Defining Core Knowledge Elements of Adaptive Augmented Reality (A^2R) through Conceptual Model Analysis

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ABSTRACT

In this paper, a number of past studies on Adaptive Augmented Reality are scrutinized in order to define the core knowledge elements of adaptive concept. Through model analysis, where four past models were considered; components of such concept were gathered and proposed as a formal definition. Such components were included in a heritage tourism app running on mobile devices. Findings indicated that such core elements are indeed accepted as necessary in defining adaptive augmented reality concept. A Usability test was administered to all the respondents in order to record the app perceived effectiveness, efficiency, learnability, satisfaction and error. The overall score gets a high mean, where all five attributes gathered positive responses from users.

Keywords: knowledge element, augmented reality, adaptive, conceptual model.

I INTRODUCTION

The use of Augmented Reality (AR) technologies as a distinctive information dissemination environment is vindicated in the study by Osadchyi et. al. (2020). Such technologies have been employed for inspiring museums with an adapted visiting experience and digital content tailored to the historical and cultural context of the museums and heritage sites. Various interaction approaches, such as sensor-based, device-based, collaborative, or hybrid interaction, have also been engaged by these immersive reality technologies to enable interaction with the virtual environments. However, the utilization of these technologies and interaction approaches is not often supported by applicable guidelines that can assist AR apps developers and cultural heritage workers to predetermine their relevance to accomplish the intended objectives of the AR applications. Therefore, we review the current literatures and eventually define the core elements of A^2R.

II PAST STUDIES

A. Augmented Reality

AR provides an overlay of virtual content (text, audio, video, 3D object) on real world view (through a monitor, mobile phone, and head-mounted display) without replacing the real environment. (Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, 2001; Milgram, Takemura, Utsumi, & Kishino, 1994) Milgram identified AR as a sub-class of Mix reality in the Reality-Virtual Continuum. While Azuma et al. (2001) defined AR system with three characteristics: 1. real and virtual object merged in a real environment, 2. Interactive and real-time, 3. Alignment of the virtual and real object. By agreeing to Azuma; Hollerer and Feiner (2004) also define an AR system as “one that combines real and computer-generated information in a real environment, interactively and in real-time, and that aligns virtual objects with physical ones.” On the other hand, the definition is given by Dudzik (2018), AR is “an interactive, real-time direct or indirect view of a physical environment that has been enhanced by the superimposing of computer-generated sensory information, such as images, sounds, videos, and haptics.” These definitions have pointing AR to some similar key term such as, interactive, real-time, and integrating with virtual content to enhance the real environment.

In the early days, AR was bulky as a ‘see through’ Head Mounted Display (HMD) had to be attached to desktop computer or laptop to operate (Milgram et al., 1994). With the advancement in technology, the size of the AR devices became smaller and more mobile such as mobile phone and google glass. AR was introduced in military and aviation manufacturing long before it came available to the public user. Due to the advancement in mobile technology, AR has been applied in various fields such as marketing, education, medical, manufacturing, entertainment, tourism and others (Mekni & Lemieux, 2014). Museum and heritage is another field taking advantage of this edge cutting technology, for examples, “Svevo Tour” is an AR project to promote famous Italian novelist, Italo Svevo (Fenu & Pittarello, 2018). AR again taking a leap when “Adaptive” is encapsulated in this technology.

B. Adaptive Augmented Reality

Adaptive augmented reality (A^2R) is the latest concept of the augmented reality that responds and adapts to a real-time context and the characteristics of the user (Damala et al., 2012; Tenemaza, de Antonio, & Ramirez, 2015). AAR concept is said to provide adaptation of 3D augmented reality and better engagement to the users (Damala & Stojanovic, 2012). These could help, for instance, the museum visitors, to be more immersed in the exhibition or artifact based on their emotional experience.

There have been a few studies recently that relate to A^{2}R in various fields, including cultural heritage, disabilities, and elderly. The latest study of A^{2}R in helping people with mild intellectual disability in Ecuador (Tenemaza, De Antonio, Ramírez, Vela, & Rosero, 2016). The newly explored concept has been used to locate the patient when they are lost and help them return home. The app developed to benefit both the patient and the caretaker because it also acknowledges the caretaker when the patient is lost. This noble application is an expansion of the researcher's previous work (Tenemaza et al., 2015). In another study related to the elderly using the application of A^{2}R is in helping them living alone in doing a daily chore (Hervás, Bravo, Fontecha, & Villarreal, 2013).

This concept of A^{2}R is based on user, environment and platform. These three pillars can foster functional ability, ease of use and portability of new augmented reality applications. Damala et.al (2013) describe in their paper three applications showing the adaptation of augmentation based on three variables: the scene illumination, the distance to the target and the ambient noise. This research was aimed at enhancing information presented to visitors based on their psychological state. They employed within the context of the creation of an AR guide for a museum visit. The interest of the visitor is monitored using physiological sensors so that the multimedia content delivered to the visitor's see-through AR display with which he can interact through gesture interaction can be adapted according to his engagement and interests. Their work has been a major breakthrough for adaptive augmented reality as applied to the heritage field.

These studies without doubt have contributed to the A^{2}R field. However, a formal definition in the form of local user, context, interaction and environment models to assist the creation of such assisted technology has yet to be proposed (Tenemaza, de Antonio, & Ramirez, 2015). Looking at all the advancement and changes that are happening in the heritage field abroad, and noticing that in Malaysia there is still a major gap and lack of development in this area, it is time a study should be proposed to lessen this gap in the local context.

III A^{2}R CONCEPTUAL MODELS

A number of AR conceptual models and frameworks have been proposed, mainly related to a number of attributes which are enjoyable informal learning, adaptive multimodal interaction, immersive experiences, value creation, user experience and acceptance.

As discussed earlier, applications of AR have grown into various fields. Traditionally, AR was associated with domains of architecture, however now this has expanded to the field of heritage too. For instance, Pendit and Zaibon (2014) built a model as a guideline to develop a mobile AR application for experiencing non-formal enjoyable learning while visiting cultural heritage site. However, this model was not produced for adaptivity in mind. The model was proposed after reviewing an existing model and realized that the previous model do not include the element of enjoyable informal learning. So, they incorporated learning theories toward AR application components (such as media elements, activity, navigation, social interaction, games and presentation style) and mobile technology component to holistically visualize the concept of enjoyable informal learning in mobile augmented reality model.

Damala & Stojanovic (2012) in their article, built a theoretical framework where they provided together with an overview of a system architecture and coined the term A^{2}R. In another article, Damala and team targeted at the ways through which A^{2}R could be employed in museum and gallery settings as an interactive Multimedia explanation medium, guiding the museum visitors. A^{2}R provides visual and acoustic augmentations that complement the artefacts or site viewed by a heritage visitor. The crucial goal is to "make every heritage visit unique, by fitting a visit with contents that are inclined to increase the affective impact of the augmented museum visiting experience and hence encourage intrinsic and self-motivated learning" (Damala & Stojanovic, 2012).

A. A^{2}R Museum Visit Augmentation Model

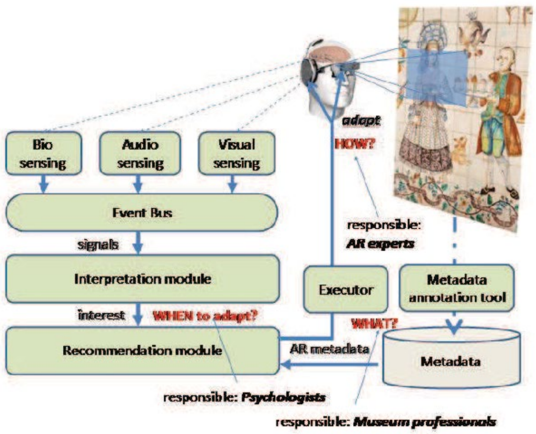

Figure 1. A2R Museum Augmentation Model by Damala & Stojanovic (2012)

A theoretical framework was developed together with an overview of the system architecture. The authors focused on the interdisciplinary, collaborative and content-informed methodology to identify the motivations and needs of the cultural heritage professionals as to the potential of the A^2R for the museum visit. Figure 1 could be considered among the earliest conceptual model for A2R.

B. Adaptive Multimodal Interaction in Mobile Augmented Reality Framework

The conceptual framework for Adaptive Multimodal Interfaces in Mobile Augmented Reality is a framework that provides a guideline to apply adaptive multimodal interaction in mobile AR (Abidin, Arshad, & Shukri, 2017). The framework has three main components: inputs modalities, multimodal adaptation module, and AR module; based on components of previous models related to adaptive interfaces, multimodal interfaces and augmented reality. From this model, the adaptation in the AR system could happen based on three input modalities: user input, Environmental changes, and mobile device changes. The input is processed in the adaptive module before the adaptive information sends to the AR controller module to proceed with the displays of relevance AR content on the AR camera view. The three components in this framework will be considered in the adaptive augmented reality conceptual model even though it lacks empirical evidence (Figure 2).

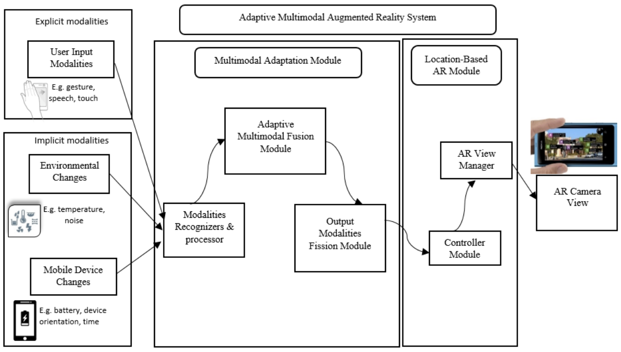

Figure 2. Conceptual framework for Adaptive Multimodal Interfaces in Mobile Augmented Reality

C. Adaptive Augmented Reality Model

Tenemaza, et al. (2015) proposed a detailed definition of the content of the User Model required for A^2R systems (Figure 3). They explored the state of the art ontologies for user modelling, and proposed a set of significant user characteristics to be modelled. They also presented an initial architectural model for such systems.

D. Context-awareness Adaptive AR Model

Hervás et al. (2013) suggested a model for supporting daily user needs using simple interactions with the environment through an augmented-reality perspective that applies proactive adaptation through knowledge representation using ontologies. The proposed architecture (i- ARA) model uses principles of context-awareness and user personalization (refer to Figure 4).

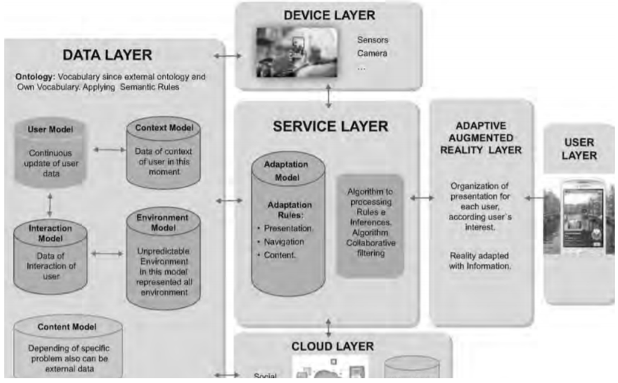

Figure 3. Conceptual framework for Adaptive Augmented Reality by Tenemaza, et al.(2015)

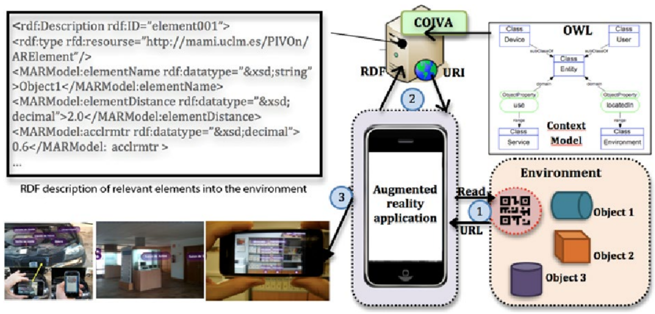

Figure 4. i- ARA Adaptive Augmented Reality (2013)

IV DEFINING A^2R CORE ELEMENTS

Four relevant past models (refer to Figure 1 to 4) were studied. The main aim is to put forward a concrete definition of A^2R for the purpose of this research.

It is clear that, in each of the AR models, user profile, media, interaction, environment data and device components are included as elements (refer to Table 1). In the proposed models described earlier, all of them include the User Profile and Environment elements as their adaptive augmented reality components. User's information (such as age, gender, height) and physiological state are retrieved to determine the characteristics of the users or their interest. The augmented content is usually based on the characteristics selected and related to the multimedia contents (images, videos, animations, text, audio comments, sounds, and 3D objects). The interaction can happen through gesture, speech, touch and gaze based on the device used to interact with the content. Most models take advantage of the sensors available on the device. For example, sensor devices are used to determine changes in user's interest through the audio, visual and biosensing data in ARtSENSE, so that relevant content will be displayed to the users (Damala & Stojanovic, 2012). While for mobile phone, information from sensor (camera, GPS, compass and etc.) were utilized to adapt useful information of interesting object, place or even person.

Table 1. Components comparative analysis.

CORE ELEMENTS / MODEL	EV medium, media, interaction, context (storytelling)	UP biodata e.g age, gender, height, etc	OC service, network, devices
A2R Museum Augmentation Model Damala & Stojanovic (2012)	-**Digital multimedia contents** -**Gaze and gesture-based interaction**	- **Bio sensing** - **Visual sensing** - **Audio sensing**	- **Sensors** from AR see-through glasses, Headset and microphone
Adaptive Multimodal Interaction in Mobile Augmented Reality Framework Abidin, Arshad, & Shukri (2017)	-**User input** gesture, speech, touch	**Adaptation module**	**Devices Sensors:** - Environment changes e.g: Temperature, noise, GPS - Mobile device changes e.g: battery, orientation, time
Adaptive Augmented Reality Model Tenemaza, et al. (2015)	- **Interaction model** - **Environment model** - **Content model**	- **User model** user profile, motion, objective task, knowledge / interest	**Devices Sensors:** Context model: this model will contain the information provided by device sensors. GPS, the encompass, the image recognizer, the touch screen, etc.
Context-awareness Adaptive AR Model Hervás et al. (2013)	- **Augmented Object** multimedia	- **User ontology** user profile	**Devices Sensors:** compass, accelerometer

In all models presented in Table 1, it is clear that **environment (EV)** and **user personalization (UP)** are the core components in adaptive apps.

EV ties to changes in context of contents being displayed; such as the visual, audio and interaction elements. UP deals mostly with the user model; sensing users' bio to adapt to EV and scenarios that have been planned. Age, gender, height are instances of bio where adaptivity could be applied. Other components (OC) depend on service or device layers. If the augmented app is targeted for mobile device, then perhaps cloud network model should be included.

We hereby proposed that the core elements of:

$A^2R = \{EV, UP, OC\}$

where

EV = {medium, media, interaction, context}

UP = {bio data such as age, gender, height, etc.}

OC = {service, networked, devices}

& whenever sensors are available, the *UP* adaptive component makes use of such sensors.

& context in *EV* refers to how creative the storytelling is applied.

A. Applying Core Elements in a Tourism Apps Prototype Development

A major difference between native mobile application and augmented reality, according to interaction design foundation, is its physical environment where digital elements to appear over real and allow interaction between user and the artefacts. AR used to direct people's attention through AR features and interactivity. Fundamentally, AR is a computer technology that uses cameras to capture and display real-world environments, objects, or images, and juxtaposes digital information onto reality in real-time. The latest technology trend that emerged is the augmented reality assisted tourism application. Consumer behavior is shifting, and technologies are undeniable revolutionized and enhance the tourist experience at visited places where valuable and additional knowledge obtained easily through AR apps. AR apps alter and enhance people's perceptions of their physical surrounding when seen through a particular device.

The user model approach uses specific algorithm that collect real time user data for user recognition method. Here, the height measurement was used as the adaptive criteria to differentiate kids and adults. The estimated adult height for this study refers to a study conducted by Ipsos (2019) suggesting that the ideal height for Malaysians men is between 178cm to 185cm, while ideal height for women was 155cm to 163cm. Researchers take into account the range between the height of males and females is estimated at 159cm to 181cm. Children in this study were defined as individual ages under 12 years old. From the past studies, kids' heights are set to below 4.75 feets (Bong, et al., 2012).

For this purpose, users are required to locate the ground or floor surface using AR camera and the apps will measure user height at the background. The A^2R app system will then measure user height from floor surface to mobile device Y height using device sensor and proposes personalize experience divided into two categories, kids and adults.

The storytelling method is best suit to deliver

Information and to shape new narrative experiences characterized by the use of rich media. This type of interaction model is expected to transform visitor experience, communicates messages and improve user engagement via A^2R tour. A good story helps the visitor to interpret an artwork in the context of the life of the artist or the social and political context in which the artwork was created. In the study described here, two different narrative paths are shown depending on the height and age of the users.

To develop a prototype consisting of all the core elements described (refer to Fig 5), the Mobile apps

Development Lifecycles by Sharp, Rogers & Preece (2011) was adopted. To ensure an effective mobile AR application development, careful planning was overseen. A functional prototype makes it easy for the user to understand the functionality and features of the application being developed.

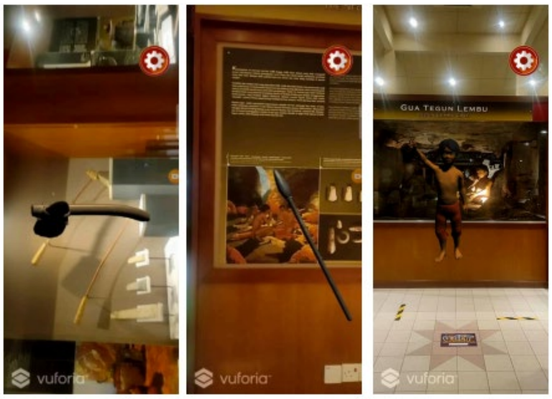

Figure 5. Museum visit A²R prototype

In total, 21 respondents participated in this study where 8 are females and 13 males. 71.4% of the respondents are in the 19 – 24 years old group. Students made up 76.2%, employed users are 9.5%, and young kids are 14.3%. Data show that all of the respondents are using android devices.

A Usability test was administered to all the respondents in order to record the app perceived effectiveness, efficiency, learnability, satisfaction and error (Table 2).

Table 2. Findings on Perceived effectiveness, efficiency, learnability, satisfaction and errors.

No	Items	Min
A. Effectiveness		
1	I am satisfied with the arrangement of the features and the layout of the screen.	4.33
2	I can easily rotate the device in portrait or landscape orientation while using this app.	4.38
3	The navigation is clear and easy to follow.	4.48
B. Efficiency		
4	This app is able to load the 3D images of the artifacts quickly.	4.10
5	It takes only a while for the mobile sensor to surface detect any object.	4.33
6	The menu buttons are user friendly in size.	4.52
7	The instructions are concise and able to direct users to the intended use or function.	4.33
C. Learnability		
8	The screen features are not flattered and spaced out efficiently.	4.29
9	The features are comprehensive with clear graphics, videos, audios and 3D elements.	4.52
10	The storytelling is relevant with pre-history facts.	5.00
D. Satisfaction		
11	This app is suitable for users as an alternative way to exploring the rich heritage using advance technology.	4.57
12	This app allows the users to actively interact with the artifacts in different ways.	4.38
E. Error		
13	This app performs favourably on my mobile device.	4.52
14	The time taken to carry out certain functions is optimised if no error message detected.	4.33

From the results in Fig 6, the overall score gets a high mean of above 4 (score 5 is max). All five attributes gathered positive responses from the users. Users are satisfied with the arrangement of the features and the layout of the app screen. By using minimal interface design makes the navigation clear and easy to follow. Efficiency attribute is high noting that the time taken to display info on artefacts and record mobile censor data, execute menu button and instruction are fast. Respondents also agree that the learnability attribute, clear screen optimization and the storytelling are engaging. All the features relevant with the prehistory facts and are comprehensive with clear graphics, videos, audios and 3D elements. The attractiveness attributes measure the apps suitability as an alternative way to exploring the rich heritage using advance technology. The app allows the users to actively interact with the artifacts in different ways. Respondents also agree that the app is compatible with their smartphones devices, which allow them to carry out certain functions if no error message is detected.

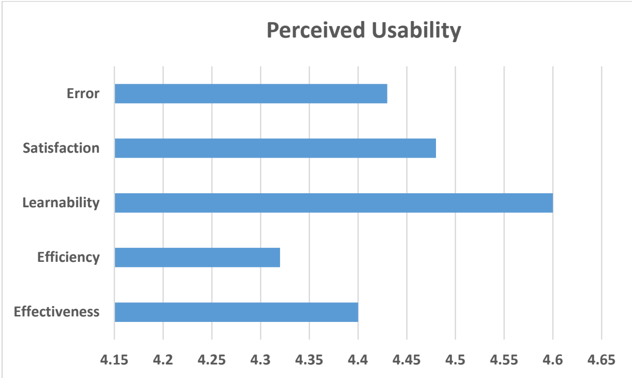

Figure 6. Average data for all variables

V CONCLUSION

A²R is a technology that can support users in their daily life with useful information for their activities which is really adapted to the user's characteristics, to the environment where the activity is taking place, and to the current context. Cultural Heritage are among of the context to benefit from this technology. A²R is able to enhance the visitors experience by providing useful information based on visitors' profile during their visits to the museum. The best example is depicted in the ARtSENSE project (Damala et al., 2012), where the main objective of the study was to enhance visiting experience by providing augmented contents based on their interest. Another success examples of AR application in heritage domain is "Svevo Tour" as the elderly visitors are emotionally engaged with the contents (Fenu & Pittarello, 2018). This article is aimed at summarizing and defining the core components of A²R. Through model analysis, components of such concept were gathered and proposed as a formal definition. In conclusion, any adaptive augmented reality application should include an adaptation module where user personalization plays an essential role in showcasing the adaptive element.

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