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DEVELOPMENT OF A PROTOTYPE VIRTUAL REALITY TRAINER FOR TACTICAL VEHICLE GROUND-GUIDING PROCEDURES

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THESIS

DEVELOPMENT OF A PROTOTYPE VIRTUAL REALITY TRAINER FOR TACTICAL VEHICLE GROUND-GUIDING PROCEDURES

by

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March 2019

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The use of virtual reality (VR) technology in the training domain brings several benefits to the training force: compared to training in the real world, VR training reduces logistical support, it eliminates high-risk safety situations, and it enables scenarios not possible otherwise. This work determines the viability of using commercial off-the-shelf technology (COTS) to develop a prototype VR trainer in support of tactical vehicle ground-guiding procedures. A task analysis was conducted to identify all steps of the task in which an individual used hand and arm signals to communicate directions and position to another individual who operated a tactical vehicle. This work was used to define elements of human performance and system requirements, and to develop a multiuser VR training system. A total of eighteen subjects participated in a user study to evaluate usability of the system. The prototype system was able to fully immerse the subjects with visual, aural, and haptic displays, successfully blocking out influences from the real world to a sufficient extent that subjects believed they were in the virtual world and could perform ground-guiding operations. Given the subjects’ responses in the Standardized Usability Scale questionnaire, the system was seen as a viable tool for training of ground-guiding procedures. The results of this study demonstrated that it is feasible to use COTS technology and create a prototype system for training in ground-guiding and driving skills.

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Submitted in partial fulfillment of the
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ABSTRACT

The use of virtual reality (VR) technology in the training domain brings several benefits to the training force: compared to training in the real world, VR training reduces logistical support, it eliminates high-risk safety situations, and it enables scenarios not possible otherwise. This work determines the viability of using commercial off-the-shelf technology (COTS) to develop a prototype VR trainer in support of tactical vehicle ground-guiding procedures. A task analysis was conducted to identify all steps of the task in which an individual used hand and arm signals to communicate directions and position to another individual who operated a tactical vehicle. This work was used to define elements of human performance and system requirements, and to develop a multiuser VR training system. A total of eighteen subjects participated in a user study to evaluate usability of the system. The prototype system was able to fully immerse the subjects with visual, aural, and haptic displays, successfully blocking out influences from the real world to a sufficient extent that subjects believed they were in the virtual world and could perform ground-guiding operations. Given the subjects' responses in the Standardized Usability Scale questionnaire, the system was seen as a viable tool for training of ground-guiding procedures. The results of this study demonstrated that it is feasible to use COTS technology and create a prototype system for training in ground-guiding and driving skills.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	3 Dimensional
CCS	Combat Convoy Simulator
COTS	Commercial off-the-Shelf
DoD	Department of Defense
HMD	Head-Mounted Display
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IRB	Institutional Review Board
NPS	Naval Postgraduate School
SSQ	Simulator Sickness Questionnaire
SUS	System Usability Scale
USMC	United States Marine Corps
VE	Virtual Environment
VR	Virtual Reality

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I. INTRODUCTION

A. RESEARCH DOMAIN

In *FRAGO 01/2016: Advance to Contact*, General Robert B. Neller, 37th Commandant of the Marine Corps, communicated his initial guidance for the direction that he wished the Marine Corps to take during his time as Commandant. Specifically, he wrote about capitalizing on existing and emerging technologies to increase the amount of training each unit and individual Marine can accomplish by leveraging the full capabilities of live and virtual "reps and sets" (Neller, 2017, p. 3). One specific task that would also benefit from these additional sets and reps is tactical vehicle ground guiding. Specifically, the task involves an individual who is using hand and arm signals to communicate directions and position to another individual—a driver operating a tactical vehicle. Due to improper adherence to procedures and lack of formal training, movement of tactical vehicles may result in equipment damage or personal injury. Exploring technology that can be used to provide realistic training in situation where the live training task may be limited by facilities, safety, or access to equipment can mitigate or reduce the losses caused by accidents.

B. RESEARCH PROBLEM AND MOTIVATION

The first issue to address is to approach that which the current training method has: it provides a static image and a description while trying to teach a kinetic activity. Without an instructor to interpret and successfully demonstrate the signal, the trainee is left open to potentially misunderstanding the signal movement requirements.

Currently, ground-guiding procedures are both formally and informally taught. The formal method of training consists of classroom instruction in which the signals are first demonstrated to the students. Next, the students will replicate the signals under the supervision of the instructor, and then they will conduct replications through practical application by executing the ground-guiding task in real life. The informal method of ground-guiding instruction consists of on-the-job training in which an individual may receive some verbal instruction of the signals or might have to learn the signals by observing others who perform ground guiding.

Additionally, there is an overall lack of adherence to standardized procedures listed in TC 3-21.60 (Headquarters, Department of the Army, 2017). Ground guides who do not go through formal training generally adopt the signals and procedures that are being utilized at the unit location. This leads to local agreed-upon procedures that may or may not be correct. Varying unit standard operating procedures prevent individuals from developing an organization-wide standard for ground guiding.

The second shortfall is that the task is often not taken seriously or individuals do not see the importance of accurate ground guiding. Often, ground guiding is conducted in busy environments where other people or vehicles are also moving about. Individuals may find themselves distracted by the environment or other factors, which takes away their attention from their task. This leads to drivers not receiving or being given poor direction from their ground guide. When personnel are moving around large tactical vehicles, often the driver will not be able to see them due to blind spots or visual distractions. This can result in personnel being severely injured. In addition to injuries, distractions can also result in damage to the vehicle or infrastructure.

There is a lack of sustainment training requirements and there is little training being formally conducted. Once personnel receive their formal or informal training, it is accepted that they possess the requisite skills and knowledge to conduct ground-guiding operations. Units rarely establish training in order to sustain or keep up to date with ground-guiding procedures. The only types of simulation tools available for tactical vehicle driving are the driving simulators used for licensing purposes and the Combat Convoy Simulator (CCS), neither of which allow for the training of ground guiding.

Current training in the procedures for ground-guiding vehicles does not provide Marines with the skills necessary to consistently and accurately execute ground-guiding procedures. The purpose of this work is to evaluate whether the task of training for tactical vehicle ground guiding can be supported using a virtual reality head-mounted display (HMD) and steering wheel device. It explores the use of multiple individuals operating within a virtual environment to improve training and personnel's ability to accomplish the assigned task.

C. RESEARCH QUESTIONS

This work will focus on the following two research questions:

1. What is the feasibility of using commercial off the shelf technology (COTS) to develop a virtual reality trainer in support of tactical vehicle ground-guiding procedures?

2. Will subjects consider a ground-guiding training system as a viable means of increasing sets and reps of the training task?

D. RESEARCH OBJECTIVES

This work has the following research objectives

- Design and develop a prototype multiuser system based off of current COTS systems that include immersive virtual reality (VR) displays and passive haptics.

- Conduct feasibility study of resulting prototype system.

- Evaluate usability of prototype training system and examine if it can serve as a viable tool to support the task of tactical vehicle ground guiding.

E. BENEFITS OF STUDY

The perceived benefits of conducting this research consist of the following:

- Increased understanding of development of multiuser environments where participants communicate using non-verbal communication and cues.

- Increased understanding of how to develop training systems using COTS components to include both hardware and software.

- Increased understanding in conducting usability studies that include the use of immersive VR technology and passive haptics.

The development and fielding of a COTS driving and ground-guiding trainer that uses COTS systems would benefit would provide the following benefits to training forces:

- Increase the opportunities and frequency of tactical vehicle driving and ground guiding

- Improve precision in vehicle navigation for ground guides

- Provide opportunities for mission rehearsals prior to execution

F. SCOPE AND LIMITATIONS

The scope of this work is to develop a prototype virtual reality simulation that could be used as a training tool for individual Marines and Soldiers in training of ground-guiding procedures. The training situation that this system will support include one individual who performs the hand and arm signals, and second individual who receives the signals visually and operates the simulated tactical vehicle

The system will be assessed via a usability study and will not assess training effectiveness nor the transfer of training in ground guiding. The user study will also only feature one environment that consists of military style structures and equipment.

G. METHODOLOGY

1. Conduct literature review.

2. Conduct task analysis.

3. Conduct analysis to determine performance concerns and domain issues including issues with current training approaches, user needs, and advice on how to evaluate resulting prototype training simulation.

4. Identify requirements for VR training simulations and scenarios used in support of training objectives.

5. Select training scenario and 3-dimensional (3D) models needed to develop that scenario.

6. Design and build prototype training simulation.

7. Conduct system testing.

8. Design and conduct user study.

9. Analyze collected data set.

H. THESIS STRUCTURE

Chapter II of this thesis examines the past literature that focused on the use of VR in the execution of non-verbal collaborative tasks in VEs, the role of passive haptics in VR immersion, VR locomotion, and cybersickness. The text also comments on the use of COTS systems when developing training solutions and elaborates the benefits of training with systems that use virtual environments (VE). Chapter III outlines the task analysis and the elements of ground-guiding procedures, the target population, and current procedure shortfalls. Following the task analysis, Chapter IV outlines the system design methodology and methods used to develop the system prototype. Chapter V outlines the user study design and methodology and its results. The final chapter presents thesis conclusions, and directions for future work.

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II. LITERATURE REVIEW

A. TRAINING WITH VIRTUAL ENVIRONMENTS

The use of VEs as a training solution brings several benefits to the training force. One major benefit is that training in VEs typically does not require larger logistical support than the training in the real world would require. Individuals who need to train ground guiding and driving cannot simply practice whenever they so desire. In order to check out a tactical vehicle for training purposes, it has to be pre-scheduled and approved in order to get added to the training schedule. Operating tactical vehicles also requires fuel for the vehicle, and fuel has a cost to it. Units have designated budgets for operations and extra ground-guiding training might not make the cut for funding allocation. An additional issue arose, during a period of sequestration the units were prohibited from purchasing fuel and could only commit to mission critical movements of tactical vehicles. However, if individuals could train using an alternative training solution like this virtual training system that relies only on low cost COTS, they could train whenever they wanted to.

Additional benefits of training ground-guiding procedures in a VE is safety. In complex environments that are either difficult to navigate within or have a large number of moving elements, the risk assessment of the ground-guiding task increases.

The last benefit of training within a VE is that it allows the trainee to train in environments and situations that they may not regularly get to experience or do not have access too. If a unit is preparing for an embarkation exercise in which they will be loading vehicles onto ship, they are not likely going to get the opportunity to practice in that type of environment until it comes time to physically execute the task. With a VR training system, ground guides and drivers could practice driving onboard ship prior to doing in the real world. Due to the relative short distances that vehicles are parked next to each other on ship, there is a high risk of collision between vehicles and other equipment staged onboard. Getting ground guides and drivers the opportunity to practice their coordination in this type of scenario would greatly decrease the risk of those incidents.

B. FUNDAMENTALS OF NON-VERBAL COMMUNICATION IN VIRTUAL ENVIRONMENTS

The term *togetherness* was introduced by Nat Durlach and Mel Slater as a "sense of being with other people in a shared virtual environment" (2000, p. 1). They report that sense of togetherness is driven by number of elements in the virtual environment such as the level of realism of the environment, acceptance of the virtual representation of others, and the real-time interactions between individuals. While verbal communication is the primary method in which humans communicate, we also rely upon non-verbal communication to pass information to each other. This non-verbal communication can be broken down into postures and expression of the face and body in addition to gestures and mimics of the head, body, and limbs (Guye-Vuilleme, Capin, Pandzic, Thalmann, & Thalmann, 1999).

The task of ground guiding a vehicle is first and foremost non-verbal. Communication is primarily initiated by the ground guide. The method in which the ground guide communicates with the driver is through a series of standardized hand and arm signals. The method in which the driver communicates to the ground guide is through the adherence to the proper response to the observed hand and arm signals. The other method the driver communicates with the ground guide is through stopping the vehicle, or not executing the given hand and arm signal. Both stopping and not executing the received signal indicates that the driver does not understand the signal, has lost sight of the ground guide, or did not receive the proper signal.

C. ROLE OF PASSIVE HAPTICS IN VR IMMERSION

Passive haptics assume the use of real physical props to provide haptic feedback for virtual objects. It is a technique that "incorporates passive physical objects into virtual environments to physically simulate the virtual objects" (Insko, Meehan, Whitton, & Brooks, 2001). The work done by Insko, Meehan, Whitton, and Brooks, demonstrated how passive haptics can be used to increase presence and improve training effectiveness in VEs (Insko et al., 2001). A study by Nagao, Matsumoto, Narumi, Tanikawa, and Hirose (2018) demonstrated the change of a user's spatial perception within a VE by using passive haptics to replicate the sensation of ascending and descending stairs.

The driver role in the prototype system that was developed for this thesis is the only one that needed to experience passive haptics while operating the system. That was accomplished by using a driving controller racing wheel featuring dual-motor force feedback provided by the passive haptics that the driver experienced. In addition to the racing wheel, the controller included pedals to provide acceleration and braking. This type of infrastructure provided driver with the most intuitive interface that closely corresponded to the actual tactical vehicle and its driving mechanisms.

D. NAVIGATION AND LOCOMATION IN VE

Different types of travel, a motor components of navigation task, were examined in a variety of studies. Authors Mahdi Nabiyouni, Ayshwarya Saktheeswaran, Doug A. Bowman, and Ambika Karanth conducted an experiment to compare a semi-natural locomotion technique with a traditional, non-natural technique, based on a game controller, and a fully natural technique, real walking (Nabiyouni et al., 2015). This experiment allowed for the exploration of human factors in VEs by defining specified locomotion techniques, identified the use of the term fidelity with respect to use in the realms of interaction and display techniques, and identified the complexity of the relationship between interaction fidelity and effectiveness. The authors categorize locomotion techniques in term of how well they mimic true human walking and again these are: non-natural, semi-natural, and fully natural. The authors utilize S. J. Gerathewohl's definition of fidelity, "the degree to which a system accurately reproduces a real-world experience and its effects" (Gerathewohl, 1969). They applied this definition in two realms; display and interaction fidelity. This categorization allowed them to "speculate that locomotion techniques with moderate interaction fidelity will often have performance inferior to both high-fidelity techniques and well-designed low fidelity techniques" (Nabiyouni et al. p. 54). When we think about locomotion techniques in VR, this categorization can be used to identify HTC Vive's hand controller as a low-fidelity interaction technique. The study reported by Nabiyouni's et al had participants walking along a straight and a multisegmented line utilizing varying locomotion and interface techniques. That experiment has "contributed to a deeper understanding of the effects of interaction fidelity on effectiveness", which has been taken as a learning point in the system design (Nabiyouni et al., 2015).

E. CYBERSICKNESS

Visually induced motion sickness (VIMS), sometimes referred to as cyber sickness, impacts the feasibility and effectiveness of virtual training platforms. The vestibular and ocular mismatch has been well documented as causing users to feel motion sick.

There are several tools that were used to measure motion sickness in individuals, the simulator sickness questionnaire (SSQ) and the Fast Motion Sickness Scale (FMS). The SSQ was developed in 1993 by researchers Kennedy, Lane, Berbaum, and Lilienthal, and it represents a validated method for evaluating sickness across three different categories, nausea, oculomotor, and disorientation (Kennedy et al., 1993). The SSQ is administered following activity in the virtual environment. Because it is only administered post-exposure, researchers are unable to gather data from subjects while experiencing environment that causes MS.

The FMS allows researchers to get real time information on sickness level of subjects. The FMS allows the user to verbally indicate a sickness level on a scale of zero (no sickness at all) to twenty (frank sickness) while in the virtual environment. Every minute, the subject provides a FMS reading (0-20) which is recorded. This allows researchers to cease activity if the subject crosses an implemented threshold. Additionally, the FMS allows researchers to determine when subjects began feeling MS and identify any movements or environments that may induce MS.

The FMS represents a validated real time sickness score. Keshavarz and Hecht (2011) found a high correlation with the FMS and the SSQ ($r = 0.785$) and the nausea subscore ($r = 0.828$). Because it provides real time information of developing MS, it is the preferred method of determining subject sickness in the study. One issue that arise from the real-time assessment of cybersickness is that it may interfere with the task that the individual is attempting to accomplish and is therefore it is not an optimal solution in training scenarios where one needs to study and assess human performance.

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III. TASK ANALYSIS

A. INTRODUCTION

Task analysis details how a "task is actually performed (performance steps), under what conditions it is performed, and how well the individual must perform it (performance standards)" (Department of Defense, 1997). By conducting task analysis, it allows us to create the strategy used to design and develop training programs and products.

The role of the ground guide is to move freely within the environment and assess the potential obstacles that the driver needs to avoid. The ground guide has full visibility of surrounding obstacles that the driver may be limited in seeing. Currently, the up armored nature of current tactical vehicles prohibits drivers from having the same field of view and level of visibility that they would share with current commercial vehicles. When the situation requires a ground guide, it is important to operate at speeds at which drivers can respond accordingly to the ground guides instructions. Vehicle speed is generally limited to five miles an hour so that the ground guide can maneuver and position himself to places in which the vehicle can move to. Therefore, maneuverability and visibility are the key components of the ground guide job.

The role of driving is focused on successfully and accurately operating a tactical vehicle. In enclosed environments, the driver is reliant upon the ground guide to ensure collisions are avoided. Following the commands given by the ground guide, keeping the ground guide out of blinds spots, and avoiding obstacles are the key components of the driver's performance.

B. CURRENT GROUND-GUIDING PROCEDURES

The main instructional document for ground-guiding vehicles is Training Circular (TC) 3-21.60 Visual Signals, Chapter Two Hand-and-Arm Signals for Ground Vehicles, published March 2017 (Headquarters, Department of the Army, 2017). The TC outlines the signals to control vehicle drivers and crews by providing a brief description of the movement to be conducted for each specific command in addition to a graphic depicting the position and movement to be executed. After analyzing the hand and arm signals in the

TC, the following were determined to be the essential signals required in order to provide the necessary input to the driver for proper navigation: move forward, move in reverse, halt or stop, right turn, and left turn. All those signals are used in daylight operations.

Figure 1 demonstrates the hand and arm signal to indicate that the ground guide wants the driver to move the vehicle forward. Palms are in a fixed position facing the ground guide and the hands are moved repeatedly towards and away from the body. This motion is to be executed during the forward movement of the vehicle. When the destination of the ground guide is significantly distant, it is not necessarily required to continuously execute the motion. This allows the ground guide to turn attention to the surrounding environment to ensure obstacles are avoided.

Figure 1. Move forward. Source: Headquarters, Department of the Army (2017).

Figure 2 demonstrates the hand and arm signal to indicate that the ground guide wants the driver to move the vehicle in reverse. Palms are in a fixed position facing the driver and the hands are moved repeatedly towards and away from the body. This motion is to be repeated for the duration of the reverse movement of the vehicle. When the vehicle has reached the position that the ground guide desires, the movement will end.

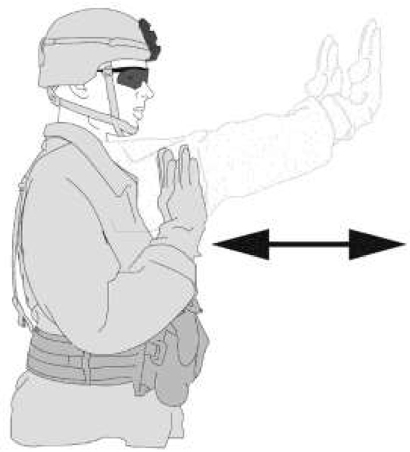

Figure 2. Move in reverse (for stationary vehicles). Source: Headquarters, Department of the Army (2017).

Figure 3 indicates that the ground guide is attempting to halt the vehicle. With the palm raised to the front, the arm is raised to the full extent of the arm and held up until the signal is recognized.

Figure 3. Halt or stop. Source: Headquarters, Department of the Army (2017).

When the ground guide extends an arm out to the side, either left or right, it is to indicate to the driver a direction in which to turn the vehicle (Figures 4 and 5). Since the ground guide is facing the driver, when the ground guide extends the right arm it is to indicate that the driver needs to turn to the left. When the ground guide extends the left arm it is to indicate that the driver needs to turn to the right. The extension of the arm to indicate movement direction of the driver will also be combined with opposite hand indicating a forward or reverse direction. Example given is that if the ground guide wants the driver to movement forward and turn left, the right arm will be extended to the side and the left arm will have the palm up facing the ground guide moving towards and away the ground guide.

Figure 4. Right turn. Source: Headquarters, Department of the Army (2017).

Figure 5. Left turn. Source: Headquarters, Department of the Army (2017).

C. TASK CHARACTERISTICS AND USER (SUBJECTS) POPULATION

For individuals that will perform ground-guiding operations, there is no restriction on age, rank, or gender. Additionally, there are no restrictions on requiring a special occupational specialty or job assignment. All subjects were military personnel fit for duty.

D. TASK REPRESENTATION

The process of ground guiding a vehicle requires a number of perceptual, physical (motor), and mental (cognitive) activities in addition to recognizing a number of task cues. The perceptual activities for both ground guide and driver include being able to receive sensory inputs and translate them into information that can be acted upon. The physical (motor) activities include the ground guide making hand and arm signals and as well as walking with the vehicle as it moves and doing arm signals, ensuring that the ground guide maintains a position in which the driver has visual contact with the ground guide. The ground guide has to have familiarity with the proper hand and arm signals and has to be able to employ them in such a manner that they are clear movements that coincide with what the ground guide is trying to communicate to the driver. Activities for the driver primarily involve the operation of the tactical vehicle. The driver must also additionally be constantly scanning for both position and visual cues from the ground guide in addition to scanning the environment for potential obstacles.

The mental (cognitive) activities for the ground guide include the spatial awareness of where they are located within the environment (this includes awareness about other moving objects like vehicles and pedestrians) and where they relative to the vehicle in which they are guiding. Additionally, ground guides have to being thinking ahead and anticipating the next command in which they will be required to give to the vehicle driver in order to ensure that the driver can navigate the upcoming event or obstacle. Activities for the driver include the recognition of the hand and arm signals being given to him by the ground guide and interpreting those into the required actions to be taken in the operation of the vehicle. Additionally, the driver is required to have a certain level of autonomy of the operation of the vehicle. Must be able to multitask, observe and recognize visual cues and simultaneously manipulate the vehicle.

The ground guide decision loop is represented in Figure 6 and the driver decision loop is represented in Figure 7.

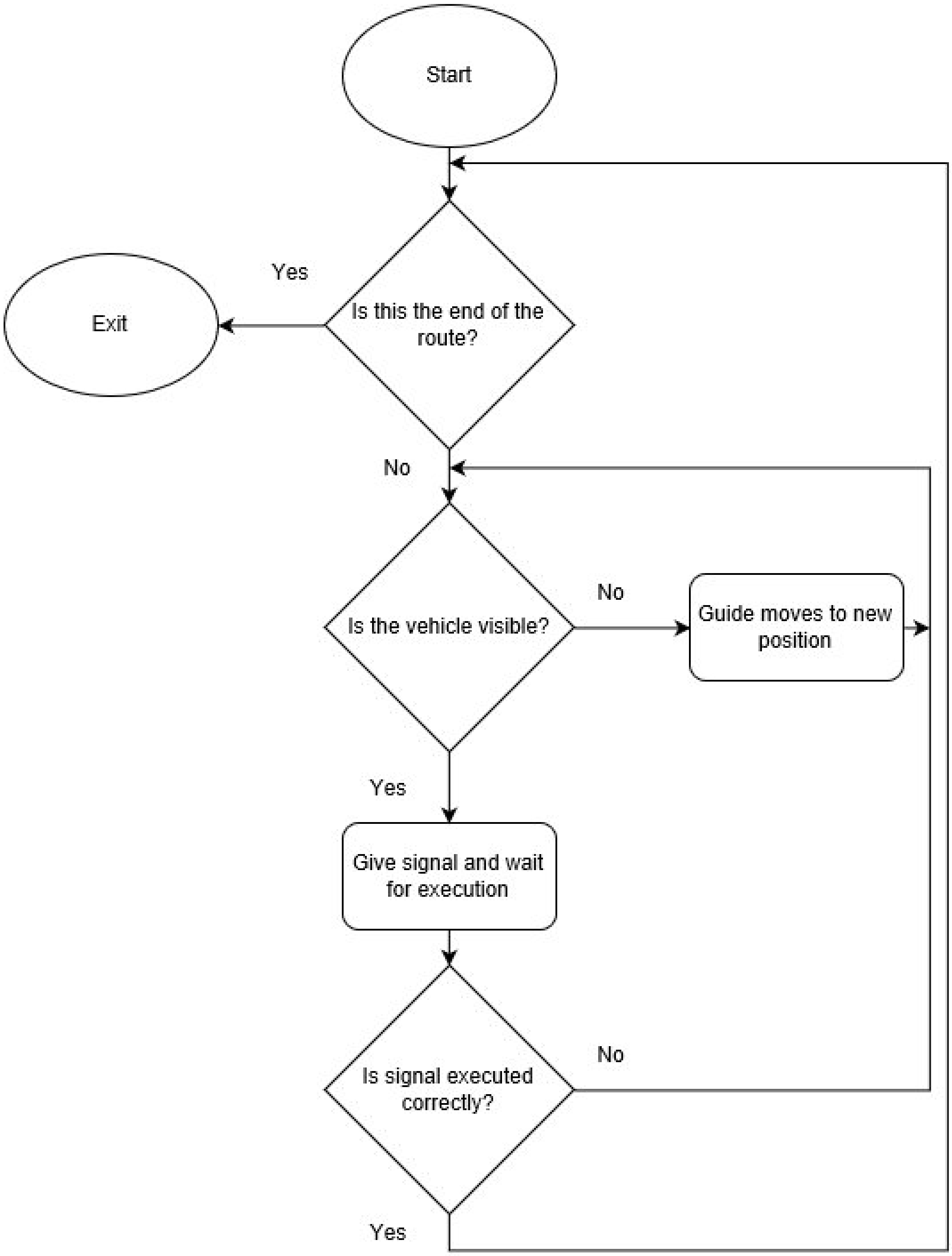

Figure 6. Ground guide decision loop

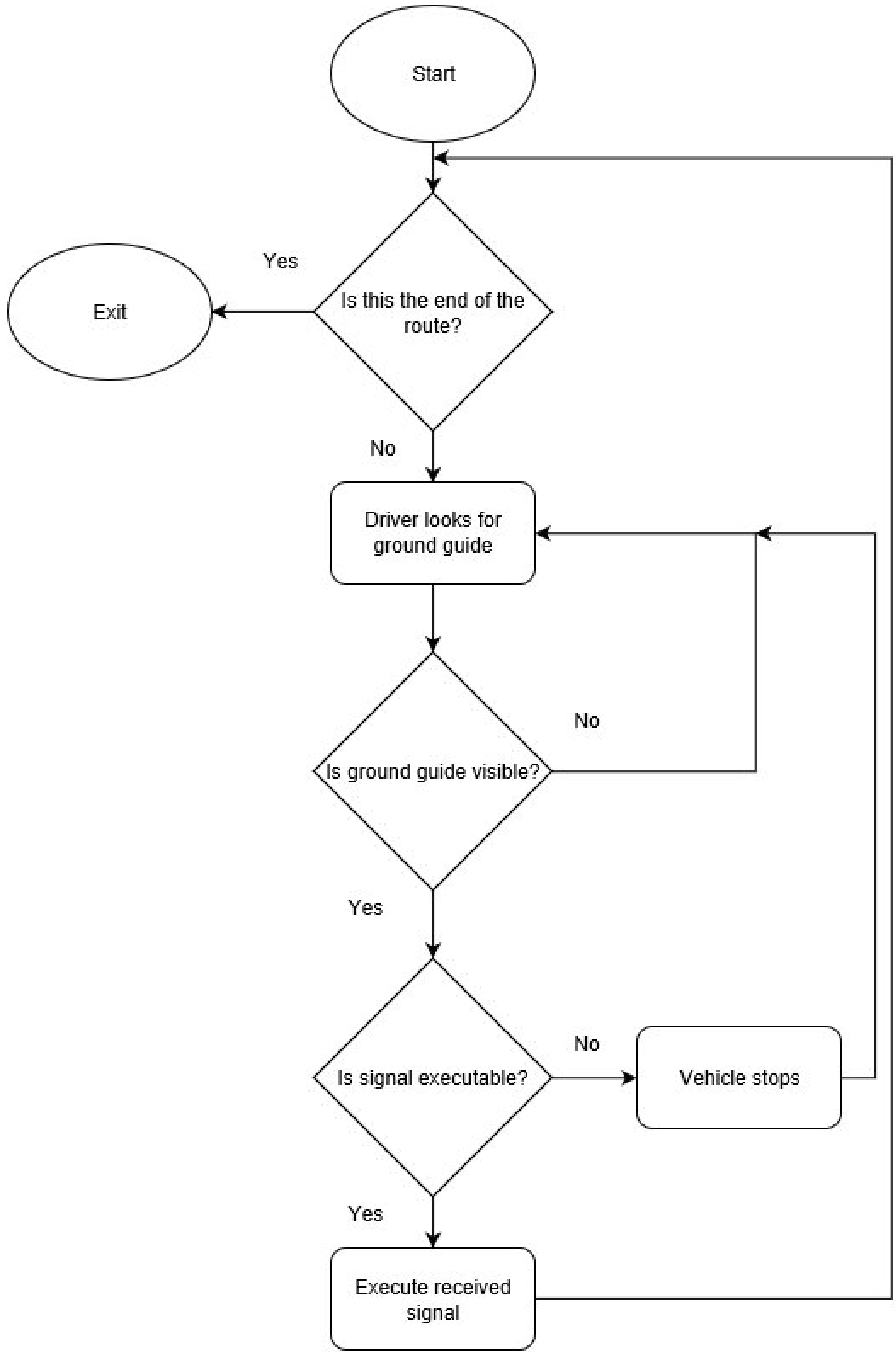

Figure 7. Driver decision loop

IV. SYSTEM DESIGN AND DEVELOPMENT

A. DESIGN METHODOLOGY

When analyzing the type of software development plan, it was determined that a waterfall approach was best suited for this system software development effort. The waterfall method of software development is a linear process in which the steps are clearly defined. Originally developed in 1970 by Dr. Winston W. Royce, it was envisioned as a method for managing large software development projects and it has since evolved into an approach that can be used to any scale software development project (Royce, 1970). Royce initially wrote that only analysis and coding were required as steps in small computer programs for internal operations. However, the waterfall methodology grew into the steps that are depicted in Figure 8.

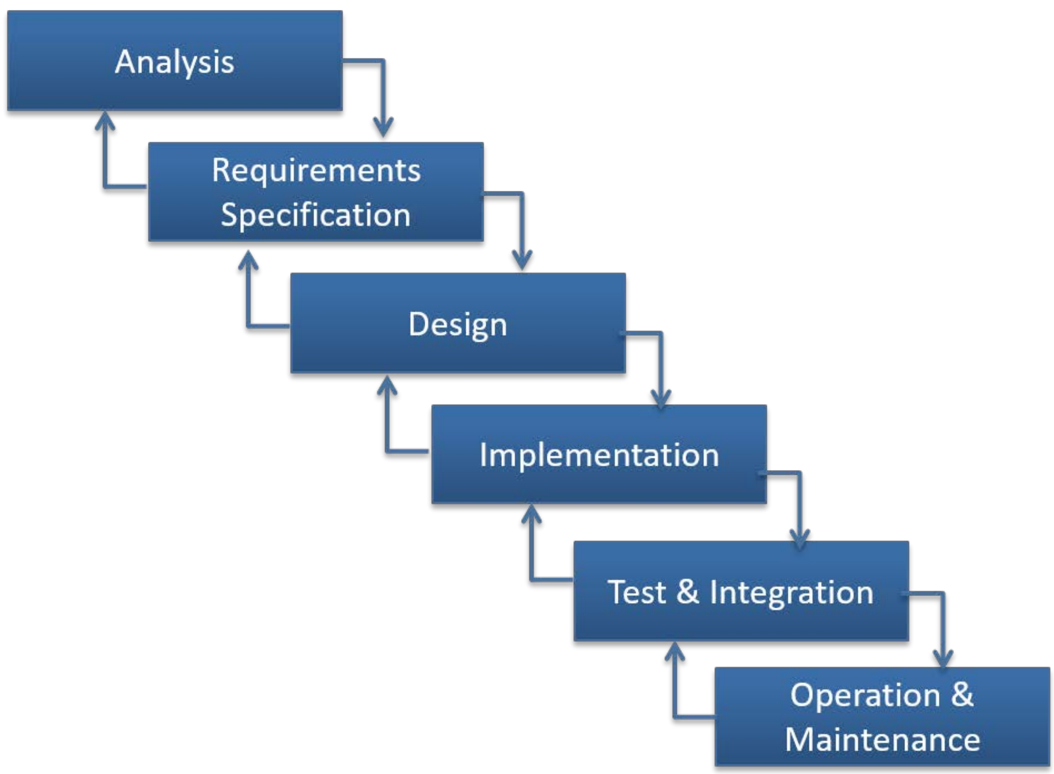

Figure 8. Waterfall software development methodology

B. SYSTEM ARCHITECTURE

Knowing that ground-guiding task requires two people, it was important to ensure that both subjects would be able to communicate with each over a centralized network and share the same virtual environments. A server-client architectural pattern has been chosen to support that functionality. Utilizing Unity's built in network manager Unity Networking (UNet), a Local Area Network (LAN) was created to network the two machines together. On Personal Computer (PC)-1, a LAN Host was established to act as a server in order to allow PC-2 to connect to PC-1 as a local client.

A visual depiction of the system architecture is presented in Figure 9.

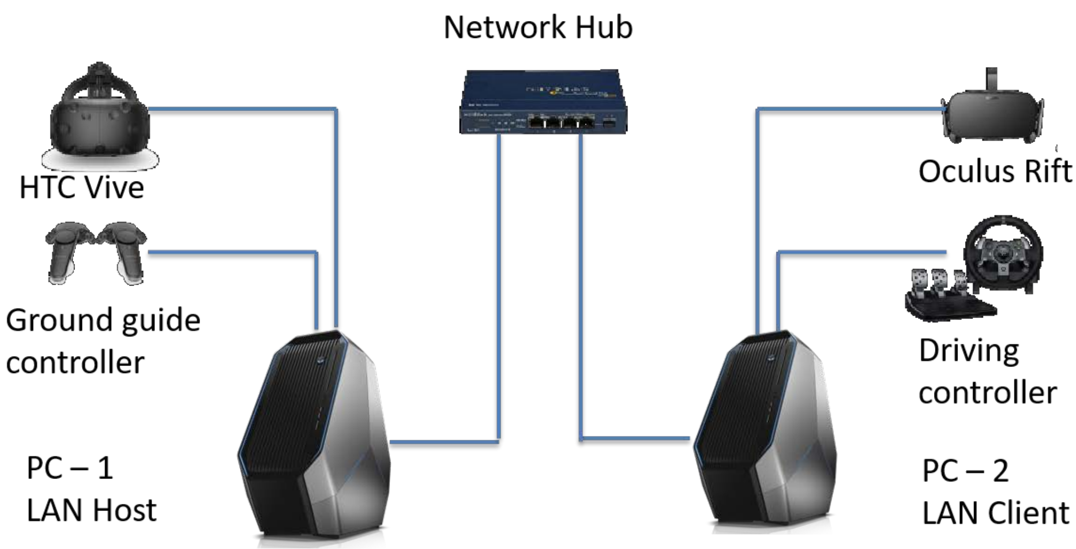

Figure 9. System architecture

The server-client relationship is initiated by establishing the local server on the ground guide's PC with the HTC Vive head-mounted display with hand controllers attached to PC-1. Once the server is created, the driver connects to the server as a client via the ground guide PC's internet protocol address with the Oculus Rift head-mounted display and driving controller attached to PC-2.

C. PROTOTYPE DEVELOPMENT

The physical configuration of the system consists of one HTC Vive headset connected to desktop computer, one Oculus Rift headset and one Logitech G920 driving controller connected to another desktop computer.

The system was created such that the two different VR systems (headsets) could be used, regardless of their type. In either the ground guide role or driver role, there is versatility in which type of system that could be used. The software was developed so that two of each system, or any mix of systems could be used. For the development of our prototype the HTC Vive was chosen for the ground guide role due to its greater tracking area, allowing the ground guide more freedom of movement. The Oculus Rift headset was chosen for the driver and as such it provides a demonstration of the interoperability of two different VR systems by the means of Unity game engine.

1. Ground Guide Application

The input and output devices utilized for the ground guide included the HTC Vive head-mounted display with hand controllers. The Vive headset has a 110 degree field of view and utilizes one screen per eye, with each having a resolution of 1080 x 1200. The system comes with wireless controllers that each have multiple input methods. The system makes use of the left hand touchpad to allow user navigation inside VR scene, and tracking of hand position. Both headset and controllers are tracked through base stations that create a 360 degree virtual space up to 15 x 15 feet. Figure 10 shows the HTC Vive setup with two base stations for tracking of the HMD and two hand controllers that allow user input regarding navigation through environment and interaction with objects.

2. Driver Application

The input and output devices utilized for the driver included Oculus Rift head-mounted display and Logitech G920 driving controller. The Oculus headset also has a 110 degree field of view, and screens with resolution of 1080 x 1200 for each eye. The headset is tracked through two sensors that create a 360 degrees wide virtual space and cover the area of up to 5 x 5 feet. Figure 11 shows the Oculus Rift system with its two sensors and

HMD. The prototype system developed for this research did not use Oculus Rift hand controllers.

Figure 10. HTC Vive system

Figure 11. Oculus Rift system

The driving controller was paired with the Oculus Rift with the main goal to provide the best interface for the driver role. No external sensors were used to track the input of the driving control to the system. The driving controller is treated as an input device within Unity and has each element programmed accordingly. The rotation of the steering wheel is treated as a joystick x-axis, the rotation of the acceleration pedal as a joystick y-axis, and the rotation of the brake pedal as a joystick z-axis. The tracking of these rotation axes allowed for the movement control of the vehicle in the scene. Figure 12 shows the driving controller used in the prototype system.

Figure 12. Logitech Racing Wheel

3. Computer System

The two desktop PCs used in the system were VR ready machines both running Unity Version 2017.3.0f3 Personal (64 bit). The following system configuration was used in PC-1 and PC-2:

- **Processor:** Intel(R) Core(TM) i7-5820K CPU @ 3.30GHz
- **Memory:** 16.0 GB
- **Graphics Cards:** NVIDEA GeForce GTX 980

- **Operating System:** Windows 10 64-bit

4. Networking Component

In order to have both PCs communicating with each other, both machines were plugged in to a router using the following network hardware:

- **Router:** NETGEAR DS108 8 Port 10/100 Mbps Dual Speed Hub

- **Cabling:** Two CAT5e cables

5. Software Development Environment

The software environment used to program the scenes was Unity game engine, an open source cross platform game engine created by Unity Technologies.

Unity was chosen as the software development environment due to the programs built-in network manager that allowed for the networking of the two PCs. Additionally, Unity is the primary contemporary software tool that is typically used to develop visual simulations and game-based applications.

The models used in the experiment environment were acquired by the Modeling, Virtual Environments and Simulation Institute at NPS for student research or from publically available sources. All scripting was done in C# and the version of Unity used was Unity version 2017.3.0f3 Personal (64 bit).

D. SCENE OBJECTS AND VISUALS

1. Environment

Two virtual environments i.e. scenes were created for the prototype system and user experience. The first scene, or training environment, was an open world sandbox environment in which subjects could familiarize themselves with the system and learn the controls for each respective role. The second scene, or experimental environment, was a portion of the scene where execution of the main experimental task was to take place.

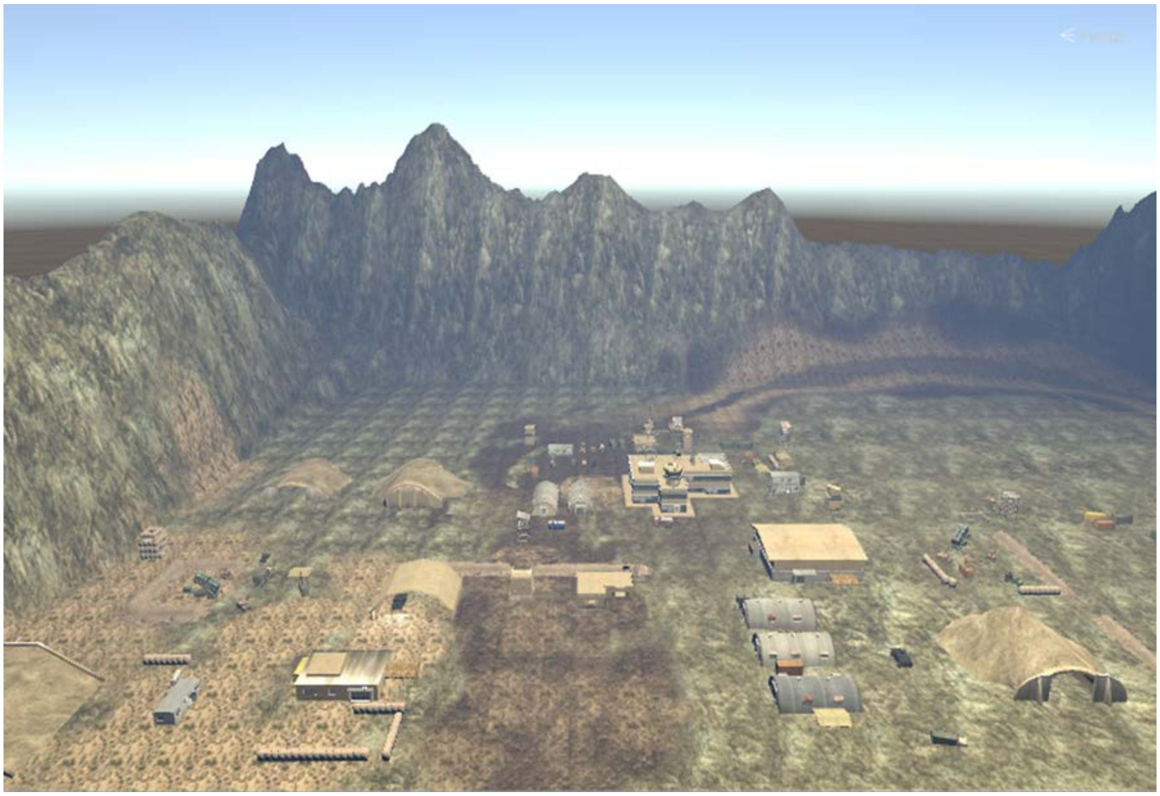

Figure 13. Scenario environment

a. Training Environment

The training environment represented the first opportunity for subjects to familiarize themselves with the system. It was designed as an open world environment with no obstacles. Two subjects were free to maneuver within the environment and familiarize themselves with the controls (hand controller and driving controller), the virtual environment setting, non-verbal communication, and they were able to collaborate with each other in the ground-guiding task. Figure 14 depicts the training environment used in the study.

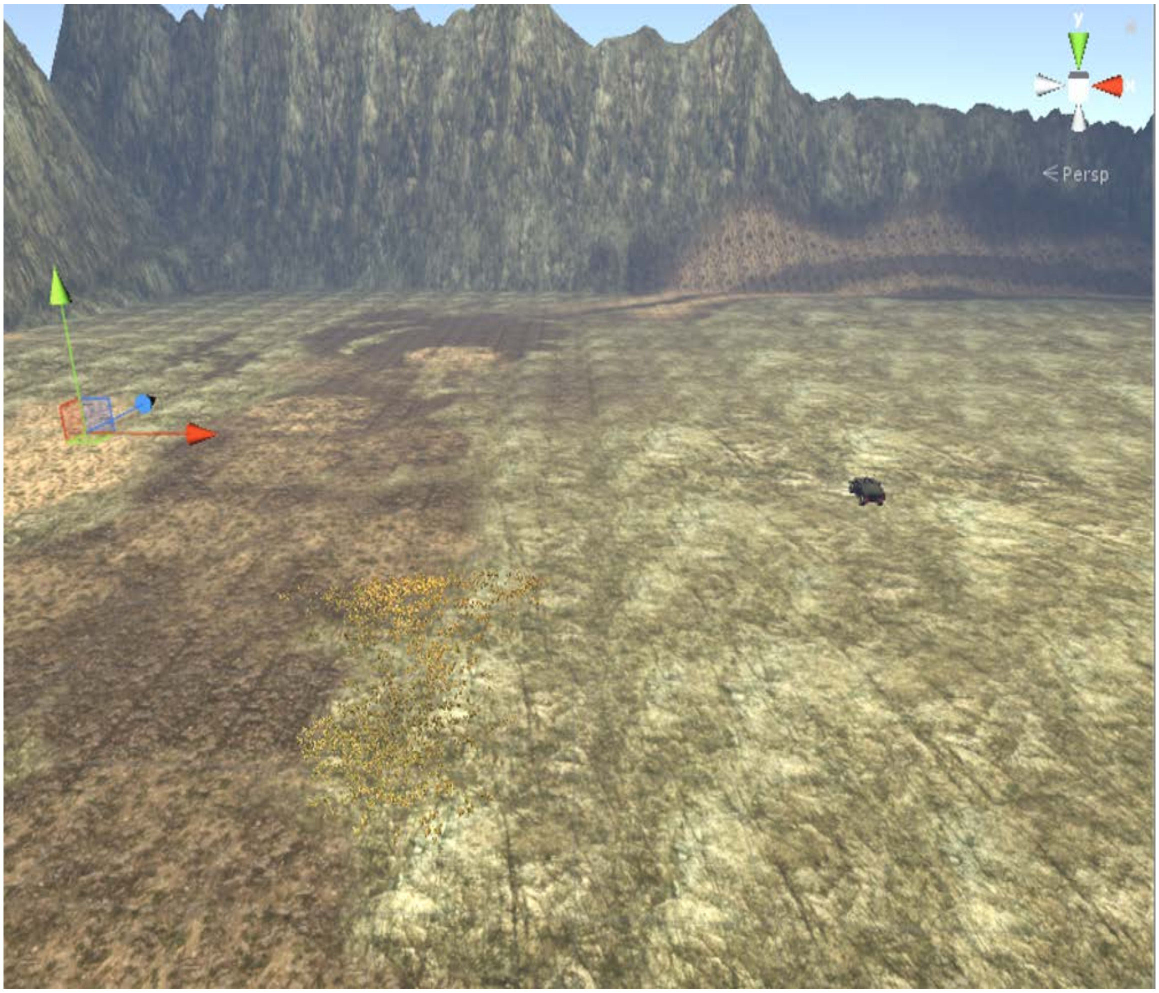

Figure 14. Training environment

b. Experimental Environment

The experimental environment was designed to resemble some real-world environment in which the ground-guiding task would normally take place. The environment was designed to look like a forward operating base with realistic building models and obstacles. Once immersed, subjects had to maneuver and move the vehicle to a location that was set as the task objective. Figure 15 depicts the experimental environment the subjects saw during the main experimental session.

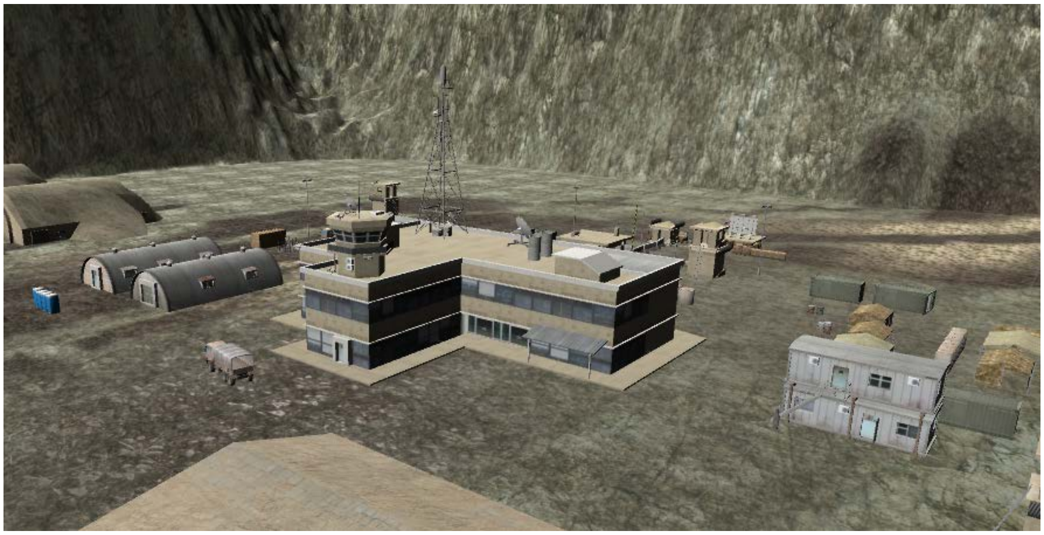

Figure 15. Experimental environment

2. Vehicle Operator Model

The vehicle that was operated by the driver was a High Mobility Multipurpose Wheeled Vehicle (HMMWV). Figure 16 depicts the driver setup and what the driver could see inside the HMD - the ground guide avatar positioned directly in front of the HMMWV.

Figure 16. Vehicle and driver close up

Figure 17 shows the side view mirrors of the vehicle which allowed the driver to see the ground guide who was indicating movement from position located behind the vehicle. Figure 18 is the overhead view of the ground guide.

Figure 17. Side mirror reflection of ground guide

Figure 18. Overhead view depicting ground guide location

Figures 19 and 20 show an individual in the driver role who sees a ground guide indicating the signal to execute a forward left hand turn.

Figure 19. Individual in driver role

Figure 20. Driver perspective in VR

3. Ground Guide Avatar Model

The model used to depict the ground guide was a humanoid avatar that was fully articulate. Using procedural animations, the avatar associated with ground guide moved in accordance to the inputs provided by the subject who acted as a ground guide and who used hand controllers to bring those inputs into the system. The HTC Vive controllers were therefore mapped to the hand positions of the ground guide avatar. Figure 21 shows the t-pose position of the ground guide avatar.

Figure 21. Avatar close up

Figures 22 and 23 depicts an individual in the ground guide role. The person is shown extending his right arm and using his left arm to indicate a forward motion.

Figure 22. Individual in ground-guide role

Figure 23. Ground-guide perspective in VR

E. TECHNICAL SYSTEM PERFORMANCE

One aspect of VR is the computational intensity required to display both images for each individual eye within the HMD. Framerates averaged 30 frames per second with peak framerates at 39 frames per second and lowest framerates at 14 frames per second. The overall size of the terrain map is set at 1000 meters by 1000 meters. Within the scene there are 122 individual game objects made up of 210,942 individual polygons.

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V. USER STUDY

This chapter outlines the design and methods of the user study, subjects who were recruited for the study, and it summarizes study results.

A. SUBJECTS

The study was conducted at the Naval Postgraduate School (NPS) and it included active Duty Navy and Army personnel. Subjects consisted of both officer and enlisted personnel that were either stationed at NPS or current students at NPS. The total number of subjects was 18; 16 were male and two were female.

Data collected on subjects included demographic information, two surveys based off their respective experiences as ground guide and driver, cybersickness assessments with Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993), and a System Usability Scale (SUS) (Brooke, 1996).

The average age of subjects in the study was 35 with the oldest subject being 47 years old and the youngest being 18 years old. Across the services, nine subjects were from the United States Army, eight were from the United States Navy, and one was from the Brazilian Air Force. Thirteen subjects in the study had ground-guided tactical vehicles before. Fifteen subjects had used a HMD in the past. Table 1 outlines the number and average age of subjects.

Table 1. Gender and age data

	Number	Average age
Female	2	29
Male	16	36
Total	18	35

B. STUDY DESIGN AND METHODOLOGY

The goal of the study was to assess the feasibility and usability of the prototype system and determine if it could be a viable tool for training ground guides in proper techniques and procedures.

1. Physical Environment

For all subjects, the physical setup for the user study was the same. This includes the two VR stations, and two desks with computers that subjects used to answer survey and demographic information. Figure 24 depicts the user study setup of both stations, while Figures 25 and 26 shows the individual stations for both ground guide and driver.

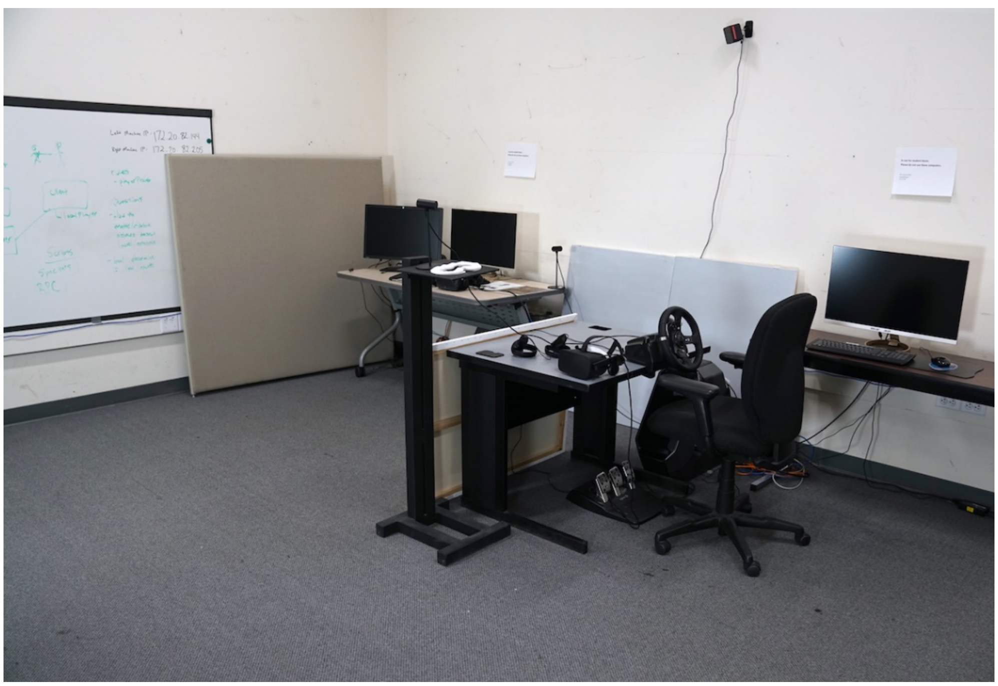

Figure 24. Ground-guide and driver stations

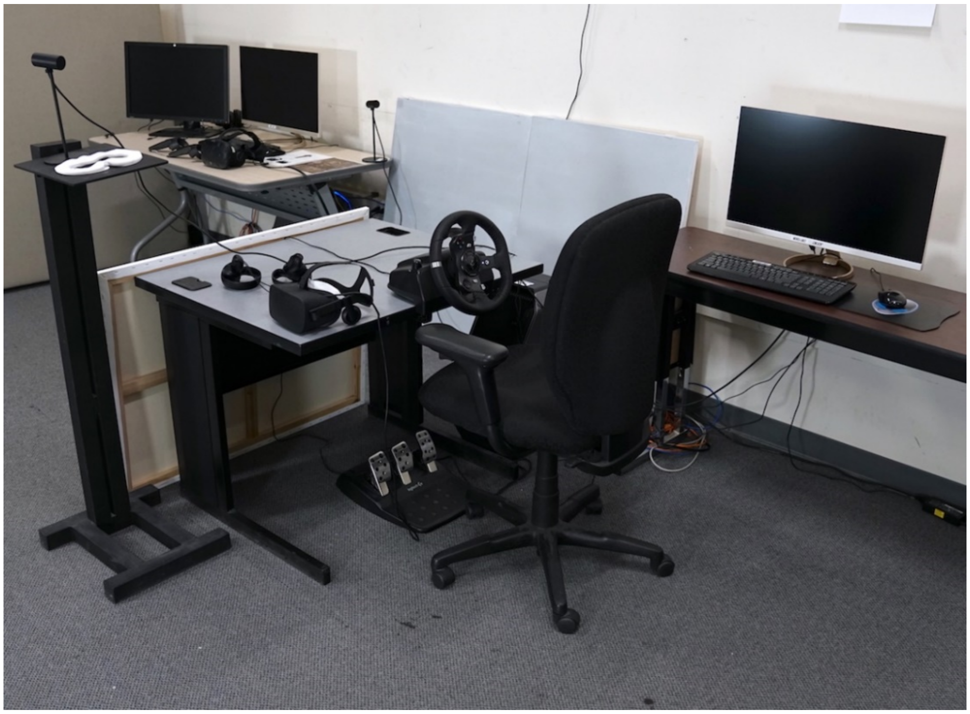

Figure 25. Driver station

Figure 26. Ground-guide station

2. Routes

Figure 27 depicts a 3D representation of a route that study subjects were to follow.

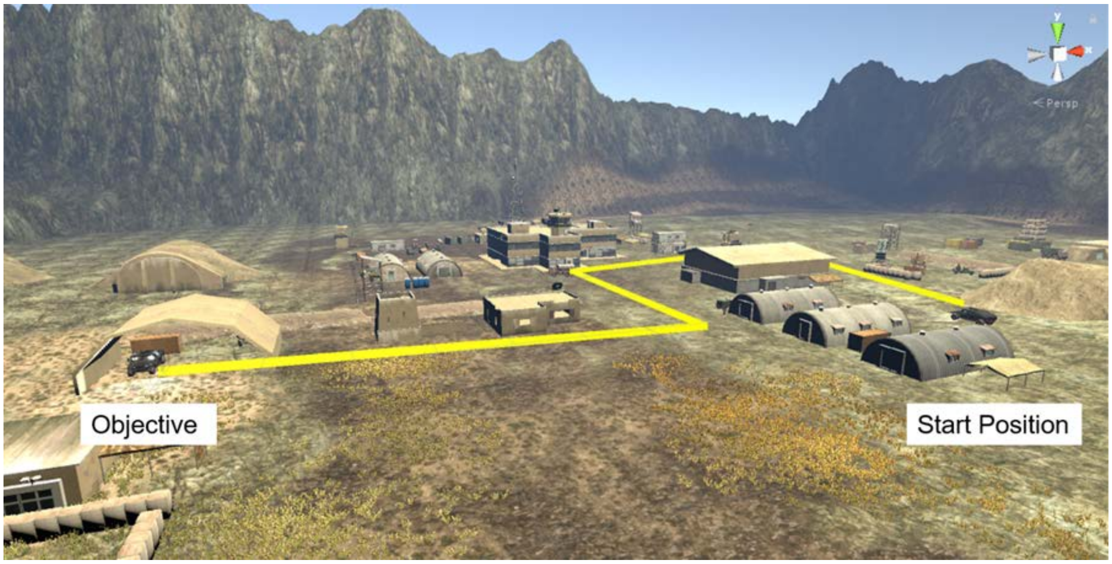

Figure 27. Driving route 1

Figures 28 and 29 show two different routes that subjects were asked to follow in the study.

Figure 28. Top-down view of route 1

Figure 29. Top-down view of route 2

3. Institutional Review Board (IRB) Process

In order to conduct the user study to evaluate the usability of the prototype system, approval from IRB was required. Once the Collaborative Institutional Training Initiative training for investigators and key research personnel was completed, the remaining IRB documentation was done. These documents included IRB application, scientific review form, conflict of interest disclosure form, informed consent form, all questionnaires, and all recruitment documentation. Once approval was granted from the IRB, we began to solicit active duty students for their participation. Recruitment activities included posting flyers (Appendix A), personal exchanges, and recruitment emails.

4. Procedure

The study was designed such that both subjects who took part in the study were asked to take both roles (role of grounding guide and role of the driver), and to evaluate both segments of the system. This was done by using two sessions approach: one subject was asked to act as a driver and another as a ground guide in first session, and then they were asked to switch the roles in second session. Management of each session was aided by following a previously developed checklist with all steps that the experimenter needed to execute during both sessions, with some steps addressing the time before the sessions with one pair of subjects started. This approach helped maintain consistency between the sessions and ensured that no step was skipped or order of the steps changed, (Appendix H).

After both subjects read and signed informed consent (Appendix F), and were briefed about the study session procedures, they were asked to fill out an initial SSQ that was used to establish subjects' baseline SSQ values. Next, the subject who had the role of ground guide in first session was provided with instruction in the hand and arm signals that were expected to be performed during their VR experience, as well as how to wear the HMDs and how to use the input devices. Likewise, subjects who had a role of driver received short introduction about driving controller and the type of HMD worn in this role. Once situated with HMDs on and positioned, both subjects received up to 10 minutes training session in training VR environment that allowed them to familiarize themselves with the system and learn how to use input devices. After the training session, both subjects removed their HMDs and completed a second SSQ. They returned to their positions in the system and started the first experimental session in experimental VR environment. The experimental session consisted of up to a 15-minute session in which the ground guide was briefed on a given route and told to ground guide the tactical vehicle to that goal objective; the driver, of course, did not know the details of that route. In case the goal destination was not reached during allotted 15 minutes, the session was stopped and final positions of both driver and ground guide was captured by saving the screenshot of their positions in VR environment. After the first experimental session ended, subjects were asked to complete their third SSQ assessment, a post session survey specific to the role that they just had, and SUS questionnaire. The second session was then a repetition of the first session except that now the subjects switched their respective roles. Each subject was briefed on the controls as before and were given the chance to complete the training session, followed by a fourth SSQ. Next, the second experimental session was performed in the same manner as the first experimental session with times and final positions annotated and screenshotted. The final task for each subject was to complete a fifth SSQ, and a survey based off of their role in the second session, the SUS questionnaire, and a demographic survey whose text can be seen in Appendix B.

5. Objective Data Set

The objective data collected during this study consisted of the total time it took for each pair of subjects to reach the objective (if successful i.e. accomplished in less than 15 minutes), the number of collision that occurred, the number of correct signals given by the ground guide, the number of correct signals given by the ground guide that were acted upon by the driver, the number of incorrect signals given by the ground guide, the number of signals erroneously acted upon by the driver, and the timestamps of verbal communication instances and who initiated it. The objective data was recorded by the experimenter and was collected in pairs as subjects attempted to reach the objective destination. Times for completion were recorded on a digital stopwatch from the experimenter's cellular device.

6. Subjective Data Set

Subjective data was collected from each subject throughout the study. This type of data included a System Usability Scale - SUS (Appendix C), Simulator Sickness Questionnaire – SSQ (Appendix G), and post-session questionnaires (Appendices D and E). Gathering subjective data allowed us to increase our insight into the results of the objective data set and assess subjects' opinions with regards to the system usability.

a. SUS

Since research objective was to evaluate the usability of the prototype training system and examine if it can be serve as a viable tool to support the task of tactical vehicle ground guiding, the SUS was chosen as a means of this evaluation. The SUS was developed by John Brooke in 1986 and was intented to be a quick and low cost solution to evaluate usability of industrial systems. He wrote that usability can only be defined as the appropriateness to a purpose of any particular artefact (Brooke, 1986). The SUS consists of ten questions assessing the opinions of the taker with a Likert scale ranging from zero, strongly disagree option, to four, strongly agree. A series of calculations are then conducted outputting a SUS score in a range from 0 to 100. For this user study, an average SUS score greater than 68 will indicate that subjects found the system prototype to be a usable system to perform and train ground guiding. The calculations are as follows:

- For questions 1, 3, 5, 7, and 9, the score contribution is the scale value minus 1.
- For questions 2, 4, 6, 8, and 10, the score contribution is 5 minus the scale value.
- The sum of all score contributions is then multiplied by 2.5 to obtain the overall score.

b. SSQ

The SSQ is a questionnaire that assesses the subjects' level of simulator sickness or cybersickness. The SSQ has three goals, "(a) to provide a more valid index of overall simulator sickness severity as distinguished from motion sickness; (b) to provide subscale scores that are more diagnostic of the locus of simulator sickness in a particular simulator for which overall severity was shown to be a problem; and (c) to provide a scoring approach to make monitoring and cumulative tracking relatively straightforward" (Kennedy et al., 1993).

c. Post-session Questionnaire

After each experimental session, subjects were asked to complete a questionnaire specific to the role that they just completed. The ground guide questionnaire consisted of eight questions and the driver question consisted of nine questions. Capturing this type of data allowed us to assess not only how willing a subject would be to use a system similar to the one development, but also to capture how realistic aspects of the system were such as the modeling of the vehicle and ground guide, the environment, and accuracy in which the vehicle and ground guide moved.

C. RESULTS

1. Objective Data Set

A total of nine pairs of ground-guide drivers took part in the study. Each pair conducted two sessions, which resulted in 18 sessions of ground-guiding data. Completion times are shown in Table 2.

Table 2. Experimental session completion times (time in minutes)

	Group	Session 1	Session 2
Times to reach objective (15 Min deadline)	1	8:01	10:32
	2	7:43	6:35
	3	8:32	9:03
	4	8:52	11:57
	5	8:11	5:14
	6	6:37	8:13
	7	9:07	13:18
	8	12:42	11:29
	9	15:00	15:00
Average:		**8:43**	**9:32**

Out of the 18 sessions completed during the user study, only one pair failed to reach the objective in both their sessions (each session had 15 minutes-long time window allotted). Average time for completion of Session 1 (Route 1) by groups one through eight was 8:43 minutes, and average time for completion of Session 2 (Route 2) was 9:32 minutes.

In addition to recording the times to complete the objective, following values were also recorded (note each signal was evaluated and value recorded by experimenter who was subject matter expert on ground-guiding operations):

1. Number of correct signals given by the ground guide
2. Number of correct signals given by the ground guide that were acted upon by the driver

3. Number of incorrect signals given by the ground guide

4. Number of signals erroneously acted upon by the driver

The totals are shown in Table 3.

Table 3. Observer reported metrics

		Signals					
	Group	**Move forward**	**Move reverse**	**Halt**	**Turn left**	**Turn right**	**Total**
Number of signals correrctly given by ground guide in each group	1	12	4	7	11	2	36
	2	2	3	2	6	5	18
	3	14	5	21	13	9	62
	4	15	3	20	7	8	53
	5	5	1	7	9	4	26
	6	12	0	2	3	0	17
	7	18	9	14	11	9	61
	8	11	5	3	2	7	28
	9	9	2	4	8	3	26
Total:		**98**	**32**	**80**	**70**	**47**	**327**
	Group	**Move forward**	**Move reverse**	**Halt**	**Turn left**	**Turn right**	**Total**
Number of all signals correctly understood and acted upon by driver in each group	1	12	4	6	10	2	34
	2	1	3	2	6	5	17
	3	14	5	21	13	9	62
	4	15	3	19	5	4	46
	5	5	1	4	8	3	21
	6	10	0	2	3	0	15
	7	16	4	14	10	7	51
	8	10	2	1	1	3	17
	9	9	2	4	5	3	23
Total:		**92**	**24**	**73**	**61**	**36**	**286**
	Group	**Move forward**	**Move reverse**	**Halt**	**Turn left**	**Turn right**	**Total**
Number of all signals erroneously given by the ground guide in each group	1	1		0	1	1	3
	2	1	0	4	0	0	5
	3	0	0	2	0	0	2
	4	0	1	1	1	1	4
	5	1	0	3	1	0	5
	6	1	0	1	1	0	3
	7	1	3	1	1	0	6
	8	1	0	6	1	0	8
	9	0	0	8	8	4	20
Total:		**6**	**4**	**26**	**14**	**6**	**56**
	Group	**Move forward**	**Move reverse**	**Halt**	**Turn left**	**Turn right**	**Total**
Number of all signals erroneously acted upon the the driver in each group	1	0	0	0	0	1	1
	2	0	0	3	0	0	3
	3	0	0	1	0	0	1
	4	2	2	1	0	1	6
	5	1	0	1	0	0	2
	6	1	0	1	0	0	2
	7	3	6	0	2	2	13
	8	2	0	0	2	1	5
	9	0	0	3	1	2	6
Total:		**9**	**8**	**10**	**5**	**7**	**39**

The most accurate signal given by the ground guide was the move forward signal and was accurately acted upon by the driver 94% of the time. Since movement of the vehicle was primarily in the forward direction this and the halt command, second most accurate signal, were the highest used signals by the ground guide. The least accurate signal given by the ground was the halt signal. The most erroneously acted upon signal by the driver was the halt signal. This was due to the drivers' awareness of the environment and intuitiveness in knowing that they needed to halt the vehicle given a particular situation even if the signal being given by the ground guide was technically accurate.

Overall, drivers were able to see and interpret the correct hand and arm signals being given to them through the ground guide avatar. Instances in which signals began to be misinterpreted were when distances between the ground guide and the vehicle became so great that the driver could not accurately see the signals being given or when the ground guide gave the incorrect hand and arm signal to the driver.

Table 4 indicates the timestamps of moments when subjects attempted to use verbal communication in the experimental session. The majority of instances occurred during the first few minutes of the session when subjects were attempting to understand and receive a confirmation of the hand and arm signals being given. Individuals that had performed ground guiding prior to participating in the study had less instances of attempting to verbally communicate than those who had not. Having familiarity with the hand and arm signals and how ground guides communicate non-verbally to the vehicle operator enhanced their ability to accomplish the assigned task.

Table 4. Timestamps of verbal communication instances and who initiated it

	Group	Driver (time from beginnig of session)	# of comm. attempts by driver	Ground guide (time from beginning of session)	# of comm. attempts by ground guide
Timestamps of verbal communication instances and who initiated it	1	/	0	0:35, 1:30	2
	2	7:50	1	/	0
	3	6:26	1	1:29, 1:32, 3:23, 8:32	4
	4	1:03, 1:23, 3:11,	6	4:43, 7:30, 10:13	3
	5	2:00, 5:19	2	2:29, 3:26, 7:38	3
	6	0:50	1	/	0
	7	0:30, 1:47, 4:17,	7	1:59, 4:05, 4:24, 10:34	4
	8	0:30, 2:20, 4:40,	5	1:14, 6:25	2
	9	5:34	1	5:00, 9:00	2
Total # of instances:		**24**	**24**	**20**	**20**

2. Subjective (Subject Reported) Data Set

The subjective data that was gathered consisted of post-session driver specific questionnaire that was completed at the end of each session by subject who had that role, a post-session ground guide specific questionnaire that was completed at the of each session by subject who had that role, SUS and SSQ questionnaires, and an additional post session survey.

a. Post-session Surveys

A goal of this questionnaire was to capture additional self-reported comments about session that was just completed by both ground guide and driver. In the role of ground guide, when asked as to how valuable it would be to use this type of system to train ground-guiding operations, three subjects responded that the system as very valuable, seven that it was valuable, five reported it as somewhat valuable, and three reported it as neutral or no opinion (Table 9). In the role of driver, when asked as to how valuable it would be to use this type of system to train ground-guiding operations, three subjects responded that the system was very valuable, seven reported it as valuable, four reported it as somewhat valuable, one reported as neutral or no opinion, one reported it as somewhat not valuable, and one reported the system as not valuable (Table 5). Subjects also commented of the difficulty in seeing the hand positions of the ground guide and sometimes the difficulty in understanding the gestures the ground guide was making.

Table 5. Value of the system as training solution (question for driver)

Question	Score	# of responses
How valuable would it be to use this type of system to train ground guiding operations?	1 - Not very valuable	0
	2 - Not valuable	0
	3 - Somewhat not valuable	0
	4 - Neutral	3
	5 - Somewhat valuable	5
	6 - Valuable	7
	7 - Very valuable	3
Total:		18

Table 6 summarizes responses to question related to difficulty in using the driving controller. Most comments addressed difficulty in finding the positions of the acceleration and brake pedals in addition to finding the reverse button on the driving control. In regards to operating the steering wheel, subjects found it intuitive since all individuals had operated a personal vehicle before.

Table 6. Difficulty in operating driving controller (question for driver)

Question	Score	# of responses
Was it difficult to operate the driving controller?	1 - Very difficult	0
	2 - Difficult	0
	3 - Somewhat difficult	3
	4 - Neutral	2
	5 - Somewhat easy	3
	6 - Easy	6
	7 - Very Easy	4
Total:		18

Table 7 presents responses to question that asked how recognizable the hand and arm signals were of the ground guide. Reviewing instances when subjects initiated verbal communication during the beginning of the experimental session, it was often the driver asking for confirmation of the signal being given. Once the driver adapted to recognizing the orientation of the ground guide’s hands, they were able to comply with the ground guide’s signals for the rest of the session.

Table 7. Recognition of hand and arm signals (question for driver)

Question	Score	# of responses
How valuable would it be to use this type of system to train ground guiding operations?	1 - Not very valuable	0
	2 - Not valuable	1
	3 - Somewhat not valuable	1
	4 - Neutral	2
	5 - Somewhat valuable	4
	6 - Valuable	7
	7 - Very valuable	3
Total:		18

Table 8 assesses the driver's opinion of their ground guide's performance. During the user study, no driver reported poor performance of the ground guide that they were partnered with.

Table 8. Evaluation of partner's performance (question for driver)

Question	Score	# of responses
How would you rate your partner's performance in the experimental session you just completed?	1 - Very poor	0
	2 - Poor	0
	3 - Somewhat poor	0
	4 - Neutral	0
	5 - Somewhat good	3
	6 - Good	8
	7 - Very good	7
Total:		18

Table 9 assesses from the ground guide's role it they thought this type of system would be good to train ground-guiding operations. No subjects found it that it had negative value with the majority of individuals finding it valuable.

Table 9. Value of the system as training solution (question for ground guide)

Question	Score	# of responses
How valuable would it be to use this type of system to train ground guiding operations?	1 - Not very valuable	0
	2 - Not valuable	0
	3 - Somewhat not valuable	0
	4 - Neutral	3
	5 - Somewhat valuable	5
	6 - Valuable	7
	7 - Very valuable	3
Total:		18

Table 10 asks if it was difficult to use the HTC vive controller for movement in the VE. Three subjects found it somewhat difficult to use and commented that it was difficult to control movement while moving backwards and looking in directions opposite to which they wanted to move.

Table 10. Difficulty in using HTC Vive hand controllers (question for ground guide)

Question	Score	# of responses
Was it difficult to use the HTC Vive hand controllers?	1 - Very difficult	0
	2 - Difficult	0
	3 - Somewhat difficult	3
	4 - Neutral	1
	5 - Somewhat easy	5
	6 - Easy	7
	7 - Very Easy	2
Total:		18

Table 11. Evaluation of partner's performance (question for ground guide)

Question	Score	# of responses
How would you rate your partner's performance in the experimental session you just completed?	1 - Very poor	0
	2 - Poor	0
	3 - Somewhat poor	0
	4 - Neutral	0
	5 - Somewhat good	3
	6 - Good	8
	7 - Very good	7
Total:		18

In regards to assessing the realism of the prototype, subjects were asked to evaluate the realism of ground gesturing, movement of vehicle, visual representation of the terrain, visual representation of objects in the rest of the scene (buildings, vehicles, obstacles), the visual realism of the vehicle, and the visual realism of the ground guide. Answers ranges along a Likert scale between one and seven. Overall, subjects expressed that the system realistically portrayed ground-guiding operations in this type of environment. Appendix I has the results from the ground guide questionnaires and Appendix J has the results from the driver questionnaires. Each question is design to gather the opinion of each participant on how realistic they viewed the visuals, movements, and physics of both ground guide and driver.

b. SUS

The SUS was developed in order to provide a quick and simple means of providing a subjective assessment of a systems usability. It consists of 10 questions with each question utilizing a Likert scale with question response values ranging from one, strongly disagree, to five, strongly agree. Table 12 shows the lowest score 57.5, highest score 90, and average score 75.28. Since the average score was higher than the SUS average of 68, we can reasonably accept that the prototype system is suitable for training ground-guiding.

Table 12. Overall SUS scores

Lowest SUS	57.50
Hightest SUS	90.00
Average SUS	75.28

Table 13 shows the averages from each individual question from the SUS.

Table 13. Average scores by question

Question	**Average Score (1 - Strongly Disagree, …, 5 - Strongly Agree)**
1. I think that I would like to use this system frequently	2.50
2. I found the system unnecessarily complex	3.17
3. I thought the system was easy to use	3.22
4. I think that I would need the support of a technical person to be able to use this sy	2.44
5. I found the various functions in this system were well integrated	3.11
6. I thought there was too much inconsistency in this system	2.89
7. I would imagine that most people would learn to use this system very quickly	3.44
8. I found the system very cumbersome to use	3.00
9. I felt very confident using the system	3.06
10. I needed to learn a lot of things before I could get going with the system	3.28

c. SSQ

The information presented in Table 1 provides the data on symptoms reported by subjects during the study sessions. Each subject completed five evaluation of the SSQ during their session for a total of 90 cybersickness assessments made for the entire user study. The first SSQ was to establish a baseline for each subject. The second SSQ was completed after their first respective training session. The third SSQ was completed after their first respective experimental session. The fourth SSQ was completed after switching roles and completing their second training session. The final (fifth) SSQ was completed after completing the second and final experimental session. Overall, most individuals did not display or report having any negative symptoms from using the system. Some of the contributing factors to this include the regular breaks between training and experimental sessions and relatively short amount of time operating the system. Table 14 shows the numbers and percentages for the overall SSQ assessment. Appendix K shows the numbers and percentage changes after each session of operating the system. For each question, subjects could have answered with the response of none, slight, moderate, or severe. The numbers in column represent the number of times each subject reported feeling that symptom at that level. The percentage column is the percentage of subjects that reported feeling that symptom. Those subjects that reported feeling moderate symptoms during their assessment all reported that they were experiencing none of the symptoms during their baseline assessment. Additionally, more subjects rated their experimental sessions with slight or moderate symptoms compared to their training session after which they reported as having with none or slight symptoms.

Table 14. SSQ results

LEVEL:	None		Slight		Moder		Severe	
SYMPTOM			N		N		N	
1. General	7	8	1	1	1	1	0	0
2. Fatigue	6	7	2	2	0	0	0	0
3. Headache	7	8	1	1	0	0	0	0
4. Eye Strain	7	8	1	1	0	0	0	0
5. Difficuluty	8	8	1	1	0	0	0	0
6. Salivation	9	1	0	0	0	0	0	0
7. Sweating	8	9	4	4	1	1	0	0
8. Nausea	8	9	3	3	2	2	0	0
9. Difficulty	8	9	3	3	0	0	0	0
10. Fullness of the	/	/	/	/	/	/	/	/
11. Blurred vision	8	9	7	7	0	0	0	0
12. Dizziness with	8	9	4	4	0	0	0	0
13. Dizziness with	8	9	5	5	3	3	0	0
14. Vertigo	8	9	2	2	0	0	0	0
15. Stomach	8	9	9	1	0	0	0	0
16. Burping	8	9	2	2	0	0	0	0

d. Experimenter's Observations

During the course of the user study, the experimenter observed a number of trends during the course of all sessions. The first observation was related to subjects' comment of the speed of the ground guide. Namely, the speed of the ground guide in the scenario was set to replicate walking speed. This was done not only to replicate the typical speed at which a human would walk, but also to control potential cybersickness symptoms. Due to such speed, it was often observed that the driver had to halt the movement and wait for the ground guide to move ahead along the route and then subsequently proceed to give the move forward signal to the driver. Subjects who had conducted ground-guiding before mitigated this stop-and-start progression by simply indicating the move forward signal and then having the driver follow in trace until it was time to give a different hand and arm signal. This procedure allowed for continual progress along the route to the objective and produced faster times in reaching the objective.

The second trend that was observed was that ‘drivers’ moved about too freely in the chair in which they were sitting. They would attempt to either try to look outside the window to observe the ground guide, something in which they would not be able to do the real world, or they moved into a seated stretched position that would not be feasible if they were inside an actual tactical vehicle. One subject was observed casually leaning back in the seat and driving with one hand similarly to how one might drive a personally operated vehicle. Creating a fixed ‘cockpit’ that the driver would sit in would replicate an actual tactical vehicle and resolve this issue.

The third trend observed was that ground guide tended to focus their line of sight on the vehicle and the driver rather than the environment that surrounded them, including the obstacles. Ground guides showed an inclination for observing whether or not the vehicle was following their hand and arm signals and did not spend enough time scanning the environment for potential obstacles that the driver might have to avoid. In more dynamic environment, this could lead to the ground guide not noticing the obstacles and lead a driver to a potential collision or other vehicular incident. During the study, only one pair of subjects experienced the vehicle colliding with an obstacle in the experimental environment. The driver was making left turn and the ground guide was positioned in front and to the right relative to the vehicle. The driver hit a barrier with the front left bumper of the vehicle. This collision was due to the driver not having updated spatial awareness and not knowing how close the front end of the vehicle was to the obstacle; at the same time the ground guide (being on the right side of the vehicle) did not have visibility of the space around front left side of the vehicle.

During the initial period of the experimental sessions (typically several minutes from the start of the session), drivers commented the difficulty of seeing the orientation of the ground guide’s hands. Up close the drivers were able to recognize the position of the hands i.e., whether palms were facing away or towards them, but as distances increased between the vehicle and the ground guide, drivers commented that it became difficult to interpret the correct hand and arm signals. This difficulty was especially noticed when the ground guide was approximately 25 to 30 feet away from the vehicle. It is worth noting that this is also an issue when conducting ground guiding in the real world, so it is important to recognize that the role that distance plays in accurate ground guiding in both real and virtual environments.

The last observation concerned subjects’ commenting on fatigue of using the ground guide controllers. This comment on developing fatigue through using the system was an isolated event, but it did bring up the issue of possible fatigue and symptoms of cybersickness by overall use of the system, regardless of role. The longest single session that subjects had using the system was 15 minutes, but if individuals were to train in longer extended sessions, they may star to experience both fatigue and symptoms associated with cybersickness. Assessing the effect of longer training sessions was not addressed in this work, and that type of research would be recommended as a follow-on work.

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

The work of this study demonstrated that it is feasible to take COTS technology and create a prototype system for training ground guiding and driving skills—targeted technical characteristics of the system have been accomplished and acceptance of the system by the subjects in user study was positive. Through the use of different VR systems, we showed that it is possible to leverage multiple forms of COTS VR technology to improve the training domain for military personnel.

The work set out to answer the following research questions:

1. What is the feasibility of using commercial off the shelf technology (COTS) to develop a virtual reality trainer in support of tactical vehicle ground-guiding procedures?

Utilizing COTS VR systems, open source software, and open source 3D models, we were successfully able to demonstrate the ability to conduct ground guiding in a fully immersive networked VE. The prototype system was able to fully immerse the subjects with visual, aural, and haptic displays that were able to successfully block out influences from the real world to sufficient extent so that they could believe they were in the virtual world and perform ground guiding operations.

2. Will subjects consider a ground-guiding training system as a viable means of increasing sets and reps of the training task?

Given the responses from subjects in the user study, we can make the claim that the system was seen as a viable tool for training of ground-guiding procedures.

B. FUTURE WORK

This thesis was meant to test the usability of a prototype system and there are a number of ways to expand upon it. The first line of future work would be to expand upon the number of experimental scenes beyond what was used in this thesis. The system prototype environment was designed to replicate a forward operating base where subjects could roam and navigate to an objective, but there are many other instances where ground guiding occurs. In the embarkation of ships, vehicles are loaded and parked next to one another with tolerances sometimes limited to just inches. Since this presents a high risk of vehicle collisions, it could benefit both the ground guide and driver to practice their loading in virtual environments prior to ever stepping foot or driving aboard an actual ship.

In the system, a HMMWV was used as the vehicle to ground guide. Since the ground-guiding task applies across a wide variety of different tactical vehicles, incorporating the array of tactical vehicles currently being field in the system would expand the audience that could take advantage of the training the system provides. Additionally, having higher fidelity models would only serve to increase the realism of the ground-guiding task and most likely have a positive effect on overall experience and sense of presence by both ground guide and driver.

Additional future work would be to take this system and conduct an experiment to determine if practicing ground guiding in the system actually improve upon an individual's ability to perform ground guiding (training effectiveness study), and also if the skills acquired in such training system do transfer to real life situations (transfer of training study). A future thesis could include visiting a unit that routinely engages in ground-guiding activities so that subject matter expertise opinion could be obtained in addition to evaluating metrics of whether or not the system actually improves accuracy and efficiency in ground guiding.

APPENDIX A. RECRUITMENT POSTER

Experience Driving and Ground Guiding in Virtual Reality (VR)

Help a fellow student's thesis research to understand the feasibility of using commercial off the shelf virtual reality technology to train tactical vehicle driving and ground-guiding procedures. You will be using VR headset in ground-guiding training system. At the end you will be asked to provide feedback via a questionnaire.

What: You and another participant will be asked to drive tactical vehicle and perform ground guiding hand and arm signals.

Purpose: Provide feedback on prototype ground guiding training system.

Who: Active duty NPS students
Where: Watkins Rm 212B
When: Any time you can spare (about 70 minutes). Study requires two participants at a time.
Contact: Cody Tackett @ cdtacket@nps.edu

Risks associated with this study are minimal. Participation is voluntary. The point of contact for risk questions or concerns is Principal Investigator Dr. Amela Sadagic asadagic@nps.edu. Prospective subjects may contact NPS IRB Chair Dr. Larry Shattuck lgshattu@nps.edu or NPS IRB IRB@nps.edu (831) 656-2998.

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APPENDIX B. DEMOGRAPHIC SURVEY

<u>VR Ground Guiding Task</u>

Date: _______

1. Year of Birth: ______

2. Which branch: (circle one that applies)

   USA
   USN
   USMC
   USAF
   USCG

3. Years of Service: ______

4. Current Rank: ______

5. Functional Area/Specialty/MOS: ___________________________________

6. Have you ever operated a tactical vehicle before?

YES NO

7. If 'YES':

   a. What type/variants? (circle all that apply)

   HMMWV
   LVSR
   MTVR
   MRAP
   Other: __________________________________

   b. For how long (all types)? ________ years.

8. Have you ever received training in ground guiding tactical vehicles before?

YES NO

9. If 'YES', what kind (circle all that apply):

   School House

Unit
Licensing Course
Informal
Other: ____

10. If ‘YES’, when did last training occur? __________ (year)

11. Have you ever ground guided a vehicle before?

YES NO

12. If ‘YES’, how many times in last 5 years? ___________

13. If ‘YES’, when was the last time? __________

14. Do you play video games?

YES NO

15. If “YES”:

a. How often? (circle one that applies)

Less than 2 hrs/wk
2-4 hrs/wk
4-8 hrs/wk
More than 8 hrs/wk

b. What percentage of game types do you play? Ensure values add to 100%.

single-player ______ % multi-player ______ %

c. What percentage of game types do you play? Ensure values add to 100%.

first-person ______ % third-person ______ %

16. Have you use used a virtual reality head mounted display before?

YES NO

17. If ‘YES’:

a. What kind? (circle all that apply)

HTC Vive
Oculus Rift

Gear VR
Google Cardboard
Hololens
Other: _________

b. How many times in last 5 years? (circle one that applies)

Only once
Less than 5 times
Between 5 and 10 times
More than 10 times

c. When was the last time you used it? (circle one that applies)

Within last 30 days
Within last 6 months
Within the last year
More than a year ago

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APPENDIX C. SYSTEM USABILITY SCALE

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

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APPENDIX D. DRIVER QUESTIONNAIRE

1. How valuable would it be to use this type of system to train ground-guiding operations?

1	2	3	4	5	6	7
Not very valuable	Not valuable	Somewhat not valuable	Neutral	Somewhat valuable	Valuable	Very valuable

2. How recognizable were the hand and arm signals?

1	2	3	4	5	6	7
Very unrecognizable	Unrecognizable	Somewhat unrecognizable	Neutral	Somewhat recognizable	Recognizable	Very recognizable

3. Was it difficult to operate the driving controller?

1	2	3	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy

4. If there was any difficulty in operating the driving controller, please explain what they were:
    a. ________________
    b. ________________
    c. ________________

5. How would you rate your partner's performance in session you just completed?

1	2	3	4	5	6	7
Very poor	Poor	Somewhat poor	Neutral	Somewhat good	Good	Very good

6. What elements of your partner's performance were done well?
    a. ________________
    b. ________________
    c. ________________

7. What elements of your partner's performance were not done well?
    a. ________________
    b. ________________
    c. ________________

8. How realistic was the portrayal of the ground-guiding operations in this environment?

    a. Ground Guide gesturing:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

b. Movement of vehicle:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

c. Visual representation of terrain:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

d. Visual representation of objects in the rest of the scene (buildings, other vehicles):

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

e. Visual realism of vehicle:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

f. Visual realism of ground guide:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

9. Additional Comments/Remarks:

____

____

APPENDIX E. GROUND GUIDE QUESTIONNAIRE

1. How valuable would it be to use this type of system to train ground-guiding operations?

1	2	3	4	5	6	7
Not very valuable	Not valuable	Somewhat not valuable	Neutral	Somewhat valuable	Valuable	Very valuable

2. Was it difficult to use the HTC Vive hand controllers?

1	2	3	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy

3. If there was any difficulty in using the HTC Vive hand controllers, please explain what they were:
   d. _______________
   e. _______________
   f. _______________

4. How would you rate your partner's performance in session you just completed?

1	2	3	4	5	6	7
Very poor	Poor	Somewhat poor	Neutral	Somewhat good	Good	Very good

5. What elements of your partner's performance were done well?

   d. _______________
   e. _______________
   f. _______________

6. What elements of your partner's performance were not done well?

   d. _______________
   e. _______________
   f. _______________

7. How realistic was the portrayal of the ground-guiding operations in this environment?

   a. Ground Guide gesturing:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

   b. Movement of vehicle:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

c. Visual representation of terrain:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

d. Visual representation of objects in the rest of the scene (buildings, other vehicles):

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

e. Visual realism of vehicle:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

f. Visual realism of ground guide:

1	2	3	4	5	6	7
Not at all realistic	Not realistic	Somewhat not realistic	Neutral	Somewhat realistic	Realistic	Very realistic

8. Additional Comments/Remarks:

____

____

____

____

APPENDIX F. CONSENT FORM

Naval Postgraduate School
Consent to Participate in Research

Introduction. You are invited to participate in a research study entitled 'Study of a virtual reality trainer for tactical vehicle ground-guiding procedures'. The purpose of the research is to determine suitability of using VR technology for training of tactical vehicle operation and ground guiding procedures.

Procedures. You will be asked to complete a military based task focused on tactical vehicle operation and ground guiding operations. After reviewing system operation and ground guiding procedures you and another subject (driver and ground guide roles), will use virtual reality system to accomplish the task. The participant acting as the ground guide will give the vehicle operator the appropriate hand and arm signals to navigate the vehicle to its goal destination. The participant acting as the vehicle operator will be requested to follow the instructions observed from the ground guide avatar and attempt to successfully navigate to the goal destinations. Both participants will be asked to complete a brief survey at the end of your task. The full duration of your participation should last approximately 70 minutes. The expected number of individuals who will have the opportunity to participate in this research study will not exceed 50.

Location. The study will take place Watkins Hall Room 212B.

Cost. There is no cost to participate in this research study.

Voluntary Nature of the Study. Your participation in this study is strictly voluntary. If you choose to participate you can change your mind at any time and withdraw from the study. You will not be penalized in any way or lose any benefits to which you would otherwise be entitled if you choose not to participate in this study or to withdraw. The alternative to participating in the research is to not participate in the research.

Potential Risks and Discomforts. Symptoms of cyber sickness can occur with exposure to immersive virtual environment; they are similar to motion sickness symptoms. While every effort in the design of the virtual environment testing platform has been made to mitigate cyber sickness, there is a possibility the subject may have symptoms present during the study. Symptoms include visual symptoms (eyestrains, blurred vision, headaches), disorientation (vertigo, imbalance) and nausea (vomiting, dizziness). If symptoms are observed by the experimenter or participants remark upon feeling any of these symptoms, participants will be removed from the study. Additionally, participants are at risk of breach of confidentiality.

Anticipated Benefits. This study with advance our understanding of the role that commercial off the shelf virtual reality systems can have in future training and education domain. You will not directly benefit from your participation in this research.

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. Survey data will be kept only on NPS approved and owned data systems. All survey data will only identify you by Subject ID that is different from your name. Only the researcher and principal investigator will have access to the collected data for analysis. The data will be stored in a secured document and the principal investigator will maintain all electronic data upon completion of the study for 10 years.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, *Dr. Amela Sadagic at (831) 656-3819* or asadagic@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Larry Shattuck, 831-656-2473, lgshattu@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

______________________________________ __________________

Participant’s Signature Date

______________________________________ __________________

Researcher’s Signature Date

APPENDIX G. SIMULATOR SICKNESS QUESTIONNAIRE

No_____________ Date__________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

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APPENDIX H. USER STUDY CHECKLIST

User Study Checklist

LONG BEFORE SUBJECTS COME:

- Make sure controllers are fully charged!
- Make sure you have extra bottles of water in case subjects need water

BEFORE SUBJECTS COME:

- Put up the sign "DO NOT DISTRURB - STUDY IN PROGRESS"
- Check videorecorder: it is staged and ready
- Check if printed consent form is ready for both subjects
- Check if electronic version of surveys for two subjects are ready
- Make sure all unity scenes for training session are loaded
- Make sure fresh/new protective liners for HMDs are attached in both headsets

EXPERIMENTAL SESSION:

- [ ] Welcome both subjects, offer them water if they need it.
- [ ] Ask subjects to complete informed consent document.
- [ ] Brief subject of study outline and schedule of events
- [ ] Make note of any subject who wears corrective lenses or glasses.
- [ ] Assign roles of driver and ground guide
- [ ] Make note who normally wears glasses but is not going to use them in experiment.
- [ ] Pass out hand and arm signals cheat sheet/driving instructions and review with participants.
- [ ] Ask both subjects if they had enough time to review ground guiding instructions and if they are ready.
- [ ] Complete initial SSQ (baseline - 1st - SSQ)
- [ ] Check if all questions were answered
- [ ] Help subjects don HMDs and take seat (driver): Adjust driver position and set up subjects with controllers and HMDs
- [ ] Start/play training environment and allow subjects familiarization period (10 min max).
- [ ] Walk each person though set of checks ('Look around… walk/move forward… ")
- [ ] Use stopwatch: Let subjects know that training session is over after 10 min.
- [ ] End training period and ask subjects to complete 2nd SSQ
- [ ] Check if all questions were answered
- [ ] Brief objective of experimental environment:

- Read the text to both subjects – make sure they know they have 15 min max to execute.
- Give ground guide map with the route.

- ☐ Turn **ON** recording equipment (camcorder).
- ☐ Load and start experimental environment and signal to the subjects that they can start the session.
- ☐ Start stopwatch
- ☐ Signal the subjects when 15 min is reached, and stop the session.
- ☐ Ask subject to SSQ (the end of 1st session – 3rd SSQ).
- ☐ Check if all questions were answered
- ☐ Take screenshot of final position for BOTH subjects
- ☐ Ask subjects to complete first round of respective post-task questionnaire
- ☐ Subjects complete SUS

Switch roles of participants

- ☐ Make note who normally wears glasses but is not going to use them in experiment.
- ☐ Pass out hand and arm signals cheat sheet/driving instructions and review with subjects.
- ☐ Ask both subjects if they had enough time to review ground guiding instructions and if they are ready.
- ☐ Help subjects don HMDs and take seat (driver): Adjust driver position and set up subjects with controllers and HMDs
- ☐ Start/play training environment and allow users familiarization period (10 min max).
- ☐ Walk each person though set of checks ('Look around… walk/move forward… ")
- ☐ Use stopwatch: Let subjects know that training session is over after 10 min.
- ☐ End training period and ask subjects to complete SSQ (4th SSQ)
- ☐ Check if all questions were answered
- ☐ Brief objective of experimental environment:
    - Read the text to both subjects – make sure they know they have 15 min max to execute.
    - Give ground guide map with the route.
- ☐ Load and start experimental environment and signal to the subjects that they can start the session.
- ☐ Start stopwatch
- ☐ Signal the subjects when 15 min is reached, and stop the session.
- ☐ Ask subject to SSQ (the end of 2st session – 5th SSQ).
- ☐ Turn **OFF** recording equipment
- ☐ Check if all questions were answered
- ☐ Take screenshot of final position for BOTH subjects

- ☐ Ask subjects to complete second round of respective post-task questionnaire
- ☐ Ask subjects to complete SUS
- ☐ Ask subjects complete demographic survey
- ☐ Check if all questions were answered

DEBRIEFING

Conduct final debriefing and answer any question that subjects may ask.

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APPENDIX I. GROUND GUIDE QUESTIONNAIRE RESULTS

How realistic was the portrayal of the ground guiding operations in this environment?	Score	# of responses
a. Ground guide gesturing:	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	2
	5 - Somewhat realistic	5
	6 - Realistic	9
	7 - Very realistic	2
Total:		18
b. Movement of vehicle:	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	1
	4 - Neutral	2
	5 - Somewhat realistic	6
	6 - Realistic	8
	7 - Very realistic	1
Total:		18
c. Visual representation of terrain:	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	0
	5 - Somewhat realistic	7
	6 - Realistic	9
	7 - Very realistic	2
Total:		18

d. Visual representation of objects in the rest of the scene (buildings, other vehicles):	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	0
	5 - Somewhat realistic	4
	6 - Realistic	12
	7 - Very realistic	2
Total:		18
e. Visual realism of vehicle:	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	0
	5 - Somewhat realistic	3
	6 - Realistic	13
	7 - Very realistic	2
Total:		18
f. Visual realism of ground guide:	1 - Not at all realistic	0
	2 - Not realistic	1
	3 - Somewhat not realistic	0
	4 - Neutral	2
	5 - Somewhat realistic	7
	6 - Realistic	7
	7 - Very realistic	1
Total:		18

APPENDIX J. DRIVER QUESTIONNAIRE RESULTS

How realistic was the portrayal of the ground guiding operations in this environment?	Score	# of responses
a. Ground guide gesturing:	1 - Not at all realistic	0
	2 - Not realistic	1
	3 - Somewhat not realistic	3
	4 - Neutral	1
	5 - Somewhat realistic	5
	6 - Realistic	6
	7 - Very realistic	2
b. Movement of vehicle:	1 - Not al all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	0
	5 - Somewhat realistic	8
	6 - Realistic	9
	7 - Very realistic	1
c. Visual representation of terrain:	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	1
	5 - Somewhat realistic	6
	6 - Realistic	9
	7 - Very realistic	2
d. Visual representation of objects in the rest of the scene (buildings, other vehicles):	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	0
	5 - Somewhat realistic	5
	6 - Realistic	11

	7 - Very realistic	2
e. Visual realism of vehicle:	1 - Not at all realistic	0
	2 - Not realistic	0
	3 - Somewhat not realistic	0
	4 - Neutral	1
	5 - Somewhat realistic	4
	6 - Realistic	11
	7 - Very realistic	2
f. Visual realism of ground guide:	1 - Not at all realistic	0
	2 - Not realistic	3
	3 - Somewhat not realistic	2
	4 - Neutral	4
	5 - Somewhat realistic	6
	6 - Realistic	2
	7 - Very realistic	1

APPENDIX K. ASSESSMENT OF SSQ SCORES AFTER EACH SESSION

Symptom	Session	Levels							
		None		Slight		Moderate		Severe	
		#	%	#	%	#	%	#	%
1. General discomfort	1st (Baseline)	17	94.44	1	5.556	0	0	0	0
	2nd	17	94.44	1	5.556	0	0	0	0
	3rd	12	66.67	5	27.78	1	5.556	0	0
	4th	16	88.89	2	11.11	0	0	0	0
	5th	14	77.78	4	22.22	0	0	0	0
2. Fatigue	1st (Baseline)	13	72.22	5	27.78	0	0	0	0
	2nd	14	77.78	4	22.22	0	0	0	0
	3rd	12	66.67	6	33.33	0	0	0	0
	4th	14	77.78	4	22.22	0	0	0	0
	5th	13	72.22	5	27.78	0	0	0	0
3. Headache	1st (Baseline)	16	88.89	2	11.11	0	0	0	0
	2nd	16	88.89	2	11.11	0	0	0	0
	3rd	12	66.67	6	33.33	0	0	0	0
	4th	15	83.33	3	16.67	0	0	0	0
	5th	14	77.78	4	22.22	0	0	0	0
4. Eye strain	1st (Baseline)	17	94.44	1	5.556	0	0	0	0
	2nd	17	94.44	1	5.556	0	0	0	0
	3rd	12	66.67	6	33.33	0	0	0	0
	4th	17	94.44	1	5.556	0	0	0	0
	5th	14	77.78	4	22.22	0	0	0	0
5. Difficulty focusing	1st (Baseline)	17	94.44	1	5.556	0	0	0	0
	2nd	17	94.44	1	5.556	0	0	0	0
	3rd	14	77.78	4	22.22	0	0	0	0
	4th	17	94.44	1	5.556	0	0	0	0
	5th	15	83.33	3	16.67	0	0	0	0
6. Salivation increasing	1st (Baseline)	18	100	0	0	0	0	0	0
	2nd	18	100	0	0	0	0	0	0
	3rd	18	100	0	0	0	0	0	0
	4th	18	100	0	0	0	0	0	0
	5th	18	100	0	0	0	0	0	0

7. Sweating	1st (Baseline)	18	100	0	0	0	0	0	0
	2nd	17	94.44	1	5.556	0	0	0	0
	3rd	16	88.89	1	5.556	0	0	0	0
	4th	16	88.89	1	5.556	0	0	0	0
	5th	15	83.33	1	5.556	2	11.11	0	0
8. Nausea	1st (Baseline)	18	100	0	0	0	0	0	0
	2nd	18	100	0	0	0	0	0	0
	3rd	16	88.89	1	5.556	1	5.556	0	0
	4th	17	94.44	1	5.556	0	0	0	0
	5th	16	88.89	1	5.556	0	0	0	0
9. Difficulty concentrating	1st (Baseline)	17	94.44	1	5.556	0	0	0	0
	2nd	18	100	0	0	0	0	0	0
	3rd	17	94.44	1	5.556	0	0	0	0
	4th	18	100	0	0	0	0	0	0
	5th	17	94.44	1	5.556	0	0	0	0
11. Blurred vision	1st (Baseline)	17	94.44	2	11.11	0	0	0	0
	2nd	18	100	0	0	0	0	0	0
	3rd	15	83.33	3	16.67	0	0	0	0
	4th	17	94.44	1	5.556	0	0	0	0
	5th	16	88.89	2	11.11	0	0	0	0
12. Dizziness with eyes open	1st (Baseline)	18	100	0	0	0	0	0	0
	2nd	18	100	0	0	0	0	0	0
	3rd	16	88.89	2	11.11	0	0	0	0
	4th	18	100	0	0	0	0	0	0
	5th	16	88.89	2	11.11	0	0	0	0
13. Dizziness with eyes closed	1st (Baseline)	17	94.44	1	5.556	0	0	0	0
	2nd	17	94.44	1	5.556	0	0	0	0
	3rd	15	83.33	2	11.11	2	11.11	0	0
	4th	17	94.44	0	0	0	0	0	0
	5th	15	83.33	2	11.11	0	0	0	0
14. *Vertigo	1st (Baseline)	18	100	0	0	0	0	0	0
	2nd	18	100	0	0	0	0	0	0
	3rd	16	88.89	2	11.11	0	0	0	0
	4th	18	100	0	0	0	0	0	0
	5th	18	100	0	0	0	0	0	0

15. **Stomach awareness	1st (Baseline)	17	94.44	1	5.556	0	0	0	0
	2nd	17	94.44	1	5.556	0	0	0	0
	3rd	16	88.89	2	11.11	0	0	0	0
	4th	16	88.89	2	11.11	0	0	0	0
	5th	15	83.33	3	16.67	0	0	0	0
16. Burping	1st (Baseline)	18	100	0	0	0	0	0	0
	2nd	18	100	0	0	0	0	0	0
	3rd	18	100	0	0	0	0	0	0
	4th	17	94.44	1	5.556	0	0	0	0
	5th	17	94.44	1	5.556	0		0	0

1st (Baseline): At the very beginning of the entire session (before any exposure to VE)

2nd: After first training period (length of exposure to immersive VE: 10 min)

3rd: After first experimental session (length of exposure to immersive VE: 15 min)

4th: After second training period (length of exposure to immersive VE: 10 min)

5th: After second experimental session (length of exposure to immersive VE: 15 min)

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

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