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IMMERSIVE VISUALIZATION EXPLORATION OF CREW STATION DESIGN FOR ACQUISITION PROGRAMS

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ABSTRACT

Crew Station design in the physical realm is complex and expensive due to the cost of fabrication and the time required to reconfigure necessary hardware to conduct studies for human factors and optimization of space claim. However, recent advances in Virtual Reality (VR) and hand tracking technologies have enabled a paradigm shift to the process. The Ground Vehicle System Center has developed an innovative approach using VR technologies to enable a trade space exploration capability which provides crews the ability to place touchscreens and switch panels as desired, then lock them into place to perform a fully recorded simulation of operating the vehicle through a virtual terrain, maneuvering through firing points and engaging moving and static targets during virtual night and day missions with simulated sensor effects for infrared and night vision. Human factors are explored and studied using hand tracking which enables operators to check reach by interacting with virtual components like flipping switches and with virtual touchscreens. This activity facilitates acquisition because it enables technology assessments and optimizations for human factors in a cost effective and time efficient manner.

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1. INTRODUCTION

Vehicles are operated through user controls and displays such as yokes, pedals, touchscreens, and switch panels which are collectively referred to as the Crew Station (CS). A CS configuration is a specific arrangement of the controls and displays necessary for operating the vehicle. Once the vehicle is fielded, the CS configuration cannot be readily changed, i.e., reconfigured. Therefore, it is critical to discover the optimal configuration during the CS design process. This challenge is compounded for Ground combat vehicles (GCVs) because they often require multiple operators where each crew member has their own CS to control a specific aspect of the vehicle. Incorporating soldier feedback, early in the CS design process, is critical for creating effective and efficient CSs. Soldiers with battlefield experience operating fielded vehicles have valuable insights that can help shape the next generation of CS implementations.

The traditional approach to effectively elicit soldier feedback during CS design is to fabricate a physical prototype of the vehicle with a full mockup of the CS for each crew member. Drawbacks to this approach for physical fabrication include that it is expensive, difficult to reconfigure, not portable, and requires significant time investments.

Recent advances in Virtual Reality (VR) technologies enable a new approach for eliciting soldier feedback which mitigates the drawbacks to physical fabrication. VR solutions have become affordable because of a growing consumer market using them for gaming. The gaming use case has also driven the hardware size and cost requirements down to an average desktop workstation which can be moved to the soldier location instead of requiring a facility which the soldier must travel to. A virtual CS can be implemented in such a way that it can reconfigured directly by the soldiers and saved for future use.

Full GCV simulation enables a crew to use the CS to maneuver through a virtual environment and engage with targets thus exercising all the vehicle capabilities in a safe and cost-efficient manner. Ground Vehicle Systems Center (GVSC) Immersive Simulation (IS) created the Virtual and Augmented Reality Immersive Crew Station (VARICS) simulation for eliciting soldier feedback. VARICS leverages VR technologies to create a trade space exploration capability by enabling crews to reconfigure their CS in the virtual environment and then perform a simulated objective using the new configuration. Objectives included navigating the vehicle through a virtual terrain and engaging with static and moving targets during both day and night conditions.

2. SUPPORTING AQUISITION

A Soldier Touch Point (STP) is an event that involves gathering data and feedback early in the design and development process of a product. GVSC has supported several STP events for gathering feedback on concept vehicles and corresponding CSs. The results of STP events are gathered into reports and data artifacts and delivered to the Program Executive Office (PEO) and Cross Functional Team (CFT). The outputs from STP events using VARICS facilitate providing valuable information to the acquisition program because actions of the crew can be programmatically analyzed from the VR tracking. For example, the HMDs track the operator's head position and orientation which can be used to show the how long each CS component was viewed during a simulation, Figure 1. The space within the vehicle is limited so this type of analysis is important.

Figure 1: User Eye Gaze Time in Seconds

Other results include determining if the crew had sufficient situational awareness through only viewing the touchscreens to complete the objectives, how long the vehicle spent on the road, and how much time the crew spent scanning for targets. These results are then used to shape revisions for requirements which in turn enable the Original Equipment Manufacturers (OEMs) to develop more effective solutions. GVSC-IS VARICS is an innovative solution for supporting acquisition by eliciting direct soldier feedback from STP events through immersive simulation providing the intuitive user interface for designing configurations of CS for operating GCVs.

3. VR TECHNOLOGIES

Recent advances in VR related technologies have enabled the development of innovative solutions like VARICS. Accomplishing a trade study of CS design requires leveraging a variety of VR related technologies including spatially tracked handheld controllers, accurate hand tracking, per user audio, advanced Head Mounted Displays (HMD), and physical and virtual environment anchoring.

VR interaction is typically accomplished using only spatially tracked handheld controllers, which while ideal for virtual CS reconfiguration, is not optimal for operating a Mixed Reality (MR) CS which is represented with a mixture of physical and virtual components. Accomplishing a CS Human Factors study using MR necessitates an accurate hand tracking solution for users to have the ability to interact with both virtual and physical components without swapping between hand tracking and handheld controllers.

The Varjo XR-3 was determined to be the best solution available because it provides the Ultraleap hand tracking solution integrated directly into the HMD [3]. Hand tracking enables the user to reach into the virtual world with their hands and without using a physical controller. Gestures such as pinching, grabbing, and interacting with virtual objects allow for a new level of immersion and fluid MR interaction. Ultraleap's hand tracking works by using LEDs to illuminate the user's hands pulsed at a framerate that matches an infrared light sensor to determine the position of each finger [3]. A purple light cone is used to illustrate the Ultraleap sensor in Figure 2.


Figure 2: Illustration of Ultraleap Sensor in Varjo XR-3

In addition to integrated hand tracking the Varjo XR-3 also provides photorealistic, true-to-life MR powered by low-latency, 12-megapixel video pass-through cameras[2]. This capability enables the VARICS simulation to facilitate a mode where the physical and virtual CS components are simultaneously visible to users to verify physical and virtual environment alignment.

The VARICS simulation also naturally relieves VR motion sickness because the surrounding virtual environment of the vehicle cab is stationary with the CS and simulated vehicle sensors shown on virtual touchscreen displays. VR motion sickness typically comes from peripheral vison blur which is further mitigated by the Varjo XR-3's wide field of view (115°).

In VARICS, the Varjo XR-3 is the HMD worn by the each of the operators. Each XR-3 requires a tether which connects to a desktop computer. The HMD is held on to the operator's head by gravity and is not fastened to the operators' head. The weight of the XR-3 is 980 g and it is pictured in Figure 3.

Figure 3: Varjo XR-3 Head Mounted Display

Leveraging this VR technology, VARICS can record the tracked positions of each operators' hands, fingers, head, and physical controller inputs for the yokes and pedals.

4. CS RECONFIGURATION

In the VARICS Virtual CS Reconfiguration mode, the vehicle crew can change the position and orientation of each CS which includes virtual switch panels and touchscreens. This is achieved with the Valve Index handheld controllers to enable crew member controls to interact with virtual components [1]. Crew members can use a Distance Interaction Beam to point out and interact with virtual components across the cab to give suggestions or even adjust components of other crew stations. This enables the crews to collaborate for CS design configuration. The crew members can also add or remove touchscreens. Figure 4 demonstrates these capabilities with an example of a reconfiguration of a driver CS.

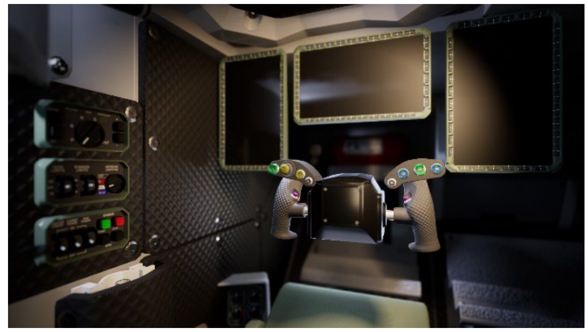

Figure 4: Driver Crew Station after Reconfiguration

When a CS component is moved and intersects with another CS component, both components change to a translucent orange to indicate the intersection. When a CS component is intersecting with a part of the cab or a physical component of the CS, the component will be changed to translucent red to indicate that placement is invalid. The yoke has a virtual cylinder over it to represent its range of rotation. CS components that intersect this range will also appear to be red to indicate invalid placement see Figure 5. Crew members can toggle white transparent outlines of displaced virtual components to display the default position of that component. The crew can use the outline as reference or even return the CS component back to a default position.

Figure 5: Reconfiguration Crew Interior Interactions

Figure 6 showcases the controls for reconfiguration on the Valve Index Controllers. The triggers of both controllers are used to pick up and drop virtual components, as well as interact with the default CS component location outlines to return the displaced CS components to their default positions. To pick up components, the operator can touch them with either controller and press and hold the trigger of that controller. To drop the component, crew members can release the trigger. While components are selected, operators can use the joysticks on the controllers to adjust the position or orientation of the component. The left joystick can be used to adjust the position across a single axis. The right joystick is used to adjust the rotation of the object on a single axis. The selected axis can be changed by pressing in the joysticks of either controller. Button B will add or remove the additional touchscreen that crew members can choose to add to their crew station. Button A will toggle the default component location outlines. This enables crew members to reposition the virtual CS components back to their default configuration locations by pressing the trigger of either controller. Both controllers can be palm squeezed to activate a Distance Selection Beam, which enables users to interact with the virtual components from a distance, rather than touching that component with the controller.

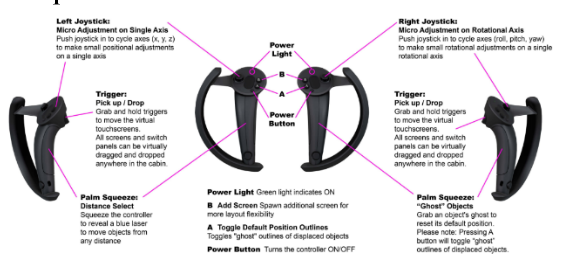

Figure 6: Reconfiguration Controls

Figure 7 shows that reconfiguration also enables the crew to orient the virtual monitors in landscape or portrait mode using the Valve Index controllers. By selecting any monitor and rotating it to the desired orientation, the display will automatically be snapped to the new orientation.

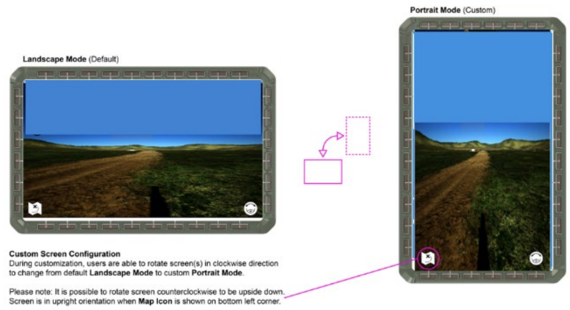

Figure 7: Touchscreen Orientation

This VARICS CS reconfiguration user-interface was found to be sufficiently intuitive for soldiers to effectively use with little training. Soldiers successfully used VARICS to design 18 unique CS which were subsequently used to operate the simulated GCV.

5. ENVIRONMENT

Operators control each crew station within VARICS via Varjo XR-3 HMD technology with a mixed reality interface of VR touchscreens and switch panels as well as a physical yoke for each of the three crew members along with pedals for the driver. Understanding the operational environment of VARICS will provide an understanding for how it was used by the crews. The following details interactions necessary for each crew member to operate the CS virtual and physical controls.

The physical controls for the driver are provided through the yoke or pedals. Palm locks must be engaged to slew, which is accomplished by steering the yoke for horizontal motion or tilting it forward or back for vertical motion. The yoke also provides zoom, laser designation, and target queue controls.

The virtual switch panels and touchscreens for the driver crew station. These virtual components can be operated to maneuver the simulated vehicle. The Power Control provides the toggle switch interface for turning the power on for the driver, CS touchscreens and the Start and Stop buttons start and stop the simulated vehicle engine. Once the simulated vehicle is powered up, the Transmission Controls are used to put the vehicle in Drive which enables the vehicle to be accelerated using the physical yoke or pedals.

The touchscreen vehicle interface is in this case, the minimum set of controls anticipated to be necessary to navigate the simulated virtual environment. The touchscreen is interacted with by physically touching the virtual touchscreen with physically tracked hands. Each touchscreen can display every sensor, but the starting sensor selection varies depending on the particular CS. Sensor views are selected for display by touching the eye icon in the lower left and then touching the view indicator sensor wheel around the vehicle that corresponds to the sensor desired. The gun views can be selected by touching the corresponding icons at the lower left and right of the vehicle sensor wheel. The touchscreen supports split displays of sensor views which can be selected by touching the vehicle in the center of the sensor wheel and the text will toggle to "Multiple View" which will cause the display to split when subsequent sensors are selected from the sensor wheel. A maximum of four sensors can be displayed at a time.

6. ANALYSIS

The primary objective for VARICS is Research and Development (R&D) exploration of a CS design for concept vehicles using VR. The capabilities of the simulated concept vehicle in VARICS are intended to provide the minimum functionality necessary for operators to conduct simulated objectives with the purpose of exploring human factors elements including the ability see, reach, and collaborate in the limited space available inside the concept vehicle cab. VARICS is a physics-based simulation, but it is not intended to be a precise and physically accurate portrayal of a fielded ground vehicle. In contrast, the focus of VARICS is to facilitate CS design and elicit soldier feedback by simulating the necessary representation of the GCV and virtual environment.

The VARICS simulation creates a data recording of the inputs received from each operator. The recorded inputs do not contain any Personally Identifiable Information (PII). The recorded data contains only the head and hand tracking detected from the HMDs, and interactions with the physical yoke and pedals. The recorded data is used to reconstruct the events that occurred during the simulated objective executions and the collaborative development of the CS configurations.

Crews use VARICS to conduct objectives with and develop their CS configurations over the course of several sessions. The three-hour time block that each crew is in VARICS apart from breaks as requested by the operators is considered a Session. The components of a Session include a VR tutorial, VR objective, a break from VR with an opportunity to review the objective execution with verbal discussion, and a VR collaborative CS reconfiguration. These components of the Session are repeated as needed, as time allows, and as the crew is comfortable with continuing. At any point during a Session, when an operator expresses a desire or need to take a break or to end the Session, the request was immediately honored. At the end of the session, crews' complete questionnaires to communicate their experience with questions like: *The touchscreen icons clearly indicated associated functionality, such as map, objectives, and split views*.

The VARICS recorded data is complete in that it can be used to fully reconstruct the sequence of events for post analysis. Analysis of the VARICS data was used to produce visual charts for timelines, time spent viewing CS components, and 2D maps showing traveled paths and engagements.

Timelines provide a way to visualize the pace of a given objective, or to find out approximately when an event happened. Timelines illustrate the vehicle's speed with dark blue background. In this example, Figure 8, when the background is the lighter shade of blue, the vehicle's speed is exceeding 15 mph, otherwise, when the background is the darker blue, the vehicle's speed is below 15 mph. The two lighter blue bars stretching across the entire line represent the gun horizontal slew speed. Like the vehicle's speed, these bars are only visible when the speed is beyond a certain threshold, presenting a more accurate picture of when the crew was scanning for targets. White lines stretching vertically represent the moment targets are destroyed. The smaller red lines at the same height as the slewing bars represent missed shots. Firing point pins are also shown on top of the bar to show progress, indicating approximately how long the crew spent at a particular firing position.

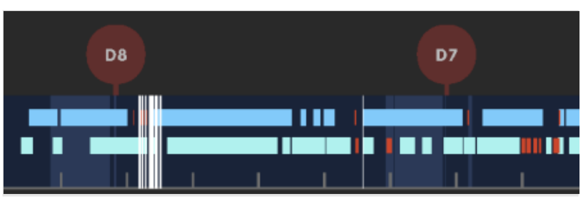

Figure 8: Timeline of crew operation of VARICS

The mapped events, Figure 9, provides a way to visualize where the vehicle travels and where shots are fired during a given objective. The white circles are firing points where targets can be engaged and the black lines from the firing points show the 2D trajectory of the shots. The green circles at the end of the trajectories indicate target hit and the red circles indicate target missed. The red trail is the path that the vehicle took showing red when it was offroad and pink when it was on the road.

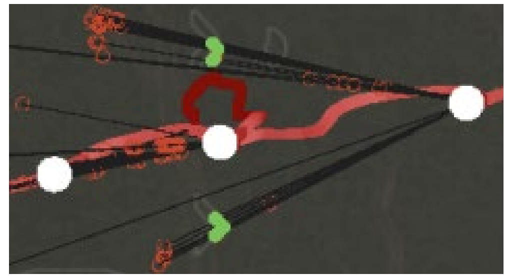
Figure 9: Mapped events of crew operation of VARICS

7. FUTURE ENHANCEMENT

Much can be expanded upon for this capability of R&D for CS design. The following is a summarized list of possible enhancements based on lessons learned and feedback from individuals involved in using the VARICS simulation:

- Study impacts of varying the seating position for the roles.
- Study impacts of having to assume multiple roles for a single seating position such as a scenario where the Driver is unable to perform for a period.
- Impacts of improving the virtual terrain to more accurate such as for target positions and types.
- Impacts of improve the inferred effect and having targets with dynamic inferred signatures.
- Impacts of improving the physical CS components to provide more forward space for repositioning CS components within.
- Impacts of better hand tracking gloves and other haptic feedback.
- Impacts of adding capabilities to the touchscreen UI to make it more representative.
- Impacts of having vehicle physics be more accurate.

A lot was learned from using VARICS. VR is a powerful technology that enables simulations to immerse operators into a virtual world where they can effectively work safely and provide valuable data that can be analyzed to provide benefits for future concept vehicles. The VR related technologies are rapidly being enhanced and so future studies will provide greater value.

8. REFERENCES

[1] Steam VALVE Index Controllers. https://store.steampowered.com/valveindex

[2] Varjo HMD https://varjo.com/ (accessed March 4, 2024)

[3] Ultraleap Motion capture tracking, https://www.ultraleap.com/ (accessed March 4, 2024)