Design Principles of Augmented Reality Focusing on the Ageing Population

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Augmented Reality (AR) is growing rapidly and becoming a mature and robust technology, which combines virtual information with the real environment and real-time performance. It is important to ensure the acceptance and success of augmented reality systems. With the growth of elderly users, evidence shows potential trends for AR systems to support the elderly, including transport, ageing in place, entertainment and training. However, there is a lack of research to provide the theoretical framework or AR design principles to support designers when developing suitable AR applications for specific populations (e.g. older people). In my PhD thesis, I will focus on the possibility of developing and applying AR design principles to support the design of applications that address older people’s requirements. In this paper, I first discuss the architecture of augmented reality and identify the relationship between different elements. Secondly, the relevant literature has been reviewed in terms of design challenges of AR and design principles. Thirdly, I formulate the five initial design principles as the fundamental work of my PhD. It is expected that design principles could help AR designers to explore quality design alternatives, which could potentially benefit the ageing population. Fourthly, I identify the AR pillbox as an example to explain how design principles can be applied to AR applications. In terms of the methodology, preparation, refinement and validation are the three main stages to achieve the research goal. Preparation stage aims to generate the preliminary AR design principles and identify the relevant scenarios that might assist the designers to understand the principles and explore the design alternatives. In the stages of refinement, a half-day workshop has been conducted to explore different design issues based on different scenarios and refine the preliminary design principles. After that, a new set of design principles will be formulated. The final stage is to validate the effectiveness of new design principles based on the previous workshop’s feedback.

Augmented Reality, Design Principles, Ageing population

1. INTRODUCTION

Augmented Reality (AR) as a technological enabler is becoming very popular in different fields such as education, design, navigation and medicine. It combines virtual information with the real environment (Liarokapis and De Freitas 2010) and enhances the user’s perception such as vision, hearing, touch and smell with the combination of real world. Due to the development of mobile devices, AR is growing rapidly and becoming more mature and robust on this platform. To ensure the acceptance and success of future AR systems, it is vital to identify suitable AR design guidelines or principles. AR research priorities have shifted towards the design of effective and easy-to-use applications (Bai and Blackwell 2012). With the growth of elderly mobile users, increasing trends in using AR system among older people have been observed (Malik, et al. 2013). It is important to design suitable augmented reality applications to bring benefits for older people. However, attempts to investigate how to develop appropriate AR applications have been fairly limited especially those with any focus upon the ageing population. There are several reasons for this. First of all, designing AR applications for elderly presents some intrinsic challenges because AR is still technically immature in some respects, for example registration and tracking problems exist (Kalalahti 2015). On the other hand, technology-driven AR has caused the development of AR applications disconnected from the users and usage contexts. Thus, user requirements, usability and design criteria have not been considered enough. In this paper, I firstly present the architecture of augmented reality system as the foundation of the
ongoing research project. It aims at AR and identifies the relationship between different AR elements. Then, I review existing design challenges and design principles of AR. A set of preliminary design principles of AR have been identified by selecting and classifying the existing literature. The AR "pillbox scenario" is used as an example to illustrate how preliminary AR design principles can be applied analytically.

2. RESEARCH QUESTIONS, GOALS AND CONTRIBUTION

The research question for this proposal is: Is it possible to establish a set of principles for AR design for ageing population? The general aim of this research is to establish a set of design principles to support AR designers to explore the quality of design alternatives which could potentially benefit ageing population. There are five research goals identified in the proposal:

(i) To understand the meaning of augmented reality and identify a set of preliminary design principles.
(ii) To identify existing AR designs that have the potential to address some of the ageing population’s requirements.
(iii) To produce different representative scenarios based on the existing AR design for elderly.
(iv) To refine a new set of design principles via exploring the design issues based on different representative scenarios.
(v) To validate the effectiveness of the new AR design principles.

By achieving these research goals, I expect to make three main contributions which will benefit AR designers to explore the quality of design alternatives for ageing population and general HCI.

(i) Identifying the generic AR elements and preliminary design principles for AR.
(ii) Creating a set of AR design alternatives which could potential benefit elderly.
(iii) Establishing the AR design principles for older people.

3. ELEMENTS OF AUGMENTED REALITY SYSTEM

AR is growing rapidly and supports people in different fields (Papagiannakis, Singh and Magnenat-Thalmann 2008). As a result, opportunities for designers and researchers to design and create new AR systems are emerging. Before discussing the challenges and principles of designing an AR system, this research has to identify what constitutes AR system and the basic definition.

In my previous work (Liang 2015), I discussed eight core elements of augmented reality including user, interaction, device, server, virtual content, real content, physical world and transmission. Since, it has become apparent that this initial definition was ambiguous for the wide range of possible AR scenarios. In this section, I will introduce eight elements including user, interaction, device, server, virtual content, real content, physical world and transmission in order to create the boundary of AR and ascertain the options available in the use of AR for particular activities. Each of these elements is briefly described below:

- User. The individual manipulates and controls an AR system and who is the immediate intended beneficiary of an AR system.
- Interaction. One entity does something and the other entity responds via different ways: users and AR device interact; users and virtual content interact; users and physical world interact.
- Device. The hardware component includes sensors, processors and display with alignment of the physical world, the real content and the physical location of the user.
- Server. A source of data and processing is not located on the device.
- Virtual content. The additionally computer-generated information presents to the user by the AR device. Commonly this is visual and audio content, the modality of virtual content could be 3D objects, 2D images or text, visual elements that vary with time (like animation, video, etc.), and sound.
- Real content. The presented data takes directly from the physical-world context of use.
- Physical world. The material world includes geographic location, physical objects and real-world environment.
- Transmission. A series of processes for generating virtual content base on the physical world (e.g. registration, responsiveness).

The range of systems that could be considered as augmented reality becomes clearer based on the above elements. The AR system architecture (see Figure 1) depicts the interrelationships between the different elements. In summary, for the purposes of this research project, AR is defined as an array of processes to present virtual content deriving information from the physical-world context and to enrich the interaction between users, virtual
content, device and physical world. From a design perspective, the most critical issue is to select an appropriate physical-world context, identifying the mechanism of transmission and creating different modalities of virtual content in an AR system. AR users will not concern too much on devices, but will be attracted by different virtual content. Odom and Pierce (2009) state that digital users often express strong curiosity to what the virtual content could provide but rarely, if ever, affection to the device itself. This AR architecture (Figure 1) is the reflection and abstraction from existing AR experiences and characteristics. Additionally, this AR architecture provides a more explicit basis on which to articulate AR elements, design challenges and the intended design principles of AR systems.

**Figure 1: Generic Augmented Reality system architecture**

**4. DESIGN CHALLENGES AND EXISTING PRINCIPLES OF AUGMENTED REALITY**

**4.1 Design Challenges of AR system**

Having described the elements of AR system, the designers’ task is to develop AR applications and figure out these elements together (Bressler and Bodzin 2013, Kaufmann and Schmalstieg 2003, Woodward, et al. 2004, Cieutat, Hugues and Ghouaiel 2012). However, ”very few guidelines, design techniques and evaluation methods have been presented in the existing literature” (Huang, Alem and Livingston 2012). For example, Kourouthanassiss et al. (2013) stated a new challenge for AR designers "how can we associate, organize, and present information into a dynamically changing real world in a way that protects users from cognitive overloads resulting from the massive amount of available information?" These challenges motivate and justify the subsequent research with a specific focus upon design principles of AR systems.

Some of existing papers discuss different suggestions for capturing and sharing design or evaluation knowledge for AR in different formats, such as design approach (Friedman and Kahn Jr 2000), design guidelines (Shi, et al. 2015, Billinghurst, Grasset and Seichter 2009, Santos, et al. 2015, Chastine, et al. 2007, Nilsen 2006, Ortman and Swedlund 2012), design patterns (Schmitz, Specht and Klemke 2012, MacWilliams, et al. 2004, Xu, et al. 2011) and usability principles (Kalalahti 2015, Ko, Chang and Ji 2013). All these suggestions provide the design knowledge for designers. However, design principles are different from other formats because principles are the high-level and more generative concepts. Design principles in this paper are not intended to replace existing design guidelines or patterns but rather complement them. Design principles could derive from psychology or technology itself. The level of abstraction has been summarised by different people at different times in different areas, which is rather confusing, inconsistent and contradicting.

There are two representative papers directly discussing about the design principles for augmented reality (Dünser, et al. 2007, Kourouthanassiss, Boletsis and Lekakos 2013).

**4.2 Two existing papers for Design Principles of AR systems**

**Table 1: Existing literatures of reviewing AR design principles**

<table>
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<th>Authors</th>
<th>Design Principles of AR</th>
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| Dünser et al. (2007) | - Affordance  
- Reducing cognitive overhead  
- Low physical effort  
- Learnability  
- User satisfaction  
- Flexibility in Use  
- Responsiveness and feedback  
- Error tolerance |
| Kourouthanassiss et al. (2013) | - Use the context for providing content  
- Deliver relevant to-the-task content  
- Inform about content privacy  
- Provide feedback about the infrastructure’s behaviour  
- Support procedural and semantic memory |

Dünser et al. (2007) investigated general HCI principles related to AR application design. They found that AR-related studies have been primarily technology driven and focused excessively on hardware and software issues. They suggest that, to develop successful AR systems researchers need to consider both user-centred design principles as well as technical issues. They analysed a number of HCI design principles and guidelines and chose appropriate design principles for AR systems based on their findings. They then
validated their studies by providing existing studies and applications that explain the relationship between the design principles and properties of AR systems.

Kourouthanassis et al. (2013) reported five different design principles in an abstract manner in order to guide the design of AR applications. They provided a formal definition for each principle and explained how these principles address the AR interaction design challenges. Additionally, they included a selective set of design examples for each principle which illustrate indicative applications of the principles in practice.

Design principles will be hard to offer direct solutions to a specific problem but they are the tools to guarantee the quality of the design. For the purpose of this research, the design principles for AR system now can be defined as the basic rules to convey the design knowledge and skills that offer the designers to create design alternatives.

4.3 Preliminary Design Principles of AR system

After selecting and classifying the previous research, some of the preliminary design principles have been identified to support the AR designers with different design concepts to generate virtual contents based on the definition of design principles in this research.

They are changeability, synchronicity, partial one to one, antecedent and hidden reality. Changeability means the virtual information can be generated changeably. Taking the Tesco finder’s AR application design as an example, additional information like opening times website or video replaces the previous virtual bubble. Designing with the content of virtual information has to be changed easily and completely. Therefore, different modality of the content can be presented properly. The definition of synchronicity is that changing the real content or clicking the virtual content should trigger the synchronous transmission on the following virtual counterpart. For example, Word lens (2012) scans foreign text and displays the text translated in real time. As the user changes his or her point of view to another word, the displayed translation on the device should be designed and presented rapidly at the same time. If the process of generating virtual information is delayed for a long time, viewers are unable to perceive the meaningful virtual information. The concept of Partial one to one describes another design concept of generating virtual content. There is one and only one real content to correspond with the virtual content. However, there might be one or more than one piece of virtual information to correspond with the real-world content. Word lens (2012) translator could display a translated word ‘¡Hola!’ in Spanish when the AR device scanned the real word ‘Hello!’ in English. The meaning of one-to-one relationship is that the virtual content ‘¡Hola!’ should only overlay the real content ‘Hello!’ and it is meaningless to superimpose on any other physical word. However, the AR translator could also be designed to render the English word ‘Hello!’ into different foreign language overlaid on one piece of real content, such as ‘¡Hola!’ in Chinese, ‘Bonjour!’ in French and etc. Antecedent means that the real content (physical text) exists or happens before the virtual content (the translated digital word). If the virtual content is created before the real-world content, the virtual content is meaningless because it has no real world interpretation. Hidden Reality means designing the virtual information will often result in the obstruction of real-world information. While users look through the AR device, the real content will be more or less hidden. Word lens (2012) AR translator generates the virtually translated words, which replace the real-world words. Users have to remove the AR device if they need to see the original words. They cannot see both the virtual and real content simultaneously. These preliminary design principles are very rough without any refinement and validation. They are potentially contradictory in some cases, for example the design trade-off between hidden reality and partial one to one. Such wide virtual content could become progressively disruptive and the more richly the designer tries to create the virtual content, the more real content will be hidden. It is also a matter of debate if such design principles are transferable to research regarding to particular group of people (e.g. ageing population).

4.4 Applying preliminary design principles for the AR design for older people - Pillbox Scenario

One representative scenario in the domain of AR for ageing has been selected to demonstrate how the design principles support the AR design. Lera et al. (2014) developed AR pillbox system overlaying the virtual graphics to the real pillbox captured by the camera in robotic platform. The system recognised the QR code stuck to the real image and synchronously generated the virtual arrow. Users will know what the next dose they should take (see Figure 2).

Nowadays, physical pillbox has a clear time indicator which presented ‘morning’, 'afternoon' and 'evening' and Monday to Sunday information (see Figure 3). That means people will not need to use the AR pillbox to know what time they need to take the next pill and the virtual content of the AR pillbox seems to be useless. However the AR design applying design principles (in section 4.3) may provide designers with different design alternatives.
to generate virtual content for medication reminders. For example, based on the partial-one-to-one concepts, the wide variety of additional information could be emerged in this scenario by different modality (text, image, 3D, audio or vibration).

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<th>Phases</th>
<th>Activities</th>
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<td>Preparation</td>
<td>Complete the preliminary design</td>
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5. METHODOLOGY

The methodological plan of this research will be based on three phases: preparation, refinement and validation.

5.1 Preparation

The preparation stage in Table 2 aims to complete the preliminary design principles (v1.0) and produce a set of design scenarios to explore the issues of existing AR application for elderly. I will put the initial five design principles into the different scenarios to illustrate and demonstrate for the designers. Scenarios enable rapid communication about usage possibilities and concerns among different designers (Rosson and Carroll 2009). Concrete examples (like scenarios) need to be interpreted and produced because people remember a prototypical example far better than they remember the abstract category to which it belongs (Rosch et al. 1976, Medin and Schaffer 1978). At that time, AR designers and experts of researching ageing population will be recruited.

5.2 Refinement

Ko et al. (Ko, Chang and Ji 2013) developed and evaluated the design principle to support AR using experts’ workshops. The aim of Ko et al.’s is to screen the preliminary principles effectively and validate the effectiveness of using these principles. In order to explore the possibility of establishing the design principles for elderly people in this research, workshops are effective technique that could collect a group of people to produce ideas together and bring benefits for them to discuss, share and shape these ideas.

In the refinement stage, the first workshop will be conducted. After that, I will analysis the feedback of first workshop, review the observation and formulate the design principles (v2.0). A new set of design scenarios (v2.0) will be produced as well. Prior to the second workshop, the second
workshop’s participants including AR designers and older people will be recruited.

5.3 Validation

In the validation stage, I will observe the effect of design principles (v2.0) and the significant relationship between design principles and the quality of AR design alternatives for elderly. After the second workshop, v3.0 design principles will be formulated. I also add another period for contingency. Some of the participants might delay the timescale to collect their data that might be ill or enjoy their holiday. If the number of participants is still inefficient, another workshop or interviews need to be organised if it is needed. When I meet some difficulties for developing the design principles or producing the design scenarios, I might need more time to deal with that.

6. CONCLUSION

This paper presented the augmented reality architecture comprised by eight elements including user, interaction, device, virtual content, real content, transmission, server and physical world by using the different examples to challenge the boundary of AR. This is also the approach to articulate the AR requirements and narrow down the definition. The review of AR principles discussed by different authors and I am currently developing the five principles for AR design. Then, I illustrate how these principles could be applied for specific area (AR pillbox). In the next stage, I would like to conduct a series of design workshops, firstly with AR designers and experts to explore different design issues and refine the design principles. Secondly, I will validate the new version of design principles and continue to formulate them.

7. ACKNOWLEDGEMENTS

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8. REFERENCES


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