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EVALUATION OF DESIGN AND OPERABILITY IN AN IMMERSIVE 3D SIMULATOR

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ABSTRACT

Operation of a virtual vehicle in order to perform dynamic evaluation of the design can be achieved through the use of augmented reality combined with a simulator. Many uses of virtual reality involve the evaluation of component packaging in a static although interactive manner. That is, the virtual reality (VR) participant can interactively view the virtual environment and perform some minor interactions such as toggling through alternative CAD models for comparison or changing the viewing position to another seat. The immersive 3D simulator system described in this paper enables the VR participant to perform operational tasks such as driving, gunnery and surveillance. Furthermore, this system incorporates augmented reality in order to allow the mixture of the virtual environment with physical controls for operating the virtual vehicle.

INTRODUCTION

Virtual Reality (VR) technology is used in many industries including building architecture, energy, medical, ground vehicle, aircraft, and ship design, Current virtual reality applications for vehicle design include crew station packaging and enable decision making such as the placement of operator controls and displays and operator internal/external visibility. Other related areas include design for manufacturing and design for maintenance.

However, these applications involve primarily static virtual environments. While the VR participant can visually interrogate the virtual environment interactively and even interact with components, the actual operation of the virtual vehicle is often not implemented. For a driver crew station design application, for example, the VR participant would benefit from being able to drive the virtual vehicle in order to evaluate the placement of controls as well as the external visibility. This capability is beneficial to military ground vehicle design in which the driver's visibility is almost always limited by the ground intercept and components placed on or around the front deck of the vehicle.

This paper details a system built and used at General Dynamics Land Systems (GDLS) that combines a ground vehicle simulator with a virtual reality system to enable the VR participant to perform operational tasks. Augmented reality is incorporated to allow the mixture of virtual and physical components. A see-through head mounted display (HMD) is used to show the vehicle CAD models and outside terrain, and its transparent displays enable the VR participant to view the physical controls in order to operate the virtual vehicle.

Benefits of this technology include risk mitigation, schedule and cost reduction and a higher quality end product. Applications of this technology, used early in design, enable decision making for modifications that would otherwise require substantially more cost and time and reduced flexibility later in the design phase. Using an augmented reality simulator enables a higher level of fidelity for evaluation and provides an early view of the design impacts on the operation of the vehicle. Moreover, performing design reviews with this technology improves the nature of the communication by enabling the customer to view the design in a way that's not possible with 2D slides and CAD models alone.

BACKGROUND

There are a wide variety of commercially available virtual reality peripherals and software and the cost varies greatly. A low-end system may include a low resolution head mounted display, a magnetic tracker, and a single off-the-shelf personal computer. A high-end system may include a multi-wall CAVE, a rendering computer cluster, high resolution projectors and optical tracking. All of these systems are aimed at immersing the operator in a virtual environment in order provide a greater understanding as well as a natural interface for visual interrogation. The main components of these systems are the display hardware, tracking system, computing resources, geometric models, virtual reality and application software, and interactive devices. Together, these components allow the VR participant to view the virtual environment in a natural manner by moving his/her head, standing and walking and interacting with the environment through hand tracking, button presses and speech recognition. The VR participant often has the capability to toggle pre-defined alternatives and fly through the environment or cycle through pre-defined viewing positions. The GDLS system incorporates multiple head mounted displays with a rendering computer cluster, camera-based tracking and world class virtual reality software.

There are a wide variety of applications of virtual reality and it is used in a number of industries. Scientific visualization applications convey complex information providing it in a manner that facilitates understanding and discussion of complex ideas. These areas include medicine, chemistry, astronomy and physics. Virtual reality is used in design for a variety of vehicles including automotive, construction, commercial and military aircraft, and military ground vehicles. Architecture applications benefit building construction as they allow insight into the flow of people, lighting and design perspective.

Obtaining source geometric models for virtual reality applications was formerly a very difficult and limiting task. Obtaining appropriately sized geometric models in a timely manner in order to enable people to make decisions is paramount to the use of this technology. The geometric models often originate in CAD systems and are too detailed and numerous for VR applications. Over the course of several years, tools evolved and became available to enable a fast turn-around from request to evaluation. Certain systems rely on a CAD-neutral format and converters with tessellation and decimation tools are readily available. Other solutions are based on a CAD system and rely on a smaller internal geometric representation to enable real time interaction. At GDLS, the process of preparing the CAD models has been streamlined and rapid turn-around enables the system to meet the needs of the demanding pace of design teams.

Ergonomics Issues Addressed in Design

In designing military vehicles, the human factors or ergonomics experts influence the operator's interfaces. In particular, the components that the operator interacts with are the chief concern of the human factors team. There are many types of controls and displays in military vehicles (Figure 1) including weapon control handles, vehicle control panels, displays, keyboards, vision blocks and keypads.

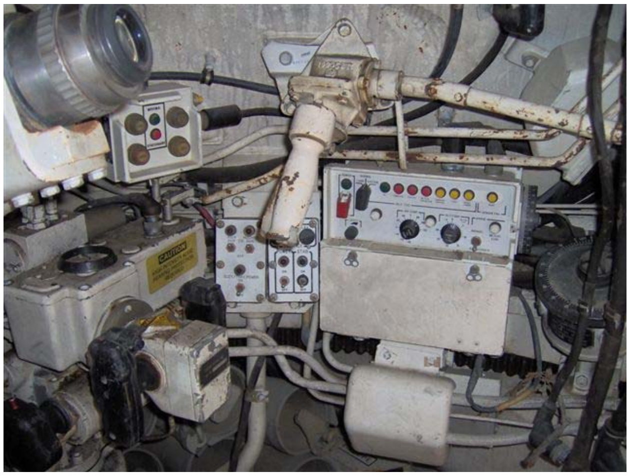

Figure 1: M60 Tank Turret

The human factors expert participates throughout the design phase. As the design matures, iterations require re-evaluation.

A variety of tools are used to assess the design. CAD models are available early in the design and at GDLS, a large assembly visualization software tool, VisMockup/Siemens, is used by the engineering team to view the model and to perform basic engineering tasks such as making measurements, performing interference detection, and analyzing swept volumes of moving parts.

A software tool with ergonomics analysis capabilities (Figure 2) is used to further evaluate the design. To address specific issues, a subset of the overall set of models is chosen. For example, to further evaluate the driver's station interior controls, parts of concern around the driver are selected. At GDLS, JACK/Siemens software is used for ergonomic evaluation. The JACK software provides a suite of ergonomic analysis tools including features for posturing manikins, calculating reach envelopes, field of view vision analysis, and scalable human figures.

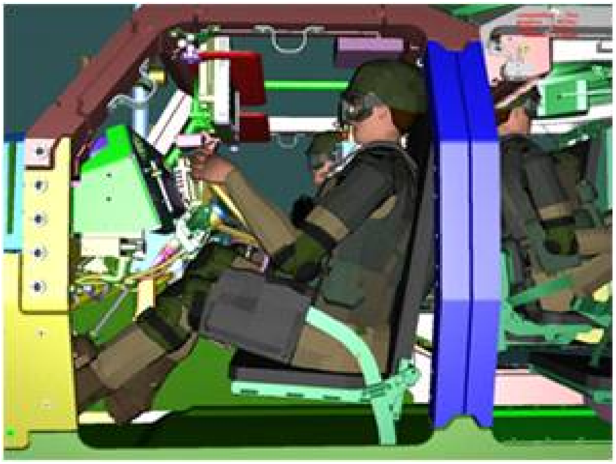

Figure 2: Anthropometric Modeling Software

At GDLS, virtual reality (Figure 3) serves as the level of fidelity for design. It provides a first-person immersive experience of the virtual vehicle. The operator sees a view of the CAD models on a head mounted display from the crewman's position. In this manner, reach and visibility can be further evaluated to achieve the best balanced design. As the design evolves, often compromises need to be made by the packaging team due to constraints. Sometimes, controls and displays are moved to accommodate other design considerations such as additional electronics, heat/airflow, additional armor, and vehicle weight constraints. The virtual reality system provides a first-person experience of the crewman's visibility and movements needed to operate the vehicle. It acts as a decision making tool.

Figure 3: Virtual Reality Participant

Human-in-the-loop simulators (Figure 4) serve as the next level of fidelity and focus on the physical operator interfaces including controls and displays. A simulator may consist of a simple wireframe platform with controls and displays mounted in the proper position to match their location in the vehicle. The purpose of low fidelity simulation is to evaluate and refine the design of the control handles and the software user interface (UI). In particular, the initial UI design is evaluated and further refined to improve crew performance and workload through iterative development and soldier user juries.

Figure 4: Low Fidelity Reconfigurable Simulator

Finally, high fidelity mockups (Figure 5) are created to validate design. Although not generally operational, these mockups are very similar in form to an actual vehicle. Developed after the major aspects of design stabilize, these mockups provide the design team and the customer with a very good sense of the actual crew station layout. While providing perhaps the best replica of the intended design, physical mockups are introduced later in design due to the time and cost to build. Physical mockups are a vital part of the design process as they provide a venue to validate the design together with the customer.

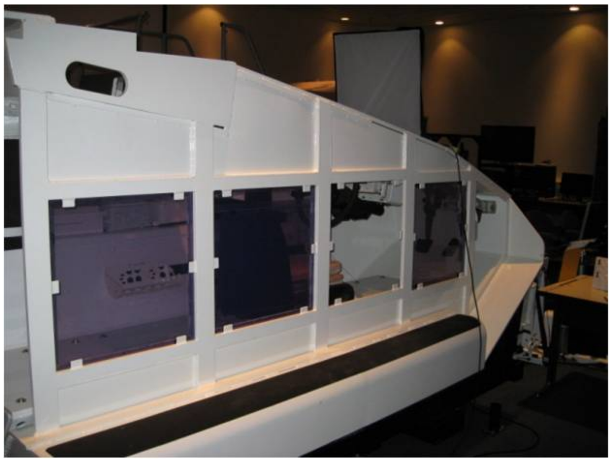

Figure 5: Physical Mockup

System Overview Description

The virtual reality and simulator systems (Figure 6) used for the work described in this paper are housed in the Warfighter Integration Lab in the Maneuver Collaboration Center at General Dynamics Land Systems Division. The Virtual Reality System (Figure 6) consists of the head mounted displays, position tracking cameras and markers, orientation trackers, computer cluster, position tracking software, virtual reality software, application scripts, CAD models, physical mockups, control handles, vehicle control panels, control station and LCD display wall.

Figure 6: GDLS Virtual Reality System

An NVIS ST60 (Figure 7) see-through HMD provides the display of visual scene of the virtual models to the operator. A WorldViz PPT camera-based tracking system provides accurate tracking for the head position. Six cameras are mounted on a lattice structure high above the floor and the camera-based system provides a wide area for tracking of up to three participants simultaneously. The operator sits in a mockup or a stand-alone military style seat within reach of the controls.

Figure 7: Head Mounted Display (HMD)

The see-through feature of the HMD allows the operator to view the virtual CAD models on the display but also to see the physical controls through it. In other words, while driving the virtual vehicle, the operator sees the view from the driver's open hatch position as if sitting in the vehicle while he/she can also see both hands on the physical driver's T-BAR directly to the front (Figure 8).

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Figure 8: Physical Mockup with Augmented Reality

An Ascension tracking system provides operator head orientation to the virtual reality software. This allows rendering of the proper viewing direction as the operator pans through the virtual environment. A computer serves as host for the head position and orientation tracking and relays the information to the cluster master computer. A rack of computers performs the rendering for each head mounted display. Vizard/WorldViz software manages the tracking information and renders the visual scenes. Application scripts are run to load the models and provide the functionality needed for the session.

The VR participant operates the control handle to drive the virtual vehicle through the simulation world. Panning his/her head while driving provides a natural interface and insight into the impact of obscuring parts is gained while performing driving tasks.

Simulation Architecture

The simulator system consists of the simulation software, control handles, and a computer. The simulation software, developed at GDLS, provides a simulation engine for driving the vehicle. It contains mobility models, turret and gun models, sensor models and, input device interfaces. The simulator takes the operators input from the control handles, shapes it, and performs mobility calculations over the terrain with the given vehicle weight and engine characteristics. The simulator keeps track of position, velocity, acceleration, and vehicle orientation and reports the position and orientation to the virtual reality system for rendering. The simulator manages other vehicle entities including their behavior and position/orientation information. Additionally the simulator performs collision detection between entities as well as objects and buildings in the terrain.

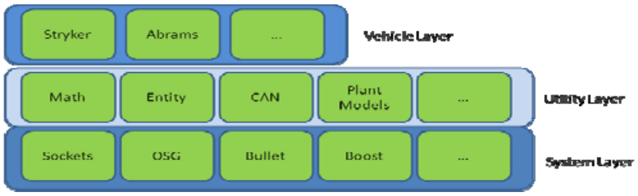

Figure 9: Simulation Software Libraries

The simulation software (Figure 9) was designed to be easily configurable in order to simulate many different vehicles. For example, the Simulator can be easily configured to be an MRAP, ABRAMS Tank, or a Stryker.

The simulation engine and its' components are written in C++ and are data driven in nature. The data and architecture of the simulation is defined in several LUA scripts. These scripts define what kind of vehicles will be simulated.

The simulation framework leverages many open source software packages including BOOST, Open Scene Graph, and Bullet Physics. While a great deal of application development was needed, these tools provide the low level libraries that are the bottom level building blocks for the system.

A utility layer provides higher level functionality including entity management, mobility and fire control plant models, and input device data shaping. The vehicle layer provides vehicle specific functionality and configuration such as the number of displays, control handles, weapon systems and sensor capabilities. The user interface code which allows interaction between the crew and the vehicle is within this layer. It presents the screens to the operators and is responsible for the user interactions and communication to the main simulation program for simulation vehicle control.

Combining VR and Simulation Systems

Prior to this project, our virtual reality equipment and simulator have been two completely different systems that use separate computing resources, peripheral devices, software and CAD models. For this project, the systems have been combined to take advantage of the capabilities of both systems together in the same application (Figure 10). The strength of the Virtual Reality System is to immerse the operator in the virtual environment. It is responsible for head tracking and scene rendering. The strength of the Simulator is to allow operation of a vehicle, including tasks such as driving, gunnery and surveillance. The simulator has many responsibilities including control handle input and shaping functions, plant models for mobility and fire control, collision detection, friendly and enemy entity control, simulation rendering and performance data measurement.

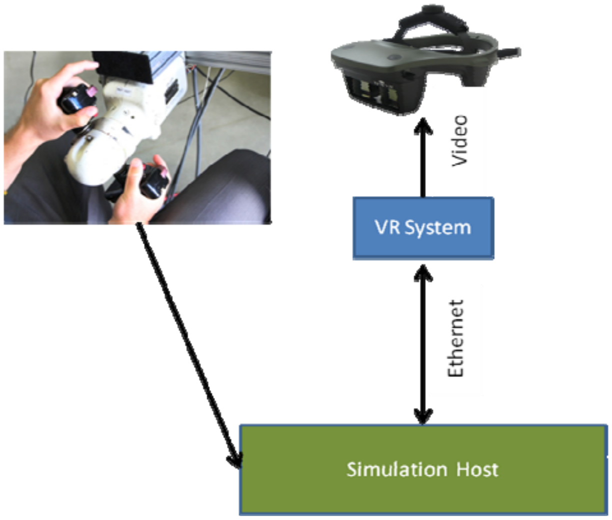

Figure 10: Hardware Communication

The software for these systems runs on separate computing resources and communicates over the network. The primary flow is for the simulator to read control handle input, perform vehicle mobility and collision detection and send vehicle position and orientation to the VR system. In this case, the simulator sends vehicle position and orientation at 60hz to the VR system. The VR system then reads the vehicle position and orientation together with the head position and orientation and renders the scene accordingly. The network bandwidth will be improved when a second order Dead Reckoning [8] algorithm is incorporated and applied to the entities sent over the network. Dead Reckoning involves each node on the network predicting changes in entity position and orientation thus requiring less frequent updates.

The VR System receives and processes the position and orientation information and combines it with the tracking system's head position and orientation information. The VR system allows the participant to look around while driving or performing surveillance, and to get a subjective impression of the visibility constraints. In particular, successive runs provide the opportunity for comparison of alternative designs. The VR participant can subjectively assess the impacts of objects that obscure a portion of the view.

The two systems, while disparate in computing resources and device control, must share certain things. In particular, they must use the same coordinate systems and terrain databases. A mapping from the simulator's coordinate system was done to transform position and orientation information into the virtual reality coordinate system. A second issue involves the visual models of the vehicle. While the simulator typically uses low polygon count models with texture mapping for detail, the virtual reality system uses CAD-derived models which have a high polygon count. The CAD-derived models used for VR applications represent only a subset of the vehicle. Due to the high polygon count of the many thousands of models, only the parts within the possible field of view of the virtual reality participant are used. While the simulation visual model appears to be a complete vehicle from the outside view, the virtual reality model does not. Parts that cannot be seen by the VR participant are not rendered, for example, the tires. Many small parts such as nuts, bolts and screws are not rendered since they would use a great deal of computer resources but don't provide much value for this application. The CAD models are shown on the head mounted display, while the simulation model is not shown to the VR participant but is used for collision detection by the simulator. Thus separate models are used by the systems but they must be similar in order to provide accurate visual depiction and analytical collision detection. Additionally, the view point of the operator must be correlated between the models for an accurate representation.

Correlation of the physical mockup and controls to the virtual environment is necessary. Unfortunately, the markers for the head mounted display do not lend themselves well to this. The markers are attached by velcro on the top of the head mounted display and an offset would be difficult to calculate, especially since the placement of the markers is slightly different every time they are removed for battery recharging. Instead, correlation is accomplished through the use of visual objects in the scene. Specifically, placing cylindrical objects and planes in the scene enables the correlation. The seat is adjusted in height and position until the view of the VR participant lines up with the virtual correlation objects. The correlation of the physical controls to the virtual controls can be observed during setup although the virtual controls are not rendered during the evaluation sessions because they are not needed. The VR participant can see the physical controls with the see-through head mounted display.

Project Description and Results

External Visibility - Bridge Operation

A true mixed-mockup application was developed for a bridge laying vehicle. Custom prototype operator controls were fabricated and the physical driver's seat mockup and driving controls were integrated with the virtual reality system to create a 3D immersive driving simulator. The operator task under evaluation was to drive the vehicle to a position to begin bridge deployment and to adjust the position of the vehicle near the point of deployment. The operator's view is severely obscured by the bridge deploying hydraulic arms as they extend the bridge directly in front of the vehicle (Figure 11) (Figure 12).

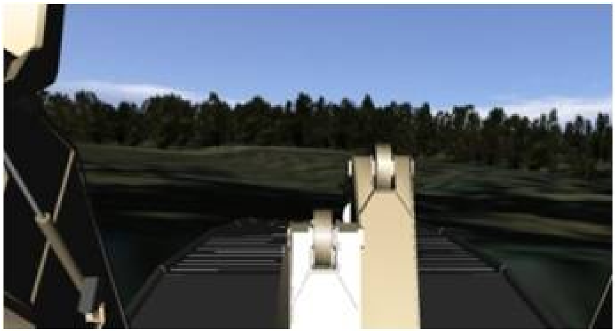

Figure 11: Operator View 1 – Bridge Operation

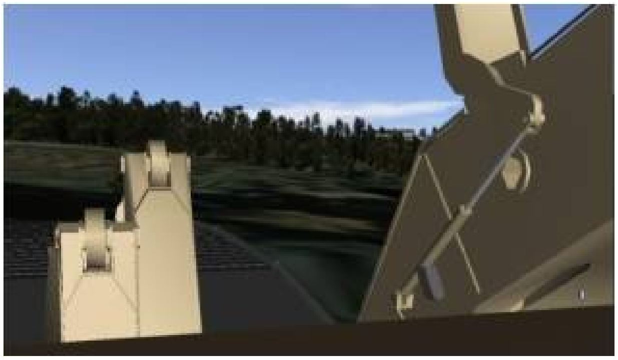

Figure 12: Operator View 2 – Bridge Operation

A separate simulation view is provided to an observer who directs the driver since the driver's view is obscured. The purpose of the application was to evaluate the visibility to help consider if an expensive camera system for aiding the driver in this task might be needed. The driver's T-BAR is connected to the simulation which performs the mobility calculations and reports the vehicle position and orientation to the virtual reality system. The custom prototype bridge controls were interfaced to the simulator and the input is provided to the virtual reality system. The dynamics for the hydraulic arm movement is a simple plant model and the calculations are performed by the virtual reality system. The engineering team utilized the 3D immersive application and provided it as part of the design review. The customer representatives employed the 3D immersive driving simulator application to perform the tasks. The system provided them with insight into the driver's visibility while performing the tasks. Additionally, the system provided the opportunity for the customers to assess the prototype bridge deploying controls. The virtual review improved the communication of the design concepts and facilitated discussion for decision making.

External Visibility – Windowed Vehicle

Evaluation of external crew visibility was the focus of 3D immersive application development for the design of a wheeled vehicle with glass windows (Figure 13).

Figure 13: External Visibility Application

The customer provided direct view field of regard requirements for the crew. The design parameters included varying the size of the side windows as well as the vertical supports for the front windshield. The main results involved the measurement of the field of view from the respective crew stations. Varying head position enabled the operator to see a wider field of view. The dynamic nature of this enabled the quantification of the field of regard. The 3D immersive application provided a first-person immersive experience of the vehicle design and gave insight into what it would be like to operate the vehicle (Figure 14). The ground intercept, that is, the nearest distance from the vehicle at which the ground can be seen from the operator's design eyepoint, was measured. The dynamic nature of the 3D immersive application provided a good environment for assessing the design.

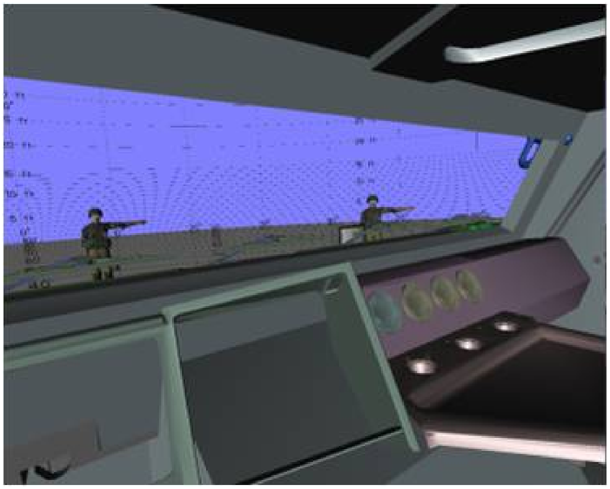

Figure 14: Operator View – External Visibility

External Visibility - Engine Hatch

As a result of incorporating a large engine into a wheeled vehicle, the driver's view became obscured by the increased size of the hatch. The engineering team requested an analysis of the impact of the design change. An application was developed as part of that analysis in order to gain insight. Several substantial iterations of the design were made in order to provide visibility similar to the baseline vehicle. This activity resulted in a design that did not degrade operator performance. The impact to cost, schedule and quality was substantial.

Benefits of Technology

Many commercial organizations have found the use of virtual reality technology beneficial. This technology has been leveraged in many industries including defense, energy, automotive, medical and architecture. Virtual reality is often used early in design when CAD models are available and before a design becomes mature enough to build physical mockups. Virtual reality provides early evaluation which impacts cost, schedule and quality. Additionally, providing opportunity to the customer to immerse themselves in the design enhances communication and promotes feedback on the design.

Virtual reality provides a spatial understanding of a design and in particular, an operator's view. Engineers can view and perform operations as if in the real vehicle by using the 3D immersive simulator. In this manner, decisions for alternative locations for parts are made and the reach and visibility are evaluated to get an impression of the physical movements or workflow to accomplish tasks. Issues that may have been overlooked with a traditional CAD system or large assembly flythrough software are found early in design. Furthermore, since the virtual environment is a natural interface, people that are not as familiar with CAD gain a very detailed understanding of the design. In essence, the virtual reality system has become a decision making tool for design and it serves as a prototype during design reviews. The customers have a first-person immersive experience and focus on the vehicle operational aspects of the design instead of trying just to conceptualize the design.

Finding and resolving design issues early whether within the internal design team, program management or with the customer, leads to savings in cost and schedule and improves quality. Delaying the finding of issues to later stages of design reduces flexibility for solutions. Later changes incur more cost, may cause delays to schedule, and less flexibility impacts the quality of the design.

This paper discusses an additional level of fidelity within the virtual environment, that is, the ability to operate the virtual vehicle. The system built at GDLS allows the VR participant to drive the virtual vehicle while immersed in a virtual environment. This enables evaluation of the external visibility while driving a virtual military vehicle. Traditional analysis can provide statistics such as the percentage of the field of view that is obscured or a plot showing which directions are obscured. However, these statistics don’t indicate how operator performance is impacted. The 3D immersive driving simulator enables the VR participant to perform operational tasks and have a first-person experience. Objects that obscure the driver’s view impact performance during the evaluation and when comparing alternative packaging solutions, the operator gets a direct comparison similar to actual use. Objective performance data used for analysis is gathered during an evaluation session with the 3D immersive simulator. The total time to complete the course as well as the obstacle collisions is recorded.

Path Forward

Additional development of scoring methods and reporting would add to the usefulness of this system. Operating the vehicle in a virtual environment provides a great deal of insight into a design. Additional methods for performing scoring that would add value include deviation from the ‘best’ path. A ‘good’ path would be determined prior to testing and a measurement of distance deviation could be calculated. There are many possibilities for analyzing this data such as where it occurs, filtering out an area of very poor performance, and interpreting deviation in a turning area. A comparison of the 3D immersive driving simulator to a real vehicle could lead to a validation of the system. A comparison would unearth improvements needed to the 3D immersive simulator and make it better. If it were desired to replace testing of a physical working vehicle in the design process, a detailed validation could be done.

Performing additional studies with this system depends on CAD models and operator controls for new vehicle programs. A rapid turn-around from request to evaluation is critical in order for the system to be used as a decision making tool during the design process. At GDLS, the process of CAD-to-VR model preparation has been streamlined. The selection of a subset of models, geometric reduction of these models and conversion to the appropriate format is very rapid due to the maturity of tools available. For the interface of new operator controls, the GDLS simulator is a very robust software platform containing the necessary common device communication and input shaping tools. Merely connecting wires for analog and digital output from the handle to the simulator is a simple procedure, and it has been conducted on many control devices within the Warfighter Integration Lab.

Additional vehicle specific applications other than driving could be developed for gunnery and surveillance tasks. Interfacing the input devices and providing simulation control is well understood with the GDLS simulation framework. The system is well suited for open-hatch activity. The simulator’s robust entity control module can be used to provide moving friendly and enemy forces during the evaluation session. Finally, the VR system has been used design for maintenance applications but could be expanded for conditions requiring operation of the virtual vehicle.

Summary

Virtual Reality technology is used in a variety of industries. Existing virtual reality applications primarily involve static virtual environments. This paper presented a system that allows operation of a virtual vehicle in order to provide a higher level of fidelity for design evaluation and review. Actually operating the virtual vehicle forces the VR participant to use the system in the same manner as a physical system and thus form a greater understanding of how the design alternatives impact performance.

The 3D immersive driving simulator represents the marriage of two disparate systems – the virtual reality system and the crew station simulator. Each system has capabilities, which when combined, provide a better tool for communication of design and decision making.

Benefits of using this system early in the design process are similar to traditional simulation. These include risk mitigation, schedule and cost reduction and a higher quality end product. Potential issues can be addressed early that would otherwise cause re-work, reduced flexibility and compromises later in the design process. Simulators and virtual reality systems enable early customer feedback, evaluation of the efficiency of design, and allow more alternatives to be considered.

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