Comparative Assessment of 2D and Mixed Reality Interfaces for Improving Situational Awareness

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***Abstract*—Environmental factors, such as fog and darkness, significantly limit the visibility of security personnel. In addition, limited field knowledge and inexperience can lead to misinterpretation of events, which may endanger both the task and human lives. Our study compares the situational awareness of participants and the effectiveness of purpose-built mobile applications and Mixed Reality (MR) glasses in security-related scenarios for navigation involving capturing a moving hostile target in a forested environment. Results of the experiments in terms of task completion time, navigation accuracy and questionnaire responses show that the utilization of MR technology improves situational awareness and user engagement compared to the 2D map-based mobile applications.**

***Keywords*—mixed reality; situational awareness; head mounted displays.**

I. Introduction

Situational Awareness (SA) is a theoretical framework that involves comprehending various events within a confined time and spatial context to gain a better understanding of the surroundings [1]. Military operations or national security frequently unfold in unfamiliar and unmapped territories. Consequently, knowing the environment becomes beneficial.

Mixed Reality is a powerful tool for security personnel in military camps, providing a comprehensive and effective approach to protect personnel, equipment, and sensitive information [2]. Mobile technologies, such as Head Mounted Displays (HMD) and MR applications, can enhance their vision by providing relevant data and minimizing distractions [3]. The effectiveness in challenging settings depends on the utilization of Command, Control, Communications, Computers, Information, and Intelligence (C4I2) tools. C4I2 tools are optimal performance that can be effective in increasing the SA of security personnel [4]. Applications of MR have proven to be valuable for security personnel, as they enhances SA and facilitate the attainment of mission objectives with greater efficiency [5]. These applications can help security personnel in foggy places obtain information in invisible places.

In this study, a radar simulation application was created using a surveillance radar as a sensor, and two purpose-built applications, which are a mobile map-based application and an MR application, were developed. This study aims to investigate potential differences in usability level between these two purpose-built applications through experiments. In experiments, participants delve into two different groups for simulating a security-related scenario. One group used the mobile application while the other group used the MR application. When the task was finished, participants were asked to fill out questionnaires. Also, task completion times and deflection errors were calculated. This analysis will provide valuable insights into the applications' efficacy and help draw meaningful conclusions about their respective performances based on the data collected from participants.

The rest of the paper is organized as follows. Section II provides and overview of the relevant studies that have contributed insights to the present study. Section III explains problem definitions and proposed applications. Section IV gives information about the experiments conducted on participants. Section V includes results. Section VI contains a discussion of potential ways for future research related to the subject matter of the study. Lastly in Section VII, results of the conducted experiments is given.

II. Literature Review

Augmented Reality (AR) and MR changed how we navigate our environment by mixing virtual and real worlds. The impact of civil navigation through various applications, advancements, and research findings was examined to evaluate how AR and MR were employed.. Jin et al. compare the effectiveness of Natural User Interface (NUI) using HMD with AR and Graphical User Interface (GUI) in storytelling [6]. The results show that NUI is more effective in terms of user engagement, immersion and enjoyment. When using NUI, participants feel more present in the story world. The GUI, on the other hand, is perceived as less immersive and interesting.

Dong et al.'s research compares the external and visual behaviors of users using AR and 2D maps for pedestrian way-finding [7]. AR offers a more intuitive and immersive experience, allowing users to see their surroundings, receive directional prompts, and adapt to their location and orientation. 2D maps are found to be less engaging and difficult to interpret.

Rocha et al. propose a mobile application that integrates AR and accessibility features [8]. The system combines AR with audio instructions and haptic feedback, providing real-time information about the user's surroundings. The findings indicate that the system displayed an enhancement in navigating unfamiliar environments.

Chimielewski et al. report on an AR system using mobile devices and sensors to aid decision-making and SA in military combat scenarios [9]. The developed system uses accelerometers and gyroscopes to provide orientation and position. The case study shows that the AR system improved soldiers' understanding of situations, assessed threats, and made informed decisions. The paper highlights the potential of AR technology to improve safety and effectiveness on the battlefield.

You et al.'s study reviews the use of AR in urban warfare scenarios, highlighting potential benefits such as enhanced SA, improved decision-making, and increased safety for soldiers [10]. The proposed system overlays real-time data onto soldiers' fields of view, providing a comprehensive picture of their surroundings and the battlefield.

Commercial products utilizing AR/MR exist, and the literature review delves into how AR and MR have shaped diverse business sectors. Eyekon is a wearable computer that uses a support system based on intelligent agents [11]. It aims to provide a comprehensive representation of real weapons to maximize SA in a battlefield environment, using smart icons. It also uses brightness for detecting depth and arrow guidance to direct attention to specific targets. Juhnke et al. accomplish their objective by constructing a framework known as the Intelligent Augmented Reality Model (iARM) [12]. iARM's objective is to establish an AR interface that bridges the gap between the physical environment and the user through the use of a smart screen. Microsoft partnered with the US Army to develop a customized version of the HoloLens called the Integrated Visual Augmentation System (IVAS) for military use [13]. The IVAS has several characteristics such as digital overlays, night vision capabilities, ballistic protection, and hearing protection which are highly suitable for military operations.

The purpose of this study is to show how MR user interfaces surpass mobile map-based applications in the context of military use, as well as to provide empirical evidence to support the hypothesis that MR user interfaces improve performance and effectiveness for security applications. This study aims to improve academic knowledge and practical use of MR user interfaces in security scenarios by carrying out an analysis.

III. Proposed Physical Security Applications

A. Problem Definition and Design Issues

The maintenance of border security holds significant importance for all countries. Since not all borders contain physical barriers, this matter poses a challenge for border security. Cameras and radars are widely utilized gadgets for safeguarding borders between countries. The utilization of radar is typically entrusted to an operator. If any atypical activity is identified on the radar display, the operator will proceed to examine the reliability of the stated activity. If the activity does not qualify as an emergency, the operator shall proceed with examining the radar screen. If it qualifies as an emergency, the operator will initiate contact and provide the required information. Security personnel will proceed to the target location to evaluate the situation. These personnel are often equipped with body armor and weaponry. They lack access to radar screens, and their sole method of obtaining information is through walkie-talkie. The issue in this particular scenario relates to communication. Enhancing the efficiency of communication could provide benefits for security personnel.

The mobile and MR applications proposed in this paper are developed to address the issue described above. Security personnel need a tool for obtaining information about the target. Having access to this information in real time can allow them to anticipate potential dangers.

B. Overview of the Proposed System

The general structure of the proposed system is shown in Figure 1. The system is composed of four fundamental components. It includes a radar, a server, a mobile device, and an HMD. Due to privacy and security issues, a simulator is used for mimicking the radar outputs in experiments.

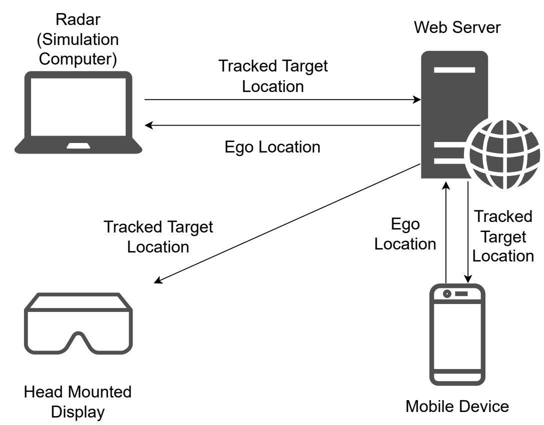

Figure 1. General structure of the proposed system.

The MR application works on an HMD while the mobile application operates on a mobile device. The web server uses a database and a server. Meanwhile, the simulation application runs on a computer.

C. Radar and Web Server

The radar produces a signal characterized by a particular frequency and subsequently examines the received signals in order to identify and classify the detected objects. The detections possess data regarding the coordinate system and processed signal outcomes. The detection algorithm receives these pieces of information as input to the algorithm which can determine whether the detected signal is a target or a false alarm. If the output of the algorithm corresponds to a specific target, additional information such as geolocation and identification (e.g., human, animal, vehicle) is computed. The utilization of a simulation is employed during the target and tracked target location creation process, followed by uploading these locations to the web server in a sequence. The generated tracked target locations correctly represent the location of the target.

The tracked location is uploaded on the web server via HTTP requests by the radar simulation. JSON is used as the data format. An example tracked target location data is presented such as {"trackId":1, "latitude":39.71, "longitude":32.15, "horizontal":43.7, "vertical":28.2}.

To determine horizontal and vertical distances, origin and tracked target location are used. The origin location is the geolocation where security personnel begin using the HMD. It is also the location where the radar is positioned. The haversine formula is used for calculating distances between two points on a spherical surface using the coordinates of the two locations. The formula to calculate the distance between the location information of the security personnel and the shortest route involves calculating the distance of the point perpendicular to the line.

Communication between simulation and mobile/MR applications is provided by the web server application. The application serves three functions: responding to requests related to the geographical origin location, responding to the geographical location of the ego (in our experiment the ego location is the participant location) and responding to requests about the tracked target location. The web server receives HTTP requests from the simulation and the mobile application and stores them in its database. When the mobile or MR application requests an update of the tracked target location, the web server responds to these requests as in Figure 1.

D. Mobile Application

A mobile application has been designed with a 2D map-based user interface to function as a physical security application. The mobile application user interface is shown in Figure 2.

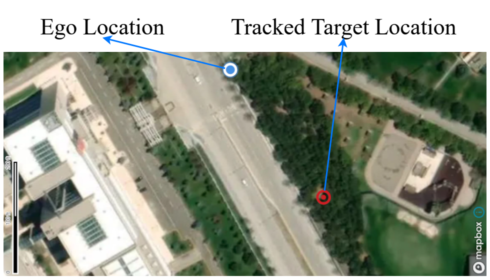

Figure 2. Mobile application user interface (when held horizontally).

Satellite images, ego and tracked target locations are visualized on the map. The ego location is acquired through the GPS and the tracked target location is retrieved from the web server.

E. MR Application

An MR application is developed and deployed on the HMD for the purpose of visualizing the tracked target location, which is aimed to serve as a security personnel HMD. The tracked target location in the web server is requested from the application and the target object can be displayed on the screen. A screenshot taken from the MR interface is shown in Figure 3.

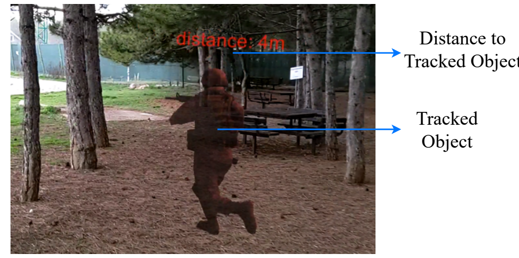

Figure 3. MR application user interface.

Since the MR engine uses object display by the coordinate system consisting of three axes (*x,y,z*) and sensory location in real-world uses geo-location, merging them on the same plane is needed. This merging is made possible through a conversion of origin location to *x,y,z* axes. For HMD's accurate object visualization, its display needs to be aligned with the north direction. This mapping can be seen in Figure 4 (N represents North for the real-word coordinate system).

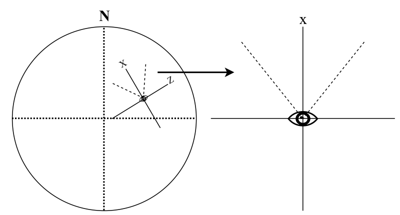

Figure 4. MR Engine (left panel) and Real-world (right panel) coordinate systems.

HoloLens 2, which was used as the main HMD in our study, has a maximum draw distance for displaying objects. A displayed virtual object is constrained to be visible up to 50 meters. An object which has a distance beyond 50 meters can not be rendered on HMD. As seen in Figure 5, the target location on the MR plane is projected on a 30 meters radius from the HMD. This will create a virtual target location so that the virtual location will always be visible regardless of how far the target is located. Calculations are made with the tracked target and ego locations and the object's virtual position is displayed on the HMD.

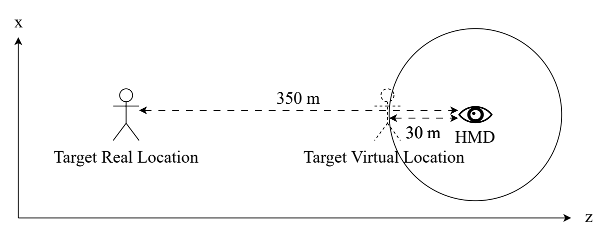

Figure 5. HMD draw distance.

The visibility of objects is significantly compromised when HMDs are used in outdoor environments. In order to enhance the visibility of the target object, a red color layer is added.

IV. Experiments

A. Hardware and Software

The web server application was developed using Firebase. To establish communication with the radar simulation, the mobile device, and the MR applications, Firebase functions were used. Meanwhile, the radar simulation application was developed for console application with Java 17 spring boot.

During the development process of the mobile application, Kotlin version 1.6 was used. Samsung S20FE smartphone was used for the deployment using Android Studio. The mobile application made use of Mapbox as its map service provider. The Microsoft HoloLens 2 was selected as the preferred HMD for the MR application. The MR application was created using the Unity platform and compiled specifically for the Advanced Reduced Instruction Set Computer (RISC) Machine (ARM) 64-bit architecture. This compilation was provided by the Mixed Reality Toolkit (MRKT).

B. Experimental Scenario

The experimental scenario was carried out in an environment with a moderate presence of trees, pathways, a pond, a bridge, man-made objects, etc. as shown in Figure 6, because the real-life surveillance, monitoring and tracking activities take place in similar environments. An average person is capable of walking the outer perimeter of this particular region in a time frame of six minutes, covering a total distance of 400 meters. Also, the best and the worst possible routes from the origin to the targeted location are shown in Figure 6. Red dots show target movement in the experiment. The movement stops shortly after the experiment begins. This ensures that participants are confident that they have reached the targeted location. The shortest path is around 170 meters while the longest path is around 250 meters.

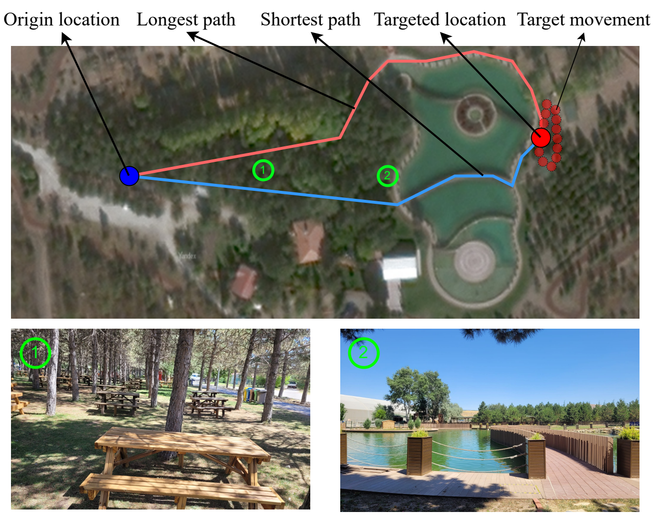

Figure 6. Experiment area (Upper panel: top view, lower panels: photos taken at the given locations).

In this experiment, participants start by positioning themselves at the origin location and proceed to use the mobile device or put on the HMD. Before starting, a hand weight is provided to the participant to simulate the security personnel's hands being occupied and physically hindered with additional weight. After the virtual data (for the 2D map or the MR content) are displayed on the application, the timer is initiated, prompting the participant to take action in locating and tracking the target. Since the simulation of the target is moving, the locations change continuously. Simultaneously with the start of the participant walking, the mobile application sends the ego location to the web server. Once the participant arrives at the tracked target location, the timer stops and the elapsed time is computed. Each participant tracked the target location once using only one application. The target location followed the same route for both applications. The experiment comes with limitations, such as the requirement to carry weight at all times and the restriction of the participant to not leave the designated area.

C. Participants

Two groups of participants were randomly selected, with each group consisting of 15 individuals, resulting in a total of 30 participants. The first group (Group 1) used the mobile application, whereas the second group (Group 2) used the MR application. All individuals within Group 1 had prior experience using a mobile navigation application of some kind. Conversely, 53 percent of the participants in Group 2 had prior experience using AR/MR applications.

D. Evaluation metrics

This study uses four evaluation methods. Objective measurements, such as task completion time and navigation accuracy measurements, are obtained through impartial methods. It was aimed to compare both mobile and MR applications in terms of guidance accuracy by calculating the deviation from the ideal shortest route toward the target. An example of deviation is shown in Figure 7. From each geographical coordinate in the participant's walking route, the perpendicular deviation from the shortest path is retrieved.

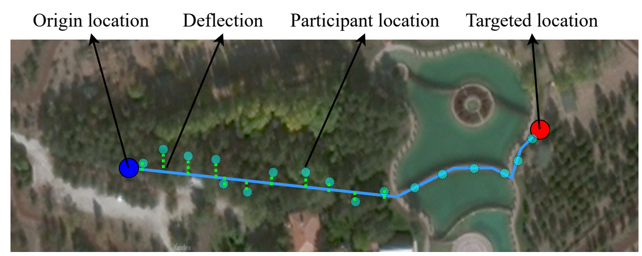

Figure 7. Illustration of the calculation of deflection error.

Subjective measurement surveys, such as NASA Task Load Index (TLX) and Post Study System Usability Questionnaire (PSSUQ), rely on subjective assessments [14] [15]. The Appendix lists the questions of the questionnaire.

V. Results

A. Task Completion Performance

Table I shows the time taken by the participants to complete the experiment. Based on the results, participants who used the MR application (Group 2) arrived quicker to the target compared to participants who used the mobile application (Group 1).

Based on the comments made by participants using the mobile application, they experienced a loss when using the application while holding the weight in their hands. They also

TABLE I
AVERAGE TASK COMPLETION TIME RESULTS

Group	Time (min.)
Group 1	3:37 ±1:01
Group 2	2:54 ±0:28

stated that they initially allocated some time to determine the optimal route to reach the targeted location on the map.

Participants in Group 2 commented that they perceived it as straightforward to determine which way to proceed initially, because they were able to see the terrain, path and environmental objects clearly while walking. However, they reported that, when faced with the obstacle of crossing the pond, it took some time to decide on the right path.

B. Navigation accuracy

The findings related to the navigation accuracy errors can be seen in Table II. Based on the results, it was observed that individuals using MR applications showed a higher degree of proximity to the shortest path in comparison to those using the mobile application.

TABLE II
AVERAGE DEFLECTION ERROR

Group	Error (meters)
Group 1	6.60 ±2.10
Group 2	3.17 ±1.34

During the experiment, the participants encountered deviations from the shortest path because of the decisions they made while navigating toward the targeted location. As a result, mobile application users exhibited both a delay and a higher degree of deviation. The participants who used the mobile application indicated that they had difficulty initially determining where they would go.

C. Results of NASA TLX Questionnaire

The findings from the NASA TLX Questionnaire are displayed in Figure 8. According to the results, the metric with the lower score is considered preferable over the others in each of the six metrics. The scale for each metric ranges from 1 (the best outcome) to 21 (the worst outcome). These scores are computed by averaging all participants' scores using the two applications.

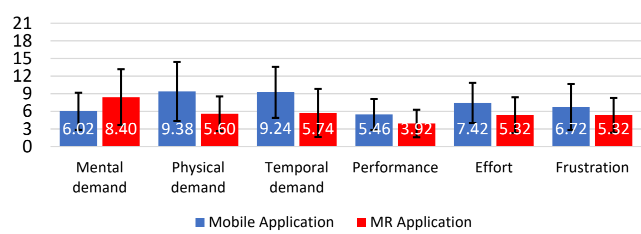

Figure 8. NASA TLX questionnaire results.

The mental demand is seen as the sole outcome in favor of the mobile application. The mental demand score is 6.02 for the mobile application and 8.4 for the MR application. Based on the t-test result, p=.118 shows that there is no important statistical difference between the results. According to the participants, the mobile application makes use of a user interface that is more recognizable. However, participants faced difficulties when trying to simultaneously participate in both the physical environment and the virtual representation using the MR application.

In all other performance categories except the mental demand, the MR application outperformed the mobile application. It is shown that physical demand has the highest difference between the mobile (9.38) and MR (5.6) applications (p=.019). The participants expressed that the physical weight they had in their hands posed challenges while using the mobile application. The temporal demand score of the mobile application (9.24) is statistically significantly higher than the MR application (5.74) (p=.031). The outcome can be related to the temporal inefficiency encountered by individuals using the mobile application. The performance of the MR application (3.92) is observed to be better than that of the mobile application (5.46) (p=.101). The participants were provided with information about task completion times and the accuracy of reaching the targeted location. Based on the findings, it was observed that the users of the MR application perceived themselves to have achieved higher levels of success. The mobile application's effort score (7.42) is higher than the MR application's (5.32) (p=.089). According to the feedback provided by participants using the mobile application, it was occasionally necessary for them to disrupt their use of the application. Due to comparable factors, it is stated that the frustration score is greater on the mobile application (6.72) in contrast to the MR application (5.32) (p=.278).

D. Results of PSSUQ

The PSSUQ enables participants to share their thoughts and recommendations regarding the interfaces they tested. PSSUQ consists of nineteen questions that assess the general system usefulness, information quality and interface quality of the applications. The scale for each metric ranges from 1 (the best outcome) to 7 (the worst outcome). These scores are computed by averaging all participants' scores using the two applications. The results of PSSUQ are presented in Figure 9. Based on the results, the overall score indicates that the MR application (2.22) showed improved usability compared to the mobile application (3.15).

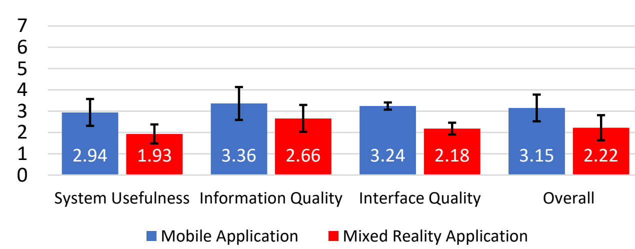

Figure 9. PSSUQ results.

System usefulness scores show that the MR application (1.93) provided better satisfaction than the mobile application (2.94). Participants reported that the MR application was easier and more comfortable for object tracking. The individual results of the system usefulness section are shown in Figure 10.

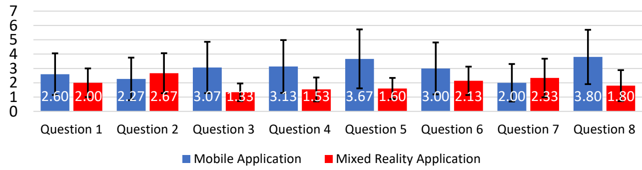

Figure 10. PSSUQ system usefulness results.

T-test two-tailed values of Q3 (p=.002), Q4 (p=.006), Q5 (p=.002) and Q8 (p=.002) show that there is a significant statistical difference in favor of the MR application. The results given by participants who used the MR application (1.33, 1.53, 1.60) in Q3, Q4, and Q5 were comparatively lower than those given by participants who used the mobile application (3.07, 3.13, 3.67). The reason for this outcome is that the participants in Group 2 said that they were able to finish the experiment with greater effectiveness, speed, and efficiency. These findings align with the outcomes of the analyses carried out on task completion time and navigation accuracy. Based on the finding of Q8, it was observed that participants had the belief that they could achieve higher levels of productivity more quickly when using the MR application (1.80) as opposed to the mobile application (3.80). The reason for this can be because of the hand weights.

The information quality shows a similar pattern. The MR application (2.66) gives higher quality information than the mobile application (3.36). The participants who used the MR application reported that they got back to the route easily when they got off the route due to obstacles in the surroundings. The results can be seen in Figure 11.

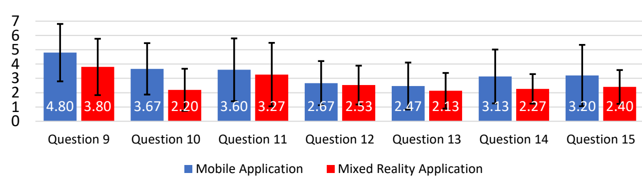

Figure 11. PSSUQ information quality results.

According to the responses to Q10, it was observed that participants who used the MR application (2.20) were able to recover more easily when they made a mistake than those who used the mobile application (3.67) (p=.021).

Interface quality difference is also in favor of the MR application (2.18) compared to the mobile application (3.24). According to the participants, the MR application shows an improved interface quality due to its ability to present the tracked object in three dimensions within a real plane. The results on interface quality are shown in Figure 12.

Both applications provided a sufficient amount of information to the participants. However, based on the responses to Q17, it was observed that the participants think the mobile application (3.07) has a lower number of required features compared to the MR application (1.87) (p=.050). This is believed to be caused by the disparity in the presentation of identical information between the two applications.

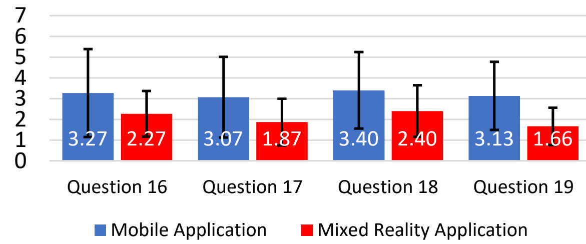

Figure 12. PSSUQ interface quality and overall satisfaction results.

Based on the findings of Q19, which is directly related to the overall system satisfaction, it can be concluded that participants expressed a higher level of satisfaction with the MR application (1.66) compared to the mobile application (3.13) (p=.006). There is no statistically significant difference observed for the remaining questions.

VI. Discussion

This study intends to contribute to the academic understanding and practical implementation of MR user interfaces in military settings. Based on the findings, it can be inferred that the utilization of mixed reality technology has the potential to provide an enhancement to the situational awareness of security personnel.

Several methods have been discussed for a more effective use of the study that has been conducted. In the beginning, to track the target more accurately, navigation arrows can be used to navigate to the tracked location.

In addition, in mixed/augmented reality systems, calibration is crucial to ensure the accurate display of information, particularly in physical security contexts. To enhance the geolocation system, it is suggested that the north calibration method could be improved by using the position of the sun and moon or by placing the surface on an elevation map.

In the future, elevation maps can be used to improve the object placement on the MR plane. Also, experimenting with different and more comprehensive security scenarios and assigning different tasks will enrich the qualitative and quantitative measurements regarding both interfaces.

VII. Conclusion

This study focused on the comparison of the mobile and MR applications, utilizing a user interface for physical security. The mobile application used a 2D map-based interface, incorporating satellite images, and user and tracked locations. The MR application used MR to visualize the targeted location. Based on the tests conducted in a forested environment, it has been observed that using the MR application resulted in an enhanced SA. We found that participants who used the MR application were more efficient than those who used the mobile application in terms of task completion times and deflections from the ideal route. According to the results of NASA TLX and PSSUQ, the mobile application is easier to learn than the MR application. Meanwhile, the MR application users believe they could become productive faster using this system.

VIII. Appendix

NASA Task Load Index questions are listed below.

- **Mental Demand:** How mentally demanding was the task?
- **Physical Demand:** How physically demanding was the task?
- **Temporal Demand:** How hurried or rushed was the pace of the task?
- **Performance:** How successful were you in accomplishing what you were asked to do?
- **Effort:** How hard did you have to work to accomplish your level of performance?
- **Frustration:** How insecure, discouraged, irritated, stressed, and annoyed were you?

The questions of Post Study System Usability Questionnaire are listed below.

- **Q1:** Overall, I am satisfied with how easy it is to use this system.
- **Q2:** It was simple to use this system.
- **Q3:** I could effectively complete the tasks and scenarios using this system.
- **Q4:** I was able to complete the tasks and scenarios quickly using this system.
- **Q5:** I was able to efficiently complete the tasks and scenarios using this system.
- **Q6:** I felt comfortable using this system.
- **Q7:** It was easy to learn to use this system.
- **Q8:** I believe I could become productive quickly using this system.
- **Q9:** The system gave error messages that clearly told me how to fix problems.
- **Q10:** Whenever I made a mistake using the system, I could recover easily and quickly.
- **Q11:** The information (such as online help, on-screen messages and other documentation) provided with this system was clear.
- **Q12:** It was easy to find the information I needed.
- **Q13:** The information provided for the system was easy to understand.
- **Q14:** The information was effective in helping me complete the tasks and scenarios.
- **Q15:** The organization of information on the system screens was clear.
- **Q16:** The interface of this system was pleasant.
- **Q17:** I liked using the interface of this system.
- **Q18:** This system has all the functions and capabilities I expect it to have.
- **Q19:** Overall, I am satisfied with this system.

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