A Usability Study of Augmented Reality Indoor Navigation using Handheld Augmented Reality Usability Scale (HARUS)

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Abstract

Augmented Reality (AR) indoor navigation has surfaced as an unprecedented and inventive method of aiding and directing users as they traverse intricate indoor landscapes, including campuses and structures. The efficacy of AR interior navigation system implementation is predominantly contingent upon the ease of use and adeptness of users in engaging with this technology. This study sets out to comprehensively evaluate the usability of AR indoor navigation with a primary focus on the manipulability and comprehensibility aspects of AR technology, assessing how effectively it facilitates navigation within indoor spaces. To achieve this, the Handheld Augmented Reality Usability Scale (HARUS) was used as the framework for evaluation. The research involved the creation of a marker-based AR indoor navigation application called "DutaNavAR," designed specifically for use within the Agape Building at Universitas Kristen Duta Wacana (Duta Wacana Christian University). The evaluation yielded noteworthy results, with the mean manipulability score averaging 75.19 and the mean comprehensibility score averaging 81.63. In summary, the overall average HARUS score obtained was 78.41. This score indicates a high level of user satisfaction with the interaction and overall experience of the indoor navigation application. These findings underscore the positive impact of AR technology in enhancing indoor navigation, emphasizing the usability and user-friendliness of AR solutions in complex indoor environments.

Keywords— Augmented Reality, HARUS, Indoor Navigation, Usability Scale

1. INTRODUCTION

The development of Augmented Reality (AR) technology has brought a significant transformation in the way individuals interact with the physical world [1]. AR offers a novel approach to a wide range of difficulties and applications by seamlessly integrating virtual elements into the real world [2]. An example of a significant application is indoor navigation using AR. AR indoor navigation allows users to find location-specific information, receive directions on optimal routes, and access integrated content relevant to their physical environment while navigating complex areas [3].

However, in the context of AR technology, the main concern is the usability aspect [4]. The potential for success and adoption of AR technology is dependent upon factors such as ease of use, streamlined user experiences, and the level of comfort associated with engaging with the technology [5]. Hence, the assessment of usability becomes crucial in determining the degree to which AR indoor navigation aligns with user expectations [6].

The usability evaluation process is a systematic approach that assesses the extent to which users can effectively and efficiently engage with a system to achieve their objectives [7]. In the field of AR indoor navigation, the idea encompasses the assessment of users' engagement with the system concerning its smoothness and coherence [8], and their ability to navigate indoor environments effortlessly and effectively achieve goals without confronting substantial barriers [9].

The instrument of evaluation used to evaluate the usability of AR indoor navigation is the Handled Augmented Reality Usability Scale (HARUS). The HARUS framework was developed with the explicit goal of evaluating the usability of AR applications[10]. The subject matter includes a range of relevant aspects, such as manipulability, which pertains to the extent to which users can effectively control AR elements, and user comprehensibility, which pertains to the degree to which users comprehend the many features and functionalities of AR [11].

Studies have been conducted on the use of usability measures in educational applications for teaching Karnaugh-Maps. Two Mobile AR-based (MAR) applications were designed and tested utilizing SUS and HARUS models. The System Usability Scale (SUS) is a widely used tool to assess the usability of a system through a 10-item questionnaire, while the Handheld Augmented Reality Usability Scale (HARUS) specifically measures the usability of handheld AR devices by evaluating aspects of manipulability and comprehensibility. In an experimental investigation, students tested two AR applications: MAR employs several markers and MAR uses a keypad matrix. Keypad matrix MAR apps had greater usability (84.57%), manipulability, and comprehensibility (total mean score = 4.17), according to the SUS and HARUS study. After using both systems, participants deemed the keypad-based AR system better for information manipulation, convenience of use, interaction, and accuracy. They found the approach more entertaining when learning complex topics like K-map. K-map is the foundation of digital electronics and aids circuit design in electronics engineering. According to the response, engineering students could learn K-Map principles using the keypad-based AR system[12].

A separate study was conducted to investigate the efficacy of HARUS in evaluating the usability of AR applications, specifically focusing on the AR-Based Home Furniture Design application. This technology offers several benefits by allowing customers to have a novel experience, enabling them to visualize the house furniture they intend to purchase. To address this issue, a proposed solution involves the development of an Android application that utilizes Augmented Reality technology. This work employs a markerless augmented reality (AR) technique to achieve the highest possible accuracy in determining the size and position of the object. Developing applications utilizing Unity and EasyAR software to enhance augmented reality technologies. The AR application was tested using the Handheld Augmented Reality Usability Scale (HARUS) computation. The results indicate a score of 74% for manipulability and 76.22% for comprehensibility. Therefore, the overall score is precisely calculated to be 75.04% [13].

An additional investigation was conducted utilizing HARUS to assess the efficacy of the AR Viewer application within the context of Architecture, Engineering, and Construction (AEC) education. Using HARUS, 15 students evaluated the efficacy of the augmented reality viewer. The application obtained an average score of 71.88, which qualifies it as "okay." Respondents encountered challenges with the selection of annotations and the legibility and size of the text when viewing the instructional sequences on their smartphones. In this case, it is possible to revise the graphical user interface (GUI) to accommodate a more precise adjustment of the font size. Additionally, utilizing a five-digit Likert scale, the students who were interviewed evaluated the application and efficacy of augmented reality in forthcoming pedagogy. With a DtO of 0.67, the statement of whether AR can enhance the learning effect was validated. In addition, the students asserted that augmented reality enhances instruction (DtO = 0.56) and expressed a desire to implement AR in the future (DtO = 0.38) [14].

Although the Handheld Augmented Reality Usability Scale (HARUS) has been employed to assess many AR applications, there is a dearth of research utilizing HARUS to explicitly evaluate indoor AR navigation systems. Not taking advantage of HARUS is a wasted chance, since it has the potential to be a valuable tool for evaluating the usability of these applications. Indoor AR navigation applications hold significant potential in assisting individuals who are unfamiliar with specific indoor settings, such as museums or shopping malls. Nevertheless, if these programs lack user-friendliness, they have the potential to cause frustration and even pose risks. HARUS can be utilized to detect usability issues in various applications, hence facilitating their enhancement. Moreover, HARUS can be employed to assess and contrast the usability of various indoor augmented reality (AR) navigation applications. This information can be utilized to assist developers in creating optimal programs for users. So the primary objective of this study is to evaluate the utility of Augmented Reality indoor navigation systems through their use of the HARUS framework [15].

The primary aim of this study is to assess the utility of indoor AR navigation systems through the HARUS framework. This research seeks to evaluate the alignment of user interactions with technology and their navigation needs in complex indoor environments. While HARUS has been applied to assess AR systems in general, this study represents one of the first to adapt it specifically for indoor AR navigation systems. In this context, HARUS was tailored to address the unique challenges associated with indoor navigation, such as spatial awareness, ease of use, and interaction efficiency within confined and dynamic spaces. The framework was adjusted to focus on specific usability dimensions relevant to indoor navigation, including user satisfaction, cognitive load, system responsiveness, and the accuracy of navigation cues [16].

By employing the HARUS framework in this context, the study aims to identify usability issues specific to indoor AR navigation applications, compare the performance of different systems, and ultimately provide guidance for developers to create more effective, user-friendly navigation solutions. This research underscores the importance of leveraging HARUS to enhance the usability and efficacy of indoor AR navigation systems, ensuring they meet the diverse needs of users in complex, indoor environments.

Furthermore, our objective is to identify possibilities that might require improvement or additional development within AR indoor navigation. The data collected throughout this research effort will provide important insights into the identification of usability difficulties, therefore enabling improvements in user experiences.

2. RESEARCH METHODS

The research project involved the development of an augmented reality (AR) indoor navigation application called "DutaNavAR" that utilizes markers for navigation. The review focuses largely on this application, specifically designed for usage within the Agape Building at Universitas Kristen Duta Wacana. Our study is focused on this particular application to ensure its relevance in real-world situations and efficiently satisfy the true needs of consumers.

The development of DutaNavAR reflects a strong commitment to both functionality and user-centered design, as illustrated in Figure 1. The system is specifically designed to address navigation challenges in indoor environments where traditional methods may fall short. By customizing the application to meet the unique needs of the Agape Building, we can tailor its features and functions to align precisely with the specific navigation requirements and user preferences of that setting.

Our objective is to improve the functionality and user satisfaction of indoor navigation by utilizing augmented reality technology. Our goal is to develop a solution that is both technically robust and user-friendly by addressing the actual needs of users in a specific situation. This project aims to close the divide between theoretical developments in augmented reality (AR) technology and their practical use in real-world situations. Ultimately, it seeks to contribute to the overall progress of AR-based indoor navigation systems.

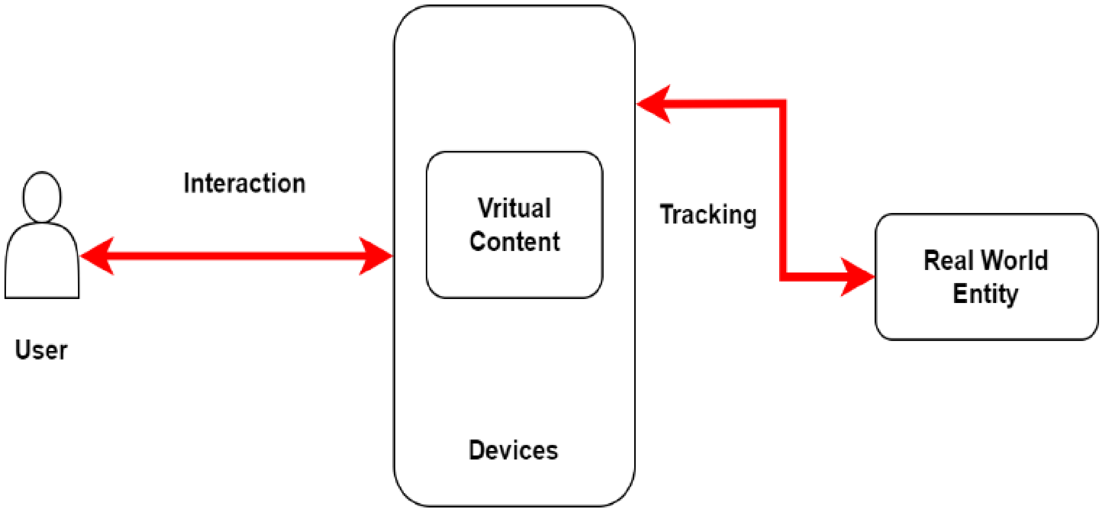

Figure 1. AR Indoor Navigation Architecture System

The main goal of this pilot project is to acquire a thorough comprehension of user interactions with augmented reality (AR) indoor navigation. The study will primarily assess the DutaNavAR application and its efficacy in facilitating indoor navigation tasks. The researchers' focus is to evaluate the usability, functionality, and overall user experience of DutaNavAR by analyzing user interactions in the context of indoor navigation. The project aims to get insights into user interactions using AR technology for indoor navigation by observing and collecting feedback from participants throughout navigation activities.

The pilot research functions as a first investigation to detect any usability problems, user inclinations, and places that might be enhanced in the DutaNavAR program. The results of this study will provide valuable insights for improving and optimizing the application's usability and efficacy in real-world indoor navigation situations.

The primary objective of the pilot project is to establish the foundation for future research and development endeavors in AR indoor navigation technology. Researchers can enhance the development of indoor navigation AR technology by acquiring a more profound comprehension of user behaviors and preferences. This will ultimately lead to improved user experience and usability of AR applications.

2.1. Participant

For optimal testing of HARUS, it would have been preferable to include a sample size of 33 people. This coincides with the recommended minimum number of participants for trials that use questionnaires, which is normally indicated to be around 30 respondents [17]. The chosen sample size guarantees a strong and statistically significant dataset for evaluating usability using the HARUS scale.

Usability studies often employ smaller sample sizes to effectively identify issues and gather user feedback. For instance, the TrackSugAR application was evaluated with 14 participants using both the System Usability Scale (SUS) and HARUS, yielding reliable usability insights [18]. Similarly, a study assessing a mobile augmented reality application for teaching Karnaugh Maps involved 30 participants, effectively employing SUS and HARUS for evaluation. These examples demonstrate that sample sizes ranging from 14 to 30 participants are common and effective in usability studies involving HARUS [19]

By including a total of 30 individuals in the study, researchers can collect a wide range of views and perspectives, hence improving the dependability and accuracy of the usability assessment. Increasing the sample size enables a wider range of responses, facilitating the identification of patterns, trends, and potential usability concerns with better accuracy. Moreover, a bigger sample size offers enhanced confidence that the results accurately reflect the characteristics of the intended user group.

2.2. Trial Setup

Participants are provided the authorization to use the DutaNavAR application on augmented reality (AR) enabled devices, such as smartphones. Users are given a short introductory session to familiarize them with the features and functionalities of the program, ensuring that they can operate it successfully. This initial session functions as a preparatory stage before participants undertake the actual assessment of the usefulness of the augmented reality indoor navigation system. During this session, users are instructed on how to utilize the DutaNavAR application's interface, becoming acquainted with its navigation tools, interactive aspects, and any other important features necessary for interior navigation.

During this introduction session, participants will acquire a comprehensive comprehension of how to engage with the program. This includes learning how to enter destinations, analyze augmented reality overlays, and efficiently employ navigation tools. In addition, participants are shown and provided with explanations of any particular gestures or interactions necessary for optimal navigation inside the program. The researchers want to reduce misunderstanding and ensure that participants can easily navigate the indoor environment during the evaluation process by giving this early instruction. This initial session not only boosts user assurance but also enables a more seamless and efficient assessment of usability, allowing participants to concentrate on offering meaningful comments regarding their experience with the DutaNavAR application.

2.3. Indoor Navigation Task

Participants are then presented with a series of indoor navigation tasks. These tasks are designed to simulate real-world scenarios, such as finding specific rooms, locating points of interest, or following a predetermined route within the indoor environment [20]. The tasks are carefully structured to cover a range of navigation challenges, including complex paths and destinations. Every participant is required to accomplish five specific tasks, which include exclusively using the stairs (without utilizing the lift) within the Agape Building at Universitas Kristen Duta Wacana. These tasks are outlined as follows:

- Participants are instructed to visually examine the markers located in the FTI2 Lab. In the case of a favorable result, the participant is instructed to locate and proceed to the office of the Master of Management. Afterward, participants were instructed to proceed with their navigation toward the Computer Lab. This task provides the purpose of evaluating the application's ability to navigate within rooms located on the same floor.
- Subsequently, the participants were provided with directions to commence their navigation towards the office of the Faculty of Theology, followed by their visit to the office of the Faculty of Information Technology. This study aims to assess the application's ability to transition from the 2nd floor to the 3rd floor.
- Subsequently, the attendees were directed to proceed to the office of the Master of Architecture. The primary objective of this task is to assess the application's vertical navigation capabilities across two stories, namely from the 3rd floor to the 5th floor.
- Subsequently, the attendees were directed to proceed to the administrative office of the Faculty of Business. The objective of this work is to assess the functionality of the application as it descends from the 5th floor to the 4th floor.
- Finally, participants were instructed to revisit FTI Lab 2. This exercise proved to be valuable in assessing the application's ability to successfully navigate down two floors, specifically from the 4th floor to the 2nd floor.

After the completion of the exercise, participants will be requested to complete a questionnaire that comprises a series of HARUS questions shown in Table 1. In addition to the above questions, several additional questions were included to categorize the existing respondent profiles based on factors such as gender and prior experience with AR applications.

Table 1. The Handheld Augmented Reality Usability Scale [11]

No.	Manipulability Measure
1.	I feel that engaging with this application needs significant effort of muscular energy.
2.	Using the application did not cause discomfort in my wrists and arms.
3.	Handling the device during application operation proved to be a challenge for me.
4.	The process of entering information into the application was effortless.
5.	I experienced hand or arm fatigue after utilizing the application.
6.	The application is, in my opinion, user-friendly.
7.	At some point, I felt as though I was losing my grasp and would drop the device.
8.	In my opinion, this application's operation is straightforward and uncomplicated.
	Comprehensibility Measure
9.	Working with this application seemingly necessitates a substantial mental investment.
10.	The quantity of information presented on the screen was deemed suitable in my opinion.
11.	The readability of the information presented on the screen was challenging in my opinion.
12.	I had the impression that the information display was sufficiently responsive.
13.	I found the information that was presented on the screen to be perplexing.
14.	The on-screen text and symbols appeared to be legible to me.
15.	I felt that the display was flickering too much.
16.	Believed that the on-screen information was consistent.

The HARUS framework has 16 statements that are designed to address typical issues faced in HAR applications. Subsequently, participants were requested to assess their level of agreement by using a 7-point Likert scale. The HARUS score was calculated using a process similar to the calculation of the SUS score [21]:

1. When dealing with positively stated things, deduct one from the user's response. To obtain the value for negatively mentioned items, deduct the user's response from seven.
2. Sum up all of these transformed responses.
3. Calculate the quotient of the number divided by 0.96 to obtain a score that falls within the range of 0 to 100.

3. RESULT AND DISCUSSION

The DutaNavAR mobile application was crafted utilizing the Unity game engine as its development platform, ARCore as the AR framework, and NavMesh as the navigation framework [22]. ARCore, developed by Google, enables augmented reality experiences by leveraging a mobile device's camera, sensors, and processing power to accurately map the environment and track the user's movements [23]. Additionally, NavMesh, a system built into Unity, is employed for navigation within the AR space. NavMesh consists of a set of interconnected triangles that define walkable areas within a 3D environment. To create a NavMesh, developers first establish the boundaries of the walkable space, then generate the mesh that allows virtual agents (e.g., users or characters) to navigate effectively [24]. NavMesh constitutes a collection of triangular shapes that delineate areas in a 3D space where characters can traverse. To establish a NavMesh, one must define the boundaries of the walkable area and construct a mesh that fits within those confines[25].

Figure 2 illustrates the functionality and workflow of the AR Indoor Navigation System, showcasing how the application operates to assist users in navigating complex indoor environments. The figure provides a visual representation of the system's core components, including its interface, interaction with the AR environment, and step-by-step navigation process. It demonstrates how the application identifies the user's current position, maps the indoor environment using ARCore, and overlays virtual navigation cues onto the real-world scene.

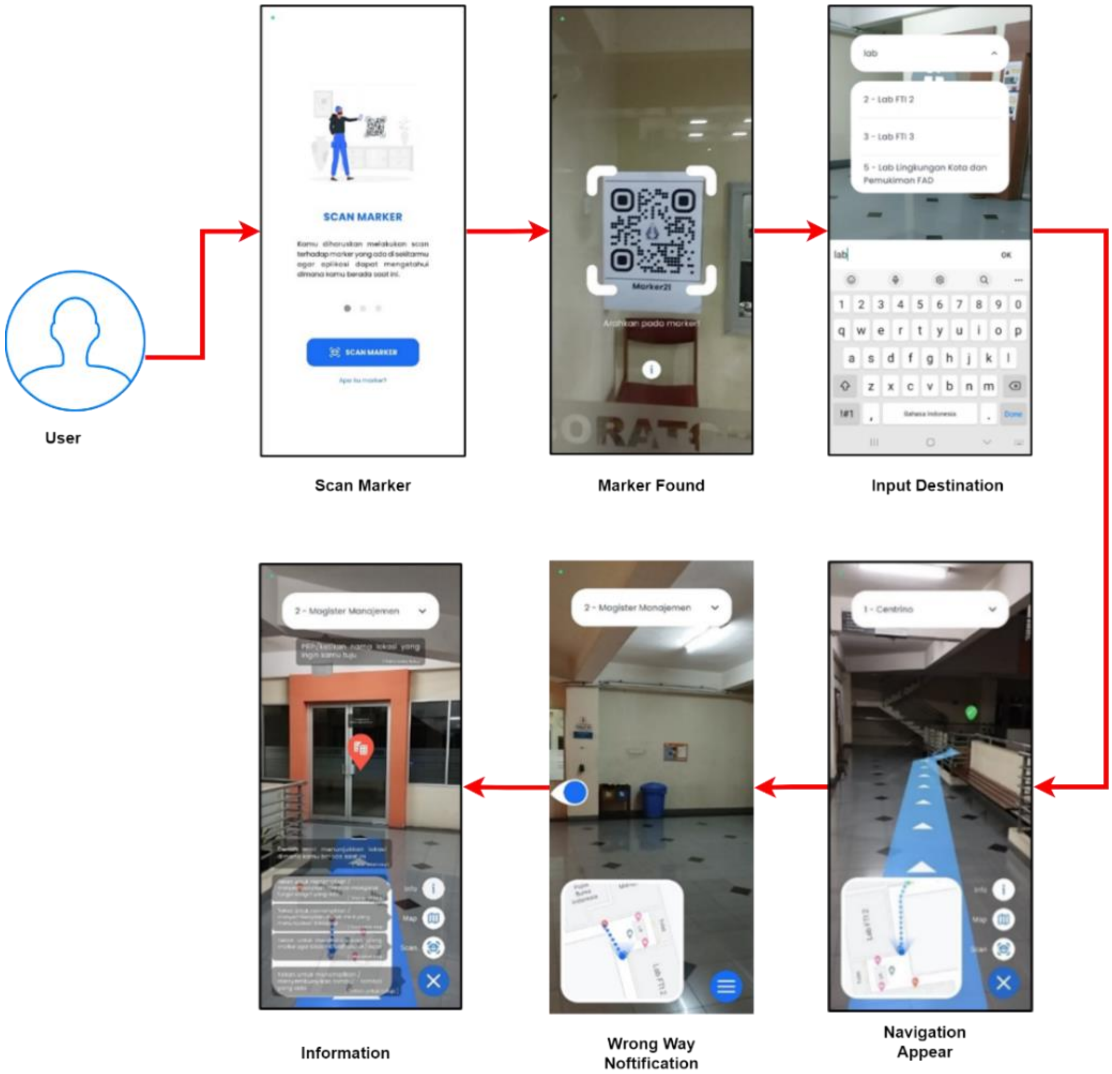

Figure 2. DutaNavAR – AR Indoor Navigation System

Additionally, the workflow highlights the integration of the navigation algorithm powered by NavMesh, which calculates the optimal path within the defined boundaries of indoor space. This figure effectively conveys the seamless interaction between the user, the AR elements, and the navigation framework, emphasizing the application's user-friendly design and efficiency in guiding users through the Agape Building.

After the application's creation was finished, a series of user trials and evaluations took place. These trials involved persons with different levels of knowledge and experience with augmented reality (AR) technology. The purpose of these experiments was to evaluate the usability and efficacy of the DutaNavAR application in enabling indoor navigation through the use of handheld augmented reality.

During the trials, participants were granted usage of the DutaNavAR application on their augmented reality (AR)-capable devices, commonly smartphones. They were thereafter led through an initial session to acquaint themselves with the features and functionalities of the application. This session guaranteed that participants were able to proficiently use the application before participating in the usability evaluation procedure.

After that, participants had to use the DutaNavAR program to navigate through indoor spaces. During this procedure, researchers observed and recorded their interactions with the application, enabling them to collect useful information regarding its usability, efficacy, and user experience.

The participant pool consisted of persons with diverse levels of experience and proficiency in utilizing augmented reality (AR) technologies. The wide range of participants' characteristics allowed researchers to gather extensive feedback and pinpoint any possible usability problems or areas for enhancement in the DutaNavAR application.

This study had a sample of 33 participants, consisting of persons of both male and female sexes. The main goal was to evaluate the participants' aptitude and skill in utilizing AR apps. The selection of participants was contingent upon their previous expertise and familiarity with augmented reality (AR) technology, as this factor was important in assessing their capacity to proficiently interact with and navigate AR applications. The attributes of the participants are reported in Table 2.

The incorporation of both male and female volunteers guaranteed a heterogeneous representation, enhancing the study's findings with unique viewpoints and experiences. The researchers sought to assess how participants' prior experience with AR technology affected their interactions and skills with AR applications. This methodology facilitated a detailed analysis of the participants' proficiency in employing augmented reality (AR) technology, so contributing to a thorough comprehension of their talents and difficulties in navigating AR apps.

Table 2. Participant Characteristics

Gender	**Familiarity With AR Application**		
	Yes	***Not Yet***	***Total***
Male	12	6	18
Female	2	13	15
Total Participant	14	19	33

The composition of participants in the study was designed to achieve a gender-balanced representation, enabling an analysis of potential variations in the utilization of augmented reality applications based on gender. It is imperative to acknowledge that there may be variations in technology adoption and usage patterns based on gender, and taking this factor into account can enhance the overall comprehension of user interactions with AR technology [26].

The gender difference in AR familiarity among participants could significantly impact the usability scores and navigation performance, as prior experience with AR often correlates with higher confidence and efficiency in interacting with AR applications. In this study, if male participants are predominantly familiar with AR while female participants are not, this familiarity bias might lead to differing results. For instance, male participants may find the application easier to use and more intuitive, reflecting positively in usability scores, while female participants might face challenges due to their unfamiliarity, potentially affecting their navigation performance and satisfaction.

This disparity emphasizes the need for a discussion about how prior AR experience influenced the outcomes. A comparative analysis of usability and performance metrics, adjusted for AR familiarity, would provide a clearer picture of whether the observed differences are due to gender or prior experience. Including this analysis could highlight areas where the application may need adjustments to support less experienced users, ensuring a more inclusive design.

The evaluation of participants' proficiency in using AR applications encompassed multiple dimensions, encompassing their skill in manipulating AR elements, and understanding the operational mechanisms of these applications [27]. The previously mentioned metrics were assessed to ascertain the participants' proficiency and ease in using AR technology for indoor navigation [28].

This study aimed to improve the comprehensiveness of opinions and experiences of the utilization of AR applications by incorporating both male and female participants. The objective of this study was to gain a deeper understanding of how gender may impact individuals' skill levels and preferences when it comes to utilizing AR technology for navigating indoor spaces [29].

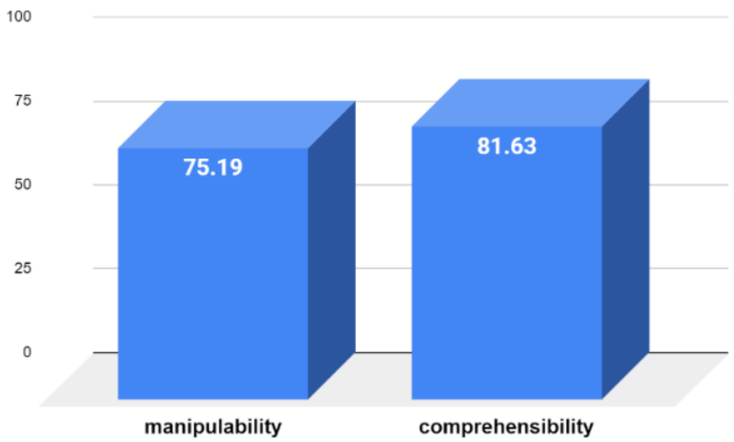

Figure 3. Scores for the Manipulability and Comprehensibility Aspects of HARUS

The results of the evaluation, which involved 33 participants using the HARUS framework are presented in Figure 3. The mean score for manipulability, a metric utilized to assess users' ability to manipulate and interact with the augmented reality elements, was 75.19, as illustrated in Figure 3. Furthermore, the average comprehensibility score, denoting the degree to which users understood the augmented reality system's functionalities and features, was 81.63.

HARUS uses the identical calculation methodology as the System Usability Scale (SUS) and later applies the SUS score interpretation scale to the obtained results to interpret them similarly [30]. The average HARUS score, as determined by the results of the calculations, was found to be 78.41. Based on the use of the SUS score interpretation scale, as depicted in Figure 4, it can be deduced that the HARUS score of 78.41 falls inside the good category, specifically Grade B. This value is above the established threshold for SUS score interpretation, which is 68 [31]. In addition, it is worth noting that the HARUS score for the indoor navigation application is within the acceptable range. This implies that the findings of this study can facilitate the utilization of a marker-based AR approach that is deemed satisfactory by users.

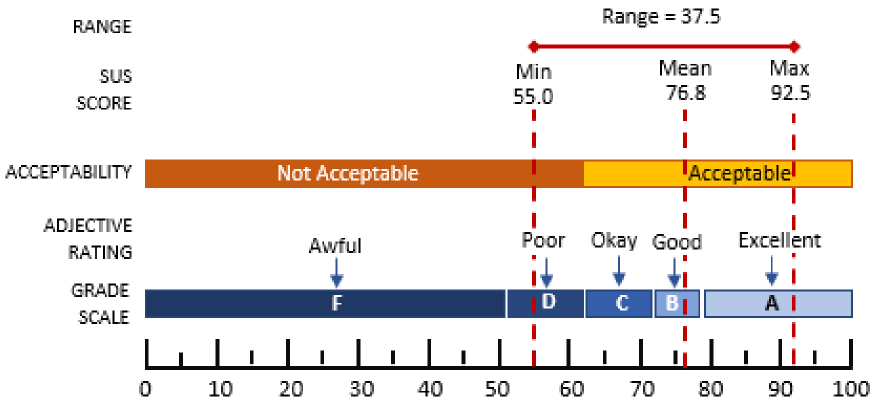

Figure 4. SUS Score Results Interpretation Scale [32]

Based on the calculation of the mean score for each extant statement, it is seen that statement 1 shows the lowest degree of manipulability, with a score of 2 being the minimum. Statement 1 has a score of 2, which is attributed to a total of 7 participants. Statement 1 is "*I Think that interacting with this application requires a lot of body muscle effort*". Among these participants, 4 males have utilized AR, 2 males have not used AR, and 1 female has also not used AR.

However, statement 16 shows the lowest comprehensibility score, registering a score of 1. Statement 16 *is "I thought that the information displayed on the screen was consistent"*. Statement 16 has been attributed to a score of 1, which was reported by a single participant. This participant is identified as a female who has utilized AR technology.

4. CONCLUSION

The insights gained from the evaluation findings of 33 participants utilizing the Handheld Augmented Reality Usability Scale (HARUS) offer significant value in understanding the usability and user satisfaction of AR indoor navigation. The mean usability score of 78.41 indicates an important level of usability, suggesting that users viewed the system as both user-friendly and efficient. The obtained manipulability score of the system 75.19 and comprehensibility score of 81.63 indicate that users possess a high level of control and understanding over the AR features. This, in turn, contributes significantly to fostering a positive user experience. HARUS focuses primarily on manipulability and comprehensibility but does not capture other critical dimensions, such as the cognitive load experienced by users, the emotional impact of interacting with the system, or long-term engagement and usability in real-world settings.

In summary, the assessment shows that the AR indoor navigation system exhibits a substantial degree of usefulness and user pleasure. These findings highlight areas for targeted enhancements in system design and functionality, paving the way for further advancements in augmented reality (AR) technology, specifically concerning indoor navigation applications.

The study's findings indicate that users perceived the AR indoor navigation system as intuitive and pleasant, which had a beneficial impact on its overall usefulness. This data provides valuable insights for improving the system to address any identified usability concerns and further increase user experience. Developers can enhance the AR technology by comprehending users' preferences and the difficulties they face when navigating. This iterative process allows for the improvement of the technology to better align with users' requirements and expectations.

Furthermore, the favorable reception of the AR indoor navigation system highlights its promise as a practical solution for navigating indoor spaces. With the ongoing advancement of technology, there is a potential for further development in augmented reality (AR) technology, particularly in enhancing interior navigation experiences. This may entail incorporating sophisticated functionalities, enhancing user interfaces, and harnessing cutting-edge technologies to develop even smoother and immersive indoor navigation solutions.

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