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Comparing Fixed and Variable Arrangement Interfaces in AR Mobile Apps: A User Experience Analysis

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Abstract: Augmented Reality (AR) technology is gradually gaining popularity. In the current AR application development process, technical aspects often receive significant attention. However, there is a relative lack of studies focusing on the design of AR interaction interfaces. Currently, the interactive interfaces of AR applications can be categorized into fixed-arrangement interface layouts and variable-arrangement interface layouts. Whether the two types of interface layouts will bring differences in user experience remains to be investigated. This study analyzed the impact of fixed and variable arrangement interface layouts on user experience with AR technology as the background. This study had built a comparative experimental application with the same content but different interface layouts. In the experimental application, participants(n=32) engaged in the same content interaction using fixed and variable arrangement interfaces, and afterward, they completed the UEQ user experience questionnaire. The results showed that fixed-arrangement interface layouts scored higher in terms of perspicuity and efficiency. Variable-arrangement interface layouts scored higher in terms of stimulation and novelty. In conclusion, fixed-arrangement interface layouts perform better in terms of practical quality, while variable-arrangement interface layouts perform better in terms of hedonic quality. Based on the research results, the researchers propose optimization suggestions. Fixed-arrangement interface layouts are more suitable for scenarios that require quick and clear information presentation and interaction, such as subway stations or elevator scan shopping. Variable-arrangement interface layouts are more effective for scenarios that aim to enhance user engagement and entertainment, such as real estate, automobile sales domains and mobile game.

Keywords: Interface Layout Design, Augmented Reality (AR), User Experience, Mobile Application

1. Introduction

Augmented Reality (AR) is a technology that overlays digital information on the real world. AR technology involves the projection of digital content from the virtual world onto the real world through tracking and positioning, allowing users to perceive this digital content. This technology can be experienced through mobile electronic devices such as smartphones and tablets, or head-mounted display devices[1]. In recent years, the importance of AR application development has been increasing day by day as it has the potential to revolutionize various industries, include the healthcare industry[2], education industry[3] and retail industry[4].

Since 2016, the popularity of AR technology has been steadily growing. Among the available options,

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while head-mounted display devices remain less mature and face limited user acceptance due to challenges in balancing computing performance, display quality, volume, and weight, mobile electronic devices have reached a high level of user acceptance, mobile devices have emerged as the dominant platform[5]. Apple's AR Kit and Google's Android AR Core technologies have significantly enhanced the usability and user experience of AR applications, fostering their widespread adoption[6]. Therefore, this study focuses on the mobile platform. Despite the increasing number of AR applications available on mobile platforms, their quality varies significantly. This variability can be attributed to the continuous evolution of AR technology during the development of these applications.

This research addresses the creation of AR applications, interaction design, content design, and the release of AR applications. The scope of this study encompasses user experience, usability, and interface layout design, in addition to AR technology. User experience encompasses practical quality, including perspicuity, efficiency, and dependability, and hedonic quality, encompassing stimulation and novelty. Usability focuses on measurement tools, methods, and conformity assessment metrics. Interface layout design primarily pertains to the arrangement of icons.

User experience, introduced by Donald Norman in the 1990s, has now become an established concept within international ergonomics standards. Unlike usability, user experience centers on evaluating users' experiences during product use. User experience can be categorized into practical quality, including perspicuity, efficiency, and dependability, and hedonic quality, encompassing stimulation and novelty. The User Experience Questionnaire (UEQ) is a widely adopted tool for measuring user experience[7][8].

While this study primarily focuses on user experience, the quality of the two interface layouts must be assessed to make meaningful comparisons. Usability testing is conducted to ensure that the test application's usability is comparable to that of applications currently available on the market, thus preserving the validity of experimental results. In this study, the System Usability Scale (SUS) is used as a standard tool for measuring usability. SUS scale is a representative usability testing tool that has been extensively researched and verified to be effective[9][10].

Traditional mobile applications primarily rely on two-dimensional (2D) graphics and text for user interaction. In contrast, AR applications involve interactions with three-dimensional (3D) models and spaces besides two-dimensional graphics and text. While the sensory input for traditional applications does not differ significantly, AR applications introduce additional layers of interaction involving human limbs, gyroscopes, and camera sensors. These changes necessitate a reevaluation of interaction interfaces, an area that remains relatively unexplored for AR applications. In terms of design, a standardized interface for AR applications is yet to be established. Therefore, it is imperative to investigate AR application interface layout design, considering user experience as the primary evaluation metric.

Fixed-arrangement interface layout design involves maintaining static positions for interactive buttons on the interface. This design is the prevalent choice for most contemporary applications. It is worth noting that the majority of interface layout research is centered on the fixed-arrangement interface layout. Researchers have explored various aspects of this design, such as studying touch interaction hot zones when holding the device with left or right hands[11], effects of interface layout design on mobile learning efficiency[12].

In contrast, the variable-arrangement interface layout is characterized by interactive buttons suspended in 3D space, relying on spatial interaction between users and the device. These buttons occupy defined positions in the virtual world and enable interaction in a 3D space. Notable examples of applications employing this approach include AR Elements, Assemblr Studio, and Easy ARMaker application. It is essential to highlight that variable-arrangement interfaces are less commonly found in today's applications, and there is limited research in this domain.

This research encompasses framework construction of AR applications, interface layout design, content design, and user experience measurement and analysis. Framework construction includes determining the relationships between the various levels of interfaces of the AR application as well as the content and functions of the interfaces and interactions at each level. Interface layout design and content design directly impact user experience, making them key areas of investigation. The release of AR applications represents the final step in development, ensuring the application's smooth operation. User experience measurement and analysis play a pivotal role in shaping the research findings. This study aimed to conduct quantitative research to compare two common AR interface layout methods and provide recommendations for optimizing AR application interface layouts. The results of this study would serve as a valuable resource for designers, offering effective design strategies to enhance the user experience of AR applications.

2. Research Methodology

2.1 Research Design

This study used an experimental method to compare two types of interface layouts for AR mobile applications: fixed and variable. The study aimed to measure and analyze the user experience of the two layouts using an experimental application with four interactive 3D models.

The researchers arranged 32 participants for each experiment, and the experiment was conducted in a research room during daily study and work. Participants were informed of content and requirements of the experiment before conducting it. All participants participated voluntarily and could refuse to continue experiment at any time during participation. The experimental steps are shown in [Table 1].

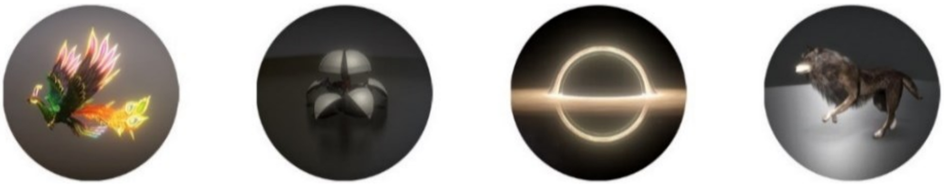
[Table 1] Experimental Process

	Completion content	Other matters
1	Participant is assigned a number before experiment.	Only number is recorded during experiment, not name.
2	Participant watches 30-second demonstration video.	Odd-numbered participants watch the fixed-arrangement interface layout video. Even-numbered participants watch the variable-arrangement interface layout video.
3	Participant has 3-minute interactive experience.	Experience interface layout corresponds to interface layout of demonstration video.
4	Participant fills out UEQ questionnaire.	Questionnaires have been collected by number and type of interaction mode.
5	Participant watches 30-second demonstration video.	Odd-numbered participants watch the variable-arrangement interface layout video. Even-numbered participants watch the fixed-arrangement interface layout video.
6	Participant has 3-minute interactive experience.	Experience interface layout corresponds to interface layout of demonstration video.
7	Participant fills out UEQ questionnaire.	

The research entails the study of the theoretical foundations of user experience and the market status of interface design. A comprehensive user experience evaluation methodology is developed based on these foundations, and an experimental application is implemented. Additionally, market research informs the summarization of user interface layout design. The study then proceeds to design an experimental application and invite participants to conduct experiments. By statistically analyzing the experimental data, researchers derive user experience scores. Ultimately, the study draws conclusions based on the experimental results.

2.2 Research Instrument

In this study, an experimental application was developed using the Unity3D engine where Google's AR CORE technology was incorporated to enable augmented reality (AR) experiences. The application consists of two modules, each with its own unique interface layout. The primary difference between the two modules lies in the layout of the user interface. Each module contains four dynamic 3D model, including (1) a flying phoenix, (2) a walking robot, (3) a running black hole, and (4) a running wolf as shown in [Fig. 1]. Each 3D model display is interactive and comprises the following elements, including an animated 3D model, matching sound effects, explanatory text and pictures. All the display materials, including 3D models and other content, were sourced entirely from www.sketchfab.com. The experimental application underwent multiple rounds of design and production improvements to enhance its quality and user experience. When the final version was developed, participants were invited to test the application to evaluate the impact of different layout methods on the user experience.



[Fig. 1] Four Dynamic 3D Model

The researchers identified four interaction buttons by analyzing the fundamental aspects of user interaction. These buttons encompass text information, audio information, picture information, and interface layout switching. These four interaction buttons were incorporated in both the fixed-arrangement interface layout and the variable-arrangement interface layout, maintaining uniformity in colors and button icon sizes across both layouts.

The experiential content of the experimental application consists of two types of layouts:

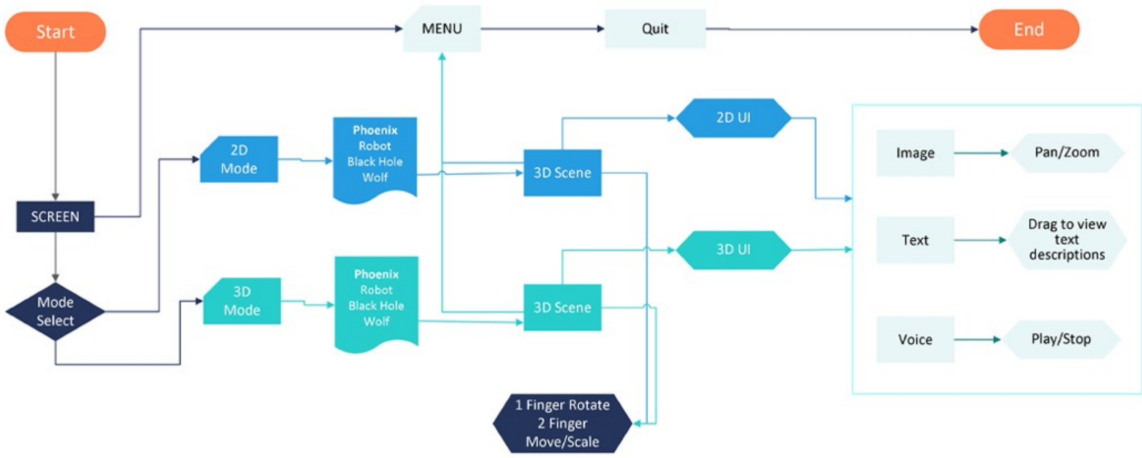
Fixed-arrangement interface layout. The fixed-arrangement interface layout, as illustrated in [Fig. 2] (left), showcases the exhibits as three-dimensional interactive models. Four interactive buttons are consistently arranged on one side of the screen. The rotation of the model has no impact on the layout of the interface buttons.

Variable-arrangement interface layout. The variable-arrangement interface layout, as depicted in [Fig. 2] (middle), presents the exhibits as three-dimensional interactive models. In this layout, an interaction button is anchored to a virtual point in three-dimensional space that corresponds to a point on the three-dimensional model. The buttons interface always faces the screen. As the three-dimensional model changes its position or angle, the position of the interaction button also adjusts accordingly.

The mobile phone interface will display the camera shooting screen, and the mobile phone will automatically recognize the plane and display a green placement icon in the center of the mobile phone screen, as shown in [Fig. 2] (right). Clicking on one of the four contents below will display related 3D models and interface layouts at the clicked location. Users can view interactive content by moving and rotating their mobile phones to adjust their positions.

[Fig. 2] Application Interface

In this study, the researchers built an AR application framework based on interaction requirements and experimental needs and drew an application running flowchart as shown in [Fig. 3].



[Fig. 3] Flowchart

After developing the basic functions, preliminary trials, improvements, re-trials and usability tests were conducted. These trials and usability tests can help developers find and solve problems in applications to ensure quality and stability of applications. During the process, developers will look for functions that affect basic experience for optimization to ensure that applications can reach above average level of existing applications to ensure effective experimentation.

For application developers, determining the quality of a newly developed application is of utmost importance. Usability, a critical quality metric for interactive products, is typically assessed through usability testing[13]. Usability encompasses the effective, efficient, and satisfactory use of a product to achieve specific goals within a specific usage scenario. Although the concept of usability dates back to the 1880s, it remains an integral part of international standards. Usability comprises factors such as effectiveness, efficiency, and user satisfaction[14]. Most applications undergo usability testing during development to ensure that users can effectively use the application's core functionality.

Six participants took part in the usability testing and focus group discussions. Usability testing and focus group discussions are common methods of analyzing usability. The usability testing was divided into multiple rounds, with the first round being a simple trial to point out problems in use. The researcher made improvements based on the comments, and after the improvements, a second round of testing was conducted until the major problems were eliminated.

In the discussion after the first round of brief use, two participants felt that the circular icon indicating gesture operation could not be interpreted as a guiding instruction for the finger. They suggested that hand-shaped icons should be used instead. Another three participants felt that although the application could be used to view interactive content by moving the phone's position during use, users were more accustomed to interacting with the touch screen. Users should be provided with another way to interact. The researchers took on board the participants' comments and replaced the prompt icon with a hand-shaped icon [Fig. 4] and added a finger-controlled touchscreen feature to allow direct interaction with the 3D model.

After further refinement, the focus group members were invited to retake the test, and no further suggestions were made by the focus group members. The researcher asked the focus group members to complete the SUS scale after the test. Average SUS score for the fixed-arrangement interface layout was 72 while average SUS score for the variable-arrangement interface layout was 69. Compared to the SUS scores of the traditional application[15], the experimental AR application scored above the good level on the usability scale. Focus group members also gave feedback that the improved application was easier to understand and better to use. This concluded the usability testing.

[Fig. 4] Pre- and Post-improvement Tip Icons

The application was released through Unity 3D engine as an Android application that needs to be installed on smartphones that support ARCORE to run. Developers used three smartphones for installation testing. After multiple runs and restarts, no abnormal situations occurred in application.

2.3 Respondents of the Study

In this study, in order to ensure that the experimental application and the regular application have approximate usability, six participants were initially invited as the focus group members to participate in the optimization of the experimental application during its development phase. The basic information of the focus group members is shown in [Table 2] (left). The study recruited 32 participants, including 16 males and 16 females. All participants were undergraduate students and faculty members at universities. Participant information is shown in [Table 2] (right). The average age of the participants was 26 years (SD±3.4), with an even gender distribution (52% female). All participants were proficient in the use of the experimental phone, with 60% having no experience with AR applications, 20% having used an AR application once, and 20% having some experience with AR applications.

[Table 2] Participant Information

	Gender	Age	Amount		Gender	Age	Amount
Focus group (SUS test)	Male	<18	0	Participants in the experiment (UEQ test)	Male	<18	1
		19-30	2			19-30	8
		31-50	1			31-50	6
	Female	<18	1		Female	<18	0
		19-30	1			19-30	9
		31-50	1			31-50	8

2.4 Data Gathering Procedures

The study collected the SUS scores of the focus group members after the usability testing. This study also collected the basic information and the UEQ scores of the participants after each interaction. This study measured the following aspects: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty.

The survey questionnaire collected the user's age and basic information. The UEQ scale consists of 26 questions and was evaluated in the form of a seven-point Likert scale from least to most consistent[15].

2.5 Statistical Tools

This study used Microsoft Excel and SPSS Statistics 26.0 for data analysis. The study used the UEQ calculation tool provided by the developer of the UEQ scale to convert the scale data into measurement analysis data and prompt for suspicious data[15]. The study also used a two-sample T-test with unequal assumptions to compare the differences between the two interface layouts.

3. Results and Discussion

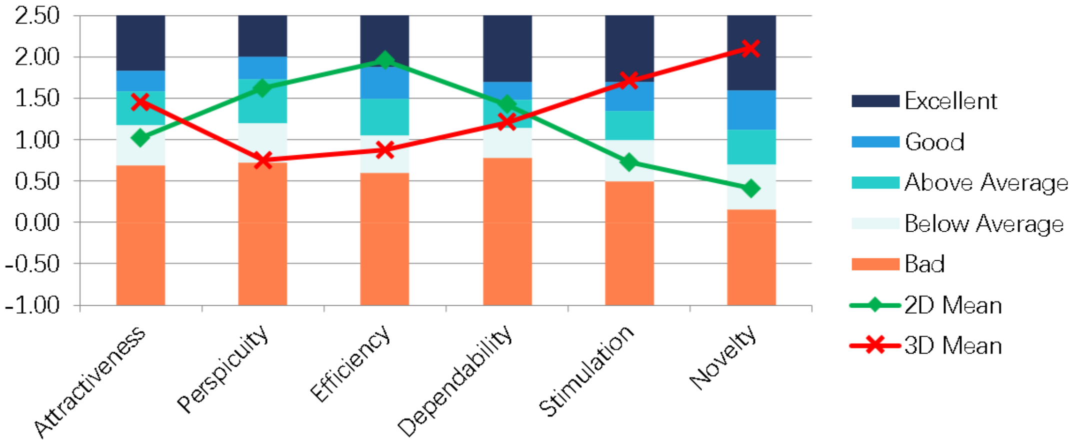
32 participants participated in the final experiment. Two participants were found to be inconsistent and were omitted from data analysis. [Table 3] shows the mean, standard deviation, confidence and confidence interval of each factor under the fixed-arrangement interface layout and the variable-arrangement interface layout within a 95% confidence interval.

[Table 3] Test Values for Each Factor Under the Fixed-arrangement and Variable-arrangement Interfaces

Fixed-arrangement Confidence intervals (p=0.05) per scale						
Scale	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence interval**	
Attractiveness	**1.022**	0.363	30	0.130	0.892	1.152
Perspicuity	**1.625**	0.477	30	0.171	1.454	1.796
Efficiency	**1.950**	0.471	30	0.168	1.782	2.118
Dependability	**1.425**	0.766	30	0.274	1.151	1.699
Stimulation	**0.725**	0.484	30	0.173	0.552	0.898
Novelty	**0.417**	0.379	30	0.136	0.281	0.552
Variable-arrangement Confidence intervals (p=0.05) per scale						
Scale	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence interval**	
Attractiveness	**1.567**	0.439	30	0.157	1.410	1.724
Perspicuity	**0.758**	0.687	30	0.246	0.513	1.004
Efficiency	**0.875**	0.694	30	0.248	0.627	1.123

Dependability	**1.192**	0.419	30	0.150	1.042	1.342
Stimulation	**1.708**	0.804	30	0.288	1.421	1.996
Novelty	**2.108**	0.779	30	0.279	1.830	2.387

[Fig. 5] shows the evaluation levels of each factor in UEQ in different colors. The division of levels is based on the UEQ score evaluation of 468 studies and 21175 sets of data from different products. Two lines show the average scores of each factor in the fixed-arrangement interface layout and the variable-arrangement interface layout respectively. The results show that in terms of Attractiveness, Efficiency and Perspicuity, the fixed-arrangement interface layout scored higher. In terms of Stimulation and Novelty, the variable-arrangement interface layout scored higher. In terms of Dependability, the values of the two interface layouts were close.



[Fig. 5] Questionnaire Measurement Factor Analysis

In order to compare whether the attributes of the fixed-arrangement and the variable-arrangement interface layouts have reached significant differences, a two-sample T-test with unequal assumptions was performed on the experimental results. As shown in [Table 4], the results show whether there is a significant difference between the average values of the two tested interface layouts (Alpha-Level=0.05). By comparison, researchers found that except for Dependability where the difference was not significant, the differences in other comparison factors were all significant.

[Table 4] Significance Test for Differences

Comparative content	Alpha Value	Significant Difference or not
Attractiveness	0.00	Significant Difference
Perspicuity	0.00	Significant Difference
Efficiency	0.00	Significant Difference
Dependability	**0.15**	**No Significant Difference**
Stimulation	0.00	Significant Difference
Novelty	0.00	Significant Difference

The fixed-arrangement interface layout demonstrated superior efficiency and clarity. On the other hand, the variable-arrangement interface layout emerged as more attractive to users overall, enhancing participants' entertainment experience. However, the suitability of interface layouts is contingent on specific usage scenarios and user needs.

In practical terms, developers and application designers should prioritize an in-depth analysis of the application's usage scenarios and environment. For instance, in scenarios characterized by a limited timeframe for decision-making, such as subway stations or elevator scan shopping, a clear and easy-to-understand fixed-arrangement interface layout with simple operation and intuitive information presentation is the more suitable choice. Conversely, in domains like real estate and automobiles, where users require a comprehensive understanding of products before making decisions, it becomes essential to prolong user engagement and deepen their impressions of products. In such cases, enhancing entertainment and increasing user participation through a variable-arrangement interface layout proves more effective. This is consistent with the findings of existing studies[16][17].

It is important to acknowledge that this study examined only six dimensions of user experience, leaving room for exploration of other factors. In addition, the geographical factor is one of the limitations of this study. Cultural differences due to geographical differences can lead to differences in user experience[18]. The participants in this study were all from East Asia, and the user experience in other regions has yet to be measured. Further research opportunities also lie in exploring the relationship between usability and user experience.

This study employed a specialized application for experimentation to eliminate interference from complex factors. However, it is essential to extend these findings to test other applications in diverse usage environments, providing a more comprehensive understanding of the effects of interface layouts on user experience in AR applications.

4. Conclusion

The primary objective of this study was to investigate the influence of different interface layouts on the user experience of AR applications, using user experience as the primary evaluation metric.

The study found that demonstrated a clear distinction in the performance of the two interface layouts. The fixed-arrangement interface layout excelled in practical quality, particularly in terms of perspicuity and efficiency. In contrast, the variable-arrangement interface layout outperformed in hedonic quality, emphasizing stimulation and novelty. Notably, there was no significant difference in Dependability between the two layouts.

The study suggested that developers and designers should analyze the usage scenarios and user needs of AR applications and choose the appropriate interface layout accordingly.

The study contributed to the understanding of user experience in AR applications and provided valuable guidance for creating more user-centered and engaging AR applications.

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