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DEVELOPMENT OF NORTHROP-GRUMMAN MARK VIIE TRAINING UNIT AND WIRELESS VIDEO SYSTEM FOR USE IN IMMERSIVE ENVIRONMENTS

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THESIS

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science in Electrical
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ABSTRACT OF THESIS

DEVELOPMENT OF NORTHROP-GRUMMAN MARK VIIE TRAINING UNIT AND WIRELESS VIDEO SYSTEM FOR USE IN IMMERSIVE ENVIRONMENTS

A training unit has been developed that allows NVESD researchers to develop training simulations within virtual environments to enhance infantry skill and awareness. A ground station was developed to house a computer, power system, and video transmission system. This station will allow for a remote operator to wirelessly send a video/audio stream to the handset. The ground station also allows the use of external video and audio inputs to be sent using onboard converters. Different wireless frequencies were evaluated to determine the best for long-range transmission of content. A handset was developed from a carbon fiber prototype shell. The handset features a video receiver, display, power system, OSD system, and external video inputs. The user can view transmitted video and audio while obtaining real-time GPS feedback from the OSD. The alternate video input allows the handset to be used within the virtual environments developed at the University of Kentucky's Center for Visualization for virtual environments. This thesis will present the research conducted in order to develop Mark VIIE training unit including the requirements for the project, the desired functionality, the NVESD provided equipment, the analysis of the prospective components, the design of custom fabricated parts, and the assembly and integration of the components into a complete system.

KEYWORDS: Defense Technology, Targeting Systems, Night Vision Sensors, Virtual Simulation, Training Devices

Randall Lee Lewis

July 11th, 2014

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1.1 Problem Introduction

In today's conflict riddled world, modern troops rely heavily on technology while in battle. In many instances, these tools can be crucial to helping a solider survive. The benefits of these devices can only surface when used by a well-trained individual. More often than not, high costs of implementation can deter the merging of new technology into training exercises and routines. As a result of these costs, inadequate training detailing the use of complex devices leaves many soldiers without the ability to utilize many of the tools at their disposal.

In recent years, advancements in technology have opened new doors in the world of troop training and readiness in the form of virtual environments and simulators. By allowing a solider to experience various battle scenarios and circumstances outside of harm's way, a more thorough and refined training skillset can be obtained. At the University of Kentucky, a team of engineers have developed a virtual environment system which can be rapidly deployed at various locations. With a relatively spacious display area, a fully equipped soldier can feel immersed in the simulated environment. Software packages such as "Virtual Battlespace II" (VBSII) are used to create scenarios that a soldier has experienced or will experience in the future.

One recently discovered limitation to simulator training is the inability to use additional equipment within the virtual environment. Not being able to use devices within the simulation poses a large problem for many squadrons who rely on an assortment of tech throughout battle. Without the ability to simulate device usage within VBSII or other environments, many troops will be unable to conduct virtual training simulations. Having to conduct mixed training types within a squadron or team further increases costs an efforts put into providing proper training for troops. The focus of this thesis is to remedy this problem for the Mark VIIE handset. A training unit of this handset will be developed to allow troops to use the unit within a virtual training environment. This will allow a wider spectrum of possibilities for training scenarios while providing more adequate training for solders.

1.2 Scope of Thesis

The information and details presented in this thesis will outline the development of the Mark VIIE training unit to be used within a virtual training environment. The research, design, fabrication, implementation, testing, and results will be presented. Any limiting factors or design changes will also be addressed. Any modifications to the problem statement will be addressed as well.

Section 2 of this thesis will provide extensive information regarding the provided equipment from the sponsor, as well as details regarding the virtual environment that the handset will be implemented within.

Section 3 will break down the sub-parts of creating the training system as well as the requirements for each. Input from the sponsor on the implementation of these sub-parts will also be given.

Section 4 will cover testing and elimination of components to determine the optimal combination of parts for achieving the functionality described in Section 3. Custom fabrication and design will also be covered.

Section 5 will document the testing of the hardware and overall functionality of the unit. Images will be provided showing the final integration and placement of components.

Section 6 will summarize the project and the research within. Ideas for future revisions will be given along with various hindsight surrounding the project.

SECTION 2: EXISTING HARDWARE AND DESIGN REVIEW

2.1 Introduction

The scope of this thesis is focused around the development of a tool to be used in combat training scenarios. Often, these trainings are conducted in conjunction with a virtual environment. The interfacing requirement to the virtual environment is a necessary topic to fully encompass the Mark VIIE design. The NVESD lab in Ft. Belvoir is home to a P.I.T. (Personal Immersion Theatre) that was developed by the University of Kentucky through a Lockheed Martin contract. This thesis will focus on the implementation of the developed Mark VIIE hardware to the P.I.T. environment. It is not within the scope to discuss multiple virtual environments or how they are constructed due to variances in display technology, computer hardware, and peripheral format.

Section 2 will focus on two primary ideas which will provide background information surrounding the project as well as detailed information about external parameters that have to be considered in order to create a successful project. The first discussion will outline the basics of the Northrop-Grumman Mark VIIE handset. This will include a brief overview of the device as well as its functionality and common usage. The second discussion will focus on the P.I.T. developed by the University of Kentucky. This will include an overview of the construction, technology, computational hardware and interfacing ability. By fully outlining these topics, the reader will be able to clearly understand the design decisions made during later sections of this thesis.

2.2.1 Brief History

Night Vision is a fairly recent technological development in the military world. Before the use of low-light sensors, flares and IR spotlights [1] were used to identify enemy targets from afar. In 1984, J.D. Maines wrote:

> In recent years, there has been a growing requirement from the Armed Forces for equipment which provides a capability for fighting 'by night as by day'; this need has led to a drive towards equipment with the capability for seeing in the dark. Past attempts to achieve this objective have included the use of flares to illuminate the battlefield – and IR (infra-red) searchlights which required IR-sensitive vision devices to observe the illuminated target…

Recently, the overwhelming push for defensive technology has led to the development of low-light vision and targeting devices that utilize camera engines to process light which allow the user to go undetected. These new devices allow the military to continue operation at night and under poor visibility conditions [2] while staying covert. By increasing the threshold of visibility, the military can form more tactical strikes at times when they were previously not possible. The U.S. Army supports a research lab focused on the advancement of night vision technology. Originally called the Night Vision Laboratory (NVL), the name was later changed to Night Vision & Electronic Sensors Directorate (NVESD) [3]. This laboratory is the sponsor of the project and is the focal point of night vision research in the U.S.

2.2.2 Mark VIIE Overview

The Northrop-Grumman Mark VIIE is a highly accurate range finding device used for target acquisition and location. Developed for the United States armed forces in 2009, the device is a revision and successor to the Mark VII rangefinder. The primary function of the device is remotely pinpointing threats to determine and initialize remote airstrikes. The VIIE features both day and night viewing modes with a state-of-the-art night vision processing unit onboard. GPS is one of the primary sensors onboard the handset as a location lock is imperative to producing accurate locations and airstrikes. One large benefit of the Mark VIIE design is the use of commercial batteries. This feature allows the user to replace depleted cells in the battlefield without having to worry about recharging or external power sources.

Figure 1: Northrop-Grumman Mark VIIE Rangefinder

2.2.3 Mark VIIE Technical Specifications

Below is the listing of the Northrop-Grumman Mark VIIE technical specifications. This data is released to the public and does not fall under any security restrictions. The shown information is known to be the most recent listing to date.

From www.northropgrumman.com:

Mark VIIE

Lightweight Handheld Target Locator

System Specifications

General

- Size: 11 x 9 x 5 inches
- Weight: 5.5 lbs with battery
- Operating Temperature: -30° C to +60° C
- Storage Temperature: -40° C to +71° C

Eyesafe Laser Transmitter

- Type: Nd:YAG with KTP OPO Converter
- Wavelength: 1.57 microns
- Pulse Rate: 4 per minute
- Minimum Range: 100 meters
- Maximum Range: 19,997 meters
- Range Increments: 2 and 3 meters
- Accuracy: +/- 3 meters
- Range Computation: Selectable First/Last and Multiple Target Counter

Night Sighting Optics

- Type: Uncooled Thermal - Microbolometer
- Thermal Electronic Zoom
- Field of View: 8.3 x 11.1 degrees (145 x 194 mils)
- Reticle: Projected, Open Center Crosshair with Laser Aiming Box

Day Sighting Optics

- Magnification: 8 x 42
- Direct View Optics: 8.2X
- Field of View: 5 x 7 degrees (88 x 122 mils)
- Reticle: Etched reticle with electronic laser aiming box

Electronic Compass

- Type: Digital Magnetic
- Accuracy: +/- 8 mil

Electronic Inclinometer

- Type: Gravity Sensor
- Accuracy: 4 mil

Data Display

- Type: Projected Electronic GUI. Range, Azimuth, Elevation, Target and Self Location, BIT, and System Messages

Data Interface

- Type: RS-232/422, PLGR and DAGR, FED and NEMA (subject to availability)

Prime Power

- Commercial Batteries: 9, CR123
- External Power: BA5590

Specifications and features are subject to change without notice

Figure 2: Mark VIIE Technical Specifications

2.3 Personal Immersion Theatre (P.I.T.)

The virtual environment the project is to be integrated into is the Personal Immersion Theatre developed by the Center for Visualization and Virtual Environments at the University of Kentucky. The next few topics of discussion will focus on the details of this virtual environment.

2.3.1 P.I.T Construction

The P.I.T. was designed around the idea of creating a virtual environment which was very robust in nature but also extremely modular and transportable. In many cases, simulators are needed in extremely harsh or unpredictable environments. The frame of the simulator has to withstand these unpredictable circumstances while still being able to retain strength and rigidity. In order to meet these criteria, the materials used were required to be extremely sturdy as well as commonly available. If something were to be damaged or lost during transport to an alternate destination, hard to locate materials would render the simulator unusable.

To retain robustness in the design, the exterior frame is constructed from common T-Slotted extruded aluminum tubing. The slots allow the tubes to be interconnected using 90 degree angle braces and T-nuts. With such a simple connection style, a previously calibrated P.I.T. can be assembled in a matter of a few hours whereas other designs may take multiple days to construct. Another huge advantage to slot-style construction is the ease of adjustability. The slots in the extrusion allow parts to slide into position making minor tweaks as simple as unfastening a single bolt. With this setup, alignment issues are quickly resolved without any headache. The tubing also comes with an externally applied coating which resists scratching and wear to the material. The durable coating allows the engineer to make markings or write measurements directly onto the extrusion without fear of it wearing off. This can further increase simulator assembly time.

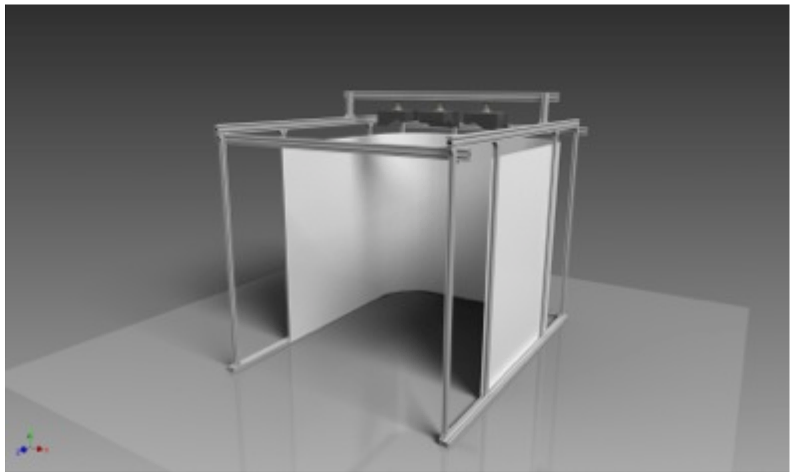

Figure 3: CAD Rendering of the P.I.T. Virtual Environment

The screen of the P.I.T. is focal point of the construction assembly. The simulator uses either a 270 or 360 degree wrap-around projection screen to immerse the user. The screen material in mounted inside of the aluminum frame in a cylindrical setup. The 360 degree model has a two-part screen so that a door can be installed. The screen material is interchangeable between projection mesh and rigid translucent polycarbonate. The two options allow the unit to be suited to a particular application. The mesh is very transportable and extremely fast to attach and remove from the aluminum structure with the use of hook-and-loop tape. However, the mesh has a higher rate of light diffusion which can create a dim projection given certain lighting conditions. The rigid polycarbonate is much less transportable and is mainly used in permanent installations. Mounting the rigid screen requires the use of various screws and bolts. The projection surface is painted with a plastic-specific paint that avoids cracking and eliminates any bulb glare from the projectors. The image quality of the rigid setup is much higher than that of the mesh. The P.I.T. used for the development of this thesis used a rigid poly-carbonate screen in the 360 degree configuration.

2.3.2 Technology and Hardware

The P.I.T. relies heavily on state-of-the art technology to power its ultra-high resolution display. The image that is projected onto the screen is created by using three ultra-short throw 3D capable projectors that project with 20% overlap on each side. Each projector displays a warped image that is created from a calibrated mesh map. When these warped images overlap, a unified, seamless image is created across the entire screen. This process is called projection blending and was developed by the University of Kentucky.

The projectors used in the P.I.T. are manufactured by Panasonic. They feature 2500 lumen bulbs and can project an image up to 110in diagonally. In the 270 degree format, three projectors are used. Four projectors must be used to achieve the 360 format. The projectors are mounted on fully adjustable tilting mounts. These mounts allow the projectors position to be set, then locked into place using set-screws. The quick release feature allows projectors to be hot-swapped without recalibration. The projectors are connected to the computing hardware using HDMI to DVI-D cables.

The most important part of the P.I.T. is the computing hardware. Only a single workstation is required to operate either the 270 or 360 degree formats. The utilization of only one machine keeps the integration of additional hardware (such as the Mark VIIE) easier that of a multi-machine setup. The machine uses two nVidia Quadro K5000 workstation graphic cards in SLi. The tandem card configuration allows for the enabling of Mosaic Display Mode. This mode enables the projection blending software to function correctly.

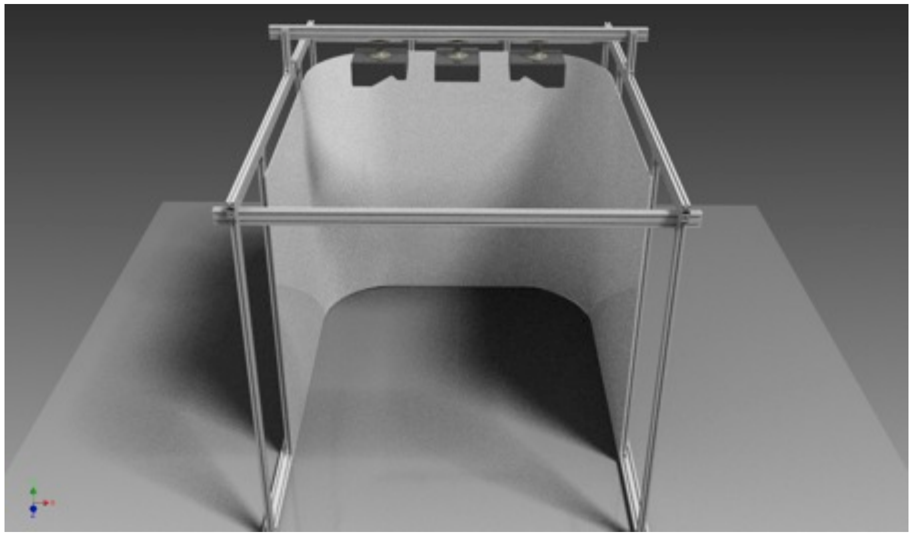

Figure 4: Top-Down view of the P.I.T. in the 270 degree format.

SECTION 3: DETAILED PROBLEM DESCRIPTION/REQUIREMENTS

3.1 Introduction

In order to develop this thesis, a detailed assessment of the problem must conducted to ensure that the sponsor's requirements are fully encompassed within the conducted research. Without a look into specific details, the scope of the project may become too broad or vague.

Section 3 will discuss the requirements and desires given by the sponsor in regards to the project. These primary points will be divided into individual discussions in which detailed information will be given to detail the purpose and vision for each section.

3.2 Project Requirements

The requirements for the project that is the basis of this thesis were given to the University of Kentucky on January 1st, 2012. At this time, NVESD presented UK with the carbon fiber outer housing of the Northrop-Grumman Mark VIIE. This housing was to be the basis for the project and this thesis and used to fulfill the requirements set in place by NVESD. These requirements were recorded in the Sub-Contract between UK and Lockheed Martin and were reiterated in the final report presented to NVESD on August 20th, 2013. The primary goal of these requirements is to prepare the Mark VIIE handset for use in the P.I.T. virtual environment. Achieving these requirement goals will set the groundwork for integrating the developed handset properly. This final report is attached as Appendix A.

From the official sub contract:

"Project 3 - Work with NVESD and the micro display in a MK VIIE laser range finder found in appendix I. The goal of this project is to help NVESD to install a micro display, micro controller, and a commercially available gyro in the mock MK VIIE. NVESD will provide the chassis (housing and simulation tools) to the UK team."

The first objective from the sponsor is to install a micro display inside of the handset housing. This display will be used to present video and images inside of the unit. The second objective from the sponsor is to install a microcontroller inside of the handset housing. The microcontroller will be used for data acquisition and parsing from any installed onboard sensors or devices. The final objective from the sponsor is to install a commercially available gyroscope and accelerometer into the handset. These will be used in conjunction with the microcontroller to obtain and record position and orientation data.

3.2.1 Micro Display

In order for the implementation of the Mark VIIE to be useful to users, a form of visual feedback needs to be present. A typical usage cycle of the actual handset involves viewing distant object through the cascading lenses and display projection engines. When a user is looking is looking through the viewfinder, the eye cup and image pathway immerse the user to eliminate outside interference such as light or physical distraction. A sanctioned field of view allows the user to remain focused on target in order to accurately decipher strike calls or strategies.

The same visually isolating experience found in the production Mark VIIE needs to be replicated within the training model developed in this thesis. The chosen micro display will need to be used in a way such as to allow the user to encounter the same experience and perception found in the production handset. Emulating this experience will provide a more realistic training encounter and will enable designers to create a more engaging simulation environment.

Signal routing is another issue with the implementation of a micro display. The handset needs to have a method of receiving video input from external sources. Adding this functionality is a necessary step to displaying footage inside of the handset. The Mark VIIE housing will need to have a standardized video input protocol and connection interfaces implemented. This connection method must also be able to be interfaced with the P.I.T. computational hardware for integration into the virtual environment. For this thesis, a low cost display and signal routing systems must be explored in order to meet the sponsor's expectations while keeping costs low.

3.2.2 Microcontroller

The sponsor requests that a microcontroller be installed into the Mark VIIE handset. The production unit uses processing units to analyze imagery as well as interpret GPS and range data read from the internal sensory array. Fragments of data are stored internally while others are transmitted as information packets for targeting use in airstrike engagements. The training version of the Mark VIIE developed throughout this thesis will only need a small amount of power compared to the production model. A microcontroller will allow the sponsor to implement code onboard the handset for data interpretation from the requested gyroscope and accelerometer sensors as well as creating video overlay information on the incoming feed to the micro display.

Due to the growth of portable electronics over the last few years, the selection of affordable microprocessors with widespread availability has grown exponentially. With this growth, many silicon manufacturers have turned to open source communities in hopes of creating useful Integrated Development Environments (IDEs). This push has resulted in a vast array of development and test boards which can be programmed in common high-level languages without any prior experience with the silicon. For this thesis, multiple micro processing options must be explored in order to meet the sponsor's expectations while keeping the cost of implementation low.

3.2.3 Gyroscope

The final request from the sponsor is that a commercially available gyroscope be installed within the Mark VIIE housing. The production unit utilizes various sensors onboard to ensure accurate targeting information as well and heading and orientation. In training, the same information that is displayed within the viewport of the production unit should also be displayed on the screen on the training model. Any handset orientation information can be obtained by the gyroscope and relayed to the microcontroller for interpretation and processing. For this thesis, various commercially available gyroscope options must be explored for implementation to meet the sponsor's expectations while keeping cost to a minimum.

3.3 Additional Requirements

Throughout the course of the project, the sponsor (NVESD) presented the team with additional requirements not stated within the official sub-contract. These were given to the team during the scheduled bi-weekly conference calls between the University of Kentucky team, Lockheed Martin, and NVESD. Due to the fact that these goals were part of the project this thesis is centered upon, they are within scope and will be covered.

3.3.1 Wireless Video Link

As part of fully implementing the Mark VIIE into the P.I.T., the sponsor requested that the handset be able to be used wirelessly within the environment. The Northrop-Grumman production unit is entirely self-contained with no external wiring exposed during use. NVESD showed concern that the effects of immersion would not be as prominent with cables being connected to the handset while within the simulation environment. For this thesis, wireless video options will be explored for implementation to meet the sponsor's requirements.

3.3.2 Base Station

With the addition of the requirement of wireless video, the sponsor showed interest in creating a centralized communication station for communication to the handset while being used in the P.I.T. After a few discussions, the requirement was set by the sponsor that a ground station accompany the handset in the final deliverable project. For this thesis, a ground station will be implemented to accompany the Mark VIIE handset which will fulfill the sponsor's requirement.

SECTION 4: COMPONENT TESTING AND SYSTEM DESIGN

4.1 Introduction

In order to complete the requirements given in Section 3, this Section 4 focuses on analyzing various system components for use in the Mark VIIE handset and ground station. The various component candidates will be tested for best fit and integration within the system with various parameters considered. Once the proper components have been selected, any necessary parts needed for assembly will be designed and fabricated. The handset and ground station will then be assembled and ready for testing. Section 4 will be split into three main parts: Component Evaluation, Part Design, and Assembly. Testing of the system will be discussed in Section 5.

4.2 Component Evaluation

In this section, each requirement from the sponsor will be considered as each the components are evaluated for potential use within the project. The parts chosen in this section will go onto the design phase for integration into the system.

4.2.1 Handset Display

The first handset component to evaluate is the micro display. Due to the handset being wireless, the display must have a low current draw. By minimizing the current draw, the onboard batteries will provide a longer training session before needing to be recharged. Longer operating times can eliminate downtime therefore reducing cost. Another key consideration factor when choosing a display is durability. The handset shell is constructed of carbon fiber and is designed to withstand drops and bumps. The chosen display must be able to withstand occasional mistreatment while continuing to perform perfectly. Display brightness and coating must also be a consideration factor. Too bright of a display will cause discomfort to the user when alternating views between the P.I.T. environment and the Mark VIIE display. A glossy coating on the display may cause unwanted screen glare and hotspots given certain circumstances. A more matte display finish would be preferred. The final main criteria is the cost of the display. An expensive display to install is also an expensive display to replace if damage occurs in the future. By keeping screen cost down, repair or replacement costs are lowered providing a more sustainable product. With the above criteria in mind, two displays were chosen for testing.

The first display is a JINWANG TFT 3.5" display panel with driver board. The screen and driver are distributed by Adafruit and cost $44.95. The screen has a resolution of 320x240 pixels, 250cd/m^2 brightness rating, and draws 150mA at 12VDC.[1] The screen does not come with any protective case, therefore a case will have to be designed and 3D printed so that the screen does not become damaged. The connection between the panel and driver board is a ZIF (Zero Insertion Force) flex cable. These cables are very fragile and can render the screen useless if damaged.

Figure 5: Jinwang 3.5" TFT Display and Driver Board

The second display is a TFT 4.3" display panel. The screen is distributed by Adafruit for $49.95 but no manufacturer information is given. The Adafruit website lists the resolution to be 480x272 pixels, 300cd/m^2 brightness, and the current draw at

12VDC to be 220mA. This display is designed for use as an automotive backup camera display and features a full molded plastic enclosure as well as an auto-off feature which turns off the display when no video signal is detected.

Both displays are connected to a bench top power supply for power regulation. A Linux computer is connected as the composite video source to both displays. The performance of the Jinwag 3.5” display is evaluated first. Immediately, the glare from the display is noticeable. At certain viewing angles, the glossy nature of the display causes the image to be unviewable. This is a stark contrast to the 4.3” display whose matte finish allows the image to be clearly displayed at almost every viewing angle. The lower resolution of the 3.5” display is noticeable compared to the slightly higher resolution of the 4.3”

Next, both displays are placed inside of the Mark VIIE inside of a dimly lit room. The screens are compared for their brightness and clarity while experiencing typical lighting conditions. The glossy interior finish of the handset shell does not favor the glossy nature of the 3.5” display. Many reflected patters are present on the screen and can be extremely distracting at times. The matte finish of the 4.3” display did not pick up an reflected light from the interior shell of the housing. The slightly brighter 4.3” display gives a more vivid image when inside of the dark housing, but not to the point of causing visual discomfort. Table 1 below shows the side-by-side comparison of both displays.

Table 1: Micro-Display Comparison

	Jingwang 3.5" Display	Adafruit 4.3" Display
Resolution	320x240 px.	480x272 px.
Brightness	250 cd/m^2	300 cd/m^2
Coating	Gloss	Matte
Current Draw	150mA @ 12VDC	220mA @ 12VDC
Video Inputs	2	2
Enclosure	No	Yes
Input Voltage	5-12VDC	5-15VDC
Price	$44.95	$49.95

After testing both displays, the 4.3" Adafruit display is chosen to be the better choice for the Mark VIIE. Not only is the image brighter, but the display is more rugged and produces no on-screen glare effects. The current draw is slightly higher, but the extra milliamps are negligible compared to the difference in quality and ease of the larger display. No enclosure will have to be designed and 3D printed which will save engineering time and material costs.

4.2.2 Video Transmission System

The second system to evaluate is the wireless display system. First, the system must be able to transmit a video signal over a series of antenna to a remote device. Also, the video receiving unit must be compact in size, and must be able to receive a video signal from long distances. The frequency of transmission must also be legal for use within the United States. With the above criteria in mind, two video systems have been chosen for evaluation.

The first video system is video over Wi-Fi. Using a Linux based machine and a wirelessly connected host, video can be transmitted over a wireless network. The display quality can be up to 1080p high definition given the proper streaming codecs. The tested streaming tool is OMXplayer. The quality of video streamed is very good, but there are numerous and repetitive connection issues. If any interruption occurs, the video feed drops out and connections must be re-established. This poses a potential problem as reconnecting can often be difficult and time consuming.

The second video system is long-range 900MHz VHF video. This video system utilizes radio frequency bands to transmit video and audio signals. The limiting factor with radio frequency video is video quality. The images transmitted are usually VGA quality or less. The tested system uses a 1.5W video transmitter that can provide up to 3 miles of transmission range. This system seems to provide a very stable video connection even when there are obstructions between antennas. The longer wavelength of the 900MHz signals vs. the 2.4 or 5.8GHz of typical Wi-Fi units allows for greater distance and object penetration. During testing, moving behind walls or around objects would cause the Wi-Fi video to drop-out and disconnect. The 900MHz system would experience slight static interference, but always stayed connected, even across long indoor environments.

After testing both systems, the more reliable choice seems to be the 900Mhz system. Despite the higher video quality of the video over Wi-Fi, the connection issues cannot be ignored. These would prove difficult in normal operation where an operator or trainee may be ignorant to networking and video connections. Additionally, the long range of the 900MHz will allow the unit to be at a much greater distance from the base station than originally planned. This opens the door to many other outdoor applications for the Mark VIIE Training unit.

4.2.3 Handset Microcontroller/Gyroscope

Other than the micro-display, the other two primary requirements from the sponsor were a microcontroller and a commercially available gyroscope. Both components must be relatively small in size to be used within the handset. There were no other criteria for these requirements. Two microcontroller/gyroscopes will be evaluated and tested.

The first combination is an ATMega328p microcontroller and a Sparkfun ITG-3200 MEMS gyroscope. The ATMega controller is a very affordable and versatile chip. It is commonly found in commercial Arduino development boards. Using the provided IDE, the chip can be programmed in C or C++. The board features 13 Digital outputs and 5 Analog ADC inputs. The MEMS gyroscope is packaged in a breakout board format along with an ADXL345 Accelerometer. Together these chips provide 6DOF when used in conjunction. The downfall of this setup is the potential size of the components when integrated into the system. The individual components are fairly small, but once things such as voltage regulation and hardware mounting come into play, the size increases considerably.

The second combination is a development package from EagleTree RC systems sold as the OSD Pro and V4 Logger w/ GPS. The system is designed as a wireless video on screen display (OSD) unit. The unit allows various overlays to be placed into incoming video feeds. Contained within the hardware is the same ATMega328p chip and an accelerometer and gyroscope board along with a built in voltage regulator circuit and GPS module. The unit can not only record sensory data but also can be programmed to overlay the data in the form of a simulated horizon on the micro display. A full software suit is included which allows non-programmers to easily enable desired functionality without writing code. The unit is plug and play, with no external wiring needed.

Due to the similar silicon components, the performance of both units is extremely comparable. During serial monitor testing, the results are nearly spot on without either unit showing any sensor drift. With more features being available from the EagleTree setup, this unit will be chosen for use in the Mark VIIE handset.

4.2.4 Ground Station Enclosure

One of the additional requirements of the project is the implementation of a ground station. The ground station will house the video transmission unit and other components that will be discussed later in section 4. Like the other components used in this project, the enclosure for the ground station must be extremely durable and able to withstand years of abuse. For most military applications, impact resistant cases produced by Pelican Case Mfg. are used. These cases are waterproof up 100m, provide dirt and dust protection, and are subjected to extensive military testing. The sponsor presented no requirements for the ground station case, therefore the Pelican 1640 Series case has been chosen to house the ground station equipment.

4.2.5 Ground Station Computer

With the additional requirement of developing a ground station for the Mark VIIE in place. The engineering team determined that a portable computer housed within the ground station would be a helpful addition to the unit. With a standalone computer onboard, the handset could be used for training simulations outside of the P.I.T. environment. The sponsor has approved this addition and showed interest in implementing the Raspberry Pi portable Linux machine into the ground station. The Raspberry Pi is a credit card sized Linux machine which provides a full desktop environment, while still consuming less than 500mA of current.

A Raspberry Pi is being used with a version of Debian Linux running on the hardware from an SD card. The Pi was placed in a CNC created aluminum housing. The housing acts a heatsink for keeping the processor cool, even during extreme conditions.

The Raspberry Pi relies on peripherals to run as a full desktop computer. The sponsor gave no requirements for the peripherals used for developing the ground station. The station will be used in a mixture of indoor or outdoor environments, therefore the display has to be viewable in various lighting conditions. Also, the current draw needs to be kept to a minimum due to the portable nature of the ground station. The display controller needs to have various inputs for versatility. The display chosen for testing is the PixelQi PQ 3Qi-01. The display is designed for rugged outdoor-use laptops and tablets. Table 2 below details the specifications of the display.

Table 2: PixelQi Display Specifications

Manufacturer	Pixel QI
Model	PQ 3Qi-01
Display Type	TFT Liquid Crystal
Backlight	LED
Connector	LVDS 40 Pin
Resolution	WSVGA(1024 x 600)
Colors	262,144
Coating	Hard, Anti-Glare

The display does not have an enclosure included. Most applications for this type of display have custom enclosures developed, therefore a manufacturer provided enclosure would be useless. To enclose the display and allow for use within the ground station, 3D design work needs to be conducted. Autodesk Inventor is used for the 3D modeling of the enclosure. Figure 6, 7, 8, and 9 show the fully modeled design.

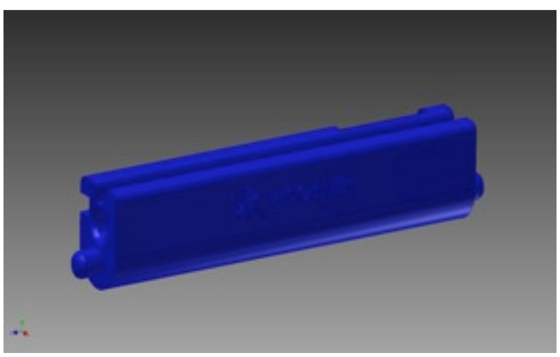

Figure 6a: Lower Support

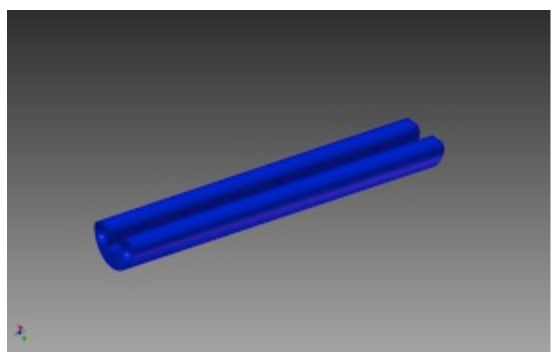

Figure 6b: Upper Support

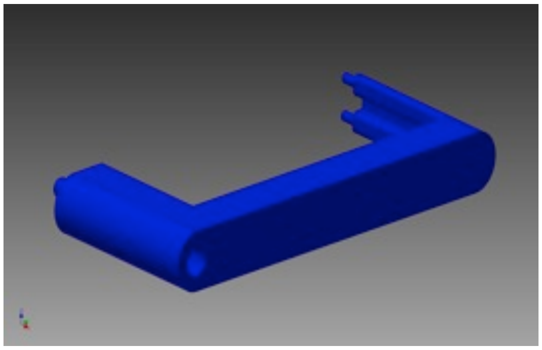

Figure 7a: Side Support

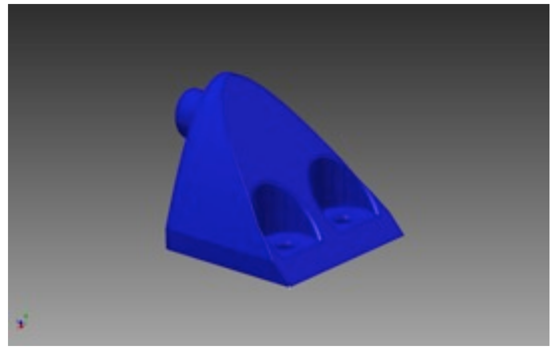

Figure 7b: Hinge

The design for the enclosure is a snap-fit style which allows the display module to be removed in the case of repair or replacement. The screen slides into a channel modeled into the enclosure for secure mounting. The hinge will ride on rubber grommets for vibration isolation. The hinge allows the display to fold down flat when the lid of the ground station is closed. The option of adjustability of viewing angle is also made possible by the hinge.

The second design challenge of the PixelQi display is the display controller board. The PCB is designed as an option for computers or tablets that may use proprietary video management systems. Because of the simplicity of the ground station setup, the option display driver board is used. Without an enclosure for the driver board, the PCB may become damaged or broken due to mistreatment or the elements. Another 3D printed solution is implemented and the design of the display driver board enclosure is shown below in Figure 8. The enclosure has to have access to the control panel buttons, power input jack, and the I/O for video connections. A slim access slot has to be designed as well to make room for the ZIF Cable which connects the driver board to the PixelQi display panel.

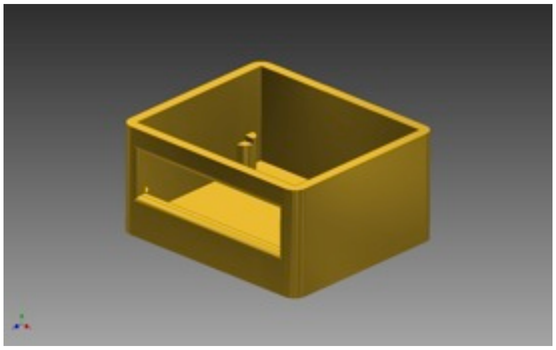

Figure 8a: Display Driver Case

Figure 8b: Display Driver Lid

4.2.5 Video Input Converter

The final requirement for the ground station is that the video transmission system be able to transmit video from the P.I.T. computing hardware to the Mark VIIE handset. This will allow the wireless usage of the handset within the P.I.T. virtual environment. The P.I.T. computational hardware has access to a VGA video output by means of an ATi FirePro GPU. This graphics engine operates separately from the Quadro units that drive the blended projection display. In order to convert a VGA input to a composite input that that wireless video system can handle, conversion hardware is needed. The sponsor did not give any requirements for this hardware.

The hardware chosen for the video conversion is the StarTech VGA2VID VGA to composite converter. This model is chosen based upon it compact size and power requirements. When the converter is active, current draw is only 100mA @ 5V. This is an acceptable current draw and will not severely impact the ground station's battery life.

SECTION 5: COMPONENT ASSEMBLY AND FINAL TESTING

5.1 Introduction

Section 5 will cover the assembly and final testing of the Mark VIIE training unit on which this thesis is based. Now that the components to be used have been determined, they must be installed into the handset and ground station. The first discussion of Section 5 will focus on the installation of components and the final placement within the respective unit. The second discussion of Section 5 will be the final testing of the ground station.

5.2 Handset Component Installation

The first component to install into the handset is the micro display. The micro display must be placed in a location where all portions of the image can be seen through the view window. The location of installation is determined and the screen is mounted into the housing using the provided mounting brackets. A small amount of epoxy is used on the corners of the screen to reinforce the mount and absorb any vibrations due to a drop or other shock. The display cables are routed to the front of the housing for integration with the video receiver and Y-Splitter. The Y-Splitter is used to allow external video feeds as well as feeds from the wireless video receiver.

The second component to be installed in the handset is the video receiver. The receiver is placed toward the front of the unit so that the receiving antenna may protrude through the lens opening. This allows the antenna to easily be removed or replaced with another 900MHz SMA antenna. The video receiver has mounting tabs which allow for installation into the housing using fasteners and light epoxy reinforcement. The video receiver requires two connections to be made: video in and 12V. The video connection is made from the Y-Splitter while the 12V connection is made from the supplied barrel plug adapter.

The third component to be installed is the EagleTree OSD Microcontroller/Gyroscope Unit. The unit is mounted inside the unit using a mounting strap provided by eagle tree. Again, a small amount of vibration absorbing epoxy was used to reinforce the mounting of the hardware. The programming port for the OSD was left exposed through the center lens opening of the Mark VIIE handset. This exposure will allow the sponsor to program the microcontroller without the need to disassemble the handset. The GPS and power regulator are connected to their proprietary ports using the custom harness.

The final component to be installed is the battery. The battery used in the handset is a Tenma 1000mAH Lithium Polymer Cell. The cell provides 12V to the micro display, video receiver, and EagleTree system. Power is connected via a custom soldered harness. The main power switch from the battery is exposed through the largest lens opening in the handset housing. The battery is installed using vibration proof epoxy.

Once all of the components have been installed, the housing halves were reconnected and the four Allen-head retainer screws were reinstalled. The handset unit was set aside while the ground station was assembled. The testing of the assembled handset will occur in Section 5.4.

5.3 Ground Station Component Installation

In order to install the ground station components into the Pelican case, a layout of components needs to be determined. By considering the power requirements of each of the components within the ground station, two native voltages are needed within the ground station. With this in mind, a power flow diagram is created. This diagram is shown in Figure 9.

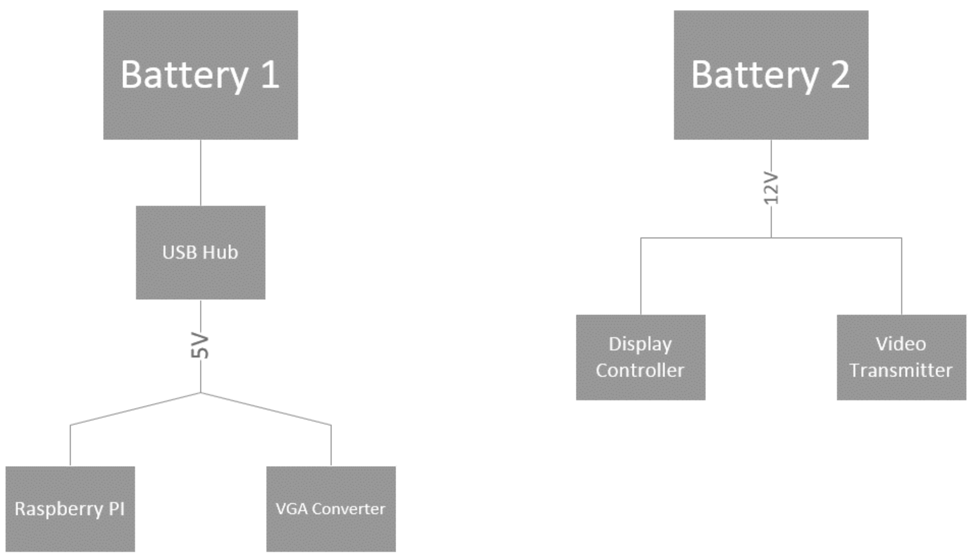

Figure 9: Ground Station Power System Layout

Using the power diagrams, the final component arrangement is determined within the case. The components are placed so that common voltage requirements are contained to a particular side of the case. This keeps power routing simple and understandable for the designers and the future operators. The final component layout is shown in Figure 10.

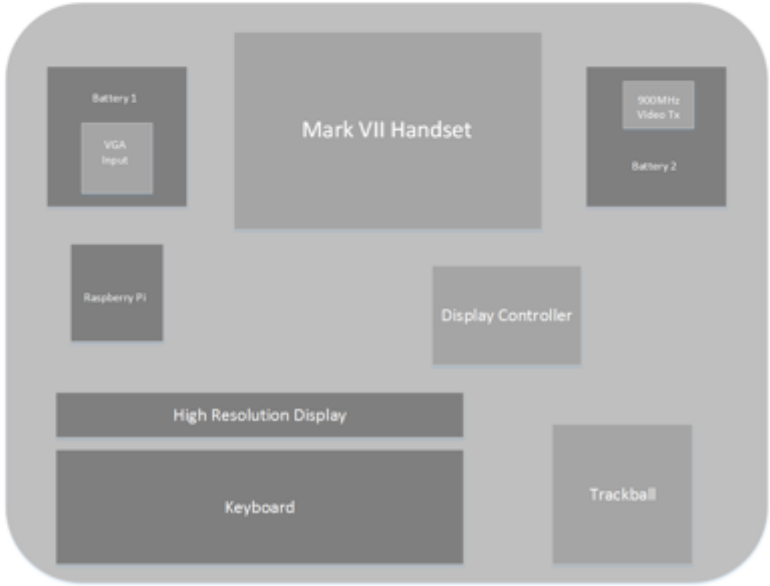

Figure 10: Final Ground Station Component Layout

The first installation to occur in the ground station is a piece of cut Lexan translucent material. The Pelican case is entirely filled with impact absorbing foam, therefore no solid mounting options are present. The Lexan is cut into a U shape to allow for storage of the Mark VIIE handset inside of the pelican case as shown in Figure 10. The Lexan is installed between the two center layers of case foam. The top layer of foam will serve as the wire concealer and for a tight seal with the lid. In order to make room for the components, the majority of the foam squares in the top layer are plucked away. An area from the bottom layer of foam is also plucked away to make room for the Mark VIIE. The Lexan is ready to have components installed.

The second installation is the 3D printed display enclosure and display controller. This is the second largest component within the ground station, next to the Mark VIIE. The mounting holes are marked then pre-drilled for four self-tapping Philips head screws. The screen is mounted in a location so that there is ample room for a keyboard and trackball to be mounted up front. These will serve as the IO for the Raspberry Pi. The display controller is mounted just to the right behind the screen with anti-vibration epoxy to the Lexan. The mounting location of the controller is chosen so that the screen may fold down when the lid of the Pelican case is closed. The ZIF cable is routed so that not additional stress from the folding of the display hinge will be incurred.

Figure 11: Mounting Location of Ground Station Display and Controller

After the screen installation, the ground station batteries are installed. For power the ground station is using two IntoCircuit 26000mAH Lithium Polymer batteries. The batteries are installed into the locations shown in Figure 10 using Velcro for quick removal and replacement. The batteries have a selectable voltage output. The selected voltages correspond to the voltage chart shown in Figure 9 with the left battery being set to 5VDC and the right battery being set to 12VDC.

The next component to install is the Video Transmission System. The transmission side requires two parts to be mounted into the case: the video transmitter and the Patch Antenna. The patch antenna is a linear antenna which works best in the vertical plane. It is because of this fact that the antenna will be installed into the lid of the Pelican case. When the lid is lifted for use of the station, the antenna will be in the correct position for transmitting video. The foam in the lid was marked so that a hole with the same dimensions at the antenna would be removed. The foam is cut away and the antenna is tested for proper fit. The antenna is glued in place using rubberized epoxy. The coaxial cable is routed down toward the lower half of the pelican case for interfacing with the transmitter. The transmitter module requires 12VDC to operate and is mounted as according to Figure 10. The unit is mounted with Velcro and is set to 910MHz transmission frequency (Channel 0).


Figure 12: Mounting Location of Ground Station Video Transmitter

The Raspberry Pi computer is installed next. The Pi requires 5VDC to operate, therefore it is located near the left battery pack. The Pi is mounted using Velcro and is positioned so that the used IO are accessible. The display and video transmitter are connected to the Pi via a composite video splitter. The power to the Pi is supplied by a micro USB cable from the left battery pack. The keyboard and trackpad are connected into the Pi's two USB 2.0 ports.

The final component to install is the VGA to Composite Video converter. The enclosure is mounted to the left battery using Velcro for ease of removal. The converter requires 5VDC to operate. Power is supplied from the left battery pack by means of USB hub. The use of the hub allows additional 5VDC devices to be powered or charged in the field. Figure 13 shows the final assembly of the left side of the ground station.

Figure 13: Final Assembly of the Ground Station, Left Side

5.4 <u>Final Testing</u>

The final assembly of the Mark VIIE and ground station is complete, but further testing must be conducted to test for component operation, proper workflow, and video transmission range. The ground station is setup inside the hard lab at the Center for Visualization and Virtual Environments. This lab is also home to a P.I.T. and will be useful for testing the Mark VIIE. The case is placed near the P.I.T. computing hardware and the testing cycle will mimic actual usage of the equipment in a typical training scenario.

The ground station is connected to the computing hardware through the VGA to Composite adapter. Once both the handset and ground station batteries are powered on, the unit becomes active. The test bench for the Mark VIIE is a simple image viewing program which displays a portion of a giga pixel image from the P.I.T. on the micro display inside the handset. If the test is successful, the component operation will be verified. The test will be conducted by both hard-wired and wireless transmission connection methods.

The first test is using the hard wired method. This method is chosen as the first test in order to avoid the extra variable of the wireless video feed. The wired connection will test the components without the risk of a misdiagnosis of hardware failure due to a weak video signal. An RCA cable is ran from the P.I.T. computing hardware to the Mark VIIE handset. The image immediately becomes visible inside of the handset. As the series of giga pixel images changes, the image on the micro display also changes. There is no image distortion; even bumps and knocks on the handset housing do not cause any adverse effects on the image quality. The OSD information is displayed in the video feed and the attitude animation changes with the movement of the handset. The wired test is successful.

Figure 14: Testing the Mark VIIE inside the P.I.T. Environment

The second test is using the wireless video feed. With the other components of the handset being verified as operational, any problems with video transmission can be identified as issues with the wireless transmission. The cable is removed from the handset and a VGA cable is connected from the computing hardware to the ground station. The transmission channel is verified to be “0” and the video converter is powered on. An image immediately appears on the display with only minor static interference. The feed continued to be solid throughout testing with the exception of large concrete or this walls coming between the ground station and handset during transmission. The comparison between the images from a typical testing session is shown below as figures 14a and 14b.

The final test of the equipment is the use of the Raspberry Pi computational

Figure 15a: Wired Video Signal Quality

Figure 15b: Wireless Video Signal Quality at 20ft.

hardware. The installed operating system is a port of Debain Linux which has been optimized for use on the Pi hardware. The display driver and Pi are both powered on. Once booted, the Pi runs through initialization routines verifying things such as region, time, RAM allotments, keyboard layout, and mass storage partitioning. When presented with the root user login, the “startx” command is given to initialize the GUI. Both the keyboard and trackball function flawlessly and are surprisingly easy to use. The display gives us no signal issues and is very vivid, despite the fluorescent lights in the lab.

Overall, the Mark VIIE performs very well, with only slight hiccups in the wireless system when large obstructions are present. The other components present no issues and are reliable even when bumped and dropped. The battery life is excellent with the ground station operation for 6 hours from a full charge and the handset running for 4 hours on a full charge. The unit is ready for packaging to be delivered to the sponsor.

SECTION 6: CONCLUSION AND FUTURE WORK

6.1 Summary

The information within this thesis presents the process of developing a training apparatus for use within virtual environments for military training applications. The basic understanding of virtual environments and simulators was explored, laying the groundwork for a project that would prove useful and acceptable to a military based sponsor. The importance of using handheld tools within these environments was also noted and described for further clarification. These topics foreshadow the problem of not having suitable portable training devices for use within simulators and virtual environments. The result from this discussion is the Mark VIIE project, the focal point of this this thesis. The development process was outlined in detail throughout the course of the document.

First the requirements given by the sponsor were outlined and discussed individually. Additional requirements were mentioned which were presented after the initial sub-contract was signed between LMCO and UK. These additions were adopted as full requirements for the project and were treated with the same importance as the initial requirements. The project was divided into two main entities: the handset and the ground station.

Next the project was broken down into individual components that would interface to fulfill the project requirements and desires of the sponsor. These were identified through a series of tests between various possible component choices. The testing reveled the best components for the project and these were selected to be used in the final design. The components were installed into their respective enclosure and interfaced so that the final outcome of the interactions would be one that produced the sponsor's desired outcome.

Finally, the project was tested within a virtual environment. This testing allowed for the verification of the project's functionality as well as the durability and performance of the components. Every aspect of the project was examined so to ensure that the project met all of the requirements listed in Section 3. Once the functionality was verified, the project was prepared for delivery to the sponsor.

The information regarding the development of the project should be clear to the reader, even in summarizing. The project developed in this thesis is an extremely effective way to implement popular handheld targeting equipment into virtual environments. The rugged design and wireless transmission also allow the unit to be adapted for use in a variety of situations beyond the scope of this thesis.

6.2 Future Work

Although the project requirements were met, there is an additional desire to continue work on an integrated platform that could be utilized in multiple targeting or generic military devices without proprietary connections or the use of separate, individual components. A platform of this type would be able to interface with multiple virtual environments, while focusing on standardized hardware for video playback, orientation, data telemetry, etc. This development would make virtual environment training simulations a reality for more military units and could potentially lead to saved lives in future years.

6.3 Conclusion

Although in a prototype stage, the Mark VIIE training unit could go on to change the way a modern solider is familiarized with his or her equipment. Although the longevity of the design is still a large consideration, initial testing showed good results and a promising adoption of virtual training using handheld devices. Therefore, the scope of this thesis is considered to be complete and the research effort is to be concluded.

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