

Augmented Reality User Interface: Analysing the Design Principles and Evaluation Methods of Augmented Reality (AR) User Interfaces to Enhance User Interaction and Experience

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ABSTRACT

This article investigates user interface design and evaluation methods for augmented reality (AR) systems and analyses existing problems. The article begins with an overview of AR technology, and then explores the principles of traditional interface design and the guiding principles of AR user interface design and their limitations. Then, user experience evaluation and AR user interface evaluation methods are outlined. Through literature search and screening, the article finds that there is a lack of universal standard AR design and evaluation guidelines. The article also discusses the relationship between traditional interface design and evaluation principles and AR interface design and evaluation principles, and points out that more in-depth research and exploration of new evaluation methods are needed in the future to further expand the library of evaluation tools for specific AR studies.

KEYWORDS

Augmented Reality; User Interface Design; User Experience Evaluation

1. INTRODUCTION

1.1. Research Background

Augmented reality (AR) technology has a long history of research. Starting with the first early prototypes more than four decades ago [1], augmented reality evolved into a full-fledged research field in the 1990s and attracted the interest of the larger academic community [2]. Augmented reality is becoming more and more common today. As a result, there is a need for UX (user experience) designers and developers to provide more sophisticated and user-friendly designs. As this is a relatively new area of design, there is no common standard set of design guidelines for designers of augmented reality user interfaces [3]. And the number of formally evaluated augmented reality systems is quite small [2].

1.2. Research Purpose

The aim of this paper is to investigate the methods of user interface design and evaluation for Augmented Reality systems and to analyse their existing problems so as to provide researchers with a resource to help them plan and design their evaluations. In this chapter, an overview of Augmented Reality (AR) technology is provided, followed by an overview of traditional interface design principles and an analysis of AR user interface design guidelines and their limitations, as well as an overview and analysis of user experience evaluation and AR user interface evaluation methodologies,

and finally the article provides an outlook on future directions for AR user interface design and evaluation guidelines.

2. LITERATURE REVIEW

2.1. Overview of Augmented Reality (AR) Technology

The overlay of computer vision on the real world is known as Augmented Reality (AR) [4]. AR achieves a perfect combination of reality and the virtual, providing an interactive experience in real time; its virtual content is accurately rendered in 3D [5].

2.2. AR User Interface Design Principles

Bloksa presents a list of design guidelines that can be used for AR user interfaces [3]. Based on the key elements covered in the AR use case scenarios, the guidelines in the guideline cover five key aspects: 1. Presentation 2. Control 3. Showing instructions 4. Navigation 5. Notifications However, these guidelines are based on the condition of being used as generally as possible, and therefore do not correspond to certain specific use cases [3].

Shukri et al. proposed user interface design guidelines for mobile AR tourism applications based on the variables affecting the design of mobile AR tourism systems [6]. Oluwadunsin Dabor et al. proposed user interface design guidelines for augmented reality applications used in simultaneous interpretation based on Cognitive load theory (CLT) [6]. However, the above series of design guidelines lack the corresponding evaluation of usability testing and other related techniques [6].

2.3. Overview of User Experience Evaluation and AR User Interface Evaluation Methods

User experience evaluation methods are abundant. Among them is usability evaluation, a method for identifying specific problems with product usability. Its methods include heuristic evaluations, cognitive walkthroughs, cognitive task analyses, think aloud method and usability surveys [7]. In usability testing, the efficiency and effectiveness of a product is usually examined rather than the user's feelings [8]. In order to understand and evaluate the user experience, it is essential to collect data from users. Most methods usually rely on observation, psychophysiological measurements and questionnaires or surveys [8].

Emerging interface domains such as Virtual Reality (VR) or AR cannot fully rely on traditional user interface design and evaluation guidelines, however, traditional usability evaluation methods may be able to identify some problems with new interfaces [2]. Research has shown that some of these heuristics, such as "natural engagement" and "compatibility with user tasks and domains" can be applied to slightly adapted AR systems [2].

Most AR user evaluations can be divided into the following four categories: 1. experiments examining human perception and cognition. 2. experiments examining user performance on tasks. 3. experiments examining collaboration between users. 4. system usability, system design evaluations [2]. Methods commonly used in AR user evaluations can be broadly differentiated between quantitative methods, qualitative methods, non-user based usability evaluation methods and informal methods [2].

3. AR USER INTERFACE DESIGN PRINCIPLES

3.1. AR Technology Fundamentals

Augmented Reality (AR) aims to merge the digital world with the physical world and is a technology that enables the overlaying and augmentation of the real world through computer vision techniques [4]. Augmented Reality (AR) can be considered as a variant of Virtual Reality (VR) [5]. VR technology allows users to be completely immersed in a synthetic environment to the extent that they are unable to perceive the real world around them. However, unlike VR, AR technology allows users to see the real world while superimposing or blending virtual objects into the real world. Thus, AR is not meant to completely replace reality, but rather serve as a supplement and enhancement to it.

Augmented Reality (AR) enables virtual content to be integrated into real environments in real time, allowing users to instantly and seamlessly perceive these virtual elements which are as closely aligned to the real environment as possible in terms of features, appearance and behaviour [5].

Augmented Reality (AR) therefore enhances the user's perceptual experience of the real environment, including the incorporation of virtual elements that allow the user to connect with the digital environment in a more natural way [9]. The core objective is not to remove the user from the real environment, but rather to enrich the user's real-world experience with the addition of 3D virtual objects, allowing the user to feel as if they are in a more multidimensional and three-dimensional environment [9]. As the word "augmentation" suggests, it is an addition to or enhancement of the original, not a complete replacement.

AR systems have three distinctive features: firstly, they realise the perfect combination of reality and virtual reality; secondly, they provide real-time interactive experiences; and lastly, their virtual content is accurately rendered in 3D [5]. For AR users, the real environment and the virtual objects within it form a coherent and unified whole. In addition, the virtual content supports real-time interaction, enabling users to more naturally integrate into the augmented reality [5].

Augmented reality systems consist of three basic phases: recognition, tracking and blending [9]. In the recognition phase, the system is able to accurately identify the picture, person or place and determine where the virtual object should be projected [9]. Once in the tracking phase, the system accurately locates the picture, object, person or environment and subsequently superimposes information in the form of video, 3D, 2D, text and other forms accurately on the appropriate location [9]. The blending phase, on the other hand, relies on sensor augmented reality technology, which continuously captures the target item through computer images using an overlay of external markers as a datum [9]. Sensors in the device process these images to predict the position, orientation and movement of the visualisation relative to the target item, resulting in a perfect blend of virtual and reality [9].

3.2. User Interface Design Principles

Interface design acts as a bridge, connecting the user to the learning content through design principles and elements. Norfadilah Kamaruddin and Shahrudin Sulaiman delved into the theory of interface design and summarised five core principles based on the frequency of their occurrence [10]: 1) Consistency: Ensure that text, colours, graphics, animations and navigation are unified in the overall design to provide a coherent user experience. 2) Hierarchy: Organise interface elements according to the importance of the content and build a hierarchical structure to enhance browsing efficiency and comprehension. 3) Contrast: Use contrast in colour, text and graphics to improve content clarity and readability. 4) Balance: Maintain balance in text and graphic layout to reduce visual confusion and cognitive load. 5) Harmony: Create a pleasing aesthetic environment, enhance the aesthetics of the interface, and facilitate the communication of learning functions and operational guidelines.

Usability is a key metric for evaluating the strengths and weaknesses of an application's user interface and interaction design [11]. It is mainly measured by the quality of the learner's experience when interacting with the application interface [11]. High usability means lower learning costs for the user and fewer errors when interacting with the system, which improves the performance of the application, enhances user satisfaction, and thus optimises the interaction quality of the interface [11].

To improve usability, user interface design should also follow Nielsen and Molich's 10 User Interface Design Guidelines: 1) Visibility of system status. 2) Match between system and the real world. 3) User control and freedom. 4) Consistency and standards. 5) Error prevention. 6) Recognition rather than recall. 7) Flexibility and efficiency of use. 8) Aesthetic and minimalist design. 9) Help users recognize, diagnose and recover from errors. 10) Help and documentation.

Eight principles of user interface design (UID) should also be emphasised when designing and developing m-learning applications [12]: 1) navigation between pages should be simple and intuitive to ensure that users can jump around easily. 2) Minimise the need for users to scroll the screen to improve ease of operation. 3) the application should be designed to be easy to use so that learners can quickly familiarise themselves with how to use it. 4) Similar functions and information displays should maintain a consistent location layout to provide a unified user experience. 5) The interface design should be responsive and adaptable to different devices and screen sizes. 6) Avoid providing redundant or irrelevant information and keep the content concise and relevant. 7) Minimise the use of plain text and use more graphics and animation to enrich the presentation of information. 8) Give users control over custom settings to enhance their personalised experience of the app.

3.3. AR User Interface Design Guidelines

Currently, the field of augmented reality user interface design lacks a unified design guidebook [3]. Existing user interfaces and design principles focus mainly on specific devices, such as Google Glass, Microsoft HoloLens, etc. Instead, significant portions of developer guides are mostly centred around computer games and virtual reality (VR) games, largely due to their widespread popularity [3].

Bloksa proposed an AR user interface design guide, which is based on key elements in AR use case scenarios, covering the following five core aspects [3]: 1) Presentation: display and control content should be designed in the natural viewing area, and need to take into account the "distance" in the proportion relationship between content and environment; recommended the use of 3D button elements; in addition, the responsiveness of UI elements and the natural visibility of the display are critical. 2) Control: The control types should be diversified and adjusted according to different situations; the response to instructions should be efficient, while the instruction input methods should be up-to-date. 3) Showing Instructions: Users should be able to close or adjust the instruction guidance by themselves; provide diversified instruction displays and give users instant feedback. 4) Navigation: Navigation should be clear and easy to understand, and the interface should be able to be adjusted according to different usage environments. 5) Notifications: Notifications should not be used as the primary means of communication; users should be able to set notification preferences to ensure that their experience is not disturbed. However, these guidelines are intended to be universally applicable and are not tailored to specific usage environments [3]. Also, the guidelines do not go into depth on control types such as voice, gesture and multimodal controls [3].

Shukri et al. proposed guidelines for user interface design that address the factors that influence the design of mobile AR travel systems [11]. These guidelines were developed by integrating the PAD theory of users' emotional states (i.e., the three dimensions of pleasure, arousal, and dominance) as well as three core concepts in HCI (human-computer interaction): ease of learning, consistency, and cognitive overhead [11]. Through this comprehensive approach, they summarised 11 specific design principles to guide the interface design of mobile AR travel applications [11]. The design guidelines are based on four main aspects [11]: 1) Using the context for providing content 2) Reducing cognitive

overhead 3) To provide easy learning ability for a user 4) 3D interaction. But the series of design guidelines lack corresponding evaluation of relevant techniques such as usability testing.

Oluwadunsin Dabor et al. proposed a user interface design guideline based on Cognitive Load Theory (CLT) for augmented reality applied in simultaneous interpretation. This guideline synthesises Shneiderman's design principles for desktop applications [13], human-computer interaction (HCI) guidelines for AR systems [14], and a model for controlling psychological demands under workspace stress. It focuses on the following four areas [11]: cater for universal usability, support user control, reduce short-term memory load, context should be used for providing information. Similarly, the limitation of this series of design guidelines is that valid evaluation validation has not yet been conducted.

Furthermore, in Augmented Reality (AR), users may encounter perceptual problems when observing and interpreting information [15]. These problems are mainly related to scene distortion and abstraction, depth distortion and object ordering, and visibility [15]. To address these issues, Cledja Rolim et al. proposed visual design guidelines for AR instructions based on AR visualisation techniques as follows [15]: 1) Indicating motion: instructions should clearly indicate the correct path and mode of motion, and in some cases the speed or acceleration. The path determines the trajectory of the movement, while the correctness ensures the exact method to reach the goal. 2) Emphasise the part to be moved or changed: this is especially important for body instructions, which clearly inform the user which part of the body needs to be moved. In commands involving objects, it is also crucial to accurately identify the part that needs to be moved when there are multiple small objects or parts. 3) Allow for a diversity of visual appearance attributes: the visual presentation of AR commands should be adapted to the environmental conditions. The user should be able to control the appearance of the commands, as certain tasks may require specific patterns to be followed. 4) Provide real-time feedback: feedback mechanisms must be included in the command process so that the user understands whether he or she is doing something correctly, whether adjustments are needed, or whether alternatives exist. This feedback needs to be provided in real time. 5) Managing occlusion and depth relationships: when communicating 3D information, such as disassembly tasks, instructions must include visual cues to help the user understand occlusion relationships, depth relationships, and distances. These design guidelines aim to improve the clarity and effectiveness of AR instructions, thereby enhancing the user experience.

4. AR USER INTERFACE EVALUATION METHODS

4.1. User Experience Assessment Methodology

Usability evaluation aims to accurately identify product usability problems. By repeatedly evaluating and optimising the usability of a product, it can effectively improve the predictability of the product, reduce the number of errors that occur during the use of the product, thus improving the efficiency of the users, better matching the needs of the users, and at the same time helping to shorten the product development cycle and reduce costs [7]. Currently, a variety of evaluation methods, including heuristic evaluation, cognitive walkthrough, cognitive task analysis, audible thinking, and usability surveys, have been widely used in the usability testing of technology-related products, and each method provides a unique analysis perspective [7].

Heuristic evaluation is a means of usability testing guided by heuristic principles proposed by Nielsen [7]. In this method, a human-computer interaction (HCI) expert identifies usability problems in a system by detecting the presence of unsatisfied heuristic principles (i.e., heuristic violations) [7].

Audible Thinking Method is a means of understanding cognitive processes by encouraging users to express what they observe, think, do, and feel in real time as they perform a task, thus allowing observers to gain insight into the cognitive processes associated with task completion [7]. By

engaging actual or intended users in "audible thinking", we can gain a deeper understanding of how users interact with the system and reveal practical usability issues related to task execution.

The results of the study showed that HCI experts were more inclined to identify generalised interface problems through heuristic evaluations, whereas users were more likely to identify interface obstacles that seriously affected the completion of their tasks through the Audible Thinking protocol [7]. Thus, the usability problems identified by experts through heuristic evaluation were mostly related to interface characteristics and had little to do with the impact of the actual operational tasks [7]. In short, HCI experts focus more on revealing "ease of use" issues, while users identify more "utility" issues [7].

However, to create great user experiences, it is crucial to gain deep insights into how users feel. Traditional usability testing tends to focus on evaluating the efficiency and functionality of a product while ignoring how users really feel. In order to understand and evaluate user experience more comprehensively and accurately, we must collect valuable data from users. The methods we often use in this process include observation, psychophysiological measures, and collecting information in the form of questionnaires or surveys [8].

Questionnaires are often used to assess user satisfaction, mood and attitudes towards the system [16]. If properly designed, both questionnaires and interviews are relatively inexpensive and easy-to-use data collection tools [16]. While interviews focus primarily on collecting qualitative data and exploring users' perspectives and experiences in depth, questionnaires allow for the systematic collection of large amounts of quantitative data, which facilitates subsequent statistical analyses [16].

Eye tracking is a popular psychological assessment method for monitoring user behavioural patterns, and is particularly important in usability testing, where it can reveal which elements of the GUI are more visible or easily overlooked [16]. However, commonly used "heat maps" can be misleadingly interpreted due to data aggregation [16]. Eye tracking has been used to study visual search strategies, to measure aspects of emotion such as interest, fatigue, or to assess arousal using gaze duration, blink rate, or pupil dilation as measures [16]. However, correctly interpreting physiological data requires extensive experience and is especially critical when dealing with issues such as illumination, reflections, and measurements in mobile or real-world environments [16].

To summarise, in order to assess mood and emotion, we can use physiological measures or utilise tools such as EmoCards [17] to assess potency and arousal. In terms of assessing contextual or temporal experiences, there exist a number of methods for mobile user experience (UX) that combine conceptual analysis studies and data collection techniques [18]. For prototype evaluation, usability evaluation methods can be enhanced by incorporating experimental elements, for example, in long-term field trials, we can use diary entries, experience sampling, questionnaires and focus groups to collect experimental data [18]. When the product has been developed and is ready for market or has been launched, we can measure the user experience of actual users [19]. This can be achieved in a number of ways, including using traditional market and user research methods to collect feedback data, but also by leveraging the latest technologies and community opportunities presented by the Internet [19]. Measurement of user experience should be inherently self-reported, trajectory-based and adaptive. Therefore, traditional techniques such as questionnaires, interviews and think aloud remain important in capturing user self-reported data [20].

Virpi Roto has collected comprehensive UX evaluation methods (UXEM) from academia and industry since 2008 and consolidated them to form examples of UX evaluation methods used to study experiences at different times, as well as UX evaluation methods for different stages of product development [21].

After a systematic review of the field of UX evaluation, the study reveals several important findings [8]: (1) psychophysiological metrics are not yet commonly used in UX evaluation; (2) researchers prefer qualitative research methods; (3) most of the current evaluations rely on manual manipulation

(and thus do not allow for real-time feedback), and usually target products that have already been developed; and (4) most of the studies do not take product changes in use over time into account in most studies.

Based on the above analyses, it was concluded that there is a need to explore additional means of evaluating user experience, which should be able to take into account changes in product usage over time as well as real-time user experience data. As mentioned earlier, the long-term use of a product relies on continued use and recommendations from users. At the same time, real-time evaluation is crucial as it effectively avoids the problem of data loss that results when information is collected at the end of an experiment.

4.2. AR Interface Effectiveness Evaluation Method

Numerous authors agree that researchers in the field of emerging interfaces such as Virtual Reality (VR) or Augmented Reality (AR) cannot rely solely on traditional user interface design and evaluation criteria [2]. Sutcliffe and Kaur [22] point out that, while traditional methods of usability evaluation may be able to reveal some of the problems with new interfaces, none of the existing methods are truly tailored to the specific needs of such interfaces [2]. For example, Nielsen's well-known usability heuristics [23] do not address issues related to positioning, object selection and manipulation in 3D space. Similarly, since the input-output modes of augmented reality interfaces can be very different, distinctive evaluation tools are required [2].

The study shows that some of the heuristics such as "natural engagement", "compatibility with the user's task and domain", "realistic feedback", "support for learning", "explicit rotation", and "consistent deviation" can be applied to AR systems as well with minor adjustments [2].

However, other heuristics such as "natural expression of actions", "close coordination of actions and representations", "faithful viewpoints", "navigational and directional support", "clear entry and exit points", and "presence" may have limited applicability in AR environments [2].

According to previous studies, most AR user evaluations can be classified into the following four categories [2]: 1) experiments that examine human perception and cognition. 2) experiments that examine user task performance. 3) experiments that examine collaboration between users. 4) system usability, system design evaluations [24]. The commonly used evaluation methods in AR user evaluations can be broadly distinguished between quantitative methods, qualitative methods, non-user based usability evaluation methods and informal methods [2]: 1) Objective measurements: These methods should produce reliable and repeatable numerical results for quantitative observations. These metrics can be automated by the system or performed by the experimenter. Common metrics include task completion time, error rate, user or object location, and test scores. 2) Subjective measurements: These rely on people's subjective judgements and include questionnaires, ratings, rankings or judgements (e.g., depth judgements). 3) Qualitative analyses: Qualitative analyses are not concerned with putting results in numbers. Data are collected through structured observation (direct observation, video analysis) or interviews (structured, unstructured). 4) Non-user-based usability evaluation techniques: This includes non-user-based evaluation techniques such as cognitive walkthroughs or heuristic evaluations, as well as techniques involving non-end users (e.g., expert-based usability evaluation). 5) Informal testing: Many published AR papers are limited to reporting informal user observations or feedback, e.g., information gathered during demonstrations. Surprisingly, reporting such limited findings still seems to be commonplace and widely accepted in the AR field. In contrast, informal evaluations are almost invisible in CHI publications [25].

5. RESEARCH METHODOLOGY (LITERATURE REVIEW METHOD)

5.1. Literature Screening and Collection

In this paper, a literature search was conducted through the Google Scholar search engine. The goal of this paper was to conduct a broad search across multiple scientific communities, and Google Scholar search was considered an appropriate method. The inclusion criteria considered in the systematic evaluation were: articles published since 2000, articles published in conferences or journals, articles available for reading (with access granted) and English writing. The search terms used were: "user interface design", "user experience evaluation", "augmented reality evaluation", "augmented reality user interface design" and other related terms.

The results of the search were as follows, with a total of 525 relevant studies found through the Google Scholar search engine. At the end of the search, there were two stages of study exclusion. The first stage consisted of applying the inclusion criteria and analysing the titles and abstracts of the studies to exclude 445 of the studies, leaving 80 studies for the second stage. The second stage consisted of reading the introduction, proposal details and conclusions, excluding 55 studies. After filtering, a total of 25 papers were retained.

6. DISCUSSION AND CONCLUSIONS

6.1. Summary of AR User Interface Design Principles

Interface design is the medium for communicating between the user and the learning content and there are five common principles: consistency, hierarchy, contrast, balance and harmony. Usability is an important measure of the quality of user interface design and interaction, and in order to improve usability, Nielsen and Molich's 10 User Interface Design Guidelines should be followed. user interface design (UID) principles such as clear and simple navigation, avoidance of frequent scrolling of the screen, etc. to improve the user experience.

However design principles for emerging interface domains such as AR cannot be fully dependent on traditional user interfaces. Many past studies have reflected on AR user interface design principles, for example, Bloksa, Shukri and Oluwadunsin Dabor et al. have proposed user interface design guidelines or guidelines for AR user interfaces, mobile AR travel applications and AR applications in simultaneous interpretation, respectively.

6.2. Summary of AR User Interface Evaluation Methods

For traditional interfaces, usability evaluation is a method of identifying product usability issues, and iterative evaluation can improve product predictability, productivity and matching user needs while saving time and cost. Heuristic evaluation and audible thinking are commonly used evaluation methods. To produce a good user experience, it is necessary to understand how users feel, and data can be collected through observation, psychophysiological measurements and questionnaires.

However traditional usability evaluation methods may not cover the specific needs of the new interface. Some of the traditional heuristic evaluation methods can be adapted and applied to AR systems. AR user evaluation can be categorised into four types of experimental studies. In AR user evaluation, evaluation methods can be broadly categorised into quantitative, qualitative, non-user-based and informal methods, which include objective measurements, subjective measurements, qualitative analyses, non-user-based usability evaluation techniques and informal testing.

6.3. Implications for AR User Interface Design and Evaluation

The realisation of digital augmentation encompasses a wide range of sensory experiences, which can be accomplished through a variety of input and output hardware devices, and is compatible with a wide range of interaction technologies. However, this variety of implementations also poses a challenge in defining a set of design and evaluation techniques that are both universal and comprehensive.

One possible solution is to construct a framework for AR systems as a basis for setting standards for design and evaluation. However, the challenge with this option is to find a suitable level of abstraction, which is integral to building such a comprehensive framework, and which would also need to support the development of practical guidelines.

Another option is to narrow the focus so that generic guidelines can be defined. For example, guidelines could be developed specifically for mobile phone AR systems. This would lead to the development of appropriate design and evaluation guidelines for different types of AR systems that would share certain characteristics.

6.4. Research Limitations and Future Perspectives

Firstly, the article explores the relationship between current traditional user interface design and evaluation principles and AR interface design and evaluation principles, but no general guidelines for AR system design and evaluation that can be applied to a wide range of domains have been identified in previous research. And there is generally no corresponding evaluation system for AR interface system design principles for special use case scenarios. This may represent a general problem in the field of AR design and evaluation, or may be due to the limitations of the literature search in this paper. In the future, we should conduct a more in-depth literature search and research in this direction.

Currently, measuring user task performance is widely adopted in the evaluation of AR technologies. However, the reason for this popularity is unclear and may be due to the lack of more appropriate evaluation tools or indeed because improving user task performance is a top priority in current research. For many AR systems, issues closely linked to the user experience are crucial. However, it is currently difficult to find effective ways to specifically measure user experience. Although researchers prefer to use qualitative assessment methods when focusing on user experience, this method has not been widely used in research in AR. In the future, we need to keep exploring and developing new assessment methods to further enrich and expand the library of assessment tools for specific AR research.

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