Fadzilah · E. H. Sukadarin (✉)
Occupational Safety and Health Programme, Faculty of Industrial Sciences and Technology (FIST), Gambang, Malaysia
e-mail: ezrin@ump.edu.my

M. Widia
Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

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still perform their work manually; manual handling, such as lifting, carrying, pushing, and pulling, are marked as risk factors for work-related musculoskeletal disorders (WMSD).

The lack of ergonomic innovations and poor manual material handling tasks could also result in musculoskeletal disorders [4]. In this regard, strenuous occupational duties involving manual handling often led to musculoskeletal injuries. WMSDs among the Malaysian workforce have escalated over the last five years. Malaysia's Social Security Organization reported that the second-highest diseases recorded by WMSDs (6.2%) in 2018 with an upper limb (28.3%) were the highest reported injuries. Wood-based industries have been considered one of the most hazardous manufacturing industry sectors in past centuries. The production of wood products is often labor-intensive and production-oriented. As a result, employees typically work rapidly, sometimes endangering their health and safety [5].

The Malaysian wood-based industry began in the early 1900s before being transformed into a large, export-oriented industry, producing a wide range of value-added products to meet domestic demand [6]. WSMDs are prevalent among sawmill workers [7]. Most workers are exposed to several occupational hazards, especially ergonomic problems, during sorting, cutting, and processing raw logs. Ali et al. [8] stated that conditions leading to MSDs were harsh environmental conditions, heavy work such as manual load handling, hazardous tools, and machinery like chainsaws. In general, the heavy workload is more vulnerable to load-carrying than the body limit of the workers. The main occupational hazards in the sawmill industry are the wood's dimensions, the heavyweight of the wood, the distance of loading of the wood, the number of tasks, and the overall length of tasks. Such exposure may cause injury, damage, or condition to the joints or other tissues' musculoskeletal mechanisms. Thus, there is an emphasis on the importance of working safely, especially in sawmills, where many employees are facing musculoskeletal disorders caused by a heavy workload.

As there are limited studies on the prevalence of WMSDs and risk factors in Malaysia's sawmill industry, this study focused on the problems and factors that lead to WMSDs. Therefore, the objectives of this study are (1) to investigate the prevalence of the work-related musculoskeletal disorder among sawmill workers; (2) to identify the ergonomic risk factors of the work-related musculoskeletal disorder among sawmill worker and; (3) to determine the association between ergonomic risk factors and work-related musculoskeletal disorder among sawmill workers.

2 Methods

2.1 Participants

A cross-sectional study is conducted among sixty-seven (n = 67) sawmill workers of different ages, gender, education level, position, job tenure, break duration, and underlying diseases. While the respondents of this study were randomly selected, they were required to declare any musculoskeletal illnesses diagnosed by a health professional in the health status section.

2.2 Disorders Evaluation

The Cornell Musculoskeletal and Hand Discomfort Questionnaire (CMDQ) evaluates musculoskeletal disorders at sedentary workers, standing workers, and hand symptoms [9]. The parts included in the checklist are the neck, right and left shoulder, upper back, right and left upper arm, lower back, right and left forearm, right and left wrist, hip or buttocks, right and left thigh, right and left knee, right and left lower leg, right and left hand. These questionnaires are used for research screening purposes rather than for diagnostic purposes. Scores could be analyzed in four ways: (1) by simply counting the number of symptoms per person; (2) by summing the rating values for each person; (3) by weighting the rating scores to more easily identify the most severe problems; (4) by multiplying the above frequency score (0, 1.5, 3.5, 5, 10) by the Discomfort score (1, 2, 3) by the interference score (1, 2, 3) [9].

2.3 Ergonomics Risk Assessment

The Initial Ergonomic Risk Assessment (iERA) was carried out to measure the exposure of risk factors contributing to the prevalence rate of musculoskeletal complaints among sawmill workers. According to the guidelines by the Department of Occupational Safety and Health (DOSH), six risk factors need to be assessed, including (1) awkward posture, static and sustained work posture, (3) forceful exertion, (4) repetitive motion, (5) vibration and (6) environmental. Nevertheless, this initial assessment relies on the type of risk factors identified in a particular workstation, implying that not all risk factors are evaluated during an assessment. Each risk factor was assessed to contain a different number of questions that need to be evaluated. Guidelines by the DOSH [9] were followed to ensure the survey and risk assessment was carried out precisely.

2.4 Statistical Package Social Science (SPSS) Software

SPSS version 24 was used for statistical analysis. After obtaining the results for both assessments, descriptive analysis was conducted to determine the findings' pattern. The Chi-square test is also being conducted to determine whether there is a significant association between the symptoms of pain or discomfort on body regions and risk factors.

2.5 Demographic Data

Table 1 shows the respondent' demographic information. The respondents' age was divided into five categories, less than 20 years old, 21–30 years old, 31–40 years old, 41–50 years old, 41–50 years old, and more than 51 years old. The highest percentage of age range is middle-aged workers, with 43.3%. The second highest percentage is 21–30 years old with 26.9%, followed by 31–40 years old with 19.4% respondent and more than 51 years old with 7.5%. The lowest percentage of age-range is less than 20 years old, with only 3% of respondents. Moreover, the frequency of male respondents is significantly higher than female respondents. Out of the 67 respondents 50 (74.6%) are male, and only 17 (25.4%) are female.

There are four categories of education level among respondents in this survey: no formal education, primary education, secondary education, and tertiary education. The majority (73.1%) of the sawmill workers have secondary education. The second-largest group is those with tertiary education (25.4%) followed by primary education with 1.5%. There are no workers who do not have formal education. Furthermore,

Table 1 Percentage of demographic data

Variable		Percentage (%)
Age	< 20 years old	3.0
	21–30 years old	26.9
	31–40 years old	19.4
	41–50 years old	43.3
	> 51 years old	7.5
Gender	Male	74.6
	Female	25.4
Education level	Primary education	1.5
	Secondary education	73.1
	Tertiary education	25.4
Position	Office staff	20.9
	Labourer	79.1
Job tenure	1–5 year	26.9
	6–9 year	26.9
	10–14 year	32.8
	> 15 year	13.5
Break duration	0–15 min	1.0
	31–45 min	14.0
	46 min–1 hour	14.0
	> 1 h	38.0
Underlying diseases	Yes	35.8
	No	64.2

the workers were also divided based on their work station and role, specifically office staff and labourers. The number of labourers is significantly higher (79.1%, 53) than office staff (20.9%, 14). The respondents' break duration is divided **into** four ranges, which are 0–15 min, 31–45 min, 46 min–1 h, and more than 1 h. As shown in Table 1, the largest percentage of respondents (38.0%) recorded a break duration of > 1 h, followed by 46 min–1 h and 31–45 min, with the same percentage at 14.0%. Only 1.0% of the respondents have a 0–15 min break. The percentage of workers diagnosed with any form of the disease is significantly lower than the percentage of workers diagnosed with any disease by a medical doctor. 24 (35.8%) respondents have been diagnosed with any diseases, while 43 (64.2%) respondents have not been diagnosed with any diseases by a doctor.

2.6 Cornell Musculoskeletal and Hand Discomfort Questionnaire (CMDQ) Evaluation

In this study, a total number of 53 sawmill workers directly involved in the production were asked about the presence of ache, pain, or discomfort during the last workweek. In the last work week, most respondents have felt pain in some parts of their body parts due to their daily work, such as carrying and loading timbers, repetitive movements, and lifting timbers, which affected their upper body parts.

According to DOSH [9], the severity of discomfort can be grouped into mild, moderate, and severe discomfort. Figure 1 was used in this study to determine the category of the severity of discomfort. The value of each category can be determined by multiplying the value of frequency score (0, 1.5, 3.5, 5, 10), discomfort score (1, 2, 3), and interference score (1, 2, 3). The lowest value is 0, and the highest value is 90. Category Mild score, Moderate score, and Severe Discomfort start from 0 to 13.5, 13.6 to 20, and 21 to 90. The mean value for each part was compared to the category of each body part.

Table 2 shows the total discomfort score, the mean and standard deviation for each respondent, and the category of the severity of discomfort. In the meantime, the graph in Fig. 1 illustrates the total discomfort scores for all respondents. Most of the sawmill workers expressed the highest complaint about discomfort on their lower back. Previous studies supported this finding and stated that sawmill workers mostly experience discomfort in their lower back region. Previous studies also found

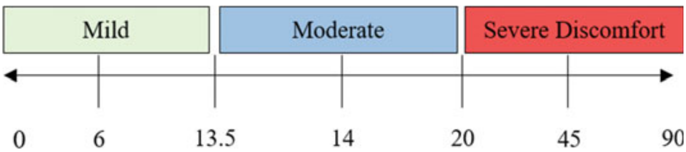

Fig. 1 Category group for Cornell musculoskeletal discomfort questionnaire

Table 2 Total discomfort score, mean, standard deviation, and category for each respondent

Body part	Total discomfort score	Mean	Std. deviation	Category
Lower Back	772	28.59	104.85	Severe discomfort
Neck	259	9.59	34.98	Mild
Hip/Buttocks	240.5	8.90	33.04	Mild
Upper Back	186.5	6.90	25.32	Mild
Shoulder R	164.5	6.09	22.78	Mild
Upper Arm L	149.5	5.53	23.51	Mild
Wrist R	139.5	5.16	19.17	Mild
Forearm L	135	5.0	18.44	Mild
Knee R	132.5	4.90	18.14	Mild
Knee L	119.5	4.42	16.84	Mild
Foot L	115	4.26	16.10	Mild
Wrist L	113	4.18	16.39	Mild
Upper Arm R	101	3.74	14.33	Mild
Forearm R	89.5	3.31	12.40	Mild
Foot R	87.5	3.24	12.09	Mild
Lower Leg R	85.5	3.16	2.42	Mild
Thigh R	85	3.15	12.11	Mild
Shoulder L	82.5	3.05	11.63	Mild
Thigh L	70	2.59	10.12	Mild
Lower Leg L	65.6	2.42	9.28	Mild

Note: *R* Right side; *L* Left side

that the body part with the highest level of complaints is the lower back, followed by their neck, wrist, and shoulder [10]. Another study conducted on grocery workers reported that they felt discomfort mostly in the upper back, lower back, and right shoulder [11].

2.7 Initial Ergonomic Risk Assessment (iERA)

2.7.1 Awkward Posture

Table 3 shows the percentage for each physical risk factor of awkward posture, focusing on shoulders, head, back, hand, elbow, wrist, leg, and knees. As the total score is 13, an advanced assessment should be conducted as it exceeds the advanced assessment benchmark of 6. The lower back pain with the high percentage of awkward posture at the head region could be due to the nature of the sawmill workers' job. They have to transport the cutting load by bending their heads and placing the cutting

Table 3 Physical risk factors percentages of awkward posture

Body parts	Physical risk factors	Explanation	Yes (%)	No (%)
Shoulder	– Working with hand above the head OR the elbow above the shoulder	Sawmill workers need to transport the log manually by placing the log on the shoulder	32.1	67.95
	– Working with shoulder raised		24.5	75.5
	– Work repetitively by raising the hand above the head OR the elbow above the shoulder more than once per minute		20.8	79.2
Head	– Working with head bent more than 45° downwards	Sawmill workers need to transport the cutting log. So the worker needs to bend their head and place the cutting log to proceed with the next process	92.5	7.5
	– Working with head bent backward		11.3	88.7
	– Working with head bent sideways		34.0	66.0
Back	– Working with back bent forward more than 30° OR bent sideways	Sawmill workers need to transport the woodchip manually to the woodchip store	84.9	15.1
	– Working with body twisted		62.3	37.7
Hand/Elbow/Wrist	– Working with wrist flexion OR extension OR radial deviation more than 15°	Sawmill workers used heavy machines such as log handlers, forklifts, and backhoe	90.6	9.4
	– Working with the arm abducted sideways		20.8	79.2
	– Working with arm extended forward more than 45° OR arm extended backward more than 20°	Sawmill workers need to transport the cutting log to the wood chip machine	83.0	17.0
Leg/Knees	– Work in a squat	Hammering activities during log processing	60.4	39.6
	– Work in a kneeling position		24.5	75.5

log at the log area before proceeding to the next process. Then, they need to transport the cutting log to the woodchip machine and transport the woodchip manually to the woodchip store. The majority of workers with 92.5 percent is reported having an awkward posture. As indicated in Table 9, an advanced ERA is necessary to obtain practical solutions to remove or reduce risk factors, since the result of iERA as much as seventy three percent.

Table 4 The percentage for the physical risk factor of static and sustained work posture

Body part	Physical risk factor	Explanation	Yes (%)	No (%)
Trunk/Head/Neck/Arm/Wrist	Work in a static awkward position	The workers must bend his head and manually transport the woodchip The use of heavy machines, such as log handlers, forklifts, and backhoe	32.1	67.9
Leg/Knees	Work in a standing position with minimal leg movement	The sawmill workers need to wait for the processing log from the machine	18.9	81.1
	Work in a seated position with minimal movement		13.2	86.8

2.7.2 Static and Sustained Work Posture

Table 4 shows the percentage for each physical risk factor of static and sustained work posture, focusing on (1) trunk, head, neck, arm, wrist, (2) leg, knees. The DOSH [9] advanced ERA was conducted as the total score is 3, which exceeds the ERA requirement benchmark for advanced assessment. Sawmill workers had to work in a static awkward position with minimal trunk movement, head, neck, arm, and wrist. Sawmill workers also need to either stand and be in seated positions with minimal movement while waiting for the log to be processed by the woodchip machine before moving them into the store. There was 32.1 percent of workers bend their heads and manually carry the woodchip during static and sustained work posture. As a result, the workers must undergo an advanced ERA because the iERA was identified at this posture at a rate of up to 43% (Table 9).

2.7.3 Forceful Exertion

Table 5 shows the percentage for each physical risk factor of forceful exertion. As stated by DOSH [9], forceful exertion involved seven manual handling activity; (1) lifting and lowering only (2) repetitive lifting and lowering, (3) twisted body posture while lifting and lowering, (4) repetitive lifting and lowering with twisted body posture, (5) pushing and pulling, (6) handling in a seated position, and lastly, (7) carrying. If YES has a score of 1 for each manual handling activity, an advanced assessment must be conducted. Sawmill workers were exposed to forceful exertion(83%) as they carry the load, lifting, and lowering load with the repetitive motion.

Table 5 The percentage of physical risk factors of forceful exertion among respondents

Physical risk factor	Explanation	Yes (%)	No (%)
Lifting and lowering only	Sawmill workers need to lifting and lowering the log It involves repetitive motion with the weight of a log between 3–10 kg Some of the sawmill workers need to carry the log about 50–55 kg	39.6	60.4
Repetitive lifting and lowering		52.83	47.17
Twisted body posture while lifting and lowering		45.28	54.72
Repetitive lifting and lowering with twisted body posture		45.28	54.72
Pushing and pulling	Sawmill workers need to transport the woodchip manually into the store The workers need to push and pull the log using a handling aid (wheelbarrow) between 5–7 m from the log section to the machine and from the machine to the store	83.02	16.98
Handling in a seated position	Sawmill workers used to check the log before the cutting process	3.77	96.23
Carrying	The floor from the log section to the machine is dry, but it becomes wets and slippery when it rains The area of the machine is provided with lighting The temperature in the area of the machine is a little bit hot due to the enclosed area	35.85	64.15

The respondents were revealed to carry log and wood chips with a weight between 3 to 10 kg with less than 10 m. In lifting and lowering the load, the sawmill workers have to lift the log manually with the weight between 50 and 55 kg in the distance, not more than 20 m. Forceful exertion during pushing and pulling, handling in a seated posture, and carrying the load was found to be a concern for eighty three percent of workers. Since the iERA reached 94%, an advanced ERA was necessary, as shown in Table 9.

2.7.4 Repetitive Motion

Table 6 shows the percentage for each physical risk factor of repetitive motion. Repetitive motion focusing on neck, shoulders, elbows, wrists, hands, and knee. As the total score for repetitive motion is 5, an advance assessment must be done for this ergonomic risk factor as it exceeds the benchmark score of 1. Sawmill workers need to lifting, lowering and carrying the log more than twice per minute. They were also exposed to work involving repetitive shoulder or arm movement with some pause or continuous movement when they needed to transport the woodchip into the wheelbarrow using a shovel. Repetitive motions in the shoulder and arm when

Table 6 The percentage for the physical risk factor of repetitive motion among respondents

Body part	Physical risk factor	Explanation	Yes (%)	No (%)
Neck, shoulder, elbows, wrist, hands, knees	Work involving a repetitive sequence of movement more than twice per minute	Sawmill workers do the lifting, lowering, and carrying logs	67.9	32.1
	Work involving intensive use of the fingers, hands, or wrist or work involving intensive data entry (key-in)	Sawmill workers are not involved in this risk factor	20.8	79.2
	Work involving repetitive shoulder/arm movement with some pauses OR continuous shoulder/arm movement	Sawmill workers need to transport the woodchip into the wheelbarrow using the shovel	77.4	22.6
	Work using the heel/base of the palm as a 'hammer' more than once per minute	Some of the sawmill workers need to break the small log. They used their hand and knee to use them as a place to break the log	9.4	90.6
	Work using the knee as a 'hammer' more than once per minute	The workers broke the small log by breaking it with their hands and knees	7.5	92.5

manually transferring woodchips in a wheelbarrow with a shovel put the majority of workers at risk (77.4%). Workers must undertake an advanced ERA as result of the iERA with eighty three percent, as shown in Table 9.

2.7.5 Vibration

Table 7 shows the percentage for each physical risk factor of vibration. Vibration is divided into two parts, which are hand-arm and whole-body vibration. The total score for vibration is 4. A score of 1 and above implies that Advanced ERA must be carried out. Sawmill workers often power tools such as cutting machines to cut the log. They are also exposed to whole-body vibration when some workers need to drive heavy machines such as log handlers, forklifts, and backhoe for more than 5 hours in 8 working hours. Seven sawmill workers involved in whole-body vibration combined with their complaint of excessive body shaking more than 3 hours in 8 working hours. Next, the fifth ergonomic risk factor was static and sustained work posture by sawmill workers where they had to work in a static awkward position with minimal movement of the trunk, head, neck, arm, and wrist. The sawmill workers

Table 7 The percentage for physical risk factor (vibration) among respondents

Body part	Physical risk factor	Explanation	Yes (%)	No (%)
Hand-Arm (segmental vibration)	Work using power tools without PPE	Sawmill workers use cutting machine to cut the log	13.2	86.8
	Work using power tools with PPE		41.5	58.5
Whole-body vibration	Work involving exposure to whole body vibration	Sawmill workers drive heavy machines such as log handlers, forklift and backhoe	32.1	67.9
	Work involving exposure to whole body vibration combined employee complaint of excessive body shaking		13.2	86.8

also need to stand or be seated with minimal movement when waiting for the logs to be processed by the woodchip machine before moving them into the store. Table 9 reveals that while utilising the cutting machine, forty two percent of sawmill workers are subjected to hand-arm vibration. Table 9 shows that the iERA result was fifty five percent, necessitating another advanced ERA evaluation.

2.7.6 Environmental Risk Factor

Table 8 shows the percentage of each environmental risk factor such as lighting, temperature, ventilation, and noise. Most respondents do not have any issue with these risk factors, with 77.4%, 58.5%, 88.7%, and 84.9%, respectively. However, because the total iERA score for an environmental risk factor for lighting, temperature, and ventilation is 1, there is evidence of inadequate lighting, extreme temperature, and inadequate air ventilation, necessitating the initiate of an advanced ERA.

Table 8 The percentage of the respondents for lighting, temperature, lighting, ventilation, and noise exposure

Physical risk factor	Explanation	Yes (%)	No (%)
Lighting	The woodchip machine area needs adequate lighting	22.64	77.35
Temperature	The log section is exposed to the sunlight The woodchip machine is under the roof	41.5	58.5
Ventilation	Open-air ventilation	11.3	88.7
Noise	The sawmill workers' woodchip is exposed to the high level of noise coming from the wood chipper machine	15.1	84.9

[9]. Furthermore, because the overall score is 2, an advanced ERA for noise is required.

In terms of lighting, one of the respondents complained about inadequate lighting and experience headaches when in a dark or bright place. He also feels that his shadow bothers him while doing his job. Meanwhile, one respondent complained about inadequate lighting and having headaches when being in a dark or bright place. Four respondents complained about inadequate lighting, four respondents complained about having headaches when being in a dark or bright place at work. In comparison, seven respondents feel their shadow bothers them while doing a task. It was observed that the log section is located at the outside (open-air) has adequate natural lighting, compared to the production section, which needs more lighting since it is located in a closed building. Even though it received natural lighting but it still not enough. The management already provides artificial lighting in the building.

Five of the respondent complained they sweat more than usual due to the high-temperature breath more quickly and deeply than normal and feel shortness of breath while working. Some of the sawmill workers are also exposed to sunlight while working. Only some areas in the sawmill factory, such as the production area where the cutting and wood-chipper machines are located, have a roof. On the other hand, the log section is exposed to sunlight. The company provided the workers with Personal Protective Equipment (PPE), including safety helmets and safety goggles. They are also provided with drinking water and shelter where they can take a break or cool themselves.

According to the company, the management already provided respirators such as N95 masks for their workers. Most of the workers follow the company's standard operating procedures and wear the mask during working hour. Six of the respondents do not wear their PPE as they feel discomfort when wearing the mask while doing a task. This situation is also linked to the extreme temperature when one of the respondents felt shortness of breath when wearing a mask during working hours.

For the noise risk factor, the management already provided ear protection such as earplugs and earmuff. Sawmill workers had to work involved exposure to the high noise level from production building, especially the wood-chipper machine. Eight of the respondents do not wear ear protection due to feel discomfort while doing a task. The sawmill workers were given four situations, and they need to tick which situations are related to their condition. Most of the workers who do not wear ear protection felt that noise in the working area is louder than busy city traffic, and they have to raise their voice to talk to someone at one metre. Two respondents complained about temporary ear ringing while another complained that he has to increase the volume of radio or television to higher than usual at the end of the work shift.

Table 9 shows the overall percentage of respondents' assessment and the need to conduct advance ERA for each environmental risk factor. The iERA result shows that forceful exertion is at 94.3%, repetitive motion is at 83.0%, awkward posture is at 73.6%, vibration is at 54.7%, static and sustained work posture (43.4%), temperature with (41.5%), lighting (22.6%), noise (15.1%) and ventilation (11.3%).

Table 9 Percentage of iERA score and requirement to conduct advanced ERA among sawmill workers (N = 53)

Risk factor	iERA (%)		Advanced ERA required?
Forceful exertion	94.3	5.7	Yes
Repetitive motion	83.0	17.0	Yes
Awkward posture	73.6	26.4	Yes
Vibration	54.7	45.3	Yes
Static and sustained work posture	43.4	56.6	Yes
Temperature	41.5	58.5	Yes
Lighting	22.6	77.4	Yes
Noise	15.1	84.9	Yes
Ventilation	11.3	88.7	Yes

2.8 Association Between Prevalence of Musculoskeletal Disorder with Ergonomic Risk Factors Among Sawmill Workers

The Guidelines on Ergonomics Risk Assessment at Workplace focused on the physical ergonomics in the workplace [9]. Physical ergonomics are related to the human body's response to physical and physiological demands, such as repetition, vibration, force, and posture. The most common occupational WMSDs are reported in the lower back, wrist, upper back, shoulders, and knees [10, 12, 13]. These WMSDs are due to repetitive activities, awkward working posture, and forceful exertion. During sawmill activities, it involves carrying a heavy load, frequent and repetitive activities. One of the reasons for lower back pain among sawmill workers is awkward working posture. Other than that, sawmill workers carry heavy loads, often for a certain distance [10]. Previous studies showed that shoulder placement exceeding 90° while lifting heavy loads is associated with shoulder pain [14]. It has been noted that posture and repetition also lead to body discomfort.

There are many studies about the association between physical risk factors and WMSDs. In this study, Pearson's Chi-Square analysis was used to verify the association between WMSDs and physical risk factors among sawmill workers by comparing the Cornell Musculoskeletal Questionnaire results with the iERA results.

In this study, the null hypothesis (H_0) states there is no association between the prevalence of WMSDs and physical risk factors. The alpha level is set at 0.05 to compare with the ρ-values achieved. When the ρ-value achieved is more than 0.05 ($\rho > \alpha$), the null hypothesis (H_0) is accepted. When the ρ-value is lower than 0.05 ($\rho < \alpha$), the null hypothesis (H_0) is rejected, implying that there is an association between WRMSDs and physical risk factors.

In this study, ρ-value will be selected using the exact test ρ-value. Selection of Exact test ρ-value is more accurate than Asymptotic ρ-value. Terms of use of Asymptotic ρ-value, when there is a cell or box with an expected frequency value of less

Table 10 The significant association between CMDQ and iERA

Ergonomic risk factor	Body region	χ^2	ρ-value
Awkward posture	Lower back	8.807	0.013
Lighting	Left lower leg	7.101	0.048

than 5, so the distribution of Pearson's Chi-Square test will be difficult to approach distribution of Chi-Square so that it will obtain inaccurate results. Therefore, when Chi-Square analysis was conducted, the ρ-value of the Exact test would be used when several cells or boxes exceeds 5. If there is no number of cells or boxes exceeding 5, then the Asymptotic ρ-value would be used [15].

2.8.1 Chi-Square Test (χ^2) Between Cornell Musculoskeletal Discomfort Questionnaire and iERA

Table 10 shows the chi-square analysis of all risk factors for CMDQ and iERA. There is a significant association between the prevalence of WMSDs and physical factors among sawmill workers since the ρ-value equal to 0.013. Based on the previous research, it was found that there is an association between lower back pain and awkward posture. Awkward posture can cause pain in the lower back due to job demands, working hours, and repetitive activities in the working area [10]. In previous studies of Sukadarin et al. [14], different variables have been found related to MSDs. In this light, simultaneous pelvic tilt and spine flexion is a leading cause of low back pain (LBP).

Meanwhile, the ρ-value of the left lower leg at the lighting factor is 0.048, indicating an association between the prevalence of WRMSDs among sawmill workers and physical factors. This situation cannot be approved since there is no evidence from previous research stated that lighting could cause ache, pain, and discomfort in the lower leg region. Sutcu et al. [16] stated that lighting factors could only cause accidents when using machinery and equipment. This situation may lead to body injuries but not musculoskeletal disorders.

3 Conclusion

This study has discussed the ergonomic issue faced by workers in the sawmill industry. Awkward postures are directly associated with WMSDs and cause conditions like lower back pain. Safety measures should be implemented to overcome the significant association between the prevalence of discomfort and ergonomic risk factors. The prevalence of lower back pain can be reduced by rearranging the workers' schedules and conducting job rotation to work effectively. Besides that, physical risk factors can be avoided through manual handling training by considering the processes while conducting activities like lifting, carrying, and lowering. More studies should be carried out by including anthropometry measurement and biomechanics factors. To understand the work activities that lead to musculoskeletal problems.

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References

1. Department of Statistics Malaysia (2019) Press release index of industrial production, Malaysia. 1–2. Websites Retrieved from https://www.dosm.gov.my (2020)
2. Ministry of International Trade and Industry (2019) Wood-based industry 21(1):1–9
3. Forestry Department of Peninsular Malaysia (2018) 2018 annual report. Websites Retrieved from https://doi.org/10.1088/1751-8113/44/8/085201
4. Rahman MS, Khan AH, Rahman MS, Biswas B (2019) Work-related musculoskeletal disorders: a case study of Sawmill workers in Bangladesh. Curr World Environ 14(2):336–345. https://doi.org/10.12944/cwe.14.2.18
5. Top Y, Adanur H, Öz M (2016) Comparison of practices related to occupational health and safety in microscale wood-product enterprises. Saf Sci 82:374–381. https://doi.org/10.1016/j.ssci.2015.10.014
6. Ministry of Plantation Industries and Coomodities Malaysia (2020) The launch of the National Timber Industry Policy (NATIP), 3–6. Websites Retrieved from https://www.mtib.gov.my/images/pdf/polisi/Natip3.pdf
7. Qutubuddin SM (2013) An ergonomic study of work-related musculoskeletal disorder risks in Indian Saw Mills. IOSR J Mech Civil Eng 7(5):07–13. https://doi.org/10.9790/1684-0750713
8. Ali A, Qutubuddin SM, Hebbal SS, Kumar ACS (2012) An ergonomic study of work-related musculoskeletal disorders among the workers working in typical Indian sawmills. Int J Eng Res 3(9):38–42
9. Department of Occupational Safety and Health (2017) Guidelines on ergonomics risk assessment at workplace 2017. In: Department of Occupational Safety and Health (p. 155). Websites Retrieved from https://doi.org/10.15713/ins.mmj.3 (2020)
10. Hedge A, Morimoto S, McCrobie D (1999) Effects of keyboard tray geometry on upper body posture and comfort. Ergonomics 42(10):1333–1349
11. Chandra A, Oha M, Ghosh S, Barman S, Dev S, Gangopadhyay S (2011) An ergonomic study on musculoskeletal health hazards among sawmill workers of West Bengal, India. J Hum Ergol 40(1–2):1–10. https://doi.org/10.11183/jhe.40.1
12. Çakıt E (2019) Ergonomic risk assessment using Cornell musculoskeletal discomfort questionnaire in a grocery store. Ergon Int J 3(6). https://doi.org/10.23880/eoij-16000222
13. Grzywiński W, Wandycz A, Tomczak A, Jelonek T (2014) The prevalence of self-reported musculoskeletal symptoms among loggers in Poland. Int J Ind Ergon 52:12–17. https://doi.org/10.1016/j.ergon.2015.07.003
14. Sukadarin EH, Ghani JA, Syazwani N, Nawi M, Ismail AR (2016) Postural assessment in pen-and-paper-based observational methods and their associated health effects: a review postural assessment in pen-and-paper-based observational methods and their associated health effects: a review. Int J Occup Saf Ergon 22(3):3–6. https://doi.org/10.1080/10803548.2016.1156924
15. Mehta CR, Patel NR (2011) IBM SPSS exact tests 1–236
16. Sütçü A, Semerci NT (2019) Occupational health problems of sawmill workers processing red pine in Turkey. Appl Ecol Environ Res 17(4):7625–7639. https://doi.org/10.15666/aeer/1704_76257639

A Systematic Review of Risk Factor Associate with Musculoskeletal Disorder: Biomechanical and Psychosocial Factor

Khairulhafiy Muhammad Ruzairi, Balqis Syahirah Jamaludin, Ezrin Hani Sukadarin, and Mirta Widia

Abstract Provide systematically graded evidence for possible associations between biomechanical and psychosocial development of musculoskeletal disorders (MSD) among workers by relating them to disease etiology. Penultimately, summarize the evidence that linking biomechanical and psychosocial risk factor that experience with disorder. Psycho-social work factors were specified as distraction elements of the work environment factors and biomechanical vibration have been well established in the literature as apparently to play a major role in the development of MSD merge it has reciprocally influence. Despite have been several systematic reviews of the literature published few years back. There is demand for an updated systematic review using the GRADE clinical practice recommendations. By means of computerized search must been meet the inclusion criteria. (i) English literature (ii) Quantified results describing the relationship of combination factor (at least one risk factor of studies investigation. (iii) In a prospective case–control study or/and emphasis on peer-reviewed report literature. (iv) Risk evaluation (working environment) and retrieve outcome (disease etiology). (v) Outcome must be related to MSD that can be more than one of disease etiology. Reliance on several publisher database, Spring CORE, Research Gate, Elsevier, and Science Direct. Fifteen scientific journals were included in this review. Based on spider web plots, in terms of biomechanical factor, substantial evidence (high grade) correlation with MSD, were an effect was a high vibration segmental, repetitive and prolonged activities and awkward work postures meanwhile on psychosocial for effort reward imbalance and low support. Insufficient proof (medium low grade) of biomechanical factor was revealed on localized contact stresses and forceful exertions. Concurrently in psychosocial inconsistency data was found on work method, social distractive and excessive working hours. There was no differential combination risk factor effect of adverse job conditions on MSD symptoms. Ultimately, that biomechanical risk factor contributes to a constituent of MSD. Along with that, it will inevitably come when combined with psychosocial factor indicate results of a distinctive. Many well-known syndromes from awful

K. M. Ruzairi · B. S. Jamaludin · E. H. Sukadarin (✉) · M. Widia
Occupational Safety and Health Program, Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang, Gambang, Malaysia
e-mail: ezrin@ump.edu.my

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biomechanical experience and psychosocial risk factor that contributing to MSD has been scientifically shown. The results of the understanding and findings of the study can help the researcher to get the latest analysis on the combining risk factor aspect for seek to solve practical problems and disseminating the knowledge as value addition to society.

Keywords Musculoskeletal disorders · Psychosocial risk factor · Biomechanical risk factor · Job demands · Work stress

1 Introduction

In Malaysia, there are more than 35,000 injuries occurred in the workplace every year. In 2012, from more than twelve million workers, there was an estimated of one thousand deaths [1]. This represent manufacturing sector is the highest of accidents reported follow by construction and mining and quarrying sector. Our study could have been showed that manufacturing can be perform Repeater and Replacer Hypothesis that perform in highly stereotype way to be at higher risk to developed MSD with experience on Individual Motor Variability (MV Traits) and 'Cinderella Hypothesis' [2]. While Construction operators have type of heavy workload [3] will be exposed to mechanical shock [4] which will often experience superimposition [5].

Ergonomic is an aspect of how to ensure humans wellbeing interact with the work environment. Diverse research studies produce a variety of meanings to explain ergonomic concepts. Te-Hsin and Kleiner [6] defined ergonomics as that coordinates the design of devices, systems and physical working conditions with the capacities and requirements of the workers [6, 7] refer as a branch of science that is concerned with the achievement of optimal relationship between workers and their work environment. Besides that, ergonomic implies as promoting compatibility between human and systems [8] with the design of the workplace, equipment, machine, tool, product, environment and system, taking into consideration the human's basic need capabilities and optimizing the effectiveness and productivity of works systems while assuring the safety and health of the workers [9].

Ergonomic philosophy as simple as job demands should not go beyond employee limits [10] or in view of the fact that it will lead to psychosocial stress [11] and physical strain that [12] can make negative impact on organization performance [11].

Commonly ergonomic objective is to improve relation between human, machine design and workplace environment into work productivity and job design efficiency by designing a job to allow for good posture, less exertion, fewer motions, and better heights and reaches. Therefore, the intention of an ergonomics is to promote a safe and productive workplace [13] as it gives comfortability to the worker [14] to fulfil the organization goals. An implementing the ergonomic, there have several major area to consider in concerned with the understanding of the interactions among humans and other elements of a system by way of reduce static load and minimize direct pressure to prevent the discomfort, fatigue and physical and psychosocial stress faced by the workers to the minimum possible [15].

MSD according to the Centers for Disease Control and International Classification of Diseases (ICD-10-M99-7; 2010 version), MSD is an injury or disruption of muscles, nerves, tendons, joints, upper and lower cartilage, neck, and lower extremities back caused, triggered, or exacerbated by sudden exertion or prolonged exposure to physical factors such as repetition, force, vibration, or awkward posture. In conformity with that, MSD cover large range of pathologies which affect the osteoarticular system, muscles, and conjunctive tissues [16]. Problems focused on tendinous, vascular, nervous, and muscular, affecting either the upper or the lower member, or the back. Commonly, these professional illnesses are complex results from the decomposition process bound up with the symptoms found on the physical part of the body and affects the psychosocial of the worker.

According to National Institute for Occupational Safety and Health, United States (NIOSH) [17], epidemiological studies was defined three component of MSD risk factor while to conduct ergonomic risk assessments, there are also three risk factors to considering that are psychosocial factor more to mental reaction of job dissatisfaction on a working condition that is possible leading to physical strain, biomechanical factor that focusing on physical body issues such as awkward posture, exerting excessive force and static loading, and individual factor linking into personal factor such as body mask index (BMI), gender, health history and age. Emphasize that MSDs are the result of a combination of biomechanical and psychosocial pathogenic risk factors for the workers' health that this study has strong reason to explore with that evidence.

Typically discussed in the field of ergonomic studies, combination factor can be state as more than two or multiple factors when combined that can contribute to the formation of MSD [13]. On the other hand, Sukadarin et al. [18] has shown that several methods, such as WERA, QEC, REBA, OWAS, PATH, and PLIBEL, can be used to evaluate posture and body area, which is essential for identifying ergonomics risk factors for MSDs.

Previous study shown that, biomechanical risk factor occurs when a person can accommodate psychosocial demands, which lead in a stress response, which in turn can produce muscle tension or static muscle loading or produce other physiological responses [13]. According to the European Agency for Safety and Health at Work [19], low social support, aggressive behavior, conflicting demands, and family problems are among the causes of the negative psychosocial impact of organizations with poor management systems. It will affect lifestyle, job satisfaction and organizational attribute. Important part is component of psychosocial have been denote significantly associated with MSD.

Indicate preceding research, there are also cases where workers experience a combination of risk factors that contribute to other levels of injury [14]. There is emerging evidence that a combination of exposure to physical and psychosocial factors at work has a stronger association than either type of factor alone [20, 21]. For that reason, authors ambitious to review and provide in the literature systematically graded evidence for possible associations between biomechanical and psychosocial development of MSD among workers by relating them to disease etiology. Penultimately, summarize the evidence that linking biomechanical and psychosocial risk factor that experience with disorder.

2 Material and Method

2.1 Article Search and Article Selection

Preferred Reporting Items for Systematic Reviews and Meta—Analyses (PRISMA) as guidance to carrying out and provision of information in this study [Fig. 1]. Search strategy conducted using relevant keywords such as ergonomics, MSD and biomechanical risk and psychosocial risk factor. Searching strategy performed using the electronic database Scopus, Springer, CORE, ResearchGate, Elsevier, ScienceDirect and Semantic Scholar. Although, possibilities reference beyond 12,000 were then the significance references be analyzed in next process.

In broad term, search strategies are conducted with a variety of significant keywords equivalent to MSD risk factors for biomechanical and psychosocial. The selection process is made using the search phrase Boolean with a combination of "OR" and "AND" Boolean operator to fulfill the identification purpose.

To ensure systematic search were relevant and comprehensive, numerous topics taken into the article search such as Hand Arm Vibration (HAV), Whole Body Vibration (WBV), Upper limb MSD consortium, Peripheral Vascular Disorder (PVD), White Finger Disorder (WFD), Lower Back Disorder (LBD), Cumulative Trauma Disorder (CTD) and Psychological and Psychosocial Stress. An article was made to ensure that all terms used as biomechanical and psychosocial of MSD risk factor are taken into consideration the fact.

2.2 Inclusion Criteria

Our inclusion criteria are a key feature to answer research question. Article out of our scope examples at screening process by means of computerized search must been meet the inclusion criteria that are articles in English language, study design must either on experiment or observational, emphasis on full or peer-reviewed report literature, outcome must be related to MSD consortium that can be more than one of disease etiology, the research covered either combination (Biomechanical and Psychosocial) or single risk factor (Biomechanical or Psychosocial).

The exclusion of searches was non-ergonomic workplace, the riddance of this because nonsignificant result of research. 153 articles were eligible, after 138 articles were removed with justification while during eligibility process, only 15 articles left.

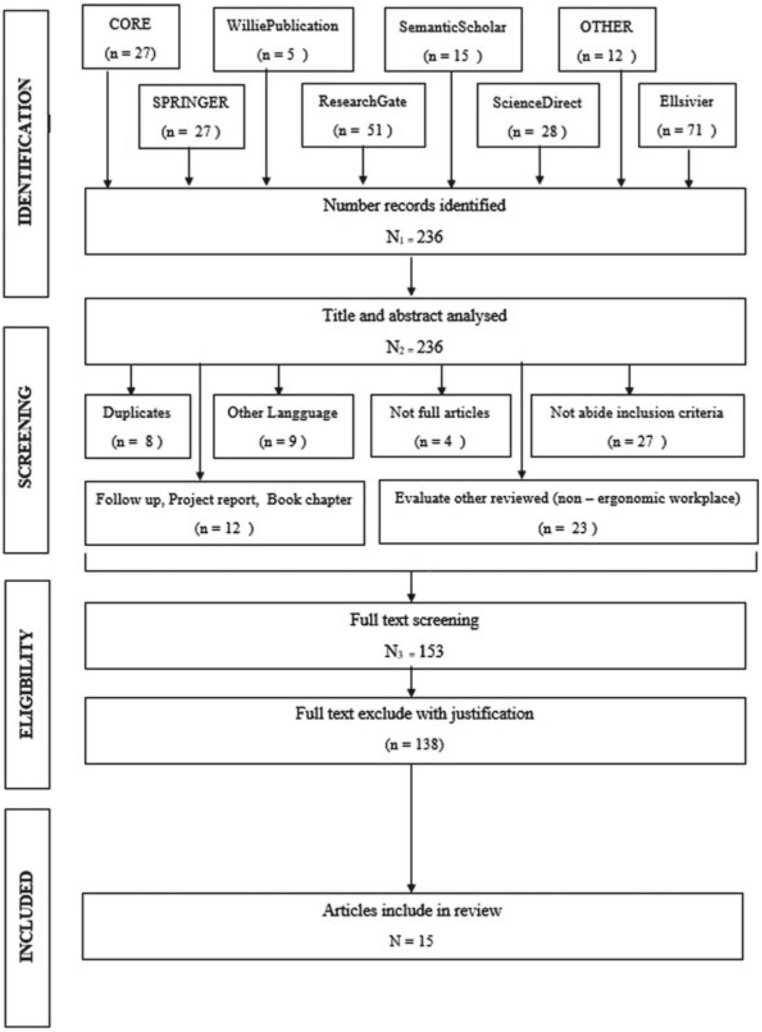

Fig. 1 Flowchart of article search design

2.3 Data Extraction

Articles that have been included will be reviewed and summarized. A summary of all the main findings related to the study were extracted in evidence Table 6 consists of studies of relevance, epidemiology of risk factor and conceptual reviews. Where necessary including the main finding and relevance fact as reviewers. These three tables are interconnected with each other, referring to the original research article.

2.4 Evidence Statement

To identify the level of research, important facts based on solid evidence and various references are taken as research material that can not be manipulated to achieve the highest level of evidence. This evidence will be processed and interpreted if it meets the requirements of the study with a certain of boundary.

2.5 Evidence Quality Assessment

This publish articles has been thoroughly evaluated, synthesized, and digested by the reviewers. 153 articles selected after the selection process were randomly checked to ensure the content meets the level of the study. 15 articles were included in the review has been evaluated the methodology through methodology quality assessment list, adaptation from Ariens [22]. Quality criteria in it has been improved to suit the objective of this study such as on exposure setting, only focus on exposure that are adequate and appropriate rather than time prior to the occurrence of the outcome and on Analysis and data Presentation, group the criteria into two categorize that are statistical analysis and visualizing. After improving the quality criteria, a quality assessment list was formed to evaluate the methodological quality of the article reviewed (Table 1).

The Grading of recommendations, assessment, development, and evaluations (GRADE) system is emerging as the dominant method for appraising controlled studies and making recommendations for systematic reviews and guidelines [23]. The GRADE of evidence for supporting risk factor for the consistency of the results between the systematic review (SR) (relevancy) was classified levels of evidence as per Table 2.

The focus of the study is based on relative risk and risk estimate that is how often the risk occurs and has an impact on workers. Through risk estimate, it can assess the probability and impact of combination risk factor based on comparative studies or previous observation studies from expert. The goal for future studies, is to assess risk exposure and risk reduction of matrix probabilities and impact. Thus, if there is no substantial relationship between MSD with the biomechanical and psychosocial risk factor the study will be re-moved from the level of evidence due to insufficient information, disputable calculations, or small parameters. Since our focus on risk factor, we detailed grading of exposure measurement, we also choose the scoring system by Sulsky [23] and adapted their assessment method for the biomechanical and psychosocial risk factor see Table 3.

Table 1 Methodological quality assessment lists

Criteria list		Description	Score		
Study purpose	a	Clearly defined research objective	+	–	?
Study population	b	Population groups clearly defined	+	–	?
	c	Participation more than 80%	+	–	?
	d	Describe the demographic characteristics of the population of interest including their age, ethnicity, socioeconomic status, education level, marital status, and work status	+	–	?
	e	Determine eligibility criteria based on inclusion and exclusion criteria of individual is qualified to be a participant in a research study	+	–	?
Exposure setting	f	Propose a definition of exposure that is consistent with the clinical/conceptual basis for the research question[a]	+	–	?
	g	Provide a rationale for choice of exposure time window[a]	+	–	?
	h	Describe the proposed data source(s) and explain how they are adequate and appropriate for defining exposure[a]	+	–	?
	i	Provide evidence of validity of the operational definition of exposure with estimates of sensitivity, specificity, and positive predictive value[a]	+	–	?
	j	Support the unit of analysis chosen for exposure measurement (e.g., person-months of exposure) and discuss for alternative units of measurement[a]	+	–	?
	k	Address issues of differential and nondifferential bias related to exposure measurement and propose strategies for reducing error and bias, where possible[a]	+	–	?
Outcome measurement	l	Determine types of outcome measures—primary, secondary, or tertiary or other variables	+	–	?
	m	Determine clinical outcome case definitions—Physician-based case, Laboratory-based case, Lay worker-based case or using secondary data sources	+	–	?
	n	Indicate behavioral and body part changes	+	–	?

(continued)

Table 1 (continued)

Criteria list		Description	Score		
	o	Conduct of a double-blind randomized trial	+	–	?
	p	Variability and Quality control issues—diagnostic procedures employed in a trial been monitored	+	–	?
Study design	q	Clearly state research question	+	–	?
	r	Clearly state research objective	+	–	?
	s	Determine phenomena of interest (include and exclude criteria)	+	–	?
	t	Clearly state main features (sampling strategies and study population)	+	–	?
	u	Clear description of cases and controls. Person suspect MSD syndrome before 90 days should be exclude	+	–	?
Analysis and data presentation	v	Confounding control	+	–	?
	w	Statistical analysis—sample justification, reasonable model, strong interpretation, multivariate analysis, variance or estimates	+	–	?
	x	Visualizing—Recurring patterns or themes enable to findings and present findings in appropriate ways	+	–	?

Note + Positive; – Negative; ? Unclear

Table 2 The GRADE system

Evidence grade	Description	Min
Solid evidence	Consistent findings in excellent quality SR (high score review): Reviewers belief that impact in the study indicate the actual impact	≥ 8
Modest evidence	Consistent findings excellent quality SR (at least one high score review): Reviewers belief that impact in the study indicate almost shows the impact, although considerably different	5–7
Reasonable evidence	Consistent findings good quality SR (significant review): True impact slightly different from the estimate	2–4
Inconclusive evidence	Concerns all other cases, e.g., consistent findings in poor quality SR, or inconsistent findings, or irrespective of the quality of this study: True impact diverge substantially from the estimate	≤ 1

Table 3 Quality assessment of risk factor

Exposure measurement	Score
Profession, job title, classification of occupation	1
Qualitative specification of exposure in different work activities (Biomechanical: standing, sitting, static or dynamic movements; Psychosocial: low social support, bad management, crude individual, health being, workplace values, offensive behavior, life satisfaction)	2
Quantitative specification of exposure in different work activities/physical strains with information on intensity (Biomechanical: repetition, force, load weight, awkward postures, or duration; Psychosocial: High psychological demand, low reward, high expectation, ability to work, burnout)	3
Quantitative specification of exposure (as above) with additional plausibility check (e.g., information on daily work output or special controls through video analysis)	4
Direct measurement or biomechanical or psychosocial model calculation of strain with specification of quantitative information (Biomechanical: repetition per time, force, load weight, awkward postures, holding time of awkward postures, amount/amplitudes, acceleration, velocity, torque; Psychosocial: labor demand does not match the size of work, low reward is not commensurate with a lot of work, ability to work was measured by work experience.)	5

3 Results and Discussion

3.1 Designation of Included Studies

Out of 236 articles, only 153 were in the full text screening process, after 83 articles were excluded at the screening stage with the criteria set. Thus, making only 15 remaining articles were included in the review. Excluded article as not applicable in the scope of ergonomic and workplace concepts. There are also articles that do not provide evidence of validity of the operational definition of exposure with estimates of sensitivity, specificity, and positive predictive value and determine clinical outcome case definitions based on MSD consortium diseases.

3.2 Included Studies Quality

3.2.1 Methodology Quality

As mention before, 15 articles were included in studies, 8 prevalence cross sectional studies, 2 cohort studies and 5 experimental studies. From 8 significant cross-sectional studies, 3 of them recorded solid and modest quality and 2 reasonable quality. Besides that, cohort studies indicate 1 solid quality and 1 reasonable quality. Furthermore, 1 experimental study recorded modest quality and 4 reasonable quality.

In general, 15 included studies were in acceptable quality. All the decision has been made through the description on evidence grading on Table 2.

Overall, the basic strength of the article lies in the cohort study design where, they have added value to the clear description of subject research where workers being affected by MSD were excluded from studies. On the other hand, cross sectional recorded a high score, but moderate quality is due to fail to satisfy reviewers belief that impact in the study indicate almost shows the impact, although considerably different.

3.2.2 Exposure Risk Factor Assessment Quality

Risk factor is as physical attributes or characteristic of the work environment and social features that potentially increase harmful situation. While risk is probability that a specific action or exposure will give rise to a negative, seriousness of the consequences or severity if something dangerous occur [13]. Risk factor is more difficult to control because his condition is variable, difficult to detect and has become a normal habit in the job. If left untreated it will threaten workers physically and psychosocially in the long run [27]. It is essential to determine the relationship of conditions for administering effective responses for complete mediation of risk maker or when making suggest attainable solutions to avoid possible mistakes in the risk evaluation [28]. The definition of the risk factor, the risk factor levels, and the theoretical minimum risk exposure level are presented in Table 4 [29].

In term of scoring of exposure risk factor assessment in generally recorded based on the quality assessment from Table 3, one article indicates 2 scoring marks, while majority recorded 3 scoring marks. Otherwise, most article present quantitative specification of exposure risk factor with information on intensity. The scoring ratio on Tables 5 and 6 shows the overall result.

Table 4 Definition of the risk factor, the risk factor levels and the theoretical minimum risk exposure level

Risk factor	Exposure to occupational risk factors defined as exposure occupationally to one or more of force exertion, demanding posture, repetitive movement, HAV, kneeling squatting and lifting or climbing
Risk factor level	Two levels 1–No exposure to occupational ergonomic risk factors 2−Any exposure to occupational ergonomic risk factors If possible, “any” exposure may be further classified into “moderate” and “high” exposure, preferably based on exposure in terms of level, frequency nor duration
Theoretical minimum risk exposure level	No exposure to occupational ergonomic risk factors

Table 5 Scoring rating

Scoring rating	Author	Total
2	Michael Uhl [29]	1
3	Yarandi [30], Baek [31], Sekkay [3], Collins [2], McDowell [33], Azizan [34], Kim [35], Roseiro [36], Xu [37], Hahhr [41]	10
5	Jackson [40], Asadi [39], Mohan [11], Yang [38]	4

Table 6 Methodological assessment list

Ref	SD	ERFAS	Criteria list methodological quality assessment																		SC	QL
			g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x		
[30]	CC	3	+	?	+	+	+	+	+	+	–	–	+	+	+	+	+	–	+	+	13[a]	Sld
[40]	CH	5	–	+	+	+	+	+	+	+	–	–	+	+	+	+	+	–	+	+	13[a]	Sld
[39]	CH	5	+	–	+	+	–	+	?	+	+	–	+	+	+	+	?	–	+	+	12[a]	Sld
[3]	CS	3	–	–	+	+	–	+	+	+	+	–	+	+	+	+	+	–	+	+	12[a]	Mod
[29]	Exp	2	–	?	+	+	–	+	–	+	–	–	?	+	+	+	?	–	+	+	8	Inc
[31]	CS	3	–	+	?	+	–	+	+	+	+	–	+	+	+	+	–	–	+	+	11[a]	Mod
[37]	Exp	3	–	–	+	+	+	+	?	+	–	–	+	+	+	+	?	–	+	+	10	Res
[32]	Exp	3	+	–	+	+	–	+	?	+	–	–	+	+	+	+	–	–	+	+	10	Res
[33]	Exp	3	–	?	+	+	–	+	+	+	–	–	?	+	+	+	+	–	+	+	10	Res
[36]	CS	3	–	?	+	+	–	+	+	+	–	–	+	+	+	+	–	–	+	+	10	Res
[11]	CC	5	–	–	+	+	+	+	+	+	–	–	+	+	+	+	+	–	+	+	12[a]	Sld
[37]	Exp	3	–	+	+	+	–	+	–	+	+	–	?	+	+	+	–	–	+	+	10	Res
[38]	CS	5	–	+	+	+	–	+	+	+	–	–	?	+	+	+	+	–	+	+	11[a]	Mod
[32]	CS	3	–	–	+	+	–	+	–	+	–	–	+	+	+	+	+	–	+	+	10	Res
[41]	CS	3	–	+	+	+	–	+	?	+	–	–	+	+	+	+	–	–	+	+	10	Res

[a]criteria a–f not listed because is about study setting. *Ref* Reference. *SD* Study design. *ERFAS* Exposure risk factor assessment. *Sld* Solid. *Mod* Modest. *Res* Reasonable. *Inc* In-conclusive. *SC* Score. *QL* Quality. *abcdef* Simply for descriptive information only, other provide validation item. Study de-sign: *Exp* Experiment *CS* cross-sectional study; *CH* cohort study; *CC* case control study. Total score calculated by counting the number of positive validity items. High score articles been mark with an asterisk ([a])

3.3 Biomechanical Factor Associated with MSD

Exposure to whole body vibration (WBV) has been identified as one of the most important risks biomechanical factor for musculoskeletal disorders (MSD) [43]. According to, DHHS NIOSH [27] WBV defined as vibration transmitted to whole-body, to be referred to self-propelled machines and means of transportation, covers a more important role, from the health point of view, in comparison with that generated by steady machines. In particular foundation, factor that influence affect WBV exposure with correlation of MSD is role played by some anthropometric characteristics, such as stature, body mass and Body Mass Index (BMI), [31, 43]. Recent, anecdotal studies providing process of whole-body vibration segmental correlation with MSD need to determine through affect of fatigue muscle. Here we report the discovery and characterization of a vast relationship between this disorder. For example, based on a case study of haul truck activity [44], off road vehicle and moving equipment increased postural requirements [45, 46] and exposes instances jarring or jolting (mechanical shock) is a component of WBV, when transmitted to the human body at the natural frequency may produce a condition known as resonance. During resonance, the body part will vibrate at magnitude higher than applied excitation force then muscles will contract in a voluntary or involuntary way and cause muscle and tissue fatigue.

Reported a significant positive association between WBV exposure and MSD in literature review and prevalence studied assigning descriptor of strong evidence to the WBV-MSD relationship [28, 43–46]. Two cohort studies showed exposure to WBV as risk for MSD [47]. Emphasized, this two-expose type of WBV exposure (i) Transient shock that contribute to degeneration of lumbar spine more than the continuous oscillatory component [48] and (ii) Multi axial exposure affect muscular stress during long drives may lead to an increased risk of musculoskeletal disorders [48].

Based on summary extracted data from included papers, shown in generally [3, 31, 32, 40, 41] present a description of exposure risk factor significant with clinical standard, towards the concept of study. A relevant information on studies [30, 33], emphasizes the reliability of exposure with preciseness of positive predictive value and estimates of sensitivity to validate the definition of biomechanical risk factor operation.

Although, with 15 articles included on this study, we can see a long list of 41 risk exposures presented and assessed, a total of 34 exposures been group in 14 attributes provided an initiative relation to the effects of MSD in Table 7. In the study Firdaous Sekkay [3] showed #1, #7, #8, #11, #14, will cause a direct effect on MSD through vibration transferred to the body part. Describe likewise where vibration can reach. Major risk for MSDs is WBV [40] and identified as element of biomechanical factors [49–51]. Recent, anecdotal studies providing process of WBV segmental correlation with MSD need to determine through affect of fatigue muscle [52]. Notably on a case study of haul truck activity [43] off road vehicle and moving equipment increased postural requirements [46] and exposes instances jarring or jolting (mechanical shock) is a component of WBV. The focus should be on the exceedingly difficult study by Amzar Azizan [34] and Haiou Yang [38], where its illustrate the measurement of significant exposure #2, #4, #7, #12, #19 to MSD consortiums such as WBV, CTD, neck shoulder disorder, LBP and traumatic and psychology stress.

In most epidemiological studies reviewed study [11, 35], showed clear clinical evidence when their findings indicate exposure #1, #2, #3, #4, #6, #7, #8, #14 has a very bad effect on body part that forms MSD. At the same time, it has been proven

Table 7 Risk factor attributes

Symbol	Risk factor (Exposure)	Symbol	Risk factor (Exposure)
#1	Forceful exertions—frequent heavy lifting, pushing, pulling and carry heavy object	#8	Work method and personnel relations
#2	Awkward Work Postures—Fixed Or Awkward Body Postures, poor lighting	#9	Noise
#3	Localized Contact Stresses—Pinch stress	#10	Body attributes—Gender, High BMI, Low nutrition
#4	Whole-body or segmental vibration	#11	Job dissatisfaction—job insecurity, effort reward imbalance, overload effort, temporal demand, high job demands, lack of task variability, excessive work pace and/or duration, inadequate work-rest cycles, unaccustomed work
#5	Hand tools and equipment	#12	Poor management—low cowerker support, low procedural and relational justice, hostile work environment, non standard work arangment
#6	Temperature extremes	#13	Education level
#7	Repetitive Motions Or Prolonged Activities—Repetitive, Forced or Prolonged Exertions	#14	Stress—Low stress management, Job stressors

over the years that workers from the construction industry and heavy machinery are vulnerable to long-term adverse effects such as depression, whole body and hand vibration, Raynaud syndrome and various mental problems.

In general, 32 significant risk factors in 14 categories indicate mutually interconnected with MSD and when installed several exposures simultaneously over a period of time it will produce worse effects such as Cumulative Trauma Disorders, Muscle pain (joint pain, swelling, numbness). Carpal Tunnel Syndrome (CTS), Peripheral Vascular Disorder (PVD) [11, 36, 37, 41]. Furthermore, while risk is probability that a specific action or exposure will give rise to a negative, serious-ness of the consequences or severity if something dangerous occur [13].

Rapid Entire Body Assessment (REBA) showed that 57% of the jobs examined fell within the high-risk category [53]. Airline maintenance face a poor biomechanics overhead works in engine change facilities, in the upper extremities when working on ladder, prolonged holding and overhead postures lead to neck shoulder syndrome that indicate head noodling and rotator cuff on shoulder [39]. This consequence weakness on rotator is also shown in the study [33] of riveting operators that must keep high pinch stress during riveting process and agriculture olive industry when forceful repetitive cutting [27].

On the contrary, apart from heavy industry, music industry workers are also affected by biomechanical risks as studied by Roseiro [12] in their study said drumstick impact to transient vibrations are prone to CTS and PVD thus concluding that drummers are exposed to higher levels of effective acceleration than the value of action recommended by European Directive 2002/44/EC. Various presence studies were state that combination factor also affect the workers likewise univariate analysis in Baek [31] Korean emotional labors studies indicate there was statistically correlation between job satisfaction, social support and hip, leg and knee pain. Strong evidence reported in Haahr [41] was correlation between incidence of elbow pain and exposure of combined risk factor such as repetition, force exertion and awkward posture. Notwithstanding, muscular activities have become a popular subject in labor research but there have been many new studies that are moving towards the study of combining factors between psychosocial and biomechanical factors.

3.4 Psychosocial Risk Factor Associated with MSD

The findings suggested that despite the substantial impact of the physical work with respect to the etiology of musculoskeletal pain, researchers should expand their focus to work-related psychosocial issues [54]. Emphasized in Lima [55] article state that psychosocial consortium has a negative impact on social (environment) and psychological (individual) which facilitates the formation of MSD. Thus, the psychosocial risk factor also represents an important and complex risk factor for various workers. The psychosocial work environment constitutes an important part of an ergonomics evaluation of a workplace that is important that workers can explain and describe their psychosocial work situation and identify problems affecting.

According to Baek [31], to show that it is true that there is a correlation between psychosocial to MSD disease, can refer to various models of psychosocial factors among those are from Bongers [56] which states that when there is a factor of biomechanical exposure to the body's energy such as localized contact stresses it will directly have an effect on stress by changing posture through stress when there is a psychosocial disorder. Furthermore, refer to Moon and Sauter [57] identified a direct pathway between work methods, including ergonomics, organizational systems, and work environments.

Other studies have indicated that different results are found for burnout muscle (exhaustion) that are relationship between psychosocial factors and Work-Related Musculoskeletal Disorder (WRMSD) [58]. Author states in findings that all these injuries are multifactorial phenomena where psychosocial and biomechanical are also among the combination factors influencing the diversity of MSD consortium such as the main findings in the article Mohan [11] said that psychosocial impact on WRMSD could be completely existent; and might be reported, for example back pain, head ache or numbness. There is a basis, when van der Molen [58] found that similar work-related psychosocial risk factors were associated with distress.

Body description and nutritional factors will also affect our daily work. This applies, in the study Yarandi [30] said the dimensions of low health responsibility, weakness of stress management, no exercise and lack of nutrition were higher in participants with musculoskeletal disorders. The above will increase BMI and affect the circular system [14] and is very dangerous to concrete sector workers when involved in filtering the sand, lifting cement, mixing concrete and pouring concrete closely come out with numbness, knee disorder and if extreme temperature can cause migraines. A combination of tired muscles due to exposure to vibrations and distress make the spinal column more [3].

As always proven in research article [30, 35] management problem has a huge impact on the employment sector. This is because, it contributes to psychosocial problems that ultimately improve MSD statistics. Proven in article [31, 32] effort-reward imbalance, low organizational justice and high job demands were associated with the largest increased risk of MSD part, varying from 60 to 90%.

Researchers began to explore psychosocial risk exposure by age and gender, as per review report by Collins [32] his study found that notable different affect for neck and shoulder disorder, where male low affected then female. Another case showed, long exposure to monotonous and repetitive work with arms lifted in front of the body or twisted hand studied in past year, was associated with elbow pain among women but not for men. [31, 41] Indeed, this elbow pain was related to biomechanical factor among women subject because of low support at work and the mental resilience abilities [41] This can give significant information that women are more likely to suffer from MSD symptoms, based on biological difference gendered behavior [32] Contradict with that, the emphasis on health aspects such as exercise and leisure activities also contributes to disease prevention [55]. With respect to work related by age, can be recognized the results finding by Collins [31] where along with increasing age, workers have been exposed for a long time so it is not impossible why the pool of subjects in old age mostly have these MSD symptoms.

Pursuant to Kim [35] indicate known complications of vibration exposure likely arise secondary to chronic, repeated exposures that give rise to subclinical stresses and may adversely affect social interaction [32]. However, Uhl [29] and Breloff [59] predict if organization give a greater social recognition to the labor, it can prevent the result of a loss of identity, stresses and decompensation by the somatic path that will results MSD that run to and from the spinal cord.

From the findings revealed that high psychological demand and monotonous work are significant association in term of how fast and how much it will be affected with the circumstance of disorder. Thus, can interpreted, where biomechanical and psychosocial risk factors have related importance when both can increase the susceptibility to the disorder [60, 23]. This is consistently across risk factor and outcome on related studies issues.

4 Conclusion

It is clear that biomechanical risk factor contributes to a constituent of MSD. Along with that, it will inevitably come when combined with psychosocial factor indicate results of a distinctive. Penultimately, the biomechanical factor experience and psychological factor exposure to workers were significantly associated and lead to MSDs. Many well-known syndromes from awful biomechanical experience and psychosocial risk factor that contributing to MSD has been scientifically shown. Significantly this study, we found that most studies agree and can prove that there is a correlation between biomechanical and psychosocial risk in influencing the formation of MSD.

High job demands and vibration are the most exposure in most of the studies reviewed. These studies were conducted experimentally but there were also self reported symptoms from observational studies. Analyzed in epidemiological studies, concerning about combining risk factor that it will be affected more outcome on variability disease.

Limitation in this study is the lack of combining risk factor study material from cohort and case control design where the possibility to get genuine evidence and long-lasting studies. Very low research results that can prove the biomechanical and psychosocial relationship in the formation of MSD. Consistent measurement and concept of survey in psychosocial study should be clear and research further. Too many studies have been done to prove the biomechanical relationship to symptoms in the neck and shoulder also upper limb. It is also necessary to study this relationship to the symptoms of knee disorder (lower limb). Definition of combining risk factor also must be revised based on symptoms and disease consistency. That are high potential in combining risk factor towards in long lasting's research studies.

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References

1. International Labour Organization (2013) ILO International Financial and Actuarial Service; ILO Regional Office for Asia and the Pacific; Social Security Organization: Malaysia: report to the Social Security Organization on the ninth actuarial valuation. Geneva, Switzerland
2. H€agg G (1991) Static workload and occupational myalgia—a new explanation model. In: Anderson P, Hobart D, Danoff J (eds) Electromyographical kinesiology. Elsevier Science Publishers, Amsterdam, pp 141–144
3. Sekkay F, Imbeau D, Chinniah Y, Dubé P-A, de Marcellis-Warin N, Beauregard N, Trépanier M (2018) Risk factors associated with self-reported musculoskeletal pain among short and long distance industrial gas delivery truck drivers. Appl Ergon 72:69–87. ISSN 0003-6870, https://doi.org/10.1016/j.apergo.2018.05.005

4. Mayton AG, Porter WL, Xu XS, Weston EB, Rubenstein EN (2018) Investigation of human body vibration exposures on haul trucks operating at U.S. surface mines/quarries relative to haul truck activity. Int J Ind Ergon 64:188–198. ISSN 0169-8141, https://doi.org/10.1016/j.ergon.2017.05.007
5. Fattorini L, Tirabasso A, Lunghi A, Di Giovanni R, Sacco F, Marchetti E (2017) Muscular synchronization and hand-arm fatigue. Int J Ind Ergon 62:13–16. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2016.07.009
6. Te-Hsin P, Kleiner BH (2001) New developments concerning the occupational safety and health act. J Manag Law 43(1/2):138–146
7. Tayyari F, Smith JL (1997) Occupational ergonomics: principles and applications. Chapman & Hall, London (Chaps. 1 and 19)
8. Lee KS. Ergonomics in total quality management: how can we sell ergonomics to management? J Ergon 48(5):547–558
9. Fernandez JE. Ergonomics in the workplace. J Facil 13(4):20–27
10. International Ergonomics Association, Definition and Domain of Ergonomics. http://www.iea.cc/whats/
11. Mohan SB (2018) Identifying and controlling ergonomic risk factors in construction. J Ergon. https://doi.org/10.4172/2165-7556.1000235
12. Roseiro LM, Paulino MF, Neto MA, Amaro AM (2018) Int J Ind Ergon 66:110–118. https://doi.org/10.1016/j.ergon.2018.02.014
13. Jaffar N, Abdul-Tharim AH, Mohd-Kamar IF, Lop NS (2011) A literature review of ergonomics risk factors in construction industry. Proc Eng 20(2011):89–97. https://doi.org/10.1016/j.proeng.2011.11.142
14. Lop NS, Salleh NM, Zain FMY, Saidin MT (2019) Ergonomic RISK FACTors (ERF) and their Association with Musculoskeletal Disorders (MSDs) among Malaysian construction trade workers: concreters. Int J Acad Res Bus Soc Sci 9(9):1269–1282. https://doi.org/10.6007/IJARBSS/v9-i9/6420
15. European Commission (2006) Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on Machinery, and Amending Directive 95/16/EC (Recast). Official J Eur Union, L 157, 9 June 2006
16. Lanfranchi J-B, Duveau A (2008) Explicative models of musculos keletal disorders (MSD): from biomechanical and psychosocial factors to clinical analysis of ergonomics. Eur J Appl Psychol 58(4):201–213. https://doi.org/10.1016/j.erap.2008.09.004
17. National Institute for Occupational Safety and Health (NIOSH) (1997) Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck. Upper Extremity, and Low Back. DHHS (NIOSH) Publication No. 97B141, Cincinnati, OH
18. Sukadarin EH, Ghani JA, Syazwani N, Nawi M, Ismail AR (2016) Postural assessment in pen-and-paper-based observational methods and their associated health effects: a review Postural assessment in pen-and-paper-based observational methods and their associated health effects: a review. August 2018. https://doi.org/10.1080/10803548.2016.1156924
19. European Agency for Safety and Health at Work (2014) What are stress and psychosocial risks? Healthy workplaces manage stress. European Agency for Safety and Health at Work, Luxembourg. Retrieved in 19 Dec 2016, from http://hw2014.healthy-workplaces.eu/en/stress-and-psychosocial-risks/what-are-stress-and-psychosocial-risks
20. Warren N, Dillon C, Morse T, Hall C, Warren A (2000) Biomechanical, psychosocial, and organizational risk factors for WRMSD: population-based estimates from the Connecticut Upper-extremity Surveillance Project (CUSP). J Occup Health Psychol 5:164–181
21. Devereux J, Rydstedt L, Kelly V, Weston P, Buckle P (2004) The role of work stress and psychological factors in the development of musculoskeletal disorders (RR 273). Health and Safety Executive, London
22. Kortum E, Leka S, Cox T (2011) Perceptions of psychosocial hazards, work-related stress and workplace priority risks in developing countries. J Occup Health, 53(2):144–155. PMid: 21325734. https://doi.org/10.1539/joh.O10016

23. Ariëns GA, van Mechelen W, Bongers PM, Bouter LM, van der Wal G (2001) Psychosocial risk factors for neck pain: a systematic review. Am J Ind Med 39(2):180–193. https://doi.org/10.1002/1097-0274(200102)39:2%3C180::AID-AJIM1005%3E3.0.CO;2-%23. PMID: 11170160
24. Goldet G, Howick J (2013) Understanding GRADE: an introduction. J Evid Based Med 6:50–54. https://doi.org/10.1111/jebm.12018
25. Sulsky SI, Carlton L, Bochmann F, Ellegast R, Glitsch U, Hartmann B, Pallapies D, Seidel D, Sun Y (2012) Epidemiological evidence for work load as a risk factor for osteoarthritis of the hip: a systematic review. PLoS ONE 7:e31521
26. DHHS (NIOSH) Publication No. 2009-107, Information Circular 9509, Ergonomics processes: implementation guide and tools for the mining industry (in press). Authors: Janet Torma-Krajewski (currently Colorado School of Mines, formerly NIOSH, jtorma@mines.edu), Lisa Steiner (NIOSH, Lsteiner@cdc.gov), Robin Burgess-Limerick (University of Queensland, robin@hms.uq.edu.au)
27. Calvo A, Romano E, Preti C, Schillaci G, Deboli R (2018) Upper limb disorders and hand-arm vibration risks with hand-held olive beaters. Int J Ind Ergon 65:36–45. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2018.01.018
28. Hulshof CTJ, Colosio C, Daams JG, Ivanov ID, Prakash KC, Kuijer PPFM, Leppink N, Mandic-Rajcevic S, Masci F, van der Molen HF, Neupane S, Nygård C-H, Oakman J, Pega F, Proper K, Prüss-Üstün AM, Ujita Y, Frings-Dresen MHW (2019) WHO/ILO work-related burden of disease and injury: protocol for systematic reviews of exposure to occupational ergonomic risk factors and of the effect of exposure to occupational ergonomic risk factors on osteoarthritis of hip or knee and selected other musculoskeletal diseases. Environ Int 125:554–566, ISSN 0160-4120. https://doi.org/10.1016/j.envint.2018.09.053
29. Uhl M, Bruchmüller T, Matthiesen S (2019) Experimental analysis of user forces by test bench and manual hammer drill experiments with regard to vibrations and productivity. Int J Ind Ergon 72:398–407. ISSN 0169-8141
30. Sadeghi Yarandi M, Ghasemi M, Ghanjal A (2020) The relationship between individual, physical and psychosocial risk factors with musculoskeletal disorders and related disabilities in flight security personnel. Int J Occup Saf Ergon JOSE 26. https://doi.org/10.1080/10803548.2020.1760528
31. Baek K, Yang S, Lee M, Chung I (2018) The association of workplace psychosocial factors and musculoskeletal pain among Korean emotional laborers. Saf Health Work 9(2):216–223. ISSN 2093-7911. https://doi.org/10.1016/j.shaw.2017.09.004
32. Collins JD, O'Sullivan LW (2015) Musculoskeletal disorder prevalence and psychosocial risk exposures by age and gender in a cohort of office based employees in two academic institutions. Int J Ind Ergon 46:85–97. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2014.12.013
33. McDowell TW, Xu XS, Warren C, Welcome DE, Dong RG (2018) The effects of feed force on rivet bucking bar vibrations. Int. J Ind. Ergon 67:145–158, ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2018.05.011
34. Azizan A, Fard M, Azari MF, Jazar R (2017) Effects of vibration on occupant driving performance under simulated driving conditions. Appl Ergon 60:348–355. ISSN 0003-6870. https://doi.org/10.1016/j.apergo.2016.12.020
35. Kim JH, Marin LS, Dennerlein JT (2018) Evaluation of commercially available seat suspensions to reduce whole body vibration exposures in mining heavy equipment vehicle operators. Appl Ergon 71:78–86. ISSN 0003-6870. https://doi.org/10.1016/j.apergo.2018.04.003
36. Roseiro LM, Paulino MF, Neto MA, Amaro AM (2018) Analysis of hand-arm vibration syndrome in drummers. Int J Indus Ergon 66:110–118. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2018.02.014
37. Xu XS, Dong RG, Welcome DE, Warren C, McDowell TW, Wu JZ (2017) Vibrations transmitted from human hands to upper arm, shoulder, back, neck, and head. Int J Indus Ergon 62:1–12. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2016.07.001
38. Yang H, Haldeman S, Lu M-L, Baker D (2016) Low back pain prevalence and related workplace psychosocial risk factors: a study using data from the 2010 national health interview survey.

J Manipulative Physiol Ther 39(7):459–472. ISSN 0161-4754. https://doi.org/10.1016/j.jmpt.2016.07.004
39. Asadi H, Denny Yu, Mott JH (2019) Risk factors for musculoskeletal injuries in airline maintenance, repair and overhaul. Int J Ind Ergon 70:107–115. https://doi.org/10.1016/j.ergon.2019.01.008
40. Jackson JA, Olsson D, Punnett L, Burdorf A, Järvholm B, Wahlström J (2019) Occupational biomechanical risk factors for surgically treated ulnar nerve en-trapment in a prospective study of male construction workers. Scand J Work Environ Health 45(1):63–72. https://doi.org/10.5271/sjweh.3757. ISSN: 0355-3140
41. Haahr JP, Andersen JH (2003) Physical and psychosocial risk factors for lateral epicondylitis: a population-based case-referent study. Occup Environ Med 2003(60):322–329
42. Caffaro F, Cremasco MM, Preti C, Cavallo E (2016) Ergonomic analysis of the effects of a telehandler's active suspended cab on whole body vibra-tion level and operator comfort. Int J Ind Ergonomics 53:19–26. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2015.10.009
43. Mayton AG, Porter WL, Xu XS, Weston EB, Rubenstein EN (2018) Investigation of human body vibration exposures on haul trucks operating at U.S. surface mines/quarries relative to haul truck activity. Int J Ind Ergonomics 64:188–198. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2017.05.007
44. Kittusamy NK, Buchholz B (2004) Whole-body vibration and postural stress among operators of construction equipment: a literature review. J Saf Res 35(3):255–61. https://doi.org/10.1016/j.jsr.2004.03.014
45. Kittusamy N (2002) Ergonomic risk factors: a study of heavy earthmoving machinery operators. Prof Saf 38–45
46. Moraes G, Sampaio R, Silva LF, Souza M (2016) Whole-body vibration and musculoskeletal diseases in professional truck drivers. Fisiotera-pia em Movimento 29:159–172. https://doi.org/10.1590/0103-5150.029.001.AR01
47. Mayton AG, Kittusamy NK, Ambrose DH, Jobes CC, Legault ML (2008) Jarring/jolting exposure and musculoskeletal symptoms among farm equipment operators. Int J Indus Ergon 38(9–10):758–766
48. Bernard B (1997) A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. National Institute for Occupational Safety and Health; Cincinnati: Musculoskeletal Disorders and Workplace Factors
49. Chaffin DB, Park K (1973) A longitudinal study of low-back pain as associated with occupational weight lifting factors. Am Ind Hyg Assoc J 34:513–524 [PubMed: 4272346]
50. Frymoyer J, Pope M, Costanza M, Rosen J, Goggin J, Wilder D (1980) Epidemiologic studies of low-backpain. Spine 5:419–442 [PubMed: 6450452]
51. NIOSH (1981) Work practices guide for manual lifting. DHSS (NIOSH); Cincinnati, OH: 1981. Publication no. 81-122
52. Moraes G, Sampaio R, Silva LF, Souza M (2016) Whole-body vibration and musculoskeletal diseases in professional truck drivers. Fisioterapia em Movimento 29:159–172. https://doi.org/10.1590/0103-5150.029.001.AR01
53. Joshi M, Deshpande V (2019) A systematic review of comparative studies on ergonomic assessment techniques. Int J Indus Ergon 74:102865. ISSN 0169-8141, https://doi.org/10.1016/j.ergon.2019.102865
54. Das D, Kumar A, Sharma M (2019) Work-related psychosocial factors associated with lower back pain among male handicraft workers in Jaipur, India. In: Proceedings of the international conference on industrial engineering and operations management Bangkok, Thailand, 5–7 Mar 2019
55. Lima TM, Coelho DA (2018) Ergonomic and psychosocial factors and musculoskeletal complaints in public sector administration—A joint monitoring approach with analysis of association. Int J Indus Ergon 66:85–94. ISSN 0169-8141. https://doi.org/10.1016/j.ergon.2018.02.006
56. Bongers PM, de Winter CR, Kompier MA, Hildebrandt VH (1993) Psychosocial factors at work and musculoskeletal disease. Scand J Work Environ Health 297e312

57. Moon SD, Sauter SL (1996) Psychosocial aspects of musculoskeletal disorders in office work. Taylor and Francis, Beyond Biomechanics
58. van der Molen HF, Nieuwenhuijsen K, Frings-Dresen MHW, de Groene G. Work-related psychosocial risk factors for stress-related mental disorders: an updated systematic review and meta-analysis. https://doi.org/10.1136/bmjopen-2019-034849
59. Breloff SP, Dutta A, Dai F, Sinsel EW, Warren CM, Ning X, Wu JZ (2019) Assessing work-related risk factors for musculoskeletal knee disorders in construction roofing tasks. Appl Ergon 81:102901. ISSN 0003-6870. https://doi.org/10.1016/j.apergo.2019.102901
60. Ferguson SA, Allread WG, Burr DL, Heaney C, Marras WS (2012, Feb) Biomechanical, psychosocial and individual risk factors predicting low back functional impairment among furniture distribution employees. Clin Biomech (Bristol, Avon) 27(2):117–23. https://doi.org/10.1016/j.clinbiomech.2011.09.002. Epub 2011 Sep 28. PMID: 21955915; PMCID: PMC3796440

Ergonomics Study in Quick Response Manufacturing (QRM) Automotive Workstation Environment to Overcome Employee Complaints

Nelfiyanti, Nik Mohamed, and M. F. F. Ab. Rashid

Abstract The assembly line is an important process in producing a complete car unit before the product is checked and delivered to the consumer. Assembly workers during working hours are affected by work position, workload, placement of components and aids during the process and equipment used in assisting heavy work processes. Work positions with non-ergonomic workloads impact the disability and musculoskeletal complaints (MSD) of workers. The purpose of this study is to identify the ergonomic risks of assembly workers. Analytical methods using the Nordic Body Map (NBM) and QRM principles were used in this study. The results of the analysis of the level of complaints of workers' MSD during the work were obtained for the categories of not sick (NS) 27.94%, slightly sick (SS) 36.76%, sick (S) 29.69% and very sick (VS) 5.6%. The most dominant complaints about S and VS complaints were shoulders, arms, back, waist, buttocks, wrists and hands. MSD complaints that employees feel are in the middle category with an average score of 64 points which means immediate remedial action is needed. Using the time-focused QRM principle, improvements in work procedures and designing ergonomic tools are needed to minimize MSD complaints that impact working hours faster, and there is no overtime.

Keywords Automotive industry · Ergonomics · Musculoskeletal disorder (MSD) · Nordic body map (NBM) · Quick response manufacturing (QRM)

1 Introduction

Development of the manufacturing industry especially in the automotive field is increasing rapidly from year to year. Definition of manufacturing is producing

Nelfiyanti (✉) · N. Mohamed · M. F. F. Ab. Rashid
College of Engineering, Universiti Malaysia Pahang, 26300 Kuantan, Pahang, Malaysia
e-mail: nelfiyanti@umj.ac.id

Nelfiyanti
Department of Industrial Engineering, Faculty of Engineering, Universitas Muhammadiyah Jakarta, 10510 Jakarta, Indonesia

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product in large quantities in global activity was started during the industrial revolution [1]. Automotive industry is the major contributor sector to the development and growth of the national economy [2]. Today's challenge for automotive industry is on how to improve and sustain the manufacturing process in an unpredictable economic situation, environmental, marketing and policy issues [3]. This is very important as the country's revenue is largely contributed by the automotive industry in driving the industrial growth [4].

Automotive companies from Malaysia and Indonesia, have a high volume of products that will be exported to several countries or imported into countries. Manpower is the main source that influences the running of the automotive industry in these two countries [5]. It uses workers as the main resource especially in the assembly line. Therefore, the assembly processes require skills from workers, and the skills possessed by the workers must be commensurate with the type of work such as checking components, making tools and operating processes [6, 7]. Workers in the assembly line regularly complain about MSD during work and after work [8]. Musculoskeletal disorders are major difficulties faced by workers at automotive assembly line [9]. The impact of these MSD complaints will take longer production time to complete the production target. Hence, the time required by the employees to complete the work in accordance with the company's target exceeds the period that has been standardized by the company.

Ergonomics is a standard approach commonly used in the analysis of the working system of interactions between humans, machines and the environment [10, 11]. Quality and productivity are influenced by work environment and work methods that are part of employee performance assessment by considering ergonomic risk factors [12–14]. There are two methods commonly used in postural risk assessment in the workplace, namely RULA (rapid Upper Limb Assessment) and REBA (Rapid Entire Body Assessment [15]. Many researchers have conducted research on ergonomics in the assembly line using a force-matching approach in determining action in ergonomic evaluation [16]; ergonomic contribution to the use of exoskeleton in the upper-limb work process [17, 18]; the process of making aids using RULA, NIOSH, MITAL guide [14, 19, 20]; and using Most and ERGOALWABP [13, 21] in the identification of problems related to ergonomics. There is no visible QRM method embedded with ergonomic approach in the ergonomic research so far. QRM itself is a strategy used to reduce waiting time from consumers' perspective [22, 23]. QRM responds to the needs of consumers by designing and making products quickly according to needs quality and lower cost [22]. So far QRM is used to complement Lean Manufacturing [24]; QRM Paradigm and Time Based Competition (TBC) in lead-times reduction [25]; become a more effective competitive strategy in targeting market needs [26]; and the application of QRM in reducing lead time to predict material needs budget [27].

Significance of the research is the use of QRM methods embedded with Ergonomic methods in the assembly line of the automotive industry to determine the complaints of MSD felt by workers that have a long impact on working hours. QRM focuses on time studies while ergonomic studies are related to humans. In this research, the object of research is the workers in the assembly section that involves the production process. QRM implanted with ergonomics studies the relationship between human comfort and the impact of longer production time or compressed production time.

2 Methodology

Figure 1 describes the flow diagram of this research methodology. This diagram consists of the following stages.

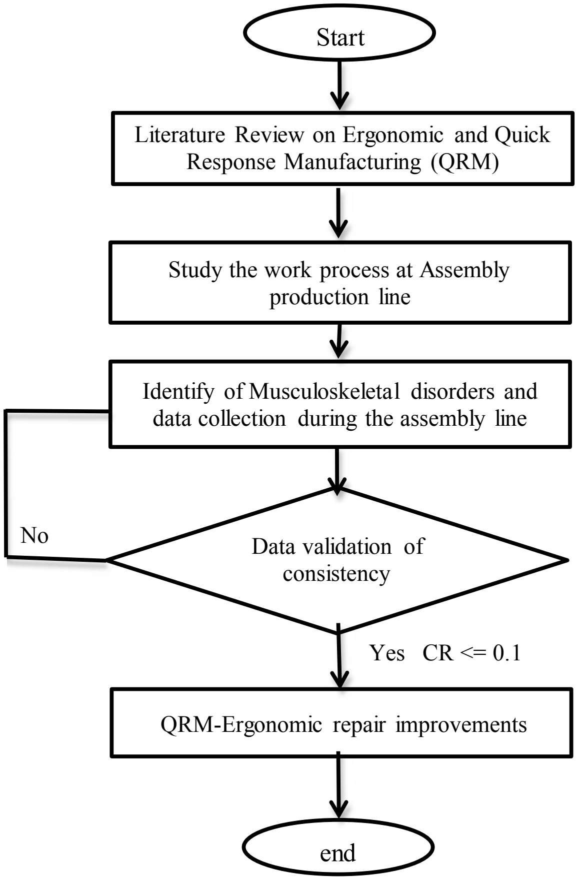

Fig. 1 Flow diagram of research methodology

2.1 Literature Review on Ergonomics and QRM

Research studies related to the topic of ergonomics and QRM are conducted to understand and deepen the application of this method to cases in the industry. Ergonomic methods are used for human-related cases, while QRM is used for processes to minimize time. From the literature review that has been read and understood, no researcher has combined ergonomic methods with QRM.

2.2 Study the Work Process at Assembly Production Line

In order to assemble parts and components, assembly lines for low to medium production are highly dependable on manpower. MSD concerns are high for this form of production set-up due to interruptions faced by workers at almost every workstation along the assembly line [28]. The key source of concerns about MSD is the inappropriate working environment, which affects the effectiveness of employees in carrying out tasks [29].

Since automotive manufacturing is classified as a heavy industry, it is very important to enforce the required ergonomic work environment in the assembly process [30]. Increasing numbers of MSD problems felt by staff are recorded in the neck, shoulders, arms, hands, back, legs and ankles on the basis of several studies [9]. The grievances from the MSD resulted in low productivity of the assembly line as the business was unable to reach the regular production goal, thus requiring overtime to cover the output losses [31]. The additional working hours needed during the assembly process impact the costs that the industry has to bear and the output rating of the customers is reduced. The automotive industry is negatively affected by overtime in terms of business efficiency and sales.

2.3 Identify of Musculoskeletal Disorders and Data Collection During the Assembly Line

Direct observations were made on the assembly lines of selected automotive industries in Indonesia in this case study. These findings were made to get an understanding of how workers function during working hours on the production line. This involves the positioning, and the distance needed to transport, of the instruments and components used in the process. This approach includes the workload of employees and the time needed in the assembly process. In addition to findings, interviews were often performed by workers to find out what the complaints they felt were. Interviews were often performed with supervisors and foremen in addition to workers, who were the representatives who managed the assembly process from upstream to downstream. These interviews were aimed at gathering data on the application of assembly principles and the usage of workstation tools [32]. The data obtained from the observations and interviews were used for the assessment of the results of the Nordic Body map (NBM) questionnaire by the workers. The assessment aims to determine the complaints that employees feel fall into the category of a low, medium, high or very high. This will affect the action that will be given.

2.4 Data Validation of Consistency

Then the next stage is the validation of the consistency ratio of the data obtained if the value of CR > 0.1 then the data is not acceptable and must be repeated. In contrast, if the value of CR $\leq$ 0.1, then accept the data so that it can perform other processes. CR values measure of consistency and not a consideration of paired comparisons.

2.5 QRM-Ergonomic Improvement

This process is a suggestion that can be given to experts in the assembly line to minimize the overtime needed by workers by reducing the risk of MSD complaints. Recommendations are given based on the results of data and analysis of preparations performed on the work process of workers in the assembly line.

3 Results and Discussion

3.1 Study the Work Process at Assembly Production Line

This study observes and analyses the work process performed by workers on the assembly line of car products so that it becomes a whole unit. The assembly process is done by assembling components from the smallest to the largest components. The work process in the assembly line consists of the retrieval of components and tools to be used, lifting, installing, pulling and running. Figures 2 and 3 show the way the liaison workers in Malaysia and Indonesia work. It can be seen that the work process performed by the automotive industry part of the assembly line in Malaysia and Indonesia can be said to be similar and use the same body posture.

Figure 2 shows some of the methods and postures used by workers during the assembly process. The way it works consists of bending while attaching components to the car body, squatting with the side of the body sideways. The neck rotating, placing the components into the car body with a slight bend, the position of the arms and hands bent and rotating during the installation process and using both feet as a force in limb defences during the process.

Fig. 2 The Malaysian automotive assembly line

Fig. 3 The Indonesian automotive assembly line

Figure 3 describes the work done by workers consisting of bending while taking components to be placed inside the car body, taking components that have been placed for the assembly process, bending during work processes for external work, body bending forward and backward during component assembly process on the roof of the car with the foot position not resting on the floor and the position of the hand raised outside the body as well as rotating and bending during the installation of components on the front of the car by focusing on the foot as a strength to hold.

3.2 Identify of Musculoskeletal Disorders and Data Collection at During the Assembly Line

Identification of musculoskeletal (MSD) complaints that workers feel through the results of observations, interviews and questionnaires Nordic Body Map (NBM) by workers. The NBM questionnaire to be filled by the workers has a choice of not sick (NS), slightly Sick (SS), Sick (S) and very sick (VS). Table 1 is the percentage of workers' complaints in the assembly line. The number of respondents used in this study is 51 workers.

Table 1 describes the percentage of MSD complaints felt by NS category workers of 27.94%, SS of 36.76%, S of 29.69% and VS of 5.60% of 51 workers in the assembly line. The largest percentage is in the SS and S categories, meaning that remedial action is needed in minimizing MSD complaints. MSD complains to assembly workers in severe pain in shoulders, arms, back, waist, buttocks, wrists and hands. Workers feel complaints about body posture due to work factors, workload, layout and equipment used. All these factors greatly affect the smoothness of the assembly production process, which affects working hours. The causative factors of MSD complaints are obtained from direct observation and brainstorming with experts in the assembly line.

Minimizing MSD complaints of assembly line workers can be done by improving the way they work and designing tools that can simplify the work process. There is no overtime in job completion related to the QRM principle.

3.3 Validation of Consistency

Validation is essential to check the accuracy of the results. The stage in the validity test is to create a pairwise comparison matrix to determine and calculate the weight of the criteria and alternative weights of each assessment criterion in the respondent's answer. The next step is to validate the consistency of the paired matrix. If the CR value is > 0.1, should make a pairwise comparison again until the CR value is $\leq$ 0.1 (consistent). Repeat the same steps for each comparison matrix between alternatives. Next, calculate the total of the multiplication between the alternative weights and the

Table 1 Percentage of assembly line workers' complaints during the work process

No	Type of complaint	Level of complaints after work									
		NS		SS		S		VS		Total	
		Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
0	Upper meet	9	0.63	23	1.61	15	1.05	4	0.28	51	3.57
1	Lower neck	9	0.63	21	1.47	19	1.33	2	0.14	51	3.57
2	Left shoulder	7	0.49	27	1.89	16	1.12	1	0.07	51	3.57
3	Right shoulder	7	0.49	13	1.26	23	1.61	3	0.21	51	3.57
4	Left upper arm	11	0.77	18	1.26	22	1.54	0	0.00	51	3.57
5	Back	8	0.56	14	0.98	18	1.26	11	0.77	51	3.57
6	Right shoulder	11	0.77	11	0.77	27	1.39	2	0.14	51	3.57
7	Waist	6	0.42	17	1.19	19	1.33	9	0.63	51	3.57
8	Buttock	14	0.98	13	0.91	22	1.54	2	0.14	51	3.57
9	Bottom	18	1.26	22	1.54	9	0.63	2	0.14	51	3.57
10	Left elbow	11	0.77	2S	1.96	8	0.56	4	0.28	51	3.57
11	Right elbow	11	0.77	21	1.47	14	0.98	5	0.35	51	3.57
12	Left lower Ami	13	0.91	14	0.98	20	1.40	4	0.28	51	3.57
13	Right Lower Ami	13	0.91	9	0.63	24	1.68	5	0.35	51	3.57
14	Left wrist	13	0.91	13	0.91	24	1.68	1	0.07	51	3.57
15	Right wrist	12	0.34	12	0.84	24	1.68	3	0.21	51	3.57
16	Left hand	16	1.12	13	0.91	21	1.47	1	0.07	51	3.57
17	Right hand	11	0.77	14	0.98	21	1.47	5	0.35	51	3.57
I8	Left thigh	18	1.26	21	1.47	11	0.77	1	0.07	51	3.57

(continued)

Table 1 (continued)

No	Type of complaint	Level of complaints after work									
		NS		SS		S		VS		Total	
		Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
19	Right thigh	21	1.47	22	1.54	3	0.56	0	0.00	51	3.57
20	Left knee	17	1.19	27	1.89	5	0.35	2	0.14	51	3.57
21	Right knee	15	1.05	23	1.61	12	0.34	1	0.07	51	3.57
22	Left calf	26	1.82	20	1.40	4	0.28	1	0.07	51	3.57
23	Right calf	22	1.54	21	1.47	3	0.56	0	0.00	51	3.57
24	Left ankle	21	1.47	25	1.75	5	0.35	0	0.00	51	3.57
25	Right ankle	21	1.47	17	1.19	S	0.56	5	0.35	51	3.57
26	Left foot	19	1.33	21	1.47	10	0.70	1	0.07	51	3.57
27	Right foot	19	1.33	20	1.40	7	0.49	5	0.35	51	3.57
	Total	399.00	27.94	525.00	36.76	424.00	29.69	80.00	5.60	1428	100.00

Table 2 Test the validity of the consistency of criteria and alternative factor elements

No	Elements factor	CR consistency validity value	Description
1	Comparing the level of importance of factor elements based on alternative objectives selects the level of process available on the assembly line	0.0708	Valid
2	Compare the level of importance of factor elements based on job position criteria	0.0441	Valid
3	Compare the level of importance of factor elements based on workload criteria	0.0557	Valid
4	Compare the level of importance of factor elements based on work layout criteria	−0.0460	Valid
5	Compare the level of importance of factor elements based on Equipment criteria	−0.0007	Valid

criteria weights. The validation test in this study uses Microsoft Excel Programming. Table 2 is the result of the consistency validation of the criteria paired matrix and the alternative paired matrix. The average consistency validity value CR ≤ 0.1.

3.4 QRM-Ergonomic Improvements

Complaints of MSD felt by workers in the assembly line belong to the medium category. This means that corrective action is needed to minimize these complaints by considering the ergonomic aspect with the QRM approach. This is because the solution that will be provided should have an impact on the reduction of overtime required by workers in completing car product units in accordance with production capacity. The solution provided can be in the form of improvement of work procedures performed by employees by considering the ergonomic aspects so that complaints of MSD can be minimized. In addition to changes in work, procedures improvements can be done with the design of ergonomic aids for workers. As for the aids that can be provided in the form of a lift car that can be adjusted up and down so as to suit the working posture condition. Figure 4 car lifter design in the car product assembly process.

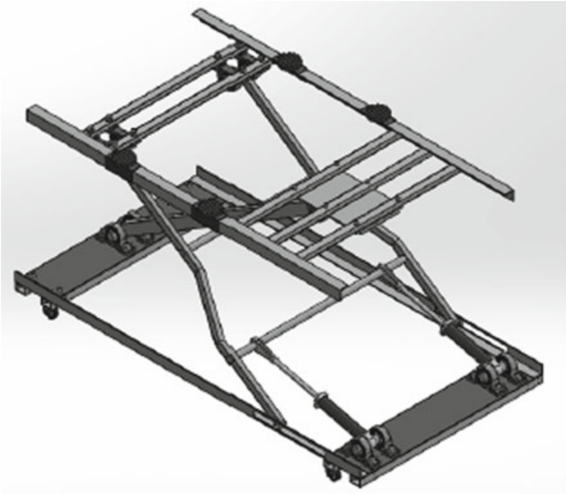

Fig. 4 Desain Lifter car in the car product assembly process

4 Conclusion

Studies conducted with ergonomic methods show that workers' MSD complaints during work are in the category of not sick (NS) of 27.94%, slightly sick (SS) of 36.76%, sick (S) of 29.69% and very sick (VS) of 5.6%. The biggest complaints are in the SS and S categories. The most dominant body posture complaints are shoulders, arms, back, waist, buttocks, wrists and hands. This complaint is at a moderate level, meaning that corrective action is needed to minimize MSD complaints to assembly line workers as soon as possible to reduce overtime in completing work using the QRM principle. Corrective action should be based on work factors, workload, the layout of facilities and equipment used for the smooth running of the work process without causing MSD complaints to employees. The improvements made can be in the form of refinement of work procedures and design of aids such as automatic lift cars that can adjust workers' height to work in comfortable conditions without having to bend and squat.

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References

1. Hamizatun, Zuki NM, Azizul Q (2019) Risks assessment at automotive manufacturing company and ergonomic working condition. IOP Conf Ser Mater Sci Eng 469(1)
2. Szirmai A, Verspagen B (2015) Manufacturing and economic growth in developing countries, 1950–2005. Struct Chang Ekon Dyn 34:46–59

3. Giampieri A, Ling-Chin J, Ma Z, Smallbone A, Roskilly AP (2019) A review of the current automotive manufacturing practice from an energy perspective. Appl Energy 261(December):2020
4. Nurcahyo R, Wibowo AD (2015) Manufacturing capability, manufacturing strategy and performance of Indonesia automotive component manufacturer. Procedia CIRP 26:653–657
5. Valadkhani A, Smyth R (2016) The effects of the motor vehicle industry on employment and research innovation in Australia. Int J Manpow 37(4):684–708
6. Wilson R (2013) Skills anticipation—the future of work and education. Int J Educ Res 61:101–110
7. Lehto M, Landry SJ (2012) Introduction to human factors and ergonomics for engineers, 2nd edn. CRC Press, 794 p
8. Mishra S, Kannan S, Manager C, Statistics A, Comments R, Alert E (2018) Comparing the effectiveness of three ergonomic risk assessment methods—RULA, LUBA, and NERPA—to predict the upper extremity musculoskeletal disorders. Indian J Occup Environ Med 22(1)17–21
9. Ferguson SA et al (2011) Musculoskeletal disorder risk as a function of vehicle rotation angle during assembly tasks. Appl Ergon 42:699–709
10. Ray P, Tewari V, Saha E (2017) Ergonomic performance and evaluation of worksystem: a few applications. In: Ergonomic design of products and worksystems-21st century perspectives of Asia. Business A. Managing the Asian Century. Springer, Singapore, pp 1–12
11. Tarwaka, Ergonomi Industri Dasar- Dasar Pengetahuan Ergonomi dan Aplikasi di Tempat Kerja, II. Semarang (2014)
12. Atici H, Gonen D, Oral A, Kaya B (2017) Ergonomic analysis of an assembly line using the anybody modeling system. Proc World Congr Mech Chem Mater Eng (125)
13. Akyol SD, Baykasoglu A (2019) ErgoALWABP: a multiple-rule based constructive randomized search algorithm for solving assembly line worker assignment and balancing problem under ergonomic risk factors. J Intell Manuf 30(31) Jan
14. Rodrigues M, Loureiro I, Leão CP (2019) An Experimental analysis of ergonomics in an assembly line in a Portuguese automotive industry. Occup Environ Saf Heal 202:485–491
15. Cremasco MM, Giustetto A, Caffaro F, Colantoni A, Cavallo E, Grigolato S (2019) Risk Assessment for musculoskeletal disorders in forestry: a comparison between RULA and REBA in the manual feeding of a wood-chipper. Int J Env. Res Public Heal 16(5):793
16. Franzke B, Walther M (2016) Force-matching. A new approach to determine action forces for the ergonomic evaluation in automotive industry. Adv Ergon Des Syst Prod Process, pp 361–372
17. Valamede LS, Zuliani M, de Lima T (2019) Technological ergonomic innovations applied at the final sector of an automotive industry assembly line. XXVI Congr. Iniciação Científica Unicamp (July), 1–1
18. Iranzoa S, Piedrabuena A, Iordanov D, Martinez-Iranzo U, Belda-Lois J-M (2020) Ergonomics assessment of passive upper-limb exoskeletons in an automotive assembly plant. Appl Ergon 87
19. Nelfiyanti IMF (2015) Chair design work with ergonomic Aspekct to reduce musculoskeletal complaints PT. Pinaco Main in Indonesia (PUI). ICETIA, 102–105
20. Rosyati D, Ahyadi H, Nelfiyanti (2019) Disain Ergonomis Tempat Operasi Khitan untuk Mengurangi Keluhan Muskuloskeletal dengan Metode Rapid Entire Body Assessment (REBA) dan Pengukuran Anthropometri. Bina Tek 15(1):69–76
21. Karim ANM, Tuan ST, Kays HME (2016) Assembly line productivity improvement as re-engineered by MOST. Int J Product Perform Manag 65(7)
22. Suri R (2010) It's about time the competitive advantage of quick response manufacturing. New York
23. Nelfiyanti, Zuki N (2020) Quick response manufacturing and ergonomic consequences in manufacturing environment. IOP Conf Ser Mater Sci Eng 788:012031
24. Gómez PFJ, Filho MG (2017) Complementing lean with quick response manufacturing: case studies. Int J Adv Manuf Technol 90(5–8):1897–1910
25. Godinho Filho M, Veloso Saes E (2013) From time-based competition (TBC) to quick response manufacturing (QRM): the evolution of research aimed at lead time reduction. Int J Adv Manuf Technol 64(5–8):1177–1191

26. Suri (2003) QRM and POLCA : a winning combination for manufacturing enterprises in the 21st Century markets are here [Technical Report, Cent. Quick Response Manuf, May 2003] May, p 30
27. de Lima AD, Bachega SJ, Filho MG, da Cruz V, Rossi JM (2013) Proposal for implementation of the approach Quick Response Manufacturing (QRM) to reduce lead-time in office operations. SciElo 23(1)
28. Nelfiyanti N, Mohamed N, Azhar NAJ (2020) Identification of ergonomic issues among Malaysian automotive assembly workers by using the Nordic body map method. Innov Manuf Mech Mater Forum
29. Ore F, Hanson L, Delfs N, Wiktorsson M (2014) Virtual evaluation of industrial human-robot cooperation : an automotive case study. In: 3rd international digital human modeling symposium (DHM2014)
30. Gopinath V, Johansen K (2016) Risk assessment process for collaborative assembly—a job safety analysis approach. Proc CIRP 44:199–203
31. Li J, Gao J (2014) Balancing manual mixed-model assembly lines using overtime work in a demand variation environment. Int J Prod Res 52(12):3552–3567
32. dos Santos ZG, Vieira L, Balbinotti G (2015) Lean manufacturing and ergonomic working conditions in the automotive industry. Proc Manuf 3(Ahfe):5947–5954

Investigation of Ergonomics Risk Assessment Among Manual Assembly Manufacturing Workers in Medical Device Industry

M. S. Md. Noh, S. A. Che Ghani, and M. H. Muhammad Sidik

Abstract Workers in manufacturing industry are exposed to work-related musculoskeletal disorders (MSD) due to ergonomics risk factors such as awkward postures, repetitive motion or workstation design. Aim of this paper is to identify work-related MSD among manual assembly manufacturing workers in multinational medical device industry in Malaysia. Medical device industry is currently a rising sector with great potential growth in Malaysia, thus available research on ergonomics risk assessment is scare. Data collection was carried out with adapted questionnaire from Guideline on Ergonomics Risk Assessment at Workplace 2017, developed by the Malaysia Department of Occupational Safety and Health (DOSH) in a company in Penang, Malaysia. The MSD assessment used under the guideline is Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) for standing operation and hand symptoms. A total of 86 manual assembly workers participated in this study. The results show that the most frequent affected body parts with the highest MSD severity scores were lower back and right shoulder. For hand assessment, the most frequent affected hand areas with the highest MSD severity scores were right thumb, right index-middle-ring fingers and right thumb-middle palm. The outcome of the study can serve as initial ergonomic risk assessment for advance ergonomics risk assessment to develop hierarchy of improvement measures as per outline in the guideline for the medical device manufacturing occupational group.

Keywords Ergonomics risk assessment · Medical device industry · Manual assembly

M. S. Md. Noh (✉) · S. A. Che Ghani · M. H. Muhammad Sidik
Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, 26600 Pahang, Malaysia

M. S. Md. Noh
B. Braun Medical Industries Sdn Bhd, P.O. Box 880, 10810 Penang, Malaysia

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1 Introduction

It is not surprising that, ergonomics issues among workers especially in Malaysia are getting more attention from the researchers. Workers in various sectors and industry are exposed to experience musculoskeletal disorder (MSD) when performing their daily operation tasks which involve movement such as performing tasks in awkward postures, repetitive task activities, lifting and carrying heavy objects. MSD includes a wide range of inflammatory and degenerative conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels, that may impact on various body areas, frequently neck, shoulder, forearm, hand, upper back, lower back, leg and feet [1].

Department of Occupational Safety and Health (DOSH) in Malaysia has reported an exponential increase of confirmed musculoskeletal disorder (MSD) cases in Malaysia from 2005 to 2018 [2] as shown in Fig. 1. As a result, industry is not only losing the occupational manhour loss, but subsequently baring the high compensation cost due to the occupational diseases. The cost has reached MYR 14 million in 2014 in comparison to slightly above MYR 2 million in 2009 [3].

MSD impact on the workers is often correlated of the nature of work, where most of work activities are dominated by certain movement using particular parts of the body, where the tasks are performed repetitively in daily operation. In recent study, workers that work at the packaging line in Malaysia experienced high prevalence of MSD at shoulder and arms region caused by dominant work activities such as pulling, pushing and lifting [4]. In another study conducted among the female school teachers in Malaysia, found that, the most affected body parts with high MSD prevalence were feet, followed by knee, upper back, and lower back [5].

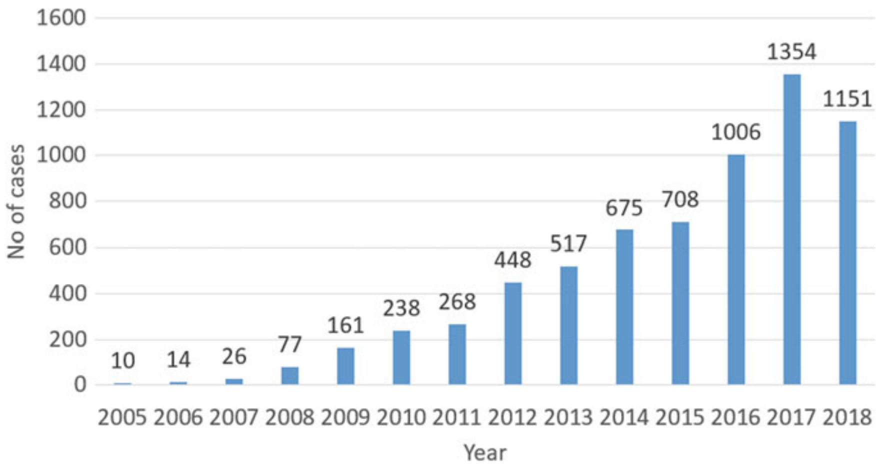

Fig. 1 Trend of reported MSDs from 2005 to 2018

In a medical device manufacturing industry, workers are assigned to produce a wide range of medical devices, defined as instrument intended for use in the diagnosis of disease or other conditions, or in the cure, mitigation, treatment, or prevention of disease, in man or other animals. This industry is growing rapidly in Malaysia with over 200 medical device manufacturers including 30 multinational companies which contributed a total international trade of RM20.4 billion in 2016 [6]. Similar to other manufacturing industries, medical device industry consists of various manufacturing processes which involve direct involvement of workers during the operation. However, due to stringent requirement to ensure user's safety, all materials, equipment and manufacturing steps must be fully validated and workers are compulsory to possess qualified skills in performing the required tasks.

This paper discusses on the MSD prevalence of manual assembly workers in medical devices industry in Malaysia using the available guideline on ergonomics assessment, developed by DOSH. The outcome of the study can be used as the first information to conduct advance assessment to identify ergonomics improvement and to develop hierarchy of improvement measures as per outline in the guideline.

2 Methodology

The study was conducted in one of the multinational medical device manufacturing company in Penang state, Malaysia. The selected production area manufactures medical infusion devices in manual assembly operation. The process flow of the study is summarized in Fig. 2.

2.1 Work Flow

The current production processes are divided into 4 major sections, namely raw material, sub-assemblies, final assembly and packaging as shown in Table 1. The number of manual handling processes is defined accordingly in each sub sections.

In this study, sub-sections of sub-pump assembly and final assembly were chosen to represent the worst-case assembly areas due to number of manual assembly processes and the type of operation which involves a mixture of standing and sitting operations. Operators that are currently working in respective sub-section are trained and allowed to perform task rotation between the processes, however, fixed at one process per day.

At current, production is running with 3 shifts in a day with the breakdown of 8 h per shift as standard working duration, defined as morning, afternoon and night shifts. The shift rotation happens every weekly. Standard working days are from Monday to Friday. Due to business needs, morning shift workers of the week are required to work extra hours on Saturday day shift for 12 h, in the first 3 weeks of the month. Sunday is a compulsory rest day for employees, where employees are not allowed

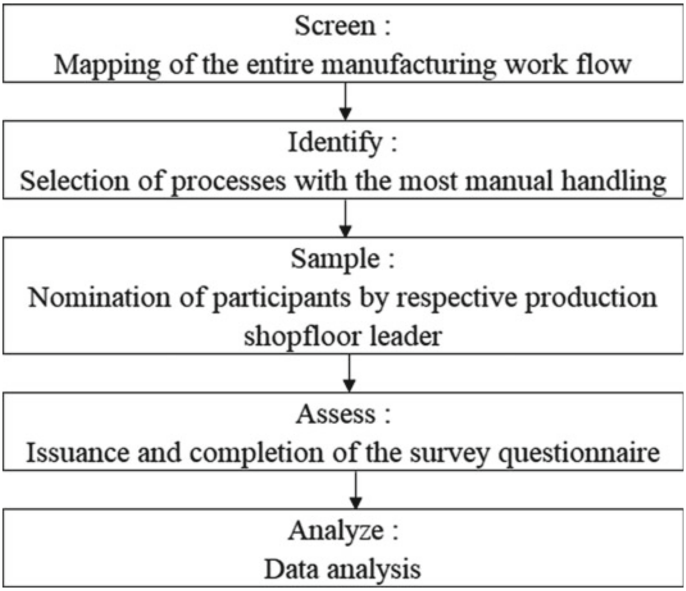

Fig. 2 Process flow of the study

to work continuously for seven days as outlined in the Malaysia Employment Act 1955 [7].

2.2 Participants

A total of 86 manual assembly workers from different shifts were randomly selected by the respective production shopfloor supervisor from sub-pump assembly and final assembly areas. The pre-requisite requirement is the worker must have worked more than 6 months in the current assembly area.

Table 2 shows distribution of total 86 workers from both selected areas. Shift C of sub-pump assembly was without any representative due to business reason.

The participants were given a detail briefing of the study purposes and potential benefits associated with study participation at the beginning of the session. At the end of briefing session, participants were given opportunity to ask for additional information before signing off the consent form as confirmation of the involvement in the study. The involvement rate was 100% from the total 86 identified workers.

Table 1 Production processes in manual assembly production of medical infusion device

Section	Raw materials		Sub-assemblies		Final assembly		Packaging
Sub-sections	Purchased components	Extrusion	Injection molding	Sub-pump assembly	Sub-Microbore assembly	Final assembly	Packing
No. of manual handling processes	0	2	2	8	8	9	5
Type of operation	0	Standing	Standing	Standing sitting	Sitting	Standing sitting	Standing sitting

Table 2 Distribution of participants from selected areas

N = 86	Sub-pump assembly, n	Final assembly, n
Shift A	15	20
Shift B	15	18
Shift C	0	18
Total	30	56

2.3 Questionnaire

Two sets of questionnaires were prepared for each participant. The first set of the questionnaire was made available in Malay and English languages. Workers were given opportunity to choose to answer the questionnaire in any preferred language. The first set of this questionnaire was adapted from Appendix 4 of the Guideline on Ergonomics Risk Assessment at Workplace 2017 [3]. Minor enhancement and additional survey questions were included in the form in order to gain better demographic information from the workers. The first set of questionnaire includes 4 sections, namely, Part A on socio-demographic background such as age, height, weight, race, educational level and marital status including the numbers of children below 6 years old. Part B consist of working condition mainly on occupational information (12 items) including date of join, no of breaktime and type of working situation (sitting or standing). Meanwhile, for Part C, a set of 3 main questions which are related to social lifestyle such as smoking behavior, hobby and no of sleeping hours. The last Part D is where workers need to input their medical history such as past accident cases, diseases or pregnancy status.

The second set of questionnaire was the standard Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) for standing operation and hand symptoms [8]. CMDQ is at the moment also available in the current DOSH Guideline on Ergonomics Risk Assessment at Workplace 2017 [3] as part of standard evaluation for the MSD assessment. There are 2 parts of the assessment. The first part was the assessment on 18 body parts, includes neck, shoulders, upper back, upper arms, lower back, forearms, wrist, hip, thighs, knees, lower legs and feet. The second part was the assessment for hand region which was divided into 6 hand areas. In total, each participant had to answer 54 items in the first assessment and 18 items in the second assessment. Each body part in the CMDQ was self-assessed by the individually by each participant, held in a group, supported by 2 research assistants. The scoring system was directly adapted from the scoring analysis in the original CMDQ [8]. Each body part in the questionnaire comprised three sections (frequency, discomfort and interference) and the scoring number is listed in Table 3. Total MSD severity score was obtained by multiplying all 3 sections for each individual body part, resulting scores range from 0 (no problem) to 90 (very high impact on MSD).

Table 3 CMDQ scoring for frequency, discomfort and interference

Frequency score	Discomfort score	Interference score
Never = 0 1–2 times/week = 1.5 3–4 times/week = 3.5 Every day = 5.0 Several times daily = 10.0	Slightly uncomfortable = 1 Moderately uncomfortable = 2 Very uncomfortable = 3	Not at all = 1 Slightly interfered = 2 Substantially interfered = 3

3 Results and Discussion

3.1 Background Information

The socio-demographic information of the participants is shown in Table 4. Average age of the participants is 28.53 years old where 45.4% of the population is between 18 and 25 years old. 83.7% of the participants are local Malay. 80.2% of the population are below 35 years old and 52.3% are still single. The average body mass index (BMI) of the population is at normal level at 24.17, however about 11.6% are underweight and another 11.6% are obese.

The average working experience is at 43.93 months which is equal to 3.7 years of working experience at the same production area. In actual operation, each operator is attached to multiple processes within the same sub-assembly operation. About 52.3% participants are working more than 50% of their time in sitting operation while 38.4% participants need to perform mix operation that allows them to sit for certain production processes and requires them to stand up for other processes. 65.1% participants are attached to final assembly while the rest is working at sub-pump assembly.

Additionally, it shows that 48.8% of the participants are actively participating physical activity in their free time which shows the practice of healthy lifestyle. As for the body recovery, about 82.6% participants are able to have enough sleep between 6 and 8 h per day whereby the average sleeping hour is at 6.79 h which is sufficient for young adults.

3.2 MSDs Prevalence

The first part of the assessment is the prevalence of MSD on full body which is shown in Table 5. Frequency (F) is the accumulated count of pain at respective body part experienced by each participant against the total participants. The scoring of CMDQ (S) is also defined as MSD severity, obtained by multiplying all 3 sections

Table 4 Socio-demographic profile (N = 86)

Variables	Total (N = 86)		
	n	%	Mean ± SD
Age (Years)			28.53 ± 6.99 years old
18–25	39	45.3	
26–35	30	34.9	
36–45	15	17.4	
> 46	2	2.3	
Ethnicity			
Malay	72	83.7	
Vietnamese	13	15.1	
Others	1	1.2	
Marital status			
Single	45	52.3	
Married	41	47.7	
Body Mass Index (BMI)			24.17 ± 7.23
Underweight (< 18.5)	10	11.6	
Normal (18.5–24.9)	51	59.3	
Overweight (25–29.9)	15	17.4	
Obese (> 30)	10	11.6	
Education level			
Primary school	1	1.2	
Secondary school	62	72.1	
Higher education	23	26.7	
Years of service			43.93 ± 23.17 months
< 12 months (1 year)	5	5.8	
12–36 months (2–3 years)	31	36	
37–60 months (4–5 years)	17	19.8	
> 60 months (> 5 years)	33	38.4	
Working position			
Sitting > 50%	45	52.3	
Sitting (50%) + Standing (50%)	33	38.4	
Standing > 50%	8	9.3	
Working area			
Sub-pump	30	34.9	
Final Assembly	56	65.1	
Physical activity			
Yes	42	48.8	

(continued)

Table 4 (continued)

Variables	Total (N = 86)		
	n	%	Mean ± SD
No	44	51.2	
No. of sleeping hours			6.79 ± 1.16 h
< 6 h	14	16.3	
6–8 h	71	82.6	
> 8 h	1	1.2	
Medical history (including current pregnancy)			
Yes	16	18.6	
No	70	81.4	

Table 5 CMDQ of full body assessment

Body parts	Frequency % (F)	Scoring CMDQ (S)
Neck	**73**	430
Shoulder (R)	**71**	**469**
Shoulder (L)	47	229
Upper back	59	276
Upper arm (R)	42	247
Upper arm (L)	27	116
Lower back	**73**	**693**
Forearm (R)	32	331
Forearm (L)	30	191
Wrist (R)	47	456
Wrist (L)	36	318
Hip/buttocks	30	235
Thigh (R)	21	140
Thigh (L)	12	69
Knee (R)	36	275
Knee (L)	32	203
Lower leg (R)	39	246
Lower leg (L)	35	132
Foot (R)	53	**567**
Foot (L)	44	338

(frequency, discomfort and interference) for each individual body part as explained in Table 3.

The most frequent affected body parts (F) were lower back (73%), right shoulder (71%) and neck (73%). The top 3 were followed by upper back (59%), right foot (53%), left shoulder (47%) and right wrist (47%). The least effected body parts were left thigh (12%), right thigh (21%) as well as left upper arm (27%). In terms of MSD severity score (S), the highest MSD severity on body parts were lower back (693), right foot (567), right shoulder (469), right wrist (456) and neck (430). The least MSD severity were right thigh (69), left upper arm (116) and left lower leg (132).

Manual assembly processes involve a lot of body movement especially during manual handling of components and tools. The most frequent body parts associated with MSD (F) resulted from the assessment were lower back, right shoulder and neck. However, for the MSD severity scoring (S), lower back, right shoulder and right foot had the highest scores. This concludes that lower back and right shoulder are two highest MSD prevalence among manual assembly workers in medical device manufacturing industry. This is in line with similar studies conducted on assembly workers at the other manufacturing industries in Malaysia where shoulder [9] and lower back [10] are the most affected body parts with MSD prevalence.

Nonetheless, the result showed that, 73% of participants still claimed to experience. discomfort at the neck. To analyse this, the lower MSD severity (S) scoring in comparison to the MSD severity (S) on the right foot shows that the discomfort at neck area had less interference on their work performance. To add on this, since only 47.7% of the participants were working in standing and mixture of sitting and standing operation, the reported discomfort frequency at the right foot could be lower in comparison to neck. However, high MSD scoring (S) of the right foot which most probably the dominance foot of most participants indicates high interference on their daily work performance. Similar study conducted to the female school teachers in Malaysia confirmed the high MSD prevalence on the feet and knee due to long standing operation in their daily task [5], supported by other researchers conducted on different standing tasks outside Malaysia [11, 12]. Yet, this study highlighted that the MSD prevalence happened at both upper body parts (neck, shoulder) and lower body parts (lower back and feet), which agreed with other earlier studies [13, 14], which were due to high repetitive motion of the upper body parts and prolonged standing together.

The second part of the CMDQ assessment was focusing specifically on right and left hands. The breakdown of the affected hand area is shown in Fig. 3. Figure 4 shows the frequency of MSD prevalence (F) from all participants and CMDQ scoring (S) for both hands in a single graph. In general, right hand is having higher frequency percentage of MSD prevalence among participants as well as higher MSD scoring. The most frequent affected (F) hand areas were right thumb (59%), right index-middle-ring fingers (58%) and right thumb-middle palm (55%). The least affected hand areas were right and left ring-pinkie fingers (20% each) and left index-middle-ring fingers (36%). The highest MSD severity scores (S) were right thumb (491), right index-middle-ring fingers (407) and right thumb-middle palm (341). The least MSD severity scores were left ring-pinkie fingers (182), left index-middle-ring fingers (200) and left thumb-middle palm (221).

The top 3 of affected hand areas for hand assessment were right thumb, right index-middle fingers and right thumb middle palm, which all 3 hand areas met both categories of the highest frequency (F) and MSD severity scores (S). The result specifies that the right hand is prominently used by the manual assembly workers

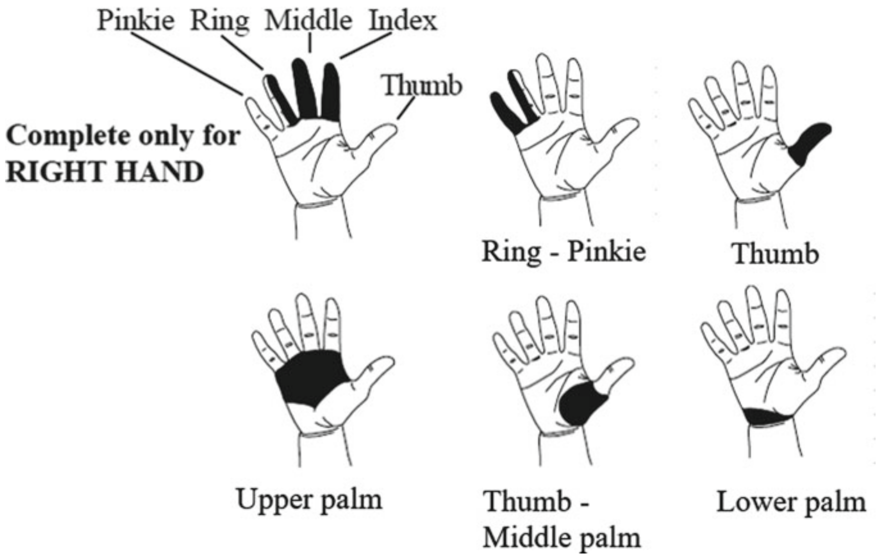

Fig. 3 CMDQ of hand area assessment

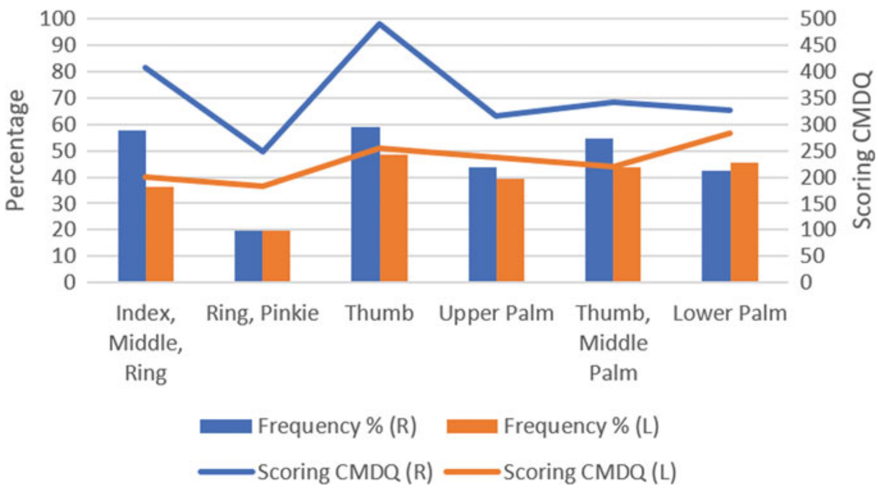

Fig. 4 CMDQ right and left hands

in their daily operational tasks, although the question of right- or left-hand dominance was not asked in the initial demographic questionnaire. The result can also be correlated to the high MSD prevalence on the right shoulder in the first full body assessment, where right hand could have been used dominantly when performing tasks. The combination between the movement of thumb-index finger-middle finger and middle palm is the key when performing manual assembly tasks, especially when performing precision pinching of small objects [15] and when pushing the assembly tools like push button. There is no similar study available especially in Malaysia to compare the MSD prevalence for hand assessment throughout the search from various journals. This shows the importance to executing more studies to explore the ergonomics risk on hands for manual assembly tasks. However, a similar assessment was conducted to a group of dentist which agreed that right thumb, right index-middle fingers and right thumb middle palm were having the highest MSD percentage [16], mainly due to holding equipment and repetitive tasks.

The prevalence of MSDs varies with the type of works mainly caused by intensified activities on certain body parts [17]. It is important to perform further evaluation on the work movement task analysis (WMTA) associated to the most frequent body parts with high MSD prevalence. At such, advance ergonomics risk assessment such as NIOSH equation, Occupational Repetitive Action (OCRA), Strain Index, Snook & Cariello, Ovako Working Posture Analysis System (OWAS), Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) can be further applied according to the ergonomic risk factors (examples: repetitive tasks, forceful exertion and awkward postures). This methodology is defined in details as the Advance Ergonomics Risk Assessment (Advance ERA) in the Guideline on Ergonomics Risk Assessment at Workplace 2017 [3].

3.3 Ergonomic Assessment

Ergonomics has made a very little impact especially in manufacturing sector in Malaysia. Ergonomics is often and mainly associated with occupational health and safety, rather than measures for general improvement on quality, cost and performance [18]. The use of ergonomic assessment enables quick identification of severe MSD prevalence among workers in the current work area. Hence, this study has taken an approach in applying the ergonomics risk assessment. Based on the available guideline, initiated by Malaysia DOSH.

Although ergonomics assessment involves high initial investment, time consuming and needs for special expertise, the results obtained are useful for managers to implement action measures [18]. There are huge opportunities for manufacturing companies in Malaysia to start adapting ergonomics as part of the company culture and growth.

4 Conclusion

In conclusion, manual assembly manufacturing workers in medical device industry in Malaysia had shown significant MSDs prevalence. The most affected body parts were lower back and right shoulder. For hands, the most affected hand areas were the right thumb, right index-middle fingers and right thumb middle palm. The result of this study can be used for advance ergonomics risk assessment to develop hierarchy of improvement measures as per outline in the Guideline on Ergonomics Risk Assessment at Workplace 2017.

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References

1. Punnett L, Wegman DH (2004) Work-related musculoskeletal disorders: The epidemiologic evidence and the debate. J Electromyogr Kinesiol. https://doi.org/10.1016/j.jelekin.2003.09.015
2. PERKESO. Annual reports. [Online]. Available: https://www.perkeso.gov.my/en/about-us/media-centre/annual-report.html. [Accessed: 16 Dec 2020].
3. DOSH (2017) "Guidelines On Ergonomics Risk Assessment At Workplace 2017". Deparment of Occupational Safety And Health, p 155
4. Shamsudin MZ, Vijaykumar V, Md Daud MY (2017) Work-related Musculoskeletal Disorders (WMSDs) among industrial packaging workers in Malaysia. Malaysian J Hum Factors Ergon
5. Alias AN, Karuppiah K, How V, Perumal V (2020) Prevalence of musculoskeletal disorders (MSDS) among primary school female teachers in Terengganu, Malaysia. Int J Ind Ergon 77(April):102957
6. MITI (2020) Medical devices industry in Malaysia [Online] Available: https://www.miti.gov.my/miti/resources/12._Medical_Devices_Industry_.pdf
7. Malaysia Employment Act (1955) Malaysia Employment Act 1955 [Online]. Available: https://www.ilo.org/dyn/natlex/docs/WEBTEXT/48055/66265/E55mys01.htm#c59 Accessed: 29 Oct 2020
8. Hedge D, Morimoto A, McCrobie S (1980) Cornell University ergonomics web. Cornell Musculoskelet Discomfort Questionnaires (CMDQ)
9. Chee H-L, Rampal KG, Chandrasakaran A (2008) Ergonomic risk factors of work processes in the semiconductor industry in Peninsular Malaysia. Ind Health 42(3):373–381
10. Yusof A, Shalahim NSM (2020) Investigation of ergonomic risk factors among male workers in a medical manufacturing company in Northern Malaysia. Malaysian J Public Heal Med
11. Balasubramanian V, Adalarasu K, Regulapati R (2009) Comparing dynamic and stationary standing postures in an assembly task. Int J Ind Ergon
12. Capodaglio EM (2017) Occupational risk and prolonged standing work in apparel sales assistants. Int J Ind Ergon
13. Sakthi Nagaraj T, Jeyapaul R, Mathiyazhagan K (2019) Evaluation of ergonomic working conditions among standing sewing machine operators in Sri Lanka. Int J Ind Ergon 70(January):70–83
14. Sakthi Nagaraj T, Jeyapaul R (2018) Ergonomic study on work postures of sewing machine operators in government industry: a case in lean environment garment industry
15. Shahid S. Anatomy of grip [Online]. Available: https://www.kenhub.com/en/library/anatomy/anatomy-of-grip. Accessed: 30 Oct 2020
16. Moosavi S, Desai R, Hallaj S, Sundaram KK, Hegde VS (2015) Ergonomic analysis to study the intensity of MSDS among practicing Indian dentists. Proc Manuf 3(Ahfe):5419–5426

17. Luttmann (2003) Preventing Musculoskeletal Disorders in the Workplace. World Heal Organ Rep Geneva (5):1–38lu
18. Loo HSS, Richardson S, Mara UT, Alam S (2012) Ergonomics issues in Malaysia centre of ergonomics. Faculty of Mechanical Engineering, Faculty of Management, Multimedia University. J Soc Sci

The Effect of Thermal Towards Human Perception of Malaysian Construction Workers Through Structural Equation Modelling (SEM)

Ahmad Rasdan Ismail, Nor Kamilah Makhtar, Raemy Md Zein, Muhamad Mat Noor, Hidayat Hamid, Nurul Husna Che Hassan, Darliana Mohamad, and Nor Kamaliana Khamis

Abstract In tropical developing countries, the workers in the construction industries are facing with high risk of thermal stress. As global temperature is estimated to be increased year by years thus constituted significant negative impacts to the workers at construction industry in Malaysia. Therefore the objective of this research paper is to highlight the findings on the perceptions of Malaysian construction workers towards the significant impact of thermal to their life. Utilizing structured questionnaire survey, there were 292 respondents response were gathered throughout Malaysian construction sector. The method of data collection used in this study is through online surveys by using Google Forms. The data have been analyzed through Structural Equation Modelling (SEM) and by using SPSS software Version 24 as well as Partial Least Squares (PLS) analysis techniques using the SmartPLS 3.0 software.

A. R. Ismail (✉) · H. Hamid · N. H. Che Hassan · D. Mohamad
Faculty of Creative Technology & Heritage, Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia
e-mail: rasdan@umk.edu.my

A. R. Ismail
Centre for Management of Environment, Occupational Safety and Health (CMeOSH), Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia

N. K. Makhtar
Department of Educational Planning and Research, Institute of Teacher Education, 16109 Kota Bharu, Kelantan, Malaysia

R. Md Zein
National Institute of Occupational Safety and Health (NIOSH), 43650 Bandar Baru Bangi, Selangor, Malaysia

M. Mat Noor
Faculty of Entrepreneurship and Business, Universiti Malaysia Kelantan, 16109 Pengkalan Chepa, Kelantan, Malaysia

N. K. Khamis
Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

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The findings indicated that the variable heat stress, task performance, and behavior among construction workers' could affect significantly the human performance.

Keywords Climatic · Psychology · Physiology · Heat stress · Performance

1 Introduction

The construction industries' workers are the most exposed to the effects of heat exposure. Furthermore, they are burdened with heavy workload which needs to be done in a period of time. Additionally, they are prone to various circumstances such as distracting noise level, contaminants and machinery malfunctions. Many of workers push themselves to their limit without considering their health just to get some extra-payment. This could increase the bad effect of the heat exposure and will lead to a lower performance in a long term especially when climate change is involved.

Hazards in the industries are divided into five which include psychosocial, ergonomic, physical, biological and also chemical. The factors that contributed to the heat stress and physical hazard are, occupational, environmental and individual factors. Individual factors that contribute to heat stress are acclimatizing, age, index of body mass, percentages of body fat, monthly income and also marital status. Regarding the occupational factors, the duration of heat exposure, period of employment, rating of perceived exertion (RPE), work shift, metabolic workload, work unit and water consumption are the contributing factors to heat stress. Environmental factors that relate to heat stress are based on the Wet Bulb Globe Temperature (WBGT) index, dry bulb temperature, wet bulb temperature, air velocity, relative humidity and globe temperature [1]. Heat is a form of energy. Heat can be generated either endogenous or exogenous process [2]. From safety and health point of view, heat stress is physical hazards which can cause health effect in direct and indirect condition to specific industrial workers.

There are four main effects of heat stress, which are physiological strain, heat related disorder, productivity and performance [3–5]. Physiological changes that have been identified that effects heat stress are as follows; heart rate, body core temperature, sweating rate, dehydration and blood pressure. Health effects are categorized into two parts which are chronic and acute health effect. Acute health effect such as lethargy, heat fatigue, dizziness, unstable movement, heat rashes, heat stroke, heat cramp, and heat collapse.

There are many factors that affect the level of heat stress based on the individual in indoors with or without air-cooling, outdoor in shade or in full sun. The time span of exposure, level, acclimatization, type of activity and clothing determine the effect of heat stress. Individual health, age, obesity, and sex also need to be considered for estimating impacts [6]. The result of studies on heat stress shows that there are two types of factors that play a role in adjusting the comfort level which are individual factors and environmental factors [7, 8].

Meanwhile, a survey study related to the human psychology, which targeted the construction industry's workers to identify effect of climate on the workers at the construction. Thus, the objectives of this study are to identify the measurement parameters for heat stress and strain index and to apply the parameters identified to do a study on the parameters' effect on the physiology, psychology and performance of the workers.

2 Methodology

After a deep research, data were collected by a survey questionnaire. Discussion related to the study, which is the perception surveys for the various environmental factors that are used include the temperature and relative humidity and also the collection and elaboration are described below.

2.1 Conceptual Model of Perception Survey

The study is a quantitative study that uses descriptive statistics (frequency, mean, standard deviation) and analytical tests causal-effective method. Al-Bouwarthan et al. [9], Venugopal et al. [10] States that studies in the field of heat stress and how it effects the worker's performance are monopolized by quantitative studies. Therefore, this study is in line with the methods used by previous study (eg; [11–14]). Figure 1 indicated the conceptual framework of the workers' perceptions study.

The perception survey will be conducted to assess the effects of two factors of heat stress, which are the relative humidity and temperature among workers in the

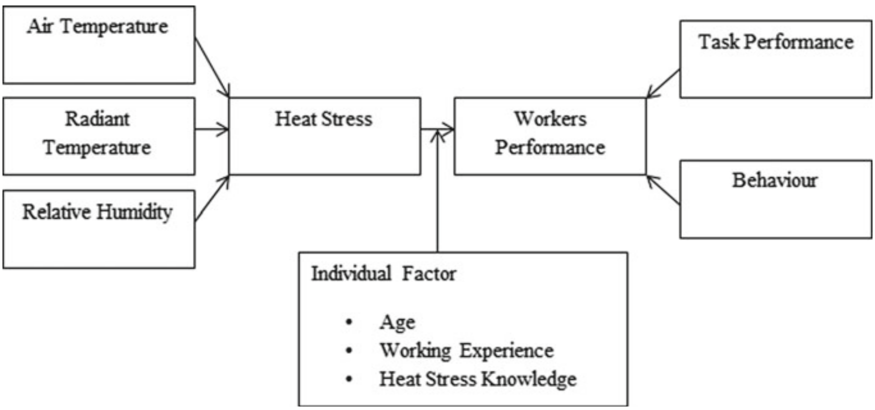

Fig. 1 Conceptual framework

construction industry in Malaysia on their performance. A questionnaire is developed based on the previous studies [6, 15]. This questionnaire has three parts: general information, the performance and the factors of heat stress.

The questionnaire will be administered to the workers who volunteered from various places in the construction sector. There will be a trained interviewer that will clarify any vague questions. The questionnaire was sent randomly to the construction workers' all over Malaysia. The used of the current strategy of sending the questionnaire which was using the google form, survey and distributing the form of all workers from Malaysian construction industry.

The method of data collection used in this research is through online surveys by using Google Forms. According to Narayanaswamy et al. [16], online surveys have become important because of fewer cost of administering a questionnaire, ability to achieve a large population, temporal and geographical advantages, which reached a unique population easily. Furthermore, the free availability of the tool and automatic recording of user response in its spreadsheet have made data collection and analysis simple. The Google Form provided by the researcher are distributed to the respondents via smartphones and also email. WhatsApp groups related to the construction sector that have been identified have been formulated to distribute the questionnaire besides using the method stated.

2.2 Survey

The workers' perception of heat stress and performance of workers due to higher heat in the workplace were consider in the statistical analysis. A good subjective perception of the heat stress among workers exposed to heat collected by using the survey questionnaire. The questionnaire was construct after a review of the literature on heat stress.

The questionnaire is adapted and modified based on the Heat Strain Score Index (HSSI) [17], the High Occupational Temperature Health and Productivity Suppression, HOTHAPS [18] and Individual Work Performance Scale [19]. In this study, optimum index was chosen by study the correlation coefficient between various indices as well as with physiological parameters. The questionnaire includes five-point scale from "Strongly dissatisfied" to "Strongly satisfied" in measuring worker's perception on heat stress and the performance while working in construction sector.

Previous studies describe that Heat Strain Score Index (HSI) indices and WBGT showed the highest correlation with other physiological parameters due to the positive features of WBGT such as calculation and ease of measurement. WBGT can be introduced as the most reliable empirical index for detecting the heat stress in heavy activity [17]. This was a concrete reason the used on the instrument for this study by the combination of these three previous instruments used by previous researchers.

The questionnaire was reviewed by relevant experts and conducting piloted among 53 outdoor construction workers. Revisions were made to ensure all questions are understandable and clear. The final questionnaire was showed in Table 1, which

Table 1 Research instrument

Construct		Items
Demographic background		i Gender ii Age iii Working experience iv Knowledge on heat stress
Heat stress	HS1	Muscle cramps, excessive sweating and thirst
	HS3	Severe heat exhaustion and syncope
Workers performance	WP1	Fall in performance
	WP2	Avail more leave due to excessive heat resulting in reduced income
Task performance	TP1	Work too much
	TP2	Uncompleted task
	TP3	Working overtime
	TP4	Less interest
Behaviour	BHV1	Hard breath
	BHV2	Too sleepy
	BHV3	Joint pain
	BHV4	Take long rest
Air temperature	AT1	Air temperature at the working place
	AT2	Feeling of the workers at the working place
	AT3	Workers adaptation due to the temperature
Radiant temperature	RT1	Present of radiant heat source at the workplace
	RT2	Feeling of the workers at the heat source
	RT3	The risk of workers contacted with the heat source surface
Relative humidity	RH1	Equipment that produces steam at workplace
	RH2	Workplace affected by external weather condition
	RH3	Complaining of the humidity of air

consisted of 4 demographic questions and 23 questions including perception of the workers on the heat stress, workers' performance, task performance, behaviour, air temperature, radiant temperature and relative humidity, previous history of heat-related injury and illness, management, heat prevention, and also perceptions of workplace higher heat exposure. Apart from that, some multiple-choice questions asking the work habits, measuring heat prevention and access to heat stress prevention information were asked. Besides, Likert-scale questions were used to measure heat-related attitudes and perceptions.

2.3 Data Analysis

The data have been analysed through Structural Equation Modelling (SEM) by using SPSS software Version 24 [20] and Partial Least Squares (PLS) analysis technique using the SmartPLS 3.0 software [21] which is to analyse the research model. By using SEM, structural relationships can be analysed by combining the multiple regression analysis and factor analysis. SEM is a multivariate statistical analysis.

3 Results and Discussion

This section discussed on the findings of the study analysis and the evaluation of the measurement model.

3.1 Descriptive Statistics

The demographic background of the respondents taken into account in this study is gender, age, working experience and knowledge on heat stress. The demographic distribution of respondents is as in Table 2. The data distribution shows 71.2% of the respondents in this study are male and 28.8% are female (Table 2). There were more male workers than female in the construction sector.

The majority of respondents in this study (48.3%) are aged between 31 and 40 years old, which is 141 people. Interestingly, there was no respondents involved in this study with the age of 10–20 years old. Respondents with 1–3 years working experience are the majority in this study with 64 people (21.9%), followed by workers with 4–6 years working experience, which are 48 people (16.4%). The rest of the data on the workers' working experience can be seen on the Table 2. Regarding to the knowledge on heat stress, 71.9% (210 workers) of the workers had knowledge on it while the rest 28.1% (82) didn't have any knowledge on heat stress.

3.2 Measurement Model

Once the descriptive analysis is conducted, then this section tests the measurement model used in this study. Testing the measurement model is the early step in the analysis using PLS. In the measurement model test, the study items will be tested to the extent of their accuracy in representing a construct which is to ensure that study items meet the standards of validity and reliability. The guidelines for testing the measurement model are based on Straub et al. [22]. Testing of the measurement model

Table 2 Demographic distributions of respondents

Demographic		Frequencies (N = 292)	Percentage/%
Gender	Male	208	71.2
	Female	84	28.8
Age	10–20 years old	–	–
	21–30 years old	98	33.6
	31–40 years old	141	48.3
	41–50 years old	32	11.0
	51 years old and above	21	7.1
Working experience	Less than 1 year	36	12.3
	1–3 years	64	21.9
	4–6 years	62	21.2
	7–9 years	40	13.7
	10–15 years	48	16.4
	More than 15 years	42	14.5
Heat stress knowledge	Yes	210	71.9
	No	82	28.1

involves the internal consistency, consistency of indicators and construct validity, which involves concentrated validity and discriminant validity.

3.2.1 Construct Validity

Construct validity is tested two methods, namely concentrating validity and discriminative validity. Concentration validity refers to the level of convergence of an item to the construct represented [23]. The method used to test consent rating validity is to measure the value of the average variance extracted (AVE) as suggested by Fornell and Larcker [24]. In addition to AVE values, convergence validity is also assessed through composite reliability values. If the composite reliability, value exceeds 0.8 [25], then the study instrument achieves the standard of concentrating validity. Furthermore, the loading factor value above 0.7 also proves that the instrument of this study achieves the standard of concentrating validity [24]. Figure 2 shows the value of AVE for this measurement model analysis while Table 3 shows the value of formal-Larcker criteria for this measurement model analysis.

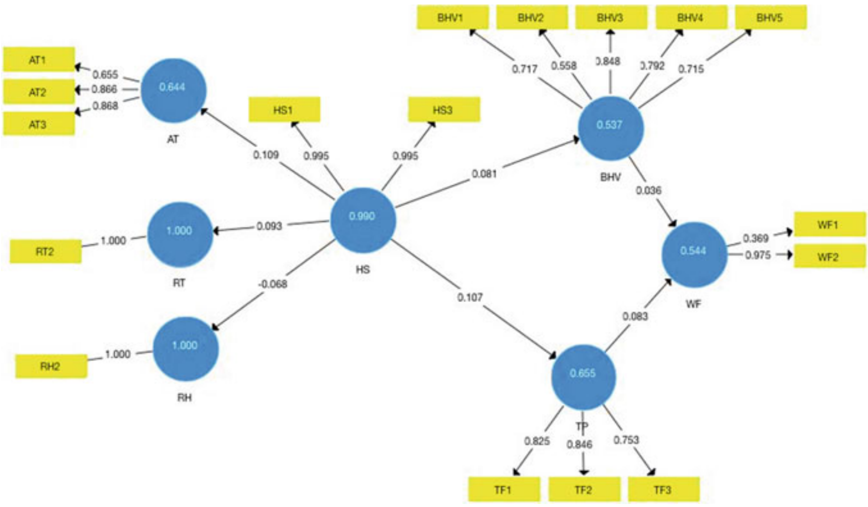

Fig. 2 AVE for measurement model analysis

Table 3 Fornel-Larcker criterion

	Air temperature	Behaviour	Heat stress	Radiant temperature	Relative humidity	Task performance	Workers performance
AT	0.822						
BHV	0.400	0.751					
HS	0.220	0.460	0.852				
RT	0.552	0.460	0.262	0.823			
RH	0.195	0.634	0.428	0.295	0.831		
TP	0.244	0.742	0.474	0.300	0.597	0.794	
WP	0.161	0.407	0.821	0.260	0.359	0.446	0.908

Note: *AT* Air Temperature; *BHV* Behaviour; *HS* Heat Stress; *RT* Radiant Temperature; *RH* Relative Humidity; *TP* Task Performance; *WP* Worker Performance

Table 4 Construct reliability and validity

	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Air temperature	0.760	0.862	0.675
Behaviour	0.754	0.690	0.563
Heat stress	0.873	0.913	0.725
Radiant temperature	0.771	0.861	0.677
Relative humidity	0.788	0.869	0.690
Task performance	0.805	0.872	0.631
Workers performance	0.786	0.903	0.824

As shown in Table 4, all study constructs exceed the predetermined values and confirm that each construct meets the standards of concentrated validity. Whereas discriminant validity refers to the degree of difference (discriminant) between one construct with another [26]. Discrimination validity testing is conducted to determine whether a construct measures what should be measured.

This study uses cross-loading item comparison table method to test discriminant validity as indicated in Table 5. This method can be implemented by correlating the items of one construct items from other constructs [27]. The loading value of an item should be higher for the constructs it represents only, and low for other constructs. In conclusion each item should not be used to measure constructs other than the constructs it represents. This study shows that item values reach the level of discriminatory validity standards (refer to Table 6).

Table 5 Cross-loading item comparison table

Latent	Air temperature	Behaviour	Heat stress	Radiant temperature	Relative humidity	Task perform	Workers performance
AT1	0.837	0.258	0.198	0.420	0.141	0.144	0.130
AT2	0.848	0.322	0.173	0.445	0.185	0.228	0.165
AT3	0.778	0.420	0.169	0.503	0.157	0.239	0.101
BHV1	0.241	0.975	0.454	0.373	0.644	0.763	0.414
BHV3	0.778	0.420	0.169	0.503	0.157	0.239	0.101
HS1	0.173	0.433	0.877	0.208	0.400	0.463	0.723
HS2	0.152	0.328	0.839	0.184	0.268	0.324	0.639
HS3	0.226	0.432	0.805	0.245	0.426	0.402	0.621
HS4	0.196	0.371	0.882	0.250	0.359	0.414	0.796
RH1	0.126	0.555	0.179	0.145	0.711	0.518	0.082
RH2	0.215	0.532	0.355	0.291	0.868	0.494	0.289
RH3	0.144	0.544	0.449	0.265	0.901	0.520	0.411
RT1	0.518	0.304	0.117	0.698	0.137	0.236	0.070
RT2	0.438	0.365	0.206	0.845	0.238	0.253	0.222
RT3	0.468	0.443	0.278	0.910	0.306	0.262	0.283
TP1	0.277	0.549	0.358	0.171	0.481	0.774	0.306
TP2	0.152	0.619	0.389	0.241	0.441	0.790	0.381
TP3	0.169	0.597	0.372	0.252	0.471	0.809	0.381
TP4	0.196	0.651	0.384	0.282	0.511	0.802	0.337
WP1	0.072	0.355	0.731	0.187	0.351	0.362	0.903
WP2	0.217	0.384	0.758	0.284	0.302	0.446	0.912

*Note: *AT* Air Temperature; *BHV* Behaviour; *HS* Heat Stress; *RH* Relative Humidity; *RT* Radiant Temperature; *TP* Task Perform; *WP* Workers Performance

Table 6 Summary of measurement model evaluation

Construct	Indicator	Indicator loading	CR	AVE	Discriminant
Air temperature	AT1	0.837	0.862	0.675	Yes[a]
	AT2	0.848			
	AT3	0.778			
Behaviour	BHV1	0.975	0.690	0.563	Yes[a]
	BHV3	0.420			
Heat stress	HS1	0.877	0.913	0.725	Yes[a]
	HS2	0.839			
	HS3	0.805			
	HS4	0.882			
Radiant temperature	RT1	0.698	0.861	0.677	Yes[a]
	RT2	0.845			
	RT3	0.910			
Relative humidity	RH1	0.711	0.869	0.690	Yes[a]
	RH2	0.868			
	RH3	0.901			
Task performance	TP1	0.774	0.872	0.631	Yes[a]
	TP1	0.790			
	TP3	0.809			
	TP4	0.802			
Workers performance	WP1	0.903	0.903	0.824	Yes[a]
	WP2	0.912			

[a]Based on the confirmation in cross-loading in Table 5 and the Fornel-Larcker criteria in Table 3

3.3 *Structural Model*

After evaluating the measurement model, the structural model is evaluated as well as testing the research hypothesis. The structural model contains arrows that give the meaning of the relationship between one construct to another (hypothesized relationship) information about beta value (β) for hypothesis testing and R2 value. The strength of the relationship value is represented by the value of β while the value of the contribution of all independent variables to the dependent variable is determined by the value of R2. Chin [27] states that the value of R2 0.67 is strong, 0.33 is moderate, and 0.19 is weak.

The value of R2 refers to the percentage value of the variance in a model and symbolizes predictive power. The results of the study in R2 values are shown in Fig. 3. The level of significance of a relationship is found by the bootstrapping method. This study has set 500 total re-sampling. This study model has a strong predictive power (predictive power) that is R2 = 0.21 for the dependent variable of heat stress and R2 = 0.68 for the dependent variable of worker's performance.

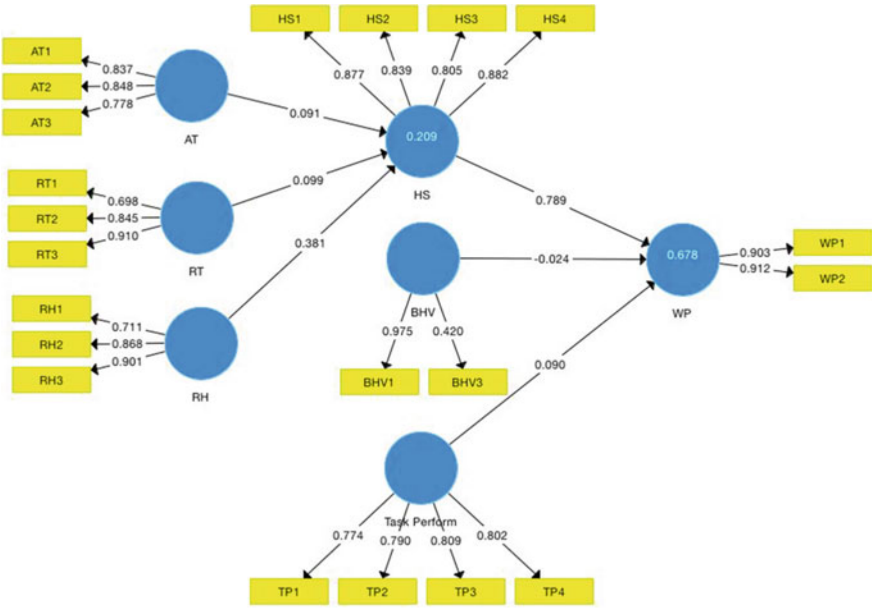

Fig. 3 Partial least square structural model of effect of heat stress on workers' performance

Based on Fig. 3, the research model explains 20.9% variants in heat stress are explained by air temperature, radiant temperature and relative humidity. The 67.8% variants in workers' performance explained by heat stress, behaviour and task performance as seen from the research model. Based on the practical conditions proposed by Chin [27], it can be concluded that the value of R2 for heat stress, behaviour and task performance, with workers' performance is strong.

3.3.1 Hypothesis Testing

Hypothesis testing findings can be seen in Table 7. Table 7 explains the hypothesis results in beta values along with other values such as p-value, t-value and effect size while Fig. 3 shows the PLS structural model with beta values of the relationship between study constructs.

Hypothesis 1 which predicted the relationship between heat stress and workers' performance was found to have a positive and significant relationship with value of β of 0.79, ($p < 0.05$). Hypothesis 2, on the other hand, which is the task performance has a positive effect on the workers' performance, with a value of β of 0.09, ($p >$ 0.05). The results of the study unsupported hypothesis 3 that behaviour has a positive effect with workers' performance of β − 0.024, ($p < 0.05$) as indicated in Table 8.

The estimated model using PLS-SEM verified the applied statistical criteria considered and the latent constructs and measured variables involved make sense to

Table 7 Path coefficients values, total Indirect Effect (IE), total Direct Effect (DE), t-Statistics and p-values

Relationship	Original sample (O)	St. Dev (STDEV)	*t*-statistics (|O/STDEV|)	*p* value
Air temperature → Heat stress	0.091	0.076	1.189	0.117
Behaviour → Workers' performance	−0.024	0.070	0.343	0.366
Heat stress → Workers' performance	0.789	0.042	18.606	0.000
Radiant temperature → Heat stress	0.099	0.077	1.281	0.100
Relative humidity → Heat stress	0.381	0.061	6.229	0.000
Task perform → Workers' performance	0.090	0.071	1.265	0.103

Table 8 Hypothesis test results

Path	Hypothesis	β-value	*t*-value	Result
HS → WP	H1: There is a positive significant correlation between heat stress on worker's performance	0.789	18.606	Accepted
TP → WP	H2: There is a positive effect of task performance on worker's performance	0.090	1.265	Accepted
BHV → WP	H3: There is a positive effect of behaviour on worker's performance	− 0.024	0.343	Rejected

Value β *significant at $p < 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$
Note AT Air Temperature; *BHV* Behaviour; *HS* Heat Stress; *RH* Relative Humidity
RT Radiant Temperature; *TP* Task Perform; *WP* Workers Performance

the light of the psychosocial theories. According to the results obtained in this case study the variables heat stress, task performance and behaviour among construction workers', which could lead them to the performance. The assessment of the structural estimated model enables to conclude that the underlying theory was empirically confirmed. The results achieved may suggest structural-level interventions in working conditions, as well as changes that may lead to an improvement in the health conditions of the workers.

4 Conclusion

In conclusion, the objectives of this research are achieved. This research conducted to investigate the heat stress problem and determine the significant factors that can contribute to acute health symptoms of heat stress in the construction industry. The estimated model using PLS-SEM showed the applied statistical criteria considered, the measured variables and latent constructs involved. According to the results, the variable of heat stress, behaviour and task performance among construction workers' lead them to the performance. The assessment of the structural estimated model was enables to conclude that the underlying theory was confirmed. Thus, this study may suggest the structural-level interventions in working conditions and changes that may contribute to an improvement in the worker's health conditions. Meanwhile, future research is to take after evaluating the measurement model is the structural model as well as testing research hypothesis. Structural model contains arrows that give the meaning of the relationship between one construct to another (hypothesized relationship) information about the beta value (β) for hypothesis testing and R2 value.

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References

1. Cui W, Cao G, Park JH, Ouyang Q, Zhu (2013) Influence of indoor air temperature on human thermal comfort, motivation and performance. Build Environ 68:114–122
2. Simon HB (1994) Hyperthermia and heatstroke. Hosp Prac 29(8):65–80, 73, 78–80
3. Thomas EB (1971) Thermal stress. In: Barbara AP (ed) Fundamental of industrial hygiene, 5th edn. National Safety Council, United States, 1080
4. Enander AE (1989) Effects of thermal stress on human performance. Scan J Work Environ Health 15(1):27–33
5. Noordin S, Hashim JH (2006) A prevalence study on the effect of heat stress among a steel plant employee in Selangor Darul Ehsan. Jurnal Kesihatan Masyarakat 12(1):1663–1675
6. Kjellstrom T (2009) Climate change, direct heat exposure, health and well-being in low and middle-income countries. Glob Health Action 2(1–3)
7. Kjellstrom T, Briggs D, Freyberg C, Lemke B, Otto M, Hyatt O (2016) Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts. Ann Rev Public Health 37(1):97–112
8. Fanger P (1970) Thermal comfort: analysis and applications in environmental engineering. Danish Technical Press
9. ASHRAE (2013) Thermal environment conditions for human occupancy Standard 55-201
10. Al-Bouwarthan M, Quinn MM, Kriebel D, Wegman DH (2019) Assessment of heat stress exposure among construction workers in the hot desert climate of Saudi Arabia. Ann Work Exposures Health 63(5):505–520
11. Venugopal V, Chinnadurai JS, Lucas RAI, Kjellstrom T (2016) Occupational heat stress profiles in selected workplaces in India. Int J Environ Res Public Health 13(89):1–13
12. Dutta P, Rajiva A, Andhare D, Azhar GS, Tiwari A, Sheffield P (2015) Perceived heat stress and health effects on construction workers Indian. J Occup Environ Med 19(3):151–158
13. Ismail AR, Yusof MYM, Makhtar NK, Deros BM, Rani MRA (2010) Optimization of temperature level to enhance worker performance in automotive industry. Am J Appl Sci 7(3):360–365

14. Kjellstrom T, Gabrysch S, Lemke B, Dear K (2009) The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies Glob Health Action 2 from http://www.globalhealthaction.net/index.php/gha/article/view/2082/2563
15. Meyer JP, Rapp R (1995) Survey of heat stress in industry. Ergonomics 38(1):36–46
16. HSE UK. Heat stress checklist. Retrieved 18 Oct 2019, from HSE UK website. http://www.hse.gov.uk/temperature/assets/docs/heat-stress-checklist.pdf
17. Narayanaswamy VR, Harinarayana NS (2016) Online survey tools: a case study of Google Forms Online. In: National Conference on "Scientific, Computational and Information Research Trends in Engineering GSSS-IETW", Mysore (January 2016), pp 1–12
18. Habibollah D, Seyed BM, Mohamad JJ, Mohamad RM (2015) Development and validation of a questionnaire for preliminary assessment of heat stress at workplace. J Res Health Sci 15(3):175–181
19. Kjellstrom T, Holmer I, Lemke B (2009) Workplace heat stress, health and productivity—an increasing challenge for low and middle-income countries during climate change. Glob Health Action 2(10)
20. Ramdani Z, Marliani R, Rahman AA (2019) The individual work performance scale: a psychometric study and its application for employee performance. Humanit Soc Sci Rev 7(5):405–414
21. Dehghan H, Mortzavi S, Bagher J, Javad M, Maracy MR (2015) The reliability and validity of questionnaire for preliminary assessment of heat stress at workplace. Iran South Med J 15(4):810
22. Sarstedt M, Ringle CM, Smith D, Reams R, Hair JF (2014) Partial least squares structural equation modeling (PLS-SEM): a useful tool for family business researchers. J Family Bus Strategy 5(1):105–115
23. Straub D, Boudreau MC, Gefen D (2004) Validation guidelines for IS positivist research. Commun Assoc Inf Syst 13(March):380–427
24. Gefen D, Straub DW (2005) A practical guide to factorial validity using PLS-graph: tutorial and annotated example. Commun Assoc Inf Syst (16):91–109
25. Fornell C, Bookstein FL (1982) Two structural equation models: LISREL and PLS applied to consumer exit-voice theory. J Mark Res (19):440–452
26. Nunnally JC, Bernstein IH (1999) Psychometric theory. J Psychoeducational Assess 17:275–280
27. Urbach N, Ahlemann F (2010) Structural equation modeling in information systems research using partial least squares. J Inf Technol Theor Appl 11(2):5–40
28. Chin WW (1998) Issues and opinion on structural equation modeling management. Inf Syst Q 22(1):vii–xvi

Optimization of Temperature and Relative Humidity with Maximum Oxygen Uptake (VO_{2max}) and Heart Rate (HR) by Using Response Surface Methodology (RSM)

Ahmad Rasdan Ismail, Norfadzilah Jusoh, Nor Kamilah Makhtar, Raemy Md Zein, Muhamad Mat Noor, and Khairul Azhar Mat Daud

Abstract The purpose of this study is to optimize the temperature and relative humidity (RH) conditions of the worker heat stress and human physiological performance namely as Maximum Oxygen Uptake (VO_{2max}) and heart rate (HR) in the construction (outdoor environment) and manufacturing (indoor environment) environment. Heat stress assessment was conducted at the workplace with two parameters of heat and relative humidity for indoor and outdoor setting conditions. The response surface methodology (RSM) was utilized in this study to analyze the results and finally to optimization the relationship of both setting for indoor and outdoor. A total number of 26 experimental runs were carried out with three male of voluntary respondents. The experiments were conducted in a well design climatic chamber with capabilities to simulate the indoor, outdoor temperature and relative humidity parameter of environments. The analysis showed that, for the indoor activities the parameter of VO_{2max} and heart rate, the temperature and relative humidity (RH) exposed to human body should be optimized at 24.2 °C and RH at 45.8%. Meanwhile, for the outdoor activities, the temperature and RH exposed to human body

A. R. Ismail (✉) · N. Jusoh · K. A. Mat Daud
Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia
e-mail: rasdan@umk.edu.my

A. R. Ismail
Centre for Management of Environment, Occupational Safety and Health (CMeOSH), Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia

N. K. Makhtar
Department of Educational Planning and Research, Institute of Teacher Education, 16109 Kota Bharu, Kelantan, Malaysia

R. Md Zein
National Institute of Occupational Safety and Health (NIOSH), 43650 Bandar Baru Bangi, Selangor, Malaysia

M. Mat Noor
Faculty of Mechanical and Manufacturing Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

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should be optimized at 24.6 °C and RH at 72.5%. Therefore, these findings are in line with the current setting of comfort under ICOP IAQ 2010, DOSH Malaysia.

Keywords Thermal · Heat stress · Optimization · Outdoor · Indoor · Response surface · Comfort

1 Introduction

In previous studies, workers in the construction industry are one of the most affected by heat stress [1]. Increasing heat exposure during summer in India effects heat and strain parameters such as cardiac strain and peak heart rate [2]. Construction sites have an organizational structure that is difficult compare to white collar industries, which can impair the level of physical health and mental and well-being of workers. Hajizadeh et al. [3] conducted an assessment of heat stress in outdoor workplaces using WBGT and ESI indexes in the Qom province in Iran. They found out that the weather conditions in hot seasons, which are in July for the study, are not recommendable for the outdoor environment with heavy workloads. This can be related to construction site where most of the workers have heavy workloads in an outdoor environment. Several factors increase the injury and risk of heat-related illness. These include the use of powered tools and machinery, heavy workload, working on elevated surfaces, simple accommodation conditions near sites, expose direct to sunlight and temporarily employed by a sub-contractor on a daily payment basis.

Workers who spend their time in workplace that contain non-air conditioned indoor facing higher risk of heat-related illness, even they are not expose directly by sunlight radiation. This incident also could higher in some workplaces that involving ovens, hot machines, molten metal and furnaces [1]. DOSH Malaysia found that workers exposed to heat stress through process of machinery and high temperature. Besides that, previous study [4] conducted the effects of environmental factors on the workers in the automotive industry. They highlight that humidity, temperature, and illumination can be optimized to increase the productivity of the workers. Another study mentioned that the increase of the ambient non-linear effects on worker productivity. They estimated that the manufacturing output had been decreased between 1971 and 2009 which show at least 3% relative to a no-warming counterfactual as a result [5]. Apart from that, Hajizadeh et al. [3] reported that workers engaged in an indoor environment experienced the highest higher levels of all environmental parameters than outdoors while this not applicable for air velocity.

However, conflicting evidence were found regarding effects of elevated environmental temperature on exercise performance and VO_{2max}. Some studies found that higher environmental temperature will decrease the amount of VO_{2max}. Besides, heat stress will have decreased VO_{2max} proportion and increase skin and core temperature which highlight in one study. Moreover, instead of that, some studies also indicate that there is no effect on VO_{2max} regarding high environmental temperature [6, 7].

Response Surface Method analysis (RSM) is a combination of mathematical methods and statistical analysis that are very useful for growing, updating and need optimize a process that involves several independent variables and one dependent variable [8]. Montgomery [9] states that the Response Surface Method is an empirical model approach to investigate the relationship between various parameters and response to the desired criteria and also to find the importance of the parameter. Through RSM, a best mathematical equation will be developed to represent the relationship between the dependent variable and the dependent variable. Using the obtained equations, an optimal value for each independent variable is proposed to obtain the desired dependent variable value [10].

A number of previous studies have been performed using RSM as an optimization analysis method in their study. Most of these studies are based on chemical and biological processes [8, 11, 12]. RSM is widely used in chemistry and biology because the experimental design of the RSM it involves values of study parameters that are within the safe limits and less necessary data in conducting the analysis [9]. However, there are also many other areas that use RSM as an optimization method. Pishgar-Komleh et al. [13] studied the condition of picker-husker harvesting losses in corn seed which were optimized. In the study, they put into account two machinery factors; the speed levels and cylinder speed. For each factor, they used three levels by applying the Central Composite Design (CCD). The result showed that the increasing of travel and cylinder speed were resulted in the increasing of travel, while cylinder speed were resulted in the increasing of harvesting losses.

Ismail et al. [14] used RSM to study the effect of humidity, WBGT and lighting on the productivity of workers. Based on the result of RSM, they proposed optimum values for these parameters. This is supported by another studied which is to identify the optimum values of environmental parameters by using the second order of RSM [10]. Belwal et al. [15] designed an experiment to maintain the antioxidant potential of Berberis asiatica fruits and extraction of phenolic compounds using RSM. They used a five-factors-three-level experiment with CCD. The results suggest that sample to solvent ratio, extraction temperature, and solvent concentration influence the variables of response. The quadratic model well suit for all the responses.

Zamani et al. [16] conducted an experimental study to investigate the operation time of solar cookers on the system's energy efficiency and the simultaneous effect of the position on the parabolic mirror by using RSM. The experiments were running in the climatic conditions of Mashhad, Iran. They claimed that the result of the study will improve the overall efficiencies of energy and mean value of the effective by 32.07% and 35.5%, respectively. Table 1 summarized the application of RSM in research.

Based on the previous study, the theory of heat stress easily to understand and can identified the relationship between performance in the manufacturing and construction industry and heat stress. The RSM as one of the Artificial Intelligence Method analysis will be utilized to identify the relation between heat stress and workers' performance, to model every parameter of the study and to provide optimum heat exposure parameter for highest performance. Therefore, the objective the study

Table 1 Summary of the findings on the application of RSM

Researchers	Findings
Montgomery [9]	RSM is an empirical model approach to investigate the relationship between response to the desired criteria and various parameters
Pishgar-Komleh et al. [13]	Studied the optimization of picker-husker harvesting losses in corn seed by RSM
Ismail et al. [14]	Studied the effect of WBGT, humidity and lighting on the productivity of the workers by RSM
Zamani et al. [16]	Investigate the simultaneous effect of the operation time of solar cookers on the system's energy efficiency and the position of the parabolic mirror by using RSM
Belwal et al. [15]	Optimize antioxidant potential of Berberis asiatica fruits and the extraction of phenolic compounds using RSM

is to optimize thermal conditions of worker heat stress in construction (outdoor environment) and manufacturing (indoor environment) by using climate chamber.

2 Methodology

2.1 Experimental

A climate chamber with 407 cm (L) × 407 cm (W) × 250 cm (H) was built to simulate the indoor and outdoor hot and humid environments. The source of the heat was provided by a reserve electric heater and two heat pump unit air conditioners. While, the source of humidity was provided by an electrode steam humidifier fixed in the system air supply. The envelopes of the chamber were insulated the thermal insulation materials. The humidity and heat source equipment were put outside the chamber. Besides that, the temperature and humidity data loggers were installed to record the humidity and temperature in the chamber. Apart from that, WBGT was used to measure directly the wet bulb temperature, air temperature, globe temperature and WBGT. However, in order to maintain the humidity and actual temperature in a stable condition, the electrode steam humidifier and the electric heater can be control. Thus, the humid and hot environment with different combination of humidity and temperature can be simulated and control.

Three university male was chosen as subjects which is no disease history and voluntary participation in this study. All subjects need to wear cotton shirts, long trousers, socks and shoes. But, before the experiment start, all the subjects need to have a good rest and they were also given and gain the knowledge about the hazard of heat stress.

Physiological index and environmental parameters were identified. Thus, the equipment and parameters are given in Table 2.

Table 2 Parameters and instruments

Parameter	Parameter name	Measuring equipment	Range
Environmental parameters	Dry bulb temperature, wet bulb temperature, relative humidity	Quest thermal environment monitor	20–120 °C
Physiological index	Heart rate	Polar H7	
	Volume oxygen uptake	Cortex MetaMax 3B	

2.2 WBGT

The WBGT instrument is the mostly used regarding heat stress index and it was adopted as an international standard [17, 18]. The WBGT consists of weighting of wet bulb temperature, dry bulb temperature and black-global temperature [19].

For outdoor;

$$\mathrm{WBGT} = 0.7\mathrm{T\_W} + [0.1\mathrm{T}]\_\mathrm{D} + [0.2\mathrm{T}] \tag{1}$$

For indoor

$$\mathrm{WBGT} = 0.7\mathrm{T\_W} + [0.3\mathrm{T}]\_\mathrm{G} \tag{2}$$

where TD is dry bulb temperature, TW is wet bulb temperature and TG is black-globe temperature.

For indoor purposes, when TG ~ TD, then

$$\mathrm{WBGT} = 0.7\mathrm{T\_W} + [0.3\mathrm{T}]\_\mathrm{D} \tag{3}$$

2.3 Evaluation of Performance

The performance value is deduced from the value of oxygen uptake (VO_{2max}) and heart rate (HR). According to recent study by Preisser et al. [20], the performance could be determined by the volume of oxygen uptake after volume of oxygen uptake ventilatory threshold (VT) of the individual and also by the value of heart rate the heartbeat rate at VT under laboratory conditions during cardiopulmonary exercise testing (CPX).

Most of studies on human performance directly use maximum oxygen uptake as the performance parameter. But they focus on the human performance for body fitness during an exercise. In this study, the focus is on the simulation of tasks in the real working environment, so the method is according to the previous study [20] who studied performance of the workers in a field study. They studied on the performance of refuse collectors from three specific groups which are residual, organic waste collection and street sweeping of the municipal sanitation department in Hamburg, Germany.

Equation 1 is the performance based on the volume of oxygen uptake for 15 min on task normalized for body weight expressed in units of ml O_2/kg/min. And the Equation 2 is the performance based on the heart rate for 15 min on task expressed in beats/min.

$$\text{Performance 1 } (\%) = \frac{\text{Volume of oxygen uptake } (15\ \text{min})}{\text{Volume of oxygen uptake VT}} \quad (4)$$

$$\text{Performance 2 } (\%) = \frac{\text{Heart rate } (15\ \text{min})}{\text{Heart rate VT}} \quad (5)$$

2.4 Design of Experiment

In this study, there are two types of analysis that will be used for the data obtained to determine the relationship and also to obtain the optimum value of each parameter studied; RSM analysis can be made by using Minitab software. These analyses were selected to allow for the relevance of each study's parameter to be evaluated using only a small amount of data [12, 14, 15, 21]. Through these methods, the relationship between the thermal factors and the performance can be interpreted.

2.5 Response Surface Method (RSM)

First, the data will be analyzed to fit the first order equation. Then, the first order equation obtained will be tested to determine the efficiency. If minimum requirements of efficiency are not achieved, a second order equation will be generated which will better reflect the pattern of data obtained [22]. The coefficient of P is an indication of the relative importance of each parameter to the value of performance. Given that the confidence level used in this study is 95%, then a model with a P value of less than 0.05 considered a significant model.

Meanwhile, the value of R^2 also needs to be taken into consideration. This value is to determine the value of the dependent variable which is represents the strength of the prediction model built with the existing data. The closer value of R^2 1.0, it will stronger the proposed model. Through RSM, the combined relationship of each parameter to performance will be shown through a contour graph and a three dimensional surface graph. Through this graph, the combined mean of each parameter can be interpreted. Through the mathematical model developed, RSM analysis will

Table 3 Factors and level used for the study of indoor environment

Symbol	Factor	Unity	Level 1	Level 2	Level 3
A	Relative humidity	(%)	30	50	70
B	Temperature	°C	22	27	32

provide the optimum value of each parameter to obtain a performance value equal to 1.0.

Before starting the experiment, a Design of Experiment (DOE) needs to be developed. For this study, DOE can be generated through RSM analysis. The values obtained from Tables 3 and 5 is constructed by taking into account the values of the parameters that have been studied by previous researchers and also the climate in Malaysia. According to a study conducted by Tsutsumi et al. [23], they used relative humidity values of 30%, 40%, 50% and 70% in an indoor study. Whereas Cui et al. [24] used 5 temperature levels (22 °C, 24 °C, 26 °C, 29 °C, 32 °C) for the study of temperature in an indoor environment. Ismail et al. [25] studied how to predict the worker's productivity based on the environmental factors. In the study, they used temperatures within the range of 19–32 °C. The relative humidity in Malaysia is around 70–90% with the temperature during the day between 29 and 34 °C [26, 27]. All of these parameter values will be combined and extracted minimum and maximum limit values to form one DOE study.

As we study two environments; indoor and outdoor. Therefore, two value range table is proposed for both environments. The outdoor environment has a higher set of relative humidity and temperature to simulate the real condition of the outdoor environment in Malaysia. The studies have been conducted based on the value of DOE constructed from these two sets of parameters. After the data is recorded, it is analyzed using the RSM. Box-Wilson Central Composite Design is used to match the RSM.

DOE as shown in Tables 4 and 6 has 13 sets of data for one subject and it is applied to three study subjects. Therefore, the total number of data sets that will be available for the whole study is 78 sets consider two types of environment (indoor and outdoor). Tables 3 and 5 shows the values of relative humidity and relative temperature that have been conduct through the DOE.

3 Results and Discussion

As previous stated, response surface methodology (RSM) was applied to analyze results optimization of the thermal indices for indoor and outdoor. Thermal indices are the criteria used for mathematical determination of the combined effects of climatic factors such as humidity, air temperature, radiation and air speed which is from the comfort body. The ANOVA analysis revealed the *p*-value for each of the

Table 4 Design of experiment of indoor environment

Run n	Random order	Coded variables		Temperature (°C)	Relative humidity (%)
		X_1	X_2		
1	7	−1	−1	22	30
2	10	1	−1	32	30
3	11	−1	1	22	70
4	2	1	1	32	70
5	13	1.414	0	34	50
6	12	−1.414	0	20	50
7	3	0	1.414	27	78
8	9	0	−1.414	27	22
9	8	0	0	27	50
10	6	0	0	27	50
11	5	0	0	27	50
12	1	0	0	27	50
13	4	0	0	27	50

Table 5 Factors and level used for the study of outdoor environment

Symbol	Factor	Unity	Level 1	Level 2	Level 3
A	Relative humidity	(%)	74	83	92
B	Temperature	°C	16	25	34

Table 6 Design of experiment outdoor environment

Run n	Random order	Coded variables		Temperature (°C)	Relative humidity (%)
		X_1	X_2		
1	7	−1	−1	16	74
2	10	1	−1	34	74
3	11	−1	1	16	92
4	2	1	1	34	92
5	13	1.414	0	38	83
6	12	−1.414	0	12	83
7	3	0	1.414	25	96
8	9	0	−1.414	25	70
9	8	0	0	25	83
10	6	0	0	25	83
11	5	0	0	25	83
12	1	0	0	25	83
13	4	0	0	25	83

Table 7 Coefficients oxygen uptake and heart rate (indoor)

	Average oxygen uptake	Average heart rate
P-value temperature	0.027	0.045
P-value RH	0.015	0.001
R^2	88.71%	92.33%
S	0.0131861	0.0085794
Lack-of-fit	0.351	0.311
Optimum value temperature	20	25.65
Optimum value RH	22	58.77

Table 8 Optimization heart rate and oxygen intake (indoor)

Parameter	Average
Optimum value temperature	24.24 °C
Optimum value RH	45.75%

environmental parameters (relative humidity and temperature) are significant for all subjects whereby $p < 0.05$, with 95% confidence respectively. RSM tested the overall model to determine the significant relationship between the temperature and relative humidity with VO_{2max} as well as heart rate of the subject. Further optimization carried out indicated that in order to optimize human performance in construction industries (for the indoor activities) based on the parameter of VO_{2max} as well as heart rate, the temperature as well as relative humidity exposed to human body should be optimized at 24–25 °C and RH at range 45–46%. Table 7 indicated the coefficients oxygen uptake and heart rate (indoor) and Table 8 indicated the optimization of heart rate and oxygen intake (indoor) (Fig. 1).

In the outdoor environment, the temperature and relative humidity exposed to human body should be optimized at 24–25 °C and RH at range 72–73%.

Table 9 indicated the coefficients oxygen uptake and heart rate (outdoor) and Table 10 indicated the optimization of heart rate and oxygen uptake (outdoor) (Fig. 2).

4 Conclusion

As a conclusion, the optimization of the thermal indices for indoor and outdoor thermal setting for industry's evidence proved the significant contribution of temperature and relative humidity to the human performance namely HR and VO_{2max}. The trend for both HR and VO_{2max} consistently fluctuating and the RSM utilized able to model the relationship between both variables with the human physiological implication had obtained. Meanwhile, the optimization of the HR and VO_{2max} for indoor

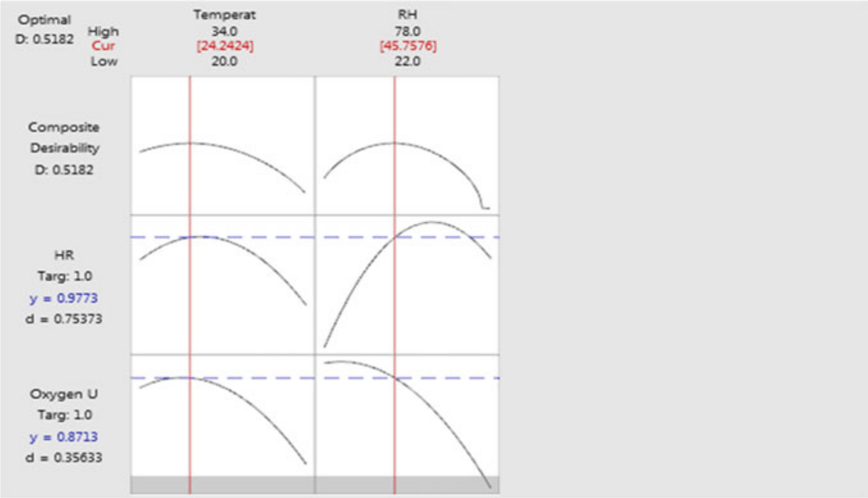

Fig. 1 Response optimization-HR, oxygen uptake

Table 9 Coefficients of oxygen uptake and heart rate (outdoor)

	Average oxygen uptake	Average heart rate
P-value temperature	0.043	0.004
P-value RH	0.000	0.028
R^2	99.38%	94.00%
S	0.0075721	0.0093828
Lack-of-fit	0.003	0.016
Optimum value temperature	24.34	24.86
Optimum value RH	74.73	75.52

Table 10 Optimization heart rate and oxygen intake (outdoor)

Parameter	Average
Optimum value temperature	24.6 °C
Optimum value RH	75.25%

in every temperature setting indicated at temperature between 24.24 °C (24–25 °C) and RH of 45.75% (45–46%). As for the outdoor setting for Malaysian construction sectors, the findings indicated that the optimization of the HR and VO_{2max} for every temperature setting indicated at temperature between 24.6 °C (24–25 °C) and RH of 72.5% (72–73%). Thus the research findings are in line with the current setting of comfort under ICOP IAQ 2010, DOSH Malaysia.

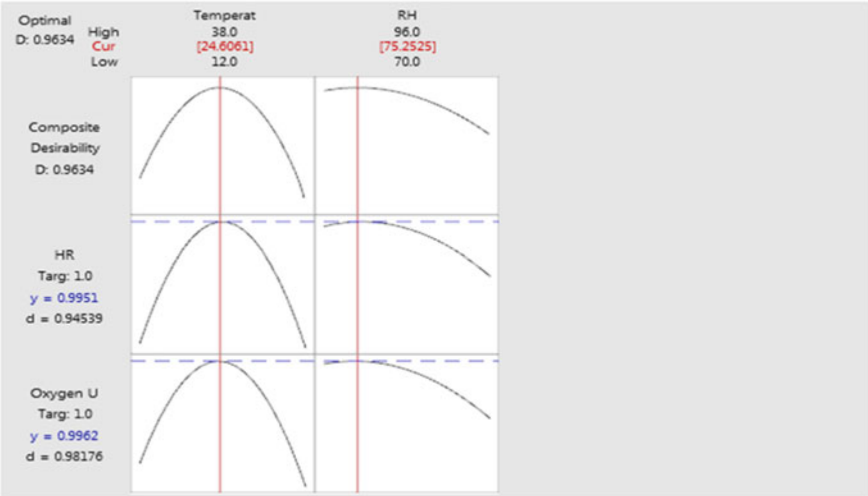

Fig. 2 Response optimization HR and oxygen uptake

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References

1. Xiang J, Bi P, Pisaniello D, Hansen A (2014) Health impacts of workplace heat exposure: an epidemiological review. Ind Health 52(2):91–101
2. Sett M, Sahu S (2014) Effects of occupational heat exposure on female brick workers in West Bengal, India. Glob Health Action 7(1):21923
3. Hajizadeh R, Golbabaei F, Dehghan SF, Beheshti MH, Jafari SM, Taheri F (2016) Validating the heat stress indices for using in heavy work activities in hot and dry climates. J Res Health Sci J 16(2):90–95
4. Ismail AR, Jusoh N, Mat Daud KA (2017) Thermal comfort. Penerbit Universiti Malaysia Kelantan, Kelantan
5. Sudarshan A, Somanathan E, Somanathan R, Tewari M (2015) The impact of temperature on productivity and labor supply—evidence from Indian manufacturing working papers, 244. Centre for Development Economics, Delhi School of Economics
6. Rowell LB, Marx HJ, Bruce RA et al (1966) Reductions in cardiac output, central blood volume, and stroke volume with thermal stress in normal men during exercise. J Clin Invest 45:1801–1816
7. Williams CG, Bredell GA, Wyndham CH et al (1962) J Appl Physiol 17:625–638
8. Bas D, Boyaci IH (2007) Modeling and optimization I: usability of response surface methodology. J Food Eng 78(3):836–845
9. Montgomery DC (1997) Response surface methods and other approaches to process optimization. Des Anal Exp 427–510
10. Yusof MYM, Deros BM, Ismail AR (2013) Effect of temperature, humidity and illuminance towards worker's performance in automotive industry. Sains Malaysiana 42(12):1815–1818

11. Desai KM, Survase SA, Saudagar PS, Lele SS, Singhal SR (2008) Comparison of artificial neural network (ANN) and response surface methodology (RSM) in fermentation media optimization: case study of fermentative production of scleroglucan. Biochem Eng J 41(3):266–273
12. Arslan-Alaton I, Tureli G, Olmez-Hanci T (2009) Treatment of azo dye production wastewaters using photo-fenton-like advanced oxidation processes: optimization by response surface methodology. J Photochem Photobiol 202(2–3):142–153
13. Pishgar-Komleh S, Keyhani A, Mostofi-Sarkari M, Jafari A (2012) Application of response surface methodology for optimization of picker-husker harvesting losses in corn seed. Iranica J Energy Environ 3(2):134–142
14. Ismail AR, Rani MRA, Md. Deros B, Makhbul ZKM, Mohd Yusof MY (2012) Response surface method in modelling the environmental factors toward workers' productivity. J Occup Saf Health 9:83–90
15. Belwal T, Dhyani P, Bhatt ID, Rawal RS, Pande V (2016) Optimization extraction conditions for improving phenolic content and antioxidant activity in Berberis asiatica fruits using response surface methodology (RSM). Food Chem 207:115–124
16. Zamani H, Moghiman M, Kianifar A (2015) Optimization of the parabolic mirror position in a solar cooker using the response surface method (RSM). Renew Energy 81:753–759
17. Ken P (2006) Heat stress standard ISO 7243 and its global application. Ind Health 44(3):368–379
18. Yaglou CP, Minard D (1957) Control of heat casualties at military training centers. Ind Health 16:302–316
19. Epstin Y, Moran DS (2006) Thermal comfort and the heat stress indices. Ind Health 44(3):388–398
20. Preisser AM, Zhou L, Garrido MV, Harth V (2016) Measured by the oxygen uptake in the field, the work of refuse collectors is particularly hard work: are the limit values for physical endurance workload too low? Int Arch Occup Environ Health 89(2):211–220
21. Papila N, Shyy W, Griffin LW, Dorney DJ (2001) Shape optimization of supersonic turbines using response surface and neural network methods. Am Inst Aeronaut Astronaut 18
22. Kadirgama K, Noor MM (2009) Prediction modelling of surface roughness for laser beam cutting on acrylic sheets. Adv Mater Res 1–8
23. Tsutsumi H, Tanabe S, Harigaya J, Iguchi Y, Nakamura G (2007) Effect of humidity on human comfort and productivity after step changes from warm and humid environment. Build Environ 42(12):4034–4042
24. Cui W, Cao G, Park JH, Ouyang Q, Zhu Y (2013) Influence of indoor air temperature on human thermal comfort, motivation and performance. Build Environ 68:114–122
25. Ismail AR, Haniff MHM, Deros BM, Makhtar NK, Makhbul ZKM, Modeling of environmental factors towards workers' productivity for automotive assembly line, CRC Press Taylor and Francis Group Publisher, pp 127–136, ISBN: 978-1-4398-3503-6
26. Ismail AR (2011) Pengenalan Keselesaan Terma. Penerbit Unversiti Malaysia Pahang, Pahang
27. Hamzah NA, Ismail AR, Che Hassan NH, Makhtar NK (2018) A study of hazard faced by Malaysian students at the school canteen. Int J Creative Future Heritage (TENIAT) 6(1):135–148. https://doi.org/10.47252/teniat.v6i1.179

Risk Factors of Musculoskeletal Disorder at Accident and Emergency Department at Malaysian Hospital

S. F. Abdull Wahab, R. Othman, and A. R. Ismail

Abstract Musculoskeletal disorder (MSD) is one of the rising health and safety issues at many industries including healthcare. The awareness on MSD can be seen by the rising numbers of studies conducted across areas of industries from construction to manufacturing. Load and postures are among risk factors that contribute to the MSD. This study is conducted with an objectives to determine whether loads and postures also contributed to the musculoskeletal disorder at accidents and emergency department of Malaysia Hospital. Ethical approval was obtained before conducting the study. Six tertiary hospitals were involved with respondents varied from nurses, medical assistants to medical officers. Questionnaire was used in the study and were distributed via post and collected during site visits at each of the participating hospitals. Data was analysed using Statistical Package for Social Sciences (SPSS) and structural equation modelling (SEM) was used to test the relationships between variables. Findings proved that P value for load is 0.04 and P value for posture is 0.00, indicating positive relationship between load and posture with risk of musculoskeletal at workplace. As a conclusion, load and postures both have a significant effect on the risk of work related musculoskeletal disorder among healthcare workers. Therefore,

S. F. A. Wahab (✉)
Department of Emergency Medicine, School of Medical Sciences, Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia
e-mail: drsfarid@usm.my

Hospital Universiti Sains Malaysia, 16150 Kubang Kerian, Kelantan, Malaysia

R. Othman
Mechanical Design Department, Kolej Kemahiran Tinggi MARA Pasir Mas, Lubok Jong, 17000 Pasir Mas, Kelantan, Malaysia

A. R. Ismail
Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, Campus Bachok, Bachok, Kelantan, Malaysia

Centre of Management Environment, Occupational Safety and Health (CMeOSH), Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia

R. Othman
e-mail: rohayu.othman@mara.gov.my

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corrective action must be done in order to reduce the risk of musculoskeletal among the healthcare worker.

Keywords Musculoskeletal disorder · Healthcare workers

1 Introduction

Accident and emergency department is one of the medical treatment department that deals with emergency and trauma medicine, where mostly acute patients come without making any appointment in advance. In Malaysia, it was previously known as Casualty Department. In the early years of services, this department was run by orthopaedic surgeons, general surgeons or generalists, such as senior medical officers. Nowadays, emergency physician take charge of the department. Apart from that the term Accident and Emergency Department or Accident and Trauma Department is used. The uniqueness of this department, it is highly stressful, with unpredictable situation every day and environment of critical care.

Patients arrived at the department twenty four hours a day and no appointment is needed. The types of patients arrived are triaged according to the severity of their illness. Green cases such as mild fever is seen within two hours, while yellow cases such as fractures is seen within 30 min. Cases triaged as red will be sees immediately. These include life threatening situation and critically ill patients such as patient with medical condition of cardiac arrest and poly traumas motor vehicle accident.

A lot activities such as patient lifting, patient transferring, procedures such as phlebotomy and resuscitation are done with awkward body postures [1]. These activities are common at any hospitals, especially at accidents and emergency department. The department is expected to fit for all types of users with multiple activities, thus emergency department is known as ergonomics worst nightmare [2].

Musculoskeletal disorder or MSDs, are conditions where soft tissue (muscles, tendons, ligaments, joints and cartilage) and nervous system experience injuries and discomfort. Work-related musculoskeletal disorders (WMSDs) are the nontraumatic soft tissue disorders that are caused and/or exacerbated by workplace exertions. MSDs are experienced by workers at many types of industries such as constructions [3].

A studies about risk of work-related musculoskeletal disorders among health care professional in a tertiary hospital India mentioned that WMSDs not only reduce the productivity and lower the quality of workers' life, it is also the most expensive form of work disability. WMSDs are an alarming problem that affects health care workers such as nurses and medical doctors [4]. In daily operation of hospitals, regardless of department, activities that involve manual handling such as patient transferring, patient lifting, repositioning of patients are seen in high frequency. Medical assistants and nurses involve directly in these activities. Patients that arrive in the accident and emergency department are pushed on the stretcher from ambulance to the red zone. Some patients, arrived on wheel chair. Patients are lifted and transferred from stretcher or wheel chair manually by group of medical assistants, nurses and sometimes medical officers. They work in groups since patients at times can be very heavy.

A study conducted in Latvia emphasized that healthcare workers are known to work in longer working hours, with forced on the same muscle group and awkward position [5]. Work related musculoskeletal disorders are perturbing issue with regards to safety and health. Developed countries and new emerging industrial country like China has massive study about this matter. This can be seen in numbers of researches done before in this area of study, that probably indicates the rise of awareness regarding this issue [6, 7]. Nurses are said to experience low back pain, as well as shoulder and neck injuries. The poor postures during working lead to discomfort, before worsen to become injuries and earlier study also found out that nurses involved a lot with non-neutral trunk position and upper arm postures when working [8].

This study was conducted at Accidents and Emergency Department of Malaysia Hospitals. All hospitals involved in the study was from tertiary categories, which means these hospitals are referral hospitals that offer consultancy on specific medical fraternity such as neuro surgery and advance care treatment. The objective of the study is to determine whether load and posture contribute to the risk of musculoskeletal disorder at these hospitals. It is the right of every healthcare workers to work in an environment that is safe and healthy.

2 Methodology

Questionnaire was used in this study and data was analysed suing SPSS and the relationship between independent and non-independent variables were tested using structural equation modelling (SEM). The questionnaire is developed to meet the objective of the study. The study involves multiple group of healthcare workers, which are medical doctors, nurses and medical assistances. Questionnaires are common method used in research related to musculoskeletal disorder [9–15].

Part A will consist of demographic questions such as age, gender, weight, height and occupations [4, 16]. Part B represents the dependent variable, which is work related musculoskeletal disorder (WMSD) among healthcare workers and independent variables, tested on the risk factors that contribute to the WMSD. Weight and size of objects will determine how the load contributes to musculoskeletal disorder (MSD) [17]. As for postures, characters of the work is used to describe the nature of the work [18]. Nature of work can be associate to unstable position of feet, forward bend of trunk, twist of trunk or unequal support between hands [19–23]. Environment of the workplace is also one of the factors that lead to MSD. However, the scope for this study is limited to load and posture only. The questionnaire is developed for bilingual languages in order to fit for all targeted respondents, from medical officers, nurses and medical assistants [24].

Face validity and content validity was conducted respectively. Questions with low factor loading was eliminated from the questionnaire. Exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were performed before the relationship between variables were tested using SEM. Quality of item is determined by KMO should be more than 0.25 and factor loading should be more than 0.5. However, a cut of value of 0.3 is commonly used in EFA [25] Item with factor loading 0.5 is considered as medium and do not necessary to be deleted [26].

3 Results

During EFA analysis, two important results have to be obtained, which are quality of items and factor overlapped. The items with values of factor loading from 0.4 and above are accepted for further analysis (Table 1).

The result obtained after CFA has been done. Comparing index value from the analysis, all value of fitness indexes achieved level of acceptance, as shown in Table 2. RMSEA value is 0.064 indicates the model has a good fit.

Table 3 shows the reliability of the measurement model. Cronbach's Alpha value for posture in 0.792, for load is 0.892, for MSD is 0.774. All values of Cronbach's Alpha is greater than 0.7. As for composite reliability (CR), all values of CR are

Table 1 Factor loading of item

Item	Factor loading
L7	0.842
L8	0.748
L9	0.702
L10	0.845
L11	0.639
P12	0.418
P14	0.612
P15	0.925
P16	0.751
P18	0.437

Table 2 The fitness Indexes for measurement model

Name of category	Name of index	Index value	Level of acceptance
Absolute fit	RMSEA	0.064	RMSEA < 0.08
Incremental fit	CFI	0.935	CFI > 0.90
Parsimonious fit	Chisq/df	2.462	Chisq/df < 3.0

Table 3 The reliability of the measurement model

	Cronbach's alpha	Construct reliability	Average variance extracted (AVE)
Load	0.892	0.921	0.699
MSD	0.774	0.848	0.531
Posture	0.792	0.858	0.549

Table 4 Discriminant validity

	Load	MSD	Posture
Load	0.836		
MSD	0.414	0.728	
Posture	0.549	0.442	0.741

above 0.6, ranging from 0.786 to 0.921. Another important criteria in determining model reliability is average variance extracted (AVE). The values of AVE should be greater than 0.5. As shown in Table 3, all values of AVE are above 0.5.

The discriminant validity index is a proved that the construct in the measurement model are discriminant of each other. This will be achieved, when the diagonal value is higher than the values in its row and column. Table 4 shown that the discriminant validity for all four constructs are achieved because the value fits the criteria mentioned above.

Figure 1 shows the relationship diagram among dependent and independent variables in the study. Table 5 shows that load and posture has positive and significant effect to MSD, where P is 0.04 for load and $P = 0.01$ for posture.

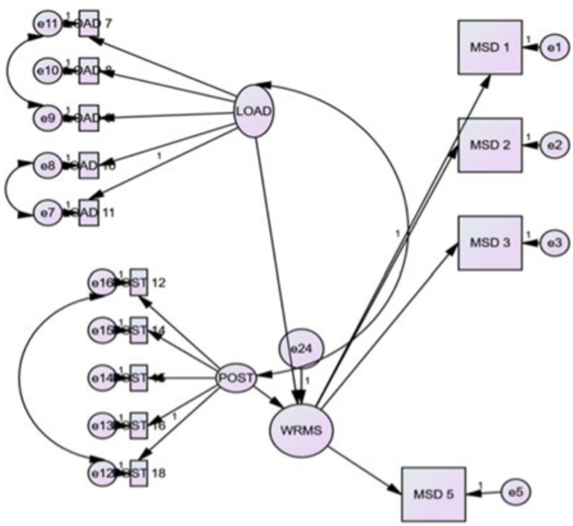

Fig. 1 Relationship diagram

Table 5 Regression weights

	Estimate	S.E.	C.R.	*P*
WRMS ⟵ LOAD	0.334	0.095	3.500	0.04
WRMS ⟵ POST	0.584	0.139	4.208	***

*** = 0.001

The finding the show the positive effect of load on work related musculoskeletal disorder is supported and agreed by previous researchers [27–30]. Similarly, significant relationship between posture as one of the risk factors that contribute to the work-related musculoskeletal disorder enhanced the results from others as well [30–32].

4 Conclusion

In order to reduce the risk of work-related musculoskeletal disorder order among healthcare personnel at accidents and emergency department, it can be start with the awareness program to make they realize the risk they are facing daily. The approach must be top to bottom. When they already have the awareness, continuous program and change of working postures and suitable practices in carrying daily tasks must be implemented.

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References

1. Pompeii LA, Lipscomb HJ, Schoenfisch AL, Dement JM (2009) Musculoskeletal injuries resulting from patient handling tasks among hospital workers. Am J Ind Med 52:571–578
2. Spear ME (2002) Ergonomics and human factors in health care settings. Ann Emerg Med 40(2):213–216
3. Jaffar N, Abdul-Tharim AH, Mohd-Kamar IF, Lop NS (2011) A literature review of ergonomics risk factors in construction industry. Procedia Eng 20:89–97
4. Yasobant S, Rajkumar P (2015) Health of the healthcare professionals: a risk assessment study on work-related musculoskeletal disorders in a tertiary hospital, Chennai, India. Int J Med Public Health 5(2):189
5. Roja Z, Kalkis H, Roja I (2015) Measuring muscle fatigue in relation to the workload of health care workers. Procedia Manuf 3:4189–4196
6. Smith DR, Wei N, Wang R-S (2005) Musculoskeletal disorders among Chinese medical students. Kurume Med J 52(4):139–146
7. Hiue HS, Hen CC, Hih TS, Ang CY, Ang YY (2008) Musculoskeletal disorder among 52,261 Chinese restaurant cooks cohort: result from the national health insurance data. J Occup Health 50:163–168

8. Pedrosa MC et al (2010) Minimizing occupational hazards in endoscopy: personal protective equipment, radiation safety, and ergonomics. Gastrointest Endosc 72(2):227–235
9. Bernal D, Campos-Serna J, Tobias A, Vargas-Prada S, Benavides FG, Serra C (2015) Work-related psychosocial risk factors and musculoskeletal disorders in hospital nurses and nursing aides: a systematic review and meta-analysis. Int J Nurs Stud 52(2):635–648
10. Jaworek M, Marek T, Karwowski W, Andrzejczak C, Genaidy AM (2010) Burnout syndrome as a mediator for the effect of work-related factors on musculoskeletal complaints among hospital nurses. Int J Ind Ergon 40(3):368–375
11. Smith DR, Mihashi M, Adachi Y, Koga H, Ishitake T (2006) A detailed analysis of musculoskeletal disorder risk factors among Japanese nurses. J Safety Res 37(2):195–200
12. Tziaferi SG, Sourtzi P, Kalokairinou A, Sgourou E, Koumoulas E, Velonakis E (2011) Risk assessment of physical hazards in Greek hospitals combining staff's perception, experts evaluation and objective measurements. Saf Health Work 2(3):260–272
13. Arsalani N, Fallahi-Khoshknab M, Josephson M, Lagerström M (2014) Musculoskeletal disorders and working conditions among Iranian nursing personnel. Int J Occup Saf Ergon 20(4):671–680
14. Forouzanfar MH et al (2015) Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: A systematic analysis for the Global Burden of Disease Study 2013. Lancet 386(10010):2287–2323
15. Moosavi S, Desai R, Hallaj S, Sundaram KK, Hegde VS (2015) Ergonomic analysis to study the intensity of MSDs among practicing Indian dentists. Procedia Manuf 3:5419–5426
16. Cole DC, Rivilis I (2004) Individual factors and musculoskeletal disorders: a framework for their consideration. J Electromyogr Kinesiol 14:121–127
17. Oakman J, Macdonald W, Wells Y (2014) Developing a comprehensive approach to risk management of musculoskeletal disorders in non-nursing health care sector employees. Appl Ergon 45(6):1634–1640
18. Finsen L, Christensen H, Bakke M (1998) Musculoskeletal disorders among dentists and variation in dental work. Appl Ergon 29(2):119–125
19. Bernal D, Campos-Serna J, Tobias A (2015) Work-related psychosocial risk factors and musculoskeletal disorders in hospital nurses and nursing aides: a systematic review and meta-analysis. Int J Nurs Stud 52(2):635–648
20. Gorner T, Simon M (2015) Using the theory of technical systems to describe the interaction between human and technical systems within the ergonomic system. Procedia Eng 100:592–601
21. Herin F, Paris C, Levant A, Vignaud M, Sobaszek A, Soulat J (2015) Links between nurses' organisational work environment and upper limb musculoskeletal symptoms: independently of effort—reward imbalance! The ORSOSA study. Pain 152(9):2006–2015
22. Sheikhzadeh A, Gore C, Zuckerman JD, Nordin M (2009) Perioperating nurses and technicians' perceptions of ergonomic risk factors in the surgical environment. Appl Ergon 40(5):833–839
23. Yeung SS, Genaidy A, Deddens J, Sauter S (2005) The relationship between protective and risk characteristics of acting and experienced workload, and musculoskeletal disorder cases among nurses. J Saf Res 36:85–95
24. McAtamney L, Corlett EN (1992) Ergonomic workplace assessment in a health care context. Ergonomics 35(9):965–978
25. Comrey AL, Lee HB (1992) A first course in factor analysis, 2nd edn. Psychology Press. http://doi.org/10.4324/9781315827506
26. Shevlin M, Milesb JNV (1998) Effects of sample size, model specification and factor loadings on the GFI in confirmatory factor analysis. Pers Individ Differ 25:85–90
27. Kim S, Barker LM, Jia B, Agnew MJ, Nussbaum MA (2009) Effects of two hospital bed design features on physical demands and usability during brake engagement and patient transportation: a repeated measures experimental study. Int J Nurs Stud 46(3):317–325
28. Ndetan HT, Rupert RL, Bae S, Singh KP (2009) Epidemiology of musculoskeletal injuries among students entering a chiropractic college. J Manipulative Physiol Ther 32(2):134–139

29. Menzel NN, Brooks SM, Bernard TE, Nelson A (2004) The physical workload of nursing personnel: association with musculoskeletal discomfort. Int J Nurs Stud 41:859–867
30. Kurowski A, Boyer J, Fulmer S, Gore R, Punnett L (2012) Changes in ergonomic exposures of nursing assistants after the introduction of a safe resident handling program in nursing homes. Int J Ind Ergon 42(6):525–532
31. Mph HTN, Ms RLR, Bae S, Singh KP (2009) Epidemiology of musculoskeletal injuries among students entering a chiropractic college. J Manipulative Physiol Ther 32(2):134–139
32. Tinubu BMS, Mbada CE, Oyeyemi AL, Fabunmi AA (2010) Work-related musculoskeletal disorders among nurses in Ibadan, South-west Nigeria: a cross-sectional survey. BMC Musculoskelet Disord 6–13