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Designing an Interactive Mixed Reality Cockpit for Enhanced Soldier-Vehicle Interaction

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ABSTRACT

This paper discusses the design and implementation of an interactive mixed reality cockpit that enhances Soldier-vehicle interaction by providing a 360-degree situational awareness system. The cockpit uses indirect vision, where cameras outside the vehicle provide a video feed of the surroundings to the cockpit. The cockpit also includes a virtual information dashboard that displays real-time information about the vehicle, mission, and crew status. The visualization of the dashboard is based on past research in information visualization, allowing Soldiers to quickly assess their operational state. The paper presents the results of a usability study on the effectiveness of the mixed reality cockpit, which compared the Vitreous interface, a Soldier-centered mixed reality head-mounted display, with two other interface and display technologies. The study found that the Vitreous UI resulted in better driving performance and better subjective evaluation of the ability to actively monitor the environment compared to the other interface and display technologies. Soldiers also reported that the Vitreous interface allowed them to maintain the highest level of situational awareness.

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1. INTRODUCTION

The effectiveness of military vehicle operations is dependent on the Soldiers' ability to accurately perceive and respond to their environment in real-time. The integration of mixed reality technology in military vehicle cockpits provides a unique opportunity to enhance Soldier-vehicle interaction by offering a 360-degree view of the environment and providing real-time information on vehicle, mission, and crew status through a virtual information dashboard. The use of indirect vision and mixed reality displays may provide Soldiers with enhanced situational awareness by providing a broader field of view and a more intuitive display of information.

In this paper, we present the design of an interactive mixed reality cockpit that utilizes indirect vision to provide a 360-degree situational awareness system. This mixed reality cockpit is designed to replace traditional screen displays that can limit the field of view of Soldiers and hinder their ability to perceive the environment. By using indirect vision, the cockpit provides a much broader field of view, which allows Soldiers to better detect and respond to potential threats.

Indirect vision refers to the use of cameras located on the outside of the vehicle to provide a video feed of the vehicle's surroundings to the cockpit (1, 2). The camera feeds are then displayed on screens inside the cockpit to provide the driver or crew with a view of the outside environment. This technology is useful for enhancing situational awareness by providing a wider field of view than is possible with traditional mirrors or direct vision using protected view ports, which can be limited by the vehicle's design. Additionally, indirect vision can provide better depth perception by using stereo cameras and can remove blind spots by providing a 360-degree view of the environment. By using indirect vision, the driver or crew can better detect and respond to potential threats, making it an important technology for enhancing Soldier-vehicle interaction.

The mixed reality cockpit includes a virtual information dashboard that displays real-time information about the vehicle, mission, and crew status. This dashboard offers an easy-to-read display of information and can provide Soldiers with important information at a glance. The visualizations have been strongly influenced by past research in information visualization (e.g., 3, 4, 5), which allows Soldiers to quickly assess their operational state.

Overall, this mixed reality cockpit presents a unique opportunity to enhance Soldier-vehicle interaction and improve mission effectiveness. By leveraging indirect vision and a virtual information dashboard, the cockpit could provide a more intuitive and effective way for Soldiers to perceive and respond to their environment. This paper will discuss the unique capabilities that mixed reality technology provides compared to traditional screen displays and present the results of a usability study on the effectiveness of the mixed reality cockpit.

2. Vitreous Interface

Indirect vision systems for mounted operations offer the potential for situational awareness comparable to an open hatch while providing the protection of closed hatch operations. Traditionally, vehicle-mounted displays have been used to show real-time camera feeds, but mixed reality head-mounted displays (HMDs) may offer benefits in terms of situation awareness, information access, and driving performance. The Vitreous project is a Soldier-centered interface designed and prototyped specifically for mixed reality HMD technology, with the goal of enhancing the capabilities of military vehicle operators.

The Vitreous interface has 3 primary components: 1) 360° situation awareness, 2) Heads-up display (HUD), and the 3) Virtual information dashboard. The following sections will provide a brief description of each.

2.1. 360 Degree Situation Awareness

Mixed reality (MR) is a blending of real and virtual elements where digital and real objects and visualizations exist together, allowing for an immersive and interactive experience (6). In the context of military vehicle operations, crew members using indirect vision wear an HMD with MR technology, providing them with a view consisting of two parts. From the shoulders up, they see real-time 360º video from cameras mounted on the exterior of the vehicle, providing enhanced situational awareness. From the shoulders down, they see the physical controls of their vehicle. Head tracking capability allows the user to move their head to look at different aspects of the outside environment in the same way they would if they were outside the vehicle looking around (Figure 1).

Figure 1. Vitreous interface with 360° view, view of physical cockpit, and the virtual information dashboard.

2.2. Heads-Up Display

A Heads-Up Display (HUD) is a transparent display that presents information without requiring the user to look away from their usual viewpoints (7). A HUD can be particularly useful for providing critical information to the operator without requiring them to look down at traditional displays. By keeping the operator's eyes focused on the 360º view described above, a HUD can enhance situational awareness, reduce reaction time, and increase safety. A HUD can also provide critical data on vehicle status, weapon systems, and other mission-critical information, allowing for faster and more informed decision-making. The Vitreous HUD is head-locked and moves with the user. It includes information about the vehicle (e.g., speed, heading, pitch/roll), weapon status, and targeting data (Figure 2).

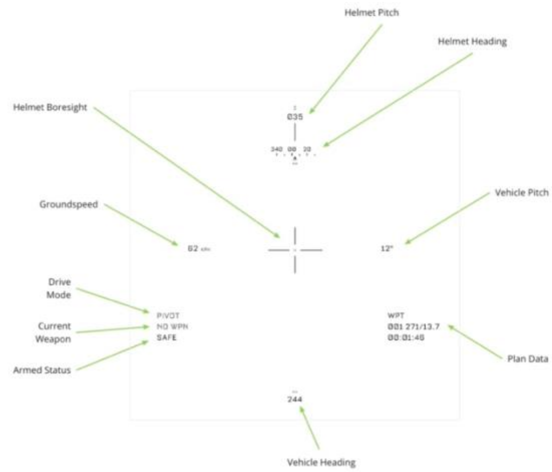

Figure 2. Heads-up display with labeled information elements. Can be customized by the Soldier.

2.3. Virtual Information Dashboard

The virtual information dashboard (VID) offers several advantages over traditional gauges or on-screen displays. One of the primary benefits is its flexibility in terms of shape and location, as there are no physical or screen size limitations. This allows critical information about the vehicle, mission, and crew to be displayed in a way that wraps around the user's field of view and is located approximately 15 degrees below the horizontal line of sight. By placing the dashboard just below the user's 360-degree view, Soldiers can maintain situational awareness of their surroundings while also having instant access to a wide range of information with a simple eye glance. The wrap-around format provides a large area to present information, reducing the need for Soldiers to spend time and cognitive effort navigating through deep menu hierarchies to find the information they need.

Another advantage of the VID is its ability to present customized information. To identify the critical information areas for the vehicle crew, we conducted a comprehensive analysis consisting of a cognitive task analysis, interviews, prior research, and manual and training materials. To ensure that the presented information is easily interpretable, we represented each critical information area with a dashboard panel. By placing related information in the same panel, we can visualize the inter-relationships across elements to enhance rapid decision making. Multiple panels make up the overall dashboard and are positioned based on their relation to other panels and their level of importance to the Soldier's role in the vehicle.

The analysis also revealed that each vehicle role, Commander, Driver, and Gunner, has unique information requirements. To reduce cognitive workload and enhance decision making, we have tailored the dashboard configuration for each of these roles. As a result, the Vitreous VID includes three configurations that are specifically designed to meet the information requirements for each vehicle role. Additionally, Soldiers can customize these base panel layouts based on their individual preferences and needs.

3. Experiment

A within-subject experiment was conducted to compare 3 interface and display technologies: 1) Vitreous with mixed reality, 2) a warfighter machine interface (WMI) with 3 touchscreens, and 3) WMI with an augmented reality view (e.g., Microsoft Hololens). Eighteen Soldiers from the 1st Cavalry Division at Ft. Hood participated in a simulation based study to examine the effects on 1) situation awareness, 2) access to information, and 3) driving performance. Soldiers drove a simulated military vehicle in a simulated environment using each of the interface and display combinations mentioned above. The task involved driving to a designated waypoint, diverting if they detected any obstacles, monitoring vehicle health, getting to the waypoint quickly while not driving off-road, and recording any signs of enemy activity in the area.

3.1. Situation Awareness Results

Situation awareness (SA) was assessed in 2 ways using repeated measures ANOVA analysis: 1) a question related to their ability to actively monitor the environment after each scenario, and 2) their SA interface/technology preference at the end of the experiment.

There was a significant difference among conditions for their subjective evaluation of how well they were able to monitor their surroundings, $F(2, 34) = 23.78$, $p < .01$. The Vitreous UI provided 20% and 45% higher evaluation by Soldiers related to their ability to actively monitor the environment compared to WMI screens and WMI AR. The posthoc tests using Bonferroni correction revealed that these differences were significant ($p < .05$).

Finally, Soldiers were asked which interface allowed them to maintain the highest level of situation awareness. All but 1 Soldier responded with the Vitreous UI (94%) while 1 Soldier responded for the WMI screens condition (6%).

3.2. Information Access Results

Providing access to relevant mission and vehicle information is critical to mission success for vehicle drivers. Information access was measured in 2 ways: 1) access to critical vehicle health parameters like engine temperature and oil pressure and 2) subjective evaluation of the usability of the interface. Soldiers were asked vehicle health questions throughout the scenarios. There was a significant difference among conditions for their ability to access vehicle related information, $F(2, 34) = 571.38$, $p < .01$. The Vitreous UI increased access to vehicle health information by 55% and 40% compared to WMI screens and WMI AR. The posthoc tests using Bonferroni correction revealed that these differences were significant (*$p < .01$*).

To assess usability of the interface, the System Usability Scale (SUS) was used. There was a significant difference among conditions for their subjective evaluation of the interface usability, $F(2, 34) = 7.53$, $p < .05$. The Vitreous UI average usability score was 30% and 23% higher than the WMI screens and WMI AR usability scores. The posthoc tests using Bonferroni correction revealed that these differences were significant (*$p < .05$*). The SUS metric has been used for decades across hundreds of interfaces. The Vitreous UI usability score of 84.9 is in the top 6% of all UIs assessed using the SUS (8).

3.3. Driver Performance Results

Driving performance was measured in 3 ways: 1) overall driving performance, 2) workload, and 3) subjective preference for which UI best supports driving tasks. An overall driving performance metric was created that included vehicle speed, off-road time, IED detection, vehicle health knowledge, warning detection, and enemy activity awareness. There was a significant difference among conditions for the overall driving performance metric, $F(2, 34) = 23.14$, $p < .01$. Vitreous UI performed 21% and 22% higher than the WMI screens and WMI AR. The posthoc tests using Bonferroni correction revealed that these differences were significant (*$p < .01$*).

The NASA TLX measure was used to assess workload (ref). There were no significant differences in workload across the 3 UIs, $F(2, 34) = 2.74$, $p > .05$. However, their ranking in terms of lowest to highest workload was as follows: Vitreous ($M = 39.5$), WMI screens ($M = 42.6$), WMI AR ($M = 50.05$). Soldiers were asked which UI best supported driving operations, 83% responded Vitreous UI, 11% WMI screens, and 6% responded WMI AR. The final preference question asked which UI they prefer for future Army vehicles, 100% responded Vitreous UI.

4. Discussion

The integration of mixed reality technology in military vehicle cockpits provides a unique opportunity to enhance Soldier-vehicle interaction and improve mission effectiveness. In this paper, we presented the design of an interactive mixed reality cockpit that utilizes indirect vision to provide a 360-degree situational awareness system. Results from this study show that the use of indirect vision and mixed reality displays can provide Soldiers with enhanced situational awareness by providing a broader field of view, a more intuitive display of information, and improved driving performance.

The Vitreous mixed reality cockpit replaces traditional screen displays that can limit the field of view of Soldiers and hinder their ability to perceive the environment. By using indirect vision and a virtual information dashboard, the results of this study show that the MR cockpit provides a more intuitive and effective way for Soldiers to perceive and respond to their environment.

The 360-degree situational awareness component of the Vitreous interface enhanced threat detection and improved overall situation awareness of the outside environment. Head tracking capability allows the user to move their head to look at different aspects of the outside environment in the same way they would if they were outside the vehicle looking around. The naturalness of this capability is one explanation of why it improved performance so much even though participants had little to no experience and only a few minutes worth of training with mixed reality technology.

The Heads-Up Display component of the Vitreous interface provides critical information to the operator without requiring them to look down at traditional displays. By keeping the operator's eyes focused on the 360º view described above, a HUD can enhance situational awareness, reduce reaction time, and increase safety. The Vitreous HUD is head-locked and moves with the user. It includes critical information about the vehicle, weapon status, and navigation information for the driver.

The Virtual Information Dashboard, a crucial feature of the Vitreous interface, provides tailored critical information to Soldiers while allowing them to maintain their situational awareness of the external environment. The dashboard presents vast amounts of information and data that would typically require 4-5 traditional monitors. This feature can be a game-changer in the limited space of a military vehicle where access to critical information is vital. Moreover, the dashboard allows for faster retrieval of role-specific information by providing instant access to multiple screens' worth of information without the need for complex menu navigation. This functionality offers Soldiers a significant advantage in accessing information more quickly and efficiently.

Two potential issues that need additional investigation with the use of HMDs is the potential of motion sickness and eye and/or head fatigue. When using an HMD with indirect vision, such as through a camera feed, there may be a lag between the movement detected by the camera and the display in the HMD. This lag can cause a mismatch between the visual and vestibular systems, which can lead to motion sickness. So it is critical in this type of system to significantly reduce the video streaming lag to avoid any motion sickness effects.

Another potential issue with using an HMD is possible eye and/or head fatigue from extended use over long periods of time. HMDs can be heavy and put strain on the neck and head, leading to discomfort and fatigue. Additionally, prolonged use of an HMD can cause eye strain due to the close proximity of the display to the eyes. Focused research of these possible effects over time need to be further explored if Soldiers will be using them as their primary viewing technology within vehicle cockpits.

In conclusion, the Vitreous interface provides a unique opportunity to enhance Soldier-vehicle interaction and improve mission effectiveness. The use of mixed reality technology in military vehicle cockpits, along with indirect vision and virtual information dashboards, offers Soldiers enhanced situational awareness and more intuitive displays of information. The integration of these technologies can reduce reaction time, provide greater situation awareness, and enhance performance, ultimately resulting in more successful missions. Future research will focus on testing the effectiveness of the Vitreous interface in various military scenarios, in moving vehicles over longer periods of time, and optimizing the interface to suit different types of military vehicles.

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