Creating a flexible LVC architecture for mixed reality training of the dismounted warfighter

by

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ABSTRACT

Physical military training within military operations in urban terrain (MOUT) environments provides a realistic experience, albeit at high cost and limited scenario flexibility. Alternatively, training within serious games, often from a laptop, provides a low cost, highly flexible platform, but lacks sufficient realism and engagement for some applications. Live, virtual, and constructive (LVC) systems attempt to combine these two and capitalize on their strengths for joint forces training. However, current LVC training environments for the dismounted warfighter often are too small for realistic squad-sized training, constructed statically without ability to reconfigure quickly into new scenarios, are developed as standalone systems dependent on specific communication protocols, and do not enable realistic interaction between LVC entities.

In response to these challenges, a rapidly reconfigurable LVC training system was developed at Iowa State University, known as the Veldt. The physical Veldt environment consists of a 44‘x60’ room with modular walls configured in unique layouts for different training scenarios. These configurations contain doorways, windows, alleys and other openings, which may contain displays rendering the virtual environment for seamless integration between the physical and virtual worlds. A tracking system gathers position and orientation information on trainees, weapons and other objects and a clustered game engine then uses this information to create virtual representations of the trainees in the virtual world. This information is sent through a communication server which distributes it to other connected components such as game engines and simulations which populate the virtual world with live and constructive entities.

This thesis presents solutions to two key challenges in creation of the Veldt: 1) how to correlate all physical and virtual worlds for seamless interaction regardless of location and 2) how to design a network architecture that is easily extendable and can accommodate multiple protocol types. The correlation of physical and virtual worlds is necessary for entities, their models, and terrain. A central communication architecture became the first element of a solution by flexibly connecting entities’ location, orientation, fire and other information

without requiring individual connections between all components.

To enable appropriate collaboration between LVC trainees within the system, models must be visually indistinguishable regardless of interaction medium. However, most game engine and simulations contain separate, sometimes proprietary, model databases. A model-matching approach was applied to overcome this challenge, requiring only minor configuration of connected components for a set of common models common to all the components' databases. This approach resulted in a less extensive, non-identical common database, but is more easily scalable and requires less resources over other methods.

Terrain correlation is required to prevent issues with collaboration and fair fight between distributed LVC entities, where improper terrain correlation could create an unrealistic training environment. Similar to model database correlation, game engine and simulation systems typically contain separate, sometimes proprietary terrains and terrain formats. Because utilizing separate tools to convert from a single source into different formats often produces non-identical terrains, a single procedural terrain modeling framework was created and implemented for the Veldt system.

The solution to the second challenge of creating a protocol independent network architecture was achieved by processing the entity information flowing through a central communication server. With this design, the communication server receives information from one component in its native protocol, converts that into a world state, and then for all interested components, converts the world state into a component's native protocol and sends the information. Therefore, the communication server only requires packing and unpacking methods to and from a world state to easily extend the network architecture to include other protocols.

These methods were first evaluated within a user study conducted by the Research Institute for Studies in Education (RISE) at Iowa State University. The study results found high ratings of the system by participants on involvement, interaction, and immersion; indicating a near seamless physical-virtual correlation between environments. A interservice demonstration of the system involving many distributed components and multiple live, virtual, and constructive entities provided further evaluation. The successfulness of this demonstration, involving collaboration between participants in live and virtual environments, further proved the successful correlation of the physical and virtual worlds. In addition, the demonstration proved success of the protocol independent network architecture, as the scenario ran in real-time with negligible latency and with two differing protocols types.

CHAPTER 1. INTRODUCTION

The United States military employs numerous physical and virtual techniques to train the dismounted warfighter. Physical training often occurs at military operations in urban terrain (MOUT) sites which incorporate simulated fire, pyrotechnics and paid actors to create realistic training experiences. While virtual efforts incorporate computer-based training through serious games which offer near limitless accessibility. Most recently a combination of these two in live, virtual, and constructive (LVC) training systems has emerged as a flexible and effective solution for training. Moreover, LVC training systems for the dismounted warfighter often incorporate mixed reality environments to merge real and virtual worlds. These mixed reality systems often consist of a smaller, physically navigable environment than MOUT sites populated with screens projecting a virtual environment for virtual and constructive entity interaction. Through mixed reality, LVC systems provide an immersive physical experience containing the flexibility of serious games for less cost than physical MOUT sites.

MILITARY TRAINING METHODS

Physical Training

Military training in physical environments attempts to mimic real-life scenarios. Components such as shoot houses, live fire, and actors can be used at varying levels of fidelity to target specific aspects of training. Shoot houses involve a physically navigable set often installed with pop-up simulated neutral and opposing forces to offer shoot-don't-shoot exercises in an extension of a firing range environment. A derivative of these shoot house environments are force-on-force exercises at MOUT sites where simulated fire and live people provide scenario unpredictability and realism. Simulated fire is defined as fire from either replica or real weapons involving blank cartridges, simunitions [1] (similar to paintball) or laser tag systems. One well implemented example of such a system is the multiple integrated laser engagement system MILES [2] [3] [4].

Figure 1. Strategic Operations MOUT site

MOUT sites provide more detail in their physical construction over shoot houses, often replicating an actual theatre or region and involving many furnished buildings. Training offered at MOUT sites and commercial training systems such as Boeing's Integrated Immersive Training Environment (I2TE) [5] contain cameras and virtual representations of the MOUT environment to provide after action review (AAR) to discuss the strength and weaknesses of a team's performance in exercises. While typical MOUT exercises offer an enhanced training experience and important AAR over shoot houses or range training, they often can lack the detail and feel of a town or battlefield as they are often constructed of old shipping containers and populated only by the soldiers training.

A more recent iteration on MOUT site training exercises attempts to provide greater immersion and similarity to real situations encountered by the warfighter, moving into a spectrum one company, Strategic Operations, has labeled Hyper-Realistic™ training [6][7]. While still constructed with shipping containers, they are endowed with significantly more detail to create streets, markets, cities, and war-torn urban areas as shown in Figure 1. These sets are then populated with actors playing roles of civilians or opposing forces, speaking local languages and moving naturally about the area to create a dynamic training environment. Pyrotechnics and olfactor systems are utilized to engage the warfighter's sense of sound and smell in order to accustom their senses to those of the battlefield. Battlefield medical simulation can involve amputees with hollywood grade makeup and actors donning “cut suits” which bleed, accommodate intravenous treatment, withstand sutres, and produce odor if internal organs are cut or punctured.

Undoubtably these extremely realistic MOUT sites have the potential to better prepare the warfighter for the battlefield, but they also result in high costs. Construction of cities, payrolls, equipment replacements, and logistical costs transporting soldiers to these locations comes to large costs to run and maintain these systems. Logistics for these exercises alone can cost millions of dollars. Likewise, due to the expendability of pyrotechnic devices, damaged props, and makeup these scenarios require significant preparation time, decreasing the number of trainees that can run through a scenario within a given day. Lastly, the intense detail of these scenes requires long planning to design alternate scenarios and then switch between alternate scenarios. Decreasing armed service budgets and proven effectiveness of virtual simulations for training have shifted much focus to low cost simulations and serious games as a solution [8].

Serious Games

The use of computers for simulation within the United States Military has undergone many changes in the last century. Modern simulators were first purchased by the United States Navy in 1931 for training pilots. Followed by the first immersive networked simulator SIMNET [9] in the 1980s and later the close combat tactical trainer program (CCTT); the immersive simulator industry was disrupted by consumer off the shelf (COTS) products in the 1990s [10]. COTS games such as Marine DOOM [11] and later America’s Army [12] were cheaply adapted for the purpose of training. These games, termed “serious games,” have since expanded beyond situational combat scenarios to medical [13], cultural [14][15] and other applications. These serious games exhibit a low cost solution to military training, are easily distributed to the warfighter, and require only seconds to switch between scenarios of different terrain, complexity, and objective. These games enable precise scenario playback for AAR and can generate statistics to provide additional information over that of a MOUT site. Most importantly, research has proven this virtual method of training to transfer into real life benefit [16][17][18][19]. However, serious games do not contain similar immersion or fidelity as realistic training, limiting their effectiveness for some applications.

Multiple Game Engine Systems

Serious games for military training utilize a great diversity of commercial and non-commercial game engines including Virtual Battlespace 2 (VBS2) [20], Delta3D [21], CryEngine [22], and Unity3D [23]. This variety indicates the absence of one game engine that can meet all training requirements of the warfighter. As requirements increase in complexity, multiple game engine systems become necessary to combine the best features of multiple engines for an effective training system. In addition, this system becomes an evolving platform that can be easily integrated with other simulations and upgraded as graphic, game engine, and simulation technology advances. Despite the advantages of multiple game engine systems, little published work exists on the development and implementation of such systems.

LVC Systems

LVC systems attempt to integrate real and virtual training to combine the benefits of distributed serious games and immersive physical training. These training systems integrate physical (live) trainees, virtual trainees within serious games, and artificially intelligent (constructive) avatars for interaction within one coherent environment. Often LVC training systems incorporate game engines for management and manipulation of the virtual aspects of that environment.

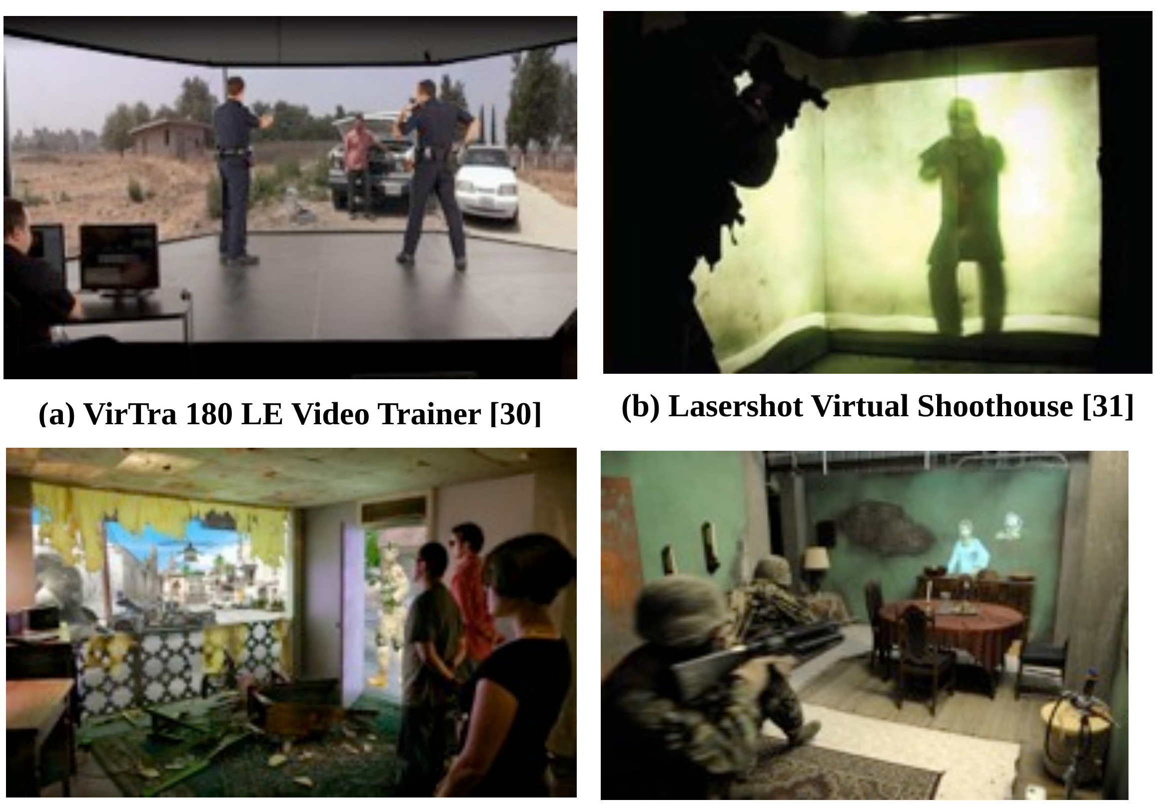
LVC training systems solutions exist for dismounted, ground, sea, and air forces. For example the Royal Australian Air Force (RAAF) identified high cost relating to live training exercises related to gathering assets for red and blue forces, fuel, vehicle wear, planning and access to live ranges [24]. To address these issues, the RAAF has utilized a mix of live, virtual and constructive entities for ground forces in live exercises and would like to improve those capabilities to involve multiple entities from multiple sites for complex exercises. Similarly the U.S. Army is leveraging COTS technology including game engines and simulators through its gaming program to develop flexible solutions through LVC training systems [25]. To meet these needs the commanders integrated training environment (CITE) was developed to provide language, cultural, and decision making training for squad and larger sized groups. While this solution was developed with LVC in mind, interoperability with live entities is only discussed as an option and not discussed within the deployed CITE package. Therefore, the CITE falls short of a true LVC system.

Mixed Reality Environments

Mixed reality environments have been examined to support transformation of training towards LVC systems [26]. The first adaptations of these environments are termed virtual trainers or virtual shoothouses which have been adopted by law enforcement as well as for military training. These systems follow physical pop-up shoot house methodology, displaying constructive neutral or opposing forces on projected screens with live video or computer graphics and even tracked weapons for trainees. Figure 2b shows one such COTS product from Lasershot [27]. Some unique systems provide the ability for trainer operators to branch scenarios depending on situation circumstances. For example, a trainer may escalate or deescalate a scenario to become either a shoot or don’t shoot situation depending on the trainee’s skills. This is often accomplished by a trainer or operator, such as in the Figure 2a. Aside from scenario branching functionality, these systems are much more constrained in terms of flexibility then many serious games. Constructive actor behavior in video-based systems is limited to content filmed, while computer graphics systems implement little intelligence for constructive actors. Furthermore, the small physical space available in these systems limits training to individuals or pairs and therefore does not directly relate to squad level training of typical dismounted soldier exercises. Lastly, the small physical area and absence of other physical objects within shoothouses can hinder natural reaction of the trainee. For example in a sniper scenario, trainees would all dive for physical cover within a realistic setting, however there often isn’t any physical cover available within shoothouse systems.

Added physical detail to the virtual shoothouse model shown in Figures 2a and 2b has yielded more immersive mixed reality systems such as FlatWorlds, as shown in Figure 2c, developed by the University of Southern California Institute for Creative Technology [28]. FlatWorlds also introduced the ability to customize the physical set of an environment for mixed reality scenario flexibility and incorporated game engines to add more intelligence to constructive actors for greater LVC interaction. The main limitations with the virtual shoothouse and FlatWorlds model is the restriction of physical movement due to the limited area, lack of adequate space for squad-based scenarios, limited virtual trainee interaction, and inability to quickly customize the environment for different training scenarios.

To overcome these limitations larger mixed reality environments such as the Infantry Immersion Trainer (IIT) [29] at Camp Pendleton, shown in Figure 2d, have been constructed. These environments expand the physical area to similar size of MOUT sites for



(a) VirTra 180 LE Video Trainer [30]

(b) Lasershot Virtual Shoothouse [31]

(c) FlatWorld [32]

(d) Infantry Immersion Trainer [29]

Figure 2. Mixed reality environments for military training

squad-based immersive training. For example, the 32,000 sq.ft. IIT contains a layout of rooms and alleys populated with both live and constructive opposing forces and civilians. While the IIT overcomes the space and squad limitations of the small training environment, the live-constructive interaction is more restricted without real-time tracking technology throughout the entire space. Furthermore, both FlatWorld and IIT still provide limited or absent ability for two way interaction between live and virtual entities by utilizing mainly constructive entities within their virtual environments.

Distributed Simulation Systems

LVC systems that attempt to combine multiple game engine systems and mixed reality environments can be similarly described as distributed simulation systems (DSS). Such DSS have been developed for combining virtual agents, such as semi-automated forces (SAF), with a game engine [33], and live tracked objects [34]. DSS has also been proposed for integration of many gaming and simulation components by Jain & Mclean [35], where they identified challenges with integrating heterogeneous software components. A conceptual prototype of the system was developed in 2006, however the serious game components were implemented on separate planning levels and did not appear to interact [36]. Finally, the most recent published work discussing this proposed architecture only suggests further implementation of the concept [37] without expanding upon this prototype. While this architecture is a conceptually viable solution for mixed reality environments, interaction between virtual entities was never been implemented, the prototype never involved live entities and no evaluation was performed of a prototype. Therefore it is impossible to determine the potential for success of the Jain & McLean architecture with the current state of the work.

While DSS offers promise over multiple game engine systems or mixed reality environments alone, challenges remain. For example, systems employing DSS often implement communication as one-way between system components, limiting true two-way entity interaction among components.

MOTIVATION

While LVC training systems for the dismounted warfighter attempt to combine the advantages of flexible serious games and realistic physical training, none of the systems reviewed contain a squad-sized physical environment nearing the scenario flexibility of a virtual system. Moreover, interaction between live and virtual entities was often constructed as one-way, falling short of the full fledged two-way interaction necessary for effective training. Mixed reality LVC DSS have the potential to achieve these goals, but no successful system was found in literature review.

Fair fight can be described as when no entity has advantage over another in terms of capability or environment. Within LVC, fair fight can be used to evaluate the reality of training systems where no entity has an advantage over another regardless of interface. An example of an advantage in capability could be the ability for live entities to engage virtual entities while virtual entities do not have the capability to engage live entities. Likewise, an example of an environmental advantage could be the ability for bullets to travel through walls in one game engine, but not in another. Specifically for live-virtual fair fight, all LVC entities must exist in all environments with comparable behaviors such as movement, posture, health and the ability to fire. For virtual-physical interaction this can be achieved by tracking live trainees in order to create their virtual representations within a virtual world. Alternatively, with mixed reality, physical-virtual interaction can be achieved for live trainees by incorporating displays within the physical environment. Therefore, mixed reality LVC training systems for the dismounted soldier that follow those two approaches have the potential for high fidelity interaction and immersion regardless of physical or virtual medium.

A flexible hardware and software architecture would also provide reconfigurability for these mixed reality systems. To enable comparable flexibility within physical environments as with virtual ones, modular structures and displays must be utilized within the physical environment. Due to the current diversity of game engines, tracking systems and communication protocols in military training systems, such a system must also provide an accommodating architecture for connecting components. For example, the system must be flexible to connect one game engine communicating with distributed interactive simulation (DIS) protocol and a tracking system with an independently defined protocol. Following these recommendations, a first of its kind system, known as the Veldt, was created at Iowa State University as a squad-sized rapidly reconfigurable and flexible LVC DSS for the dismounted warfighter.

THESIS ORGANIZATION

This thesis focuses on the development of a flexible and reconfigurable LVC DSS software architecture for training the dismounted warfighter. This includes implementation of a protocol independent network architecture and synchronizing environments across all interfaces for fair fight. Chapter 2 will provide the background of the mixed reality LVC DSS known as the Veldt which acts as a platform for this research. In Chapter 3 a paper from the Proceedings of The Engineering Reality of Virtual Reality, SPIE Electronic Imaging 2012 establishes the methodology for this thesis and provides brief results. Chapter 4 discusses a user study and a complex scenario demonstration involving the Veldt system using the methodology presented in Chapter 3. Chapter 5 provides a summery of the thesis and future work for the Veldt system.

CHAPTER 2. BACKGROUND

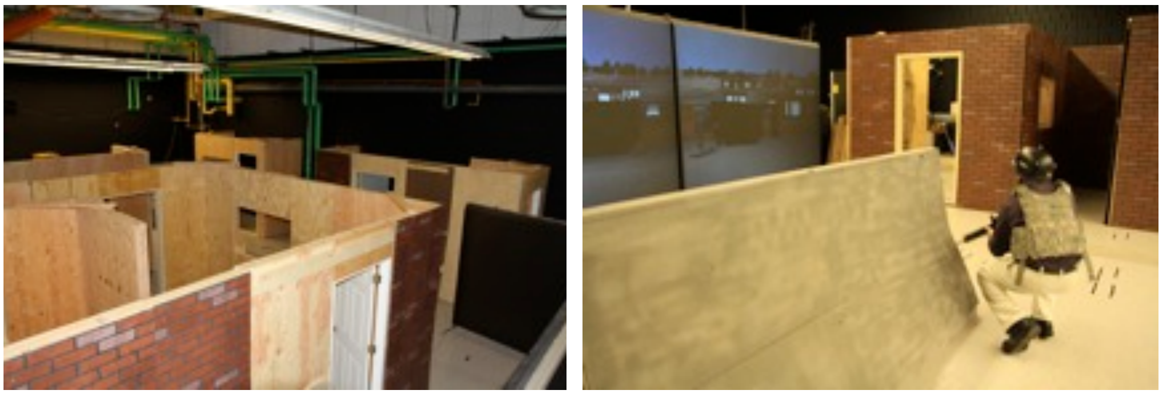
Creation of a flexible, reconfigurable immersive mixed reality LVC training system for the dismounted warfighter required solutions for a series of challenges: construction of a large reconfigurable physical set, tracking in an occluded environment, live-virtual kinetic interaction, development of a clusterizable game engine, and design of a protocol-independent communication system. The result would be the framework for an immersive training system where live trainees within a physical space and virtual trainees within first person shooter (FPS) and other virtual environments could collaboratively train as if co-located.

THE VELDT

Physical Construction of the Veldt

As discussed in the background, realistic MOUT sites may use shipping containers, cement, and concrete to create fixed town layouts that are difficult if not impossible to alter. The FlatWorld mixed reality environment is one example of a reconfigurable training system, however its reconfiguration model could take weeks, isn't scalable and its small size lends the system toward individual training.

The physical Veldt at Iowa State University was constructed by a large team from the Virtual Reality Application Center as the first large (44' x 60' x 18' high), quickly reconfigurable training system for squad-based training of the dismounted warfighter. To build a reconfigurable physical set, modular U-, L-, and corner shaped wall components were designed using computer aided design (CAD) software and constructed from wood. Regardless of shape, each wall shape was constructed from combinations of 4.5' x 0.5' x 8' or 9' x 0.5' x 8' high wall sections and bolted together through 4" x 4" x 8' posts. Aside from modularity constraints, walls were designed considering cost, weight and stability. A number of walls were also designed to include windows, handled doors and breach doors. Breach doors replaced door handles with a kick plate and a slot created on the interior side of the wall section using another metal plate. To simulate physical door breaching, a trainee must kick the door's kick plate with enough force to break through one to three 8" x 0.5" x 0.5" pieces of plywood bridging the interior metal slot and the door opening. After construction, 12 wall modules, each weighing 300-500 pounds, and two additional wooden barriers were created. These wall modules are shown in an initial configuration in Figure 3a and a final configuration in Figure 3b.



(a) (b)

Figure 3. Reconfigurable Veldt wall modules

Modules were then augmented with a reusable texturing design in which textured panels could quickly be added or removed to walls to simulate a variety of materials, shown in Figures 4a and 4b. A rolling caster design lifts the walls off their base to enable a single person to easily move 300-500 pound wall modules from one location to another. The caster design enable complete reconfigurability of the physical Veldt from distinctly different scenario layouts in under thirty minutes.

(a) (b)

Figure 4. Reusable Veldt wall texturing

Tracking in an Occluded Environment

For LVC training, live trainee and physical prop locations and orientations must be collected from the physical world in order to create an accurate virtual model. Position and orientation data should be collected with enough accuracy for identical physical and virtual representations and enough collection frequency to enable fair fight within LVC systems. This high accuracy is necessary to create weapon trajectories, visualize cover, and determine live trainee positions. Commercial-off-the-shelf (COTS) products exist for many different tracking technologies with varying ranges and accuracies. Commercialization of global positioning system (GPS) technology provides a low cost solution to collecting such data for outdoors environments at low cost, however appropriate accuracy can be difficult to attain with thee systems. In addition, building structures significantly weaken GPS signals resulting in high inaccuracies in location information [38] making this technology inappropriate for indoor LVC training.

Ultra-wide bandwidth radio frequency tracking systems are non-line-of-sight technology; therefore, they can send signals through most obstructions present in indoor environments. This technology often incorporates small tracking tags which are much less intrusive than tracking technologies requiring reflective markers on objects. However, often these systems are not capable of skeletal tracking and do not provide high enough tracking precision for LVC training. For example, Ubisense systems [39] quote tracking accuracy within 15 cm [40].

Less common systems such as Wi-Fi and magnetic tracking are also not appropriate. Wi-Fi tracking technology similarly has positional inaccuracies [41], while magnetic tracking systems have appropriate accuracy they may have range limitations [42] and measurements are often affected by the common presence of metal in the tracking environment.

Optical markerless and markered tracking technologies were identified as appropriate for range and accuracy for an indoor training environment. Both optical technologies involve capturing tracking information through cameras, while markered technologies disperse infrared light to illuminate reflective markers in order to located their positions. There are also two methods of employing these tracking systems, outside-in and inside-out. Outside-in systems mount cameras around the environment to observe objects for tracking, while inside-out tracking requires mounting camera hardware on the objects and calculate location and orientation changes from differences in camera images. Outside-in indoor tracking systems often require a near ideal, contained, unobstructed environment. In the Veldt people, props and walls obstruct tracking thereby reducing tracking precision and creating "blind spots" where tracking is not possible. While inside-out systems have achieved high precision tracking within indoor environments [43] for dismounted warfighter training, they require equipment on trainees and weapons that can significantly hinder immersion. Due to these issues, an outside-in infrared tracking system was selected for the Veldt.

This system a 24 camera Motion Analysis Raptor-H Digital Real Time System, shown in Figure 5, was installed within the Veldt. Each camera is capable of 640x480 pixel resolution with capture speeds up to 250 frames per second and interface with Motion Analysis's Cortex software package for creating marker sets and motion captures. The tracked area is covered with infrared light from LEDs and captures reflections with the cameras. Marker sets are created by installing highly reflective balls on objects in unique

Figure 5. Motion Analysis Tracking Configuration within Veldt

layouts and then configuring those marker sets as objects in the Cortex software. For the Veldt system, trainee and weapon positions and orientations were tracked from unique configurations on helmets and simulated weapons, respectively.

The tracking system must also collect this data at high rates for the real-time updates required for live-virtual fair fight LVC interaction. In large mixed reality or distributed LVC training environments, this real-time tracking is necessary to enable the realistic live-virtual entity interaction often lacking in current mixed reality systems. Real-time tracking also has the potential to offer more advanced after action review (AAR) given additional information on the trainee such as position, orientation and posture at any point in time of an exercise.

JerryBoards: Simulated Weapons

Live-virtual interactions commonly occur through weapon engagements, tactile vests [44][45], or verbally through conversations. In the Veldt, LVC interaction was primarily implemented for kinetic weapon engagements. To accomplish this, four replica M4 Airsoft weapons were wired with custom electronics to transmit trigger fire information. An early prototype of one of these simulated weapons is shown in Figure 6. The stock replica weapon hardware signals an internal electric motor to drive a mechanism that quickly compresses air upon each trigger pull to produce auditory simulation of weapon fire in the physical world. A sensor board, termed JerryBoard, was developed by Jerry Stoner to transmit this internal electrical signal and other information via radio frequency to a base station connected to the master Veldt computer through a serial to USB converter. When the base station receives this signal it examines the message and then releases the digital information to the Veldt software for processing. The JerryBoard transmission

Figure 6. Replica M4 with prototype JerryBoard

protocol consists of the logic status of a digital input, a digital input identifier and a board identifier.

DeltaJug: A Clusterizable Game Engine

To achieve the goal in LVC training of imparting the flexibility of serious games on the physical environment, multiple displays must be configured throughout the Veldt. In the physical Veldt space, a mixed reality environment is created by integrating many displays, varying in size, model and technology, in roads, alleys, windows, doors, and buildings as shown in Figure 7. The integration of these displays throughout the Veldt imparts the ability to extend a scenario beyond the physical constraints of the room. Using displays as seamless extensions into the virtual world through which live trainees can interact. This type of mixed reality environment provides enhanced immersion over virtual shoothouse systems. For these virtual extensions to behave similar to the physical world and enable their quick configuration, they must be synchronized as a cohesive virtual scene. However, this places unique constraints upon the game engine driving the system. For a synchronous scene among the displays, each display must render the exact same frame at the exact same moment, albeit through a different view frustum. Swap locking of slave nodes by a master node controlled through transmission control protocol (TCP) communication and a high-bandwidth network with relatively few users virtually eliminates latency between each display. This clustered graphics approach is critical to allowing the scene to be continuous on the various disjointed display surfaces, but adds additional network complexity. Most commercial and open source game engines do not allow scalability for clustered graphics beyond a few

Figure 7. Integrated Veldt display

nodes of a computer system. Thus, one had to be designed for the many nodes required, sometimes as many as 96.

The open source game engine Delta3D [46] provided a platform for military training [47][48] with low-level source code access that could be altered to provide the clustered graphics capabilities required. Delta3D was combined with VR Juggler, a networking and hardware abstraction API commonly used for clustered graphics application development [49][50]. This clusterizable game engine developed by a team including Christian Noon, Brandon Newendorp and Brice Pollock was termed DeltaJug [51][52].

Through gadgeteer plugins developed by Ken Kopecky, DeltaJug has the ability to connect to a diverse set of hardware components such as the tracking systems and radio frequencies boards previously described. These components are added to a DeltaJug application through XML-based configuration files, thereby eliminating specific code changes when switching hardware systems. This allows the same application code to be used on a single monoscopic wall system with sonic tracking and a multisided, stereoscopic, immersive virtual reality system with optical tracking with only a change in a configuration file. While DeltaJug solved a major implementation issue of graphics node synchronization; it does not contain an extensive model library, allow quick and easy scenario authoring, or contain a polished after action review tool.

Virtual Battlespace 2

Virtual Battlespace 2 (VBS2), a commercial game engine common to U.S. military training [20][53], contained all these features within a straightforward interface. While VBS2 was determined most appropriate for the Veldt implementation, other common game engines used in military training such as Unity3D or CryEngine could have been implemented with similar ease. VBS2's scenario authoring ability allows quick creation of scenarios and assigning behaviors for constructive entities. Virtual trainees can interact in VBS2 through a first person shooter style interface. Multiple virtual trainees can interact from multiple instances of the game engine through VBS2's networked mission capability.

Trainers can additionally participate in the scenario as observers and record a mission along with virtual and live entity performance metrics for AAR.

Communication Server: Protocol-Independent Communication

Thus far the Veldt has various hardware and software components, but no networking architecture to connect them. Developing communication between all components in an LVC, distributed, or mixed reality training system often presents a challenge. For example, tracking systems do not typically broadcast protocol data units (PDUs) in a simulation standard. Also, the incorporation of multiple game engines or simulation applications will involve components communicating through different standards such as Distributed Interactive Simulation (DIS), High Level Architecture (HLA), Test and Training Enabling Architecture (TENA), or simply transmission control protocol (TCP) or user datagram protocol (UDP).

In many DSS and LVC architectures, inflexible conversion portals remain a dominant feature. These portals typically support one-way communication and restrict inter-component communication to one or two protocols [33][34]. A standalone weapons trainer implementing inflexible portals cannot easily incorporate other simulators within exercises nor other communication protocols.

To realize the true benefits of a flexible mixed reality LVC training system, such as the Veldt, a flexible architecture is required to quickly accommodate any variety of component combinations and communication protocols. Such a flexible architecture could quickly integrate new technologies, interoperate with existing simulators, and perform interservice LVC training to simulate the frequent interservice interaction found in the field within an LVC training environment.

An additional challenge of this distributed system is information must be communicated in real-time for LVC fair fight. Regardless of system specifics, distributed systems are known to have network latency, hardware architecture differences, software system delays, and other potential challenges [54]. Previous research has also identified protocol communication, such as DIS, between simulations to have high network bandwidth costs [55]. However, technical advancements have largely overcome these challenges. Network latency between simulations can result in different states among components. For example, severe network latency could cause virtual and real worlds to slip out of synchronization disrupting the mixed reality blending of the two worlds with the introduction of “lag.” Computational methods exist to assist correction of these latencies [56], however the best approach is to minimize this issue locally through system design.

To achieve both a flexible and low-latency networking architecture a central communication server was developed by Christian Noon and implemented by Brice Pollock for the Veldt system to connect system components using various protocols. The server accepts communication from all components in the system and converts their data from the sending component’s protocol into a world state object within the communication server. This world state object is then compared against the list of active world state objects. If an object exists matching the world state update then the update replaces the object as the most recent world state. By only keeping the most recent world state object in memory and not backlogging every update, the latency of the system depends on the CPU and network speed to send one update not a cache. After conversion, the communication server identifies which components have requested particular information and the data is converted from the world state into a receiving component’s local protocol for transmission. This process can be seen in the diagram in Figure 8. The communication server was designed to accommodate communication protocols from many components and to distribute data as quickly

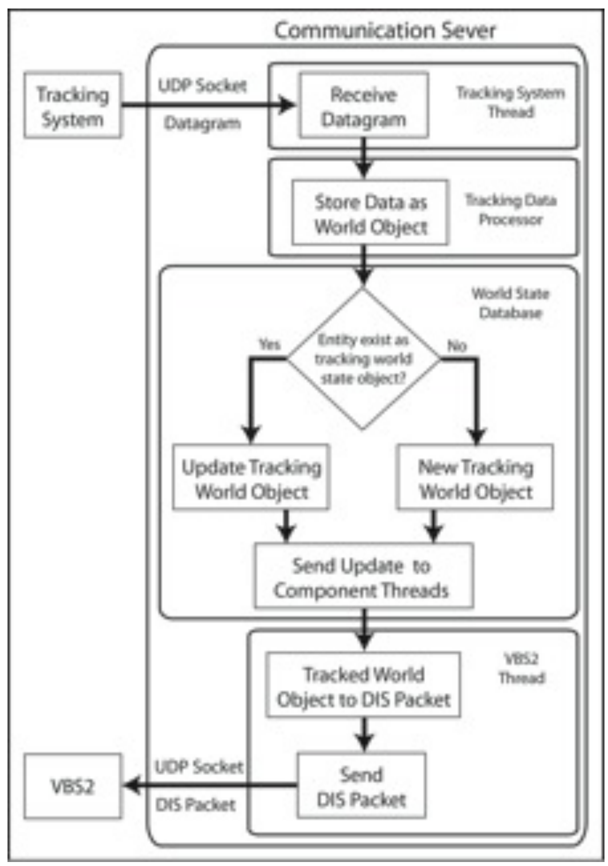


Figure 8. Communication server translation process diagram

as possible to minimize latency.

Veldt Scenarios

For initial study of the feasibility and usability of the Veldt, two diverse scenarios were drafted based on common battlefield situations: Security Checkpoint and Clear a Room. While each scenario targets slightly different training objectives, both commonly test a trainee's ability to communicate with other team members, follow the rules of engagement, identify challenges evaluating complex situations quickly, ability to make quick decisions in a stressful environment, and practicing shoot/don't shoot situations. In these scenarios, friendly entities are termed BLUEFOR or blue forces, enemy forces are termed OPFOR or opposing forces and civilians are termed NEUTRAL, which are neither opposing or friendly forces.

Security Checkpoint

The checkpoint layout, as shown in Figure 10a, contains a single, centered street through the Veldt with buildings on either side. In this scenario, a combination of live and virtual blue (friendly) forces are positioned around barriers in the checkpoint area observing civilian traffic down the road. The U.S. soldiers at the checkpoint are military police (MPs) responsible for checking IDs and verifying security clearances overseas. Virtual and constructive entities exist down the road as well as through the windows of the various buildings adjacent to the checkpoint.

A typical interaction in this scenario is as follows. A vehicle approaches the checkpoint at high speed and is viewed down the road. Despite soldiers commanding this vehicle to halt, its speed does not decrease. After following the appropriate rules of engagement the MPs fire on the vehicle to disable it. Multiple virtual and constructive opposing force actors exit the vehicle and fire upon the MPs using the vehicle as a barrier. MPs return fire using checkpoint barriers as cover. Throughout the scenario civilians can be seen around driving away from the opposing force vehicle and also in the windows of the buildings around the checkpoint. Variations of this scenario could replace opposing forces with neutral forces, interference from a crowd of people, reveal opposing forces in surrounding buildings, or be performed in diverse weather and daylight conditions.

Clear a Room

The clear a room scenario layout, as shown in Figure 10b, consists of alleys surrounded by various separate buildings and eventually leading out of the town. In this scenario, multiple live soldiers start at one end of the scenario and navigate towards a building suspected to contain opposing forces. Blue forces are instructed to breach the building and perform a systematic search at high speed while being aware of possible boobytraps. If blue forces receive fire they are instructed to return fire. Multiple live, virtual and constructive opposing and neutral forces can be present within the breach building and the surrounding environment. While the raid is underway by the blue forces a truck may approach the area from out of town and virtual or constructive opposing forces will exit and take up firing positions. Blue forces can engage these additional opposing forces either from a window within the breach building, a door within the breach building or the alleyway outside of the breach building. Variations of this scenario may increase or decrease the number of neutral or opposing forces and place virtual or live/simulated boobytraps. In addition to the training objectives described, the clear a room scenario evaluates trainees abilities to follow U.S. Army procedures for precision room clearing [57].

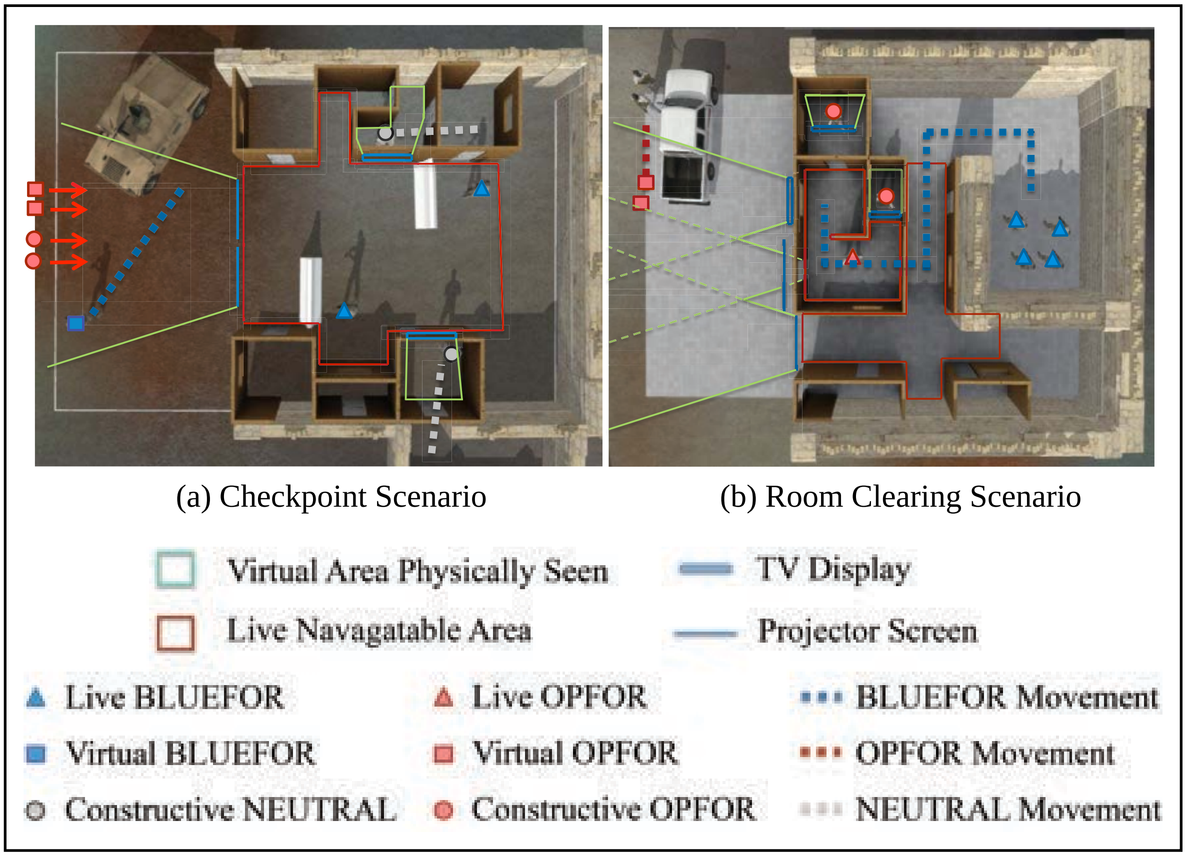


Figure 10. Checkpoint and Room Clearing scenarios. Images are from a VBS2 top down view, annotated with time-dependent and physical environment information.

RESEARCH ISSUES

Literature review of mixed reality training systems for the dismounted warfighter has shown no system has met all requirements for squad-level LVC interaction. The Veldt architecture has been developed to create such a mixed reality system. The critical research issues addressed for the research in this thesis are as follows:

1) **How can virtual and physical worlds be correlated for joint scenario flexibility and reconfigurability?**

Fair fight and collaboration between live, virtual and constructive entities require every physical and virtual environment to maintain high consistency with the others in entity locations, models, and terrain. This task is difficult alone, however all these environments must additionally be flexible and reconfigurable to accommodate multiple scenarios. Solving this issue would make the Veldt system the first large, reconfigurable LVC DSS for the dismounted warfighter.

2) **Is it feasible to connect live, virtual, and constructive entities across a distributed system involving multiple protocols?**

   To create a truly flexible LVC DSS, it must be possible to easily add, remove or exchange simulations, game engines and other components such as tracking systems. Typical distributed LVC systems have developed one-way portals for protocol conversion, however these are easily reusable or extendable to accommodate new systems. The communication server yields itself for this reusable network architecture, however it has yet to be implemented and tested.

CHAPTER 3. LVC INTERACTION WITHIN A MIXED REALITY TRAINING SYSTEM

Modified from a paper published in Proceedings of The Engineering Reality of Virtual Reality, SPIE Electronic Imaging.

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Abstract

The United States military is increasingly pursuing advanced live, virtual, and constructive (LVC) training systems for reduced cost, greater training flexibility, and decreased training times. Combining the advantages of realistic training environments and virtual worlds, mixed reality LVC training systems can enable live and virtual trainee interaction as if co-located. However, LVC interaction in these systems often requires constructing immersive environments, developing hardware for live-virtual interaction, tracking in occluded environments, and an architecture that supports real-time transfer of entity information across many systems. This paper discusses a system that overcomes these challenges to empower LVC interaction in a reconfigurable, mixed reality environment.

This system was developed and tested in an immersive, reconfigurable, and mixed reality LVC training system for the dismounted warfighter at ISU, known as the Veldt, to overcome LVC interaction challenges and as a test bed for cutting-edge technology to meet future U.S. Army battlefield requirements. Trainees interact physically in the Veldt and

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virtually through commercial and developed game engines. Evaluation involving military trained personnel found this system to be effective, immersive, and useful for developing the critical decision-making skills necessary for the battlefield. Procedural terrain modeling, model-matching database techniques, and a central communication server process all live and virtual entity data from system components to create a cohesive virtual world across all distributed simulators and game engines in real-time. This system achieves rare LVC interaction within multiple physical and virtual immersive environments for training in real-time across many distributed systems.

Background

Physical training for the United States military provides a realistic environment for the warfighter, however these solutions are hindered by high costs and scenario inflexibility. Alternatively, virtual serious games offer high scenario flexibility and low cost, but seriously reduce scenario immersion and realism. Live, virtual and constructive training systems attempt to combine these two approaches into an effective, flexible and low cost solution to training.

Physical Training Systems

Military operations in urban terrain (MOUT) sites are the typical locations for force-on-force physical training involving live opposing forces and simulated fire. Commonly the size of a town, MOUT sites are constructed of permanent materials and require personnel transportation to the site for training. More recently constructed MOUT sites also involve highly detailed sets, actors and pyrotechnics[1]. These sets are populated with native speaking actors from the theatre of war moving about markets, cooking food, and engaging in other civilian behavior. Scripted hostile engagements prompt pyrotechnics and olfactory deployments to accustom the warfighter’s senses to the battlefield. Battlefield medical simulation can involve amputees with Hollywood grade makeup and actors donning “cut suits” which bleed, accommodate intravenous treatment, withstand sutras, and produce odors. The high fidelity of interaction for these exercises come at the cost of static city layouts, long scenario changeover, high overhead and large logistic cost. Decreasing armed service budgets and proven effectiveness of virtual training[2] have shifted much focus to low cost simulations and serious games as a solution[3].

Virtual Serious Games

Serious games commonly involve game engines and range in application from medical[4] to combat situational[5] to language and cultural[6,7]. These games exhibit a low cost, easily distributable solution requiring only seconds to switch between scenarios of different terrain, complexity and objective. After action review (AAR) modules can replay training scenarios and generate statistics to provide individual and group information over typical MOUT site capabilities.

A review of existing training applications reveals great diversity of game engines involved in military training. Often employing first-person-shooter (FPS) interfaces, these engines consist of both commercially and non-commercially developed systems including Virtual Battlespace 2 (VBS2), Delta3D, CryEngine, and Unity3D. This diversity indicates there is no single engine that best fulfills the vast array of training requirements for the warfighter. As these requirements increase in complexity, combining multiple game engines becomes necessary to incorporate the best features of each to meet these requirements.

LVC training systems integrate physical (live) trainees, (virtual) trainees controlling avatars, and artificially intelligent (constructive) avatars for interaction within one coherent environment. Often LVC training systems incorporate game engines for management and manipulation of the virtual aspects of that environment. Successfully combining multiple game engines into a single architecture would enable a training environment with the individual strengths of each engine. In addition, this system becomes an evolving platform that can be easily integrated with other simulations and upgraded as graphics, game engine, and simulation technology advance. Despite the advantages of multiple game engine systems, little published work exists on the development and implementation of such systems.

Mixed Reality Training Environments

Mixed reality environments for LVC training offer physical interaction while maintaining many advantages of serious games. These systems typically use a single game engine, but integrate additional components such as tracking systems, haptic devices, and mobile devices into the training experience. While multiple game engine systems are rare, a number of successful mixed reality LVC training environments for the dismounted warfighter have been developed.

FlatWorld[8] is an example of a small, room-sized mixed reality environment, which uses rear screen projectors, sound, and props within a room to immerse the trainee. The main limitations with this small area environment are the restriction of physical movement, lack of adequate space for squad-based scenarios, limited virtual trainee interaction, and inability to quickly customize the environment for different training scenarios.

The Infantry Immersion Trainer (IIT) at Camp Pendleton is an example of a large environment for squad-based immersive training. The 32,000 sq.ft. IIT contains a layout of rooms and alleys populated with both live and constructive opposing forces and civilians. The IIT overcomes the space and squad limitations of the small training environment, however the live-constructive interaction is restricted without real-time tracking technology throughout the entire space. Indicative of the challenges when creating a LVC mixed reality training system, both FlatWorld and IIT still provide limited or absent ability for interaction between some LVC entities (i.e. physical-virtual, constructive-virtual, etc.).

Distributed Simulation Systems

Distributed simulation systems (DSS) attempt to combine multiple game engine systems and mixed reality environments. Distributed simulation systems have been developed for combining virtual agents, such as semi-automated forces (SAF), with a game engine[9] and live tracked objects[10].

Another DSS proposed for integration of many gaming and simulation components[11] identified challenges when integrating heterogeneous software components. The architecture is a conceptually viable solution for mixed reality environments, but has not yet been implemented. Also, the proposed system is limited in applicability to an LVC system as it describes a purely virtual training system.

While DSS offers promise over multiple game engine systems or mixed reality environments alone, challenges remain. For example, communication is often one-way between system components, limiting true entity interaction among those components.

The Veldt Environment

The training environments surveyed provide many unique capabilities, but none meet all of the requirements necessary for an adaptive, customizable LVC training system incorporating multiple game engines, stereo vision, and virtual and live tracked entities. In addition to these requirements, all the varying data feeds must be processed and transmitted quickly enough to enable real-time updates of the entire distributed system.

Figure 1: Veldt Mixed Reality Environment

To provide a test bed for such a system, the Veldt was developed at Iowa State University (ISU) as a flexible mixed reality LVC training environment for the dismounted warfighter. This system combines the advantages of a physical environment where trainees can train through physical navigation and natural reaction with the flexibility of virtual training through integrated displays within a physical scene as shown in Figure 1.

In the physical space, replica weapons, helmets, and vests along with a reconfigurable set of walls outfitted with façades immerse the trainees in the mixed reality environment. Trainees, weapons, and props are tracked in real time by a uniquely configured infrared tracking system capable of millimeter precision. Trigger pulls from weapons are recorded via radio frequency (RF) through custom electronics. Real ballistics are not fired, but trajectories are calculated geometrically based on the position of the weapon at time of trigger pull to enable virtual ballistics to be displayed on the integrated displays as well as other networked game engines.

The physical set was constructed to be modular through “L”-shaped wall segments. These segments feature interchangeable texture facades (e.g., brick, stone, and plaster) to allow quick customization for different training scenarios. For example, the Veldt can be reconfigured from a checkpoint scenario in an open street with industrial style buildings to a close quarters tactical raid scenario in a residential marketplace in less than 30 minutes.

For the reconfigurability of the virtual components of this mixed reality environment, multiple stereoscopic displays are utilized throughout the Veldt. These integrated displays range in size and projection technology to fit in windows, alleys, doorways, roads, and rooms. This allows views to extend far beyond the physical limitations of the room in which the Veldt is housed. In addition, this configuration allows multiple virtual and constructive entities to interact with live participants in various training scenarios.

LVC Mixed Reality Interaction

DeltaJug

Live trainee interaction occurs through multiple distributed displays and simulated weapon fire within the Veldt. While screen modularity allows quick reconfiguration between various scenarios, such as a checkpoint or network of rooms, it also required the development of a clusterizable game engine DeltaJug for synchronized stereo visualizations of the virtual world on multiple displays.

The implementation of multiple displays within a training environment is necessary to increase environment flexibility and blend both virtual and real worlds seamlessly. This provides enhanced immersion over “shooting gallery” type single display systems. Multiple display systems also place unique restrictions upon the game engine driving the system. For a synchronous scene among the displays, each display must render the exact same frame at the exact same moment, albeit through a different view frustum. Swap locking of slave nodes by a master node is controlled through transmission control protocol (TCP) communication, which virtually eliminates latency between each display. This clustered graphics approach is critical to allowing the scene to be continuous on the various disjointed display surfaces, but adds additional network complexity. Most commercial and open source game engines do not allow scalability for clustered graphics beyond a few nodes of a computer system. Thus, one had to be designed for the many nodes required, sometimes as many as 96.

The open source game engine Delta3D[12] provided a platform for military training[13,14] with low-level source code access that could be altered to provide the clustered graphics capabilities required. Delta3D was combined with VR Juggler, a networking and hardware abstraction API commonly used for clustered graphics application development. This clusterizable game engine was termed DeltaJug[15].

As an open source game engine based upon a virtual reality framework, DeltaJug can readily integrate multiple tracking systems and hardware components associated with the physical environment. These components are added to a DeltaJug application through XML-based configuration files, thereby eliminating specific code changes when switching hardware systems. This allows the same application code to be used on a single wall monoscopic system with sonic tracking and a multisided, stereoscopic, immersive virtual reality system with optical tracking with only a change in configuration file.

In the Veldt, DeltaJug receives all information about physical trainees and objects from the tracking system and RF signals from weapon trigger electronics; therefore it is responsible for the creation and management of all live entities in the virtual world. DeltaJug creates virtual representations of these live entities on initialization and updates them each frame with information supplied from the tracking system and weapon triggers. DeltaJug applies these entity updates across the graphics node cluster running the various displays in the Veldt for synchronous entity updates every frame.

Virtual Battlespace 2

DeltaJug solved a major implementation issue of synchronization, however it does not contain an extensive model library, allow quick and easy scenario authoring, or contain a polished after action review tool. Therefore, a commercial game engine common to U.S. military training, Virtual Battlespace 2 (VBS2)[4,16], was utilized to employ these features. While VBS2 was determined most appropriate for the Veldt implementation, other common game engines such as Unity3D or CryEngine could have been implemented with similarly ease.

VBS2's scenario authoring ability enables trainers to easily create scenarios and assign behaviors for virtual and constructive entities. Trainees can virtually interact with the system through VBS2's FPS style interface, Figure 2, and multiple virtual trainees can interact from multiple instances of the game engine through VBS2's networked mission capability. Trainers can additionally participate in the scenario as observers and record the mission along with virtual and live entity performance metrics for AAR.

C6 Collaboration

Interservice capability is offered within the C6, a high-resolution six sided cave automatic virtual environment (CAVE), running Battlespace[17,18], a command and control application for semi-autonomous unmanned aerial vehicles (UAVs). The Battlespace application was developed at Iowa State University using OpenSceneGraph to enable one operator to control a large area through simultaneous control of multiple UAVs through semi-autonomous path planning. In addition to UAV planning, Battlespace provides a commander perspective of the entire ground scenario, shown in Figure 3.

Figure 2: VBS2 FPS interface

Figure 3: C6 Battlespace application in command and control exercise

Architecture

This modular design localizes control of entity virtual representation to their respective applications. For synchronizing virtual worlds between distributed systems, a central communication server was created to disperse state updates to all applications connected to the distributed system.

Central Communication Server

To create a true DSS between the Veldt and multiple game engines, a central communication server was designed to connect all system components using various communication protocols. The server accepts communication from all components in the system and converts their data from the sending component's protocol into a world state within the communication server. After conversion, the communication server identifies which components have requested particular information and the data is converted from the world state into a receiving component's local protocol for transmission. The communication server was designed to accommodate any communication protocol from many components and to distribute data as quickly as possible to minimize latency. This process is similar for all components connected to the communication server and this architecture can be extended to include live vehicles and mobile devices as well as other game engines and simulations.

With all communication between major components managed by a central communication server, shown in Figure 4, the addition of game engines or simulators need to communicate only with this server, not all other components. Additional components require registration and possibly a new method convertor in the communication server. As a result, this central communication server reduces integration of components for a DSS, multiple game engine, and mixed reality LVC training environment.

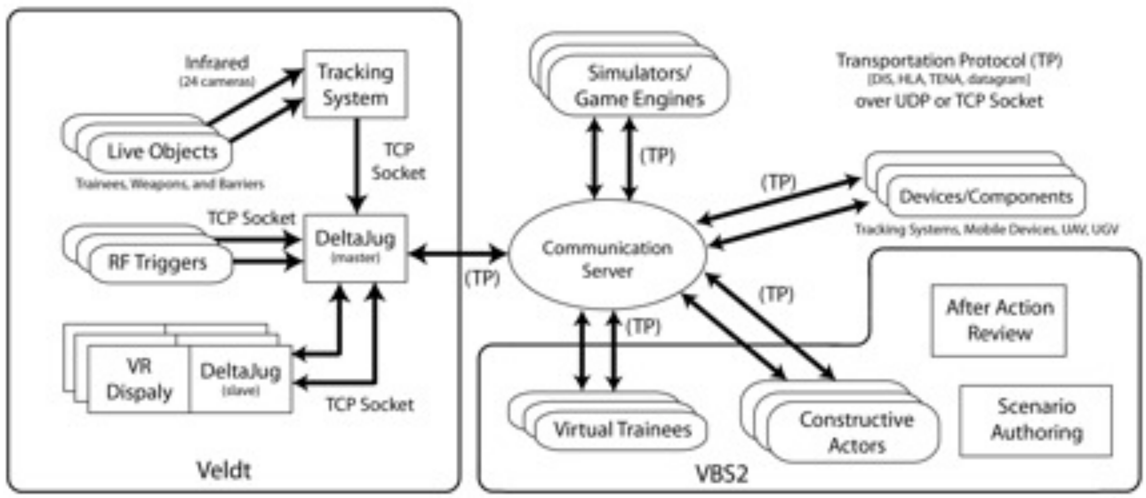

Figure 4. Multiple game engine architecture implemented within Veldt training environment

Challenges

Numerous challenges were overcome throughout the creation of this flexible LVC training system. The primary challenges of a multiple game engine system involve scene synchronization, terrain generation, and real-time tracking in a reconfigurable environment.

Distributed Simulation Issues

LVC training systems contain similar issues as other distributed software architectures. Regardless of system specifics, these systems are known to have network latency, hardware architecture differences, software system delays, and other potential challenges. Previous research has also identified protocol communication, such as DIS, between simulations to have high network bandwidth costs[19], however technical advancements since have largely overcome these challenges.

Network latency between simulations can result in different states among components. For example, high network latency would cause VBS2 controlled actors represented within DeltaJug to not properly synchronize across the system, affecting training. Computational methods exist for correcting for this unavoidable latency[20], however the best approach is to minimize this issue locally through system design.

To test system latency, many components spread between two buildings were connected in an interservice LVC exercise at Iowa State University. This exercise involved one master and two slave DeltaJug nodes, the Veldt tracking system, and two VBS2 instances in the Veldt and command and control room, Battlespace in the C6, and an additional tracking system external to the Veldt and C6. Both Veldt and UAV simulator computer clusters' nodes were synchronized through the same swap locking mechanism present within VRJuggler. Network speed, software delays, and hardware differences were not identified as an issue for latency. This exercise occurred in real-time with multiple entity updates a second for all components, and all component information transported through the communication server.

Scene Synchronization

Scene synchronization of both game engines and the physical environment is necessary for a cohesive view of the scenario regardless of live or virtual interaction. The first challenge for scene synchronization is coordinate conversion among various components. Each tracking system, game engine, and simulation could potentially have its own unique origin and coordinate system. The conversion of entity information for each component is vital to proper representation of entities within game engines. Scene synchronization also involves model database consistency across each game engine for collaboration between the trainees of those engines. When two game engines are visualizing a vehicle entity, it cannot resemble a white pickup truck in one game engine and a red dump truck in another game engine for proper communication between live and virtual trainees or AAR. This mismatch of models associated with an entity is often a result of improper communication configuration and model database inconsistencies between engines.

Many commercial game engines contain extensive model databases, but these are typically proprietary. Model databases available for open source game engines are more limited. For a multiple game engine system, a consistent model database must be configured for the entire system. This model database can be created or purchased if the model database is flexible enough to export to a variety of proprietary and open source formats from source, but this exportation approach has several drawbacks. The entire model database must be exported for each game engine added to the system utilizing an alternative model format and it is not guaranteed models can be exported proprietary formats, as may be required by some commercial game engines. An exportation approach assures identical models across the system, but incurs large costs in time, resources, and flexibility.

An alternate model-matching approach, implemented in the Veldt system, required less time and resources, utilizing the local model databases within open source and commercial engines. For this approach, a set of common model entities among the databases was identified. For example, a civilian pickup truck, an insurgent armed with an AK-74, and a desert HMMWV. Although the models might vary in appearance amongst the different engines, their native configuration makes entity creation and control much easier within those engines. Minimal visual differences were found to exist between local model databases because often models were created to represent the same physical object. Supplemental configuration of entity type identifiers may also be necessary within each game engine. Addition of an alternative game engine would only require configuration of protocol identifier information within either the communication server or within the added game engine to match the model database structure.

This model-matching approach provides a consistent database among components using existing models within each local database and can quickly add new components to the system through minimal configuration for each new database. Model-matching can result in a less extensive and non-exact database compared to the model exportation approach, however matching is more flexible when adding components. Model-matching also requires less time and expense than a model exploration solution, which requires exportation of the model database in each game engine’s format.

Real-Time Tracking of a Reconfigurable Environment

Another difficult challenge involved the tracking of physical objects and entities within the Veldt for representation in virtual environments. Many optical and infrared tracking systems are designed to track in an open environment. However, the Veldt or any other physical immersive environment contains many obstructions to line of sight tracking cameras such as barriers, doors, walls, and people. Initial attempts at designing a tracking system to account for these additional challenges were to involve 24 cameras for tracking in the Veldt space, more than typically used in an open environment, with specific positions and orientations. For example, to track a soldier crouched in a narrow hallway, at least three cameras needed line-of-sight to tracking markers on the soldier. To define the positioning of the cameras, a number of Veldt wall configurations were drafted and tracking areas of high importance were identified for each scenario. Lastly, it was understood that some tracking cameras might need relocation for some configurations. With the inclusion of more cameras this relocation could be eliminated, however with additional cost.

Evaluation

The Research Institute for Studies in Education (RISE) at ISU performed an initial evaluation of this system. In this evaluation twelve participants from the ISU Reserve Officer Training Corps (ROTC) took part in a single training scenario within the Veldt. These participants took part in a room-clearing scenario in teams of two involving live, virtual, and constructive opposing forces.

First a team was oriented to the environment. Teams put on their helmets and practiced firing their replica weapons. Next, the team was given a briefing of the scenario identifying what forces were believed to be located within the Veldt environment (e.g. number of live and virtual warfighters and insurgents). After orientation and briefing, each team took part in the simulation, completing the exercise twice.

Immediately upon completion of both runs of the scenario, each team was taken to a separate room for evaluation by RISE staff. Participants completed a web-based survey individually and teammates were verbally asked questions by RISE staff on their experiences within the Veldt. In addition, video recording and after action review provided location, orientation, weapon use, and accuracy information for each participant. The survey drew heavily from the Presence Questionnaire developed by Witmer and Singer[21]. Theory for development of the survey followed work on the factor structure of the presence questionnaire[22].

Web Survey Results

The web survey yielded three main findings: the Veldt is an effective system for training, the mixed reality environment was visually immersive and engaging, and sound is essential to improve immersion.

When asked how their ability to meet training objectives had changed based on their Veldt experience, 84% of participants reported *Moderate* or *Vast improvement* in their ability to engage enemy combatants. 75% reported *Moderate* or *Vast improvement* in their ability to make quick decisions in a stressful environment. Teams also demonstrated a noticeable increase in completion speed of the scenario their second time.

All participants (100%) agreed (indicated either *Agree somewhat* or *Agree completely*) that the visual aspects of the Veldt environment involved them. While 83% agreed that their senses were completely engaged, 84% agreed that they felt involved in the virtual environment and 67% agreed that their interactions in the Veldt environment seemed natural or true to life.

Finally, participants reported that absence of sound appeared to diminish immersion with most participants (67%) rated the ability to locate enemy fire by sound as *Poor* or *Very Poor*. However, most participants (58%) could locate the source of enemy fire visually with responses of *Good* or *Very Good*.

Team Interview Responses

Interviews with the teams by RISE staff provided responses indicating participants felt that engaging in these activities prior to entering combat situations would increase their understanding of decision-making, especially as it pertained to engaging with noncombatants. One participant remarked, tracking provides useful information in terms of a trainee's accuracy in shooting and can determine if they follow procedures. This reinforces the advantages of real-time tracking that offers trainers more data and trainees another level of feedback.

In congruence with survey responses, participants provided several suggestions on ways to improve the Veldt environment including adding more "friction" or gunfire, obstacles, ambient noise, and ambiguous directions. While participants were generally positive on the visual immersion of the Veldt environment they indicated they would welcome greater physical details such as flooring, ceilings, furniture, and holes in walls to enhance the realism of the environment.

Discussion

The developed mixed reality LVC training system provided an immersive, flexible environment more engaging then computer based training with less cost than live training exercises. This system included live entity tracking, multiple game engines, virtual & constructive entities, replica weapons & apparel and high-end graphic simulations. This framework utilizes the best features of multiple game engines, creating a system that can evolve with technological advances, and lessens the integration challenges of interservice LVC training. The Veldt was the first test bed of such a system that met all of the requirements necessary for a multiple game engine, mixed reality, DSS LVC training system for the dismounted warfighter.

Throughout development, precise tracking of people and weapons within a complex obstructed environment remains difficult for tracking technology. Despite this challenge, visualization of tracked entities within two training scenarios and one interservice exercise occurred in real-time across all game engines with accurate location, orientation, and posture. Future work involving advanced tracking of entities through motion capture for skeletal models of live entities would improve the virtual realism of these entities. Further work could also examine to what extent this information could be provided to commercial game engines through network communication without source modification.

Each graphics display viewpoint in the Veldt is statically determined according to scenario layout[23]. Tracking system data provides adequate information to render views from participants' head locations however both software and hardware solutions for multiple head tracking would reduce immersion within the mixed reality environment and are often not easily scalable. Future work will investigate the perception issues driving head tracking solutions in order to implement a multiple head tracking solution.

All study participants found the Veldt visually engaging, 83% felt their senses were completely engaged and a majority felt their interaction as true to life. While these study results are encouraging, improved tracking, implementation of spatial sound and integration of tactile feedback will be investigated to enhance immersion and interaction. For example, future work on tactile feedback could provide physical indication of injury and potentially act as a nonverbal intelligent tutoring indicator.

Technological improvements to game engines for clusterizable situations and openness of commercial code for simulation will improve the LVC training situation. However, a uniform game engine across the military training and simulation field is not foreseen in the near future. As training environments become more complex and distributed, connecting the various hardware and software components will become more difficult. Continued trends of standalone solutions will further fragment these complex training systems when integration is necessary for interservice LVC training. This research offers a solution to this problem by providing a framework to integrate just about any live, virtual, or constructive training system.

The created multiple game engine, mixed reality, DSS LVC training system eliminates standalone dependency on specific components such as game engines and tracking systems. Without this dependency, training systems can combine the benefits of different technologies for a superior system customizable to a system’s training requirements. This research has proven the ability of such mixed reality LVC training systems to offer effective training, immersive interaction and scenario flexibility. Additionally, the challenges and areas for improvement identified in the Veldt will help guide future attempts to create low cost, mixed reality, LVC training solutions for the dismounted warfighter.

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CHAPTER 4. RESULTS

The physical-virtual correlation of the Veldt training system was primarily evaluated using the Research Institute for Studies in Education (RISE) [58] Veldt evaluation took place over the course of two days starting September 30, 2010. In this study, twelve participants from the Iowa State University (ISU) Reserve Officer Training Corps (ROTC) completed the *Clear a Room* scenario twice, responded to a web-based questionnaire, and were afterward interviewed by RISE staff. From these and other data collected throughout the exercise it was possible to provide insight on participants' sense of presence and the effectiveness of system for training. High ratings on these criteria would indicate a near seamless live-virtual interaction and therefore a highly correlated physical and virtual worlds.

The effectiveness of the protocol independent network architecture was evaluated through an interservice bomb defusal scenario demonstration involving three physical locations, two protocol types, two virtual environments and multiple live, virtual and constructive entities. This demonstration also provided further evaluation of the physical-virtual correlation of the system and any latency within the communication server network architecture when involving multiple protocols.

IOWA STATE UNIVERSITY VELDT PROJECT EVALUATION STUDY

Study Design

Three key research questions guided the RISE team when crafting their evaluation study:

1. How effective are LVC training technologies?
2. How can this technology usage be improved?
3. How can individual or squad performance be matched to learning objectives and skill outcomes for assessment?

The design of the RISE evaluation was influenced by several studies conducted by the United States Army Research Institute for Behavioral and Social Sciences on various simulation training systems [59][60][61][62][63]. Several findings and recommendations from these studies utilized for the Veldt evaluation were:

- Virtual exercises should last ~16 minutes
- A web-based questionnaire is successful in soliciting input from a large amount of participants
- Realistic representation of terrain with different weather conditions and dynamic terrain is ideal
- Locomotion devices can provide realistic perception of movement
- Realistic weapons should be utilized
- Virtual and/or constructive BLUEFOR, OPFOR and NEUTRAL forces should be incorporated
- Warfighter movements should be portrayed accurately
- Systems should provide adequate feedback

While the evaluation was originally designed for 100 or more participants, various technical and logistic difficulties required this study to represent an initial small-scale evaluation with a larger, followup evaluation in the future. As a result twelve participants from the ISU ROTC were selected to take part. Of the twelve participants, all had received some level of military training and two had previous combat experience. Participants were grouped into six unique teams of two with all teams completing the evaluations within two days, starting September 30, 2010.

At the start of the evaluation, each participant pair was first oriented to the Veldt environment by allowing them to put on their helmets and practice firing their weapons on a virtual range within the Veldt. Next each pair was shown a presentation providing details of the scenario and the number of virtual and real opposing forces. Finally, the participants took part in the *Clear A Room* scenario twice, with a short break between exercises. The evaluation scenario was similar to the *Clear A Room* scenario previously presented in Chapter 2, however the two constructive opposing forces and their respective displays were not included.

Immediately upon completing both scenarios, the participants were taken to a separate room external to the Veldt supervised by the RISE staff. Within the supervised environment, participants were instructed to complete a 10-15 minute web-based survey administered on a laptop computer about their experiences within the Veldt. After completing this survey, participant groups were interviewed by RISE staff about their experiences within the Veldt. In addition to study and interview data, after action review (AAR) and video were recorded containing weapon and participant location, orientation, posture, and weapon accuracy. Web-based survey questions and results can be found in Appendix A, interview questions and responses can be found in Appendix B.

Survey Design

The survey developed by RISE staff was developed after a comprehensive review of literature on serious games, decision-making skill assessments, situational awareness, and presence in virtual settings [64][65][66][67]. Specifically, the web-based survey draws heavily from the Presence Questionnaire developed by Witmer and Singer [66]. As a result, the Veldt evaluation's web-based survey asks similar questions in different ways when investigating what elements of the Veldt system require further improvement, participant presence, and gauging the effectiveness of the system in improving combat skills.

To correctly measure participants' presence, the factor structure theory of the presence questionnaire by Witmer, Jerome & Singer [67] was used. From this questionnaire the factors in Table 1 were identified:

Table 1. Factor structures from Presence questionnaire by Witmer, Jerome & Singer

Factor	Definition
Involvement	Focusing one's mind and attention on an activity or task.
Immersion	Involvement in one's environment.
Sensory Fidelity	Amount auditory and sight contribute to experience.
Interface Quality	Ease of interaction within physical environment.

Witmer, Jerome & Singer also found involvement of these four factors was the most dominant when using a presence-based questionnaire.

Results

From the survey data, several themes were found addressing immersion, interaction and involvement. On the visual aspects of the physical Veldt, all participants rated the ability to identify opposing forces, maneuver around object and corners, move quickly to the point of attack, engage targets, coordinate with teammates, determine teammate position and execute a planned assault as *Good* or *Very Good*. High ratings involving coordination, maneuverability and visual identification within the Veldt's physical environment indicate it adequately meets the needs of the warfighter as a training system. Moreover, these results suggest the reconfigurability of the physical Veldt did not decrease the effectiveness of the space.

On the ability to locate the source of opposing forces' fire using visual and auditory cues, a majority of participants reported on their ability to visually locate the source of enemy fire as *Good* or *Very Good* (58%). However, a majority of participants (67%) also responded on their ability to locate source of enemy fire by sound as *Poor* or *Very Poor*. From this data, it was apparent that more immersive sound is needed within the Veldt. At the time of this study, two speakers behind one of the displays was the only source of sound within the Veldt and gunfire the only sound producing element. Since that time, an eight channel audio system has been installed in the corners of the Veldt. Future work on improving sound will be discussed in Chapter 5.

On the ability to accurately aim and fire their weapon, the survey found that 75% of the participants responded on their ability to aim their weapon as *Good* or *Very Good* and 75% of participants responded on their ability to fire their weapon accurately as *Very Poor*. This lowly rated ability of participants to fire their weapon likely contributed to the *No Improvement* response regarding marksmanship as reported by 67% of participants.

Technical tracking system issues, largely due to the occluded nature of the *Clear A Room* scenario, were the primary cause for these issues regarding participants' ability to accurately fire their weapons. Communication with the vender, Motion Analysis, on this issue with the tracking system found that tracking systems cameras were also installed and configured in such a way that the distance of some tracking markers to the cameras exceeded camera specifications. Specifically, this was a problem with cameras configured to point at at high interest trackable locations, locations were engagement might occur. Since the time of the survey, the Veldt research team has thusly lowered the cameras to bring markers within camera specifications and fine-tuned the calibration to provide higher fidelity tracking.

On the ability of participants to engage opposing forces, all participants responded with *Good* or *Very Good* on their ability to identify and engage the enemy. Participant majorities responded *Very Good* on their ability to identify (92%) and engage (59%) opposing forces. This data affirms that in spite of technical issues with tracking affecting weapon accuracy, the Veldt employs appropriate interaction between live and virtual entities. This interaction relies heavily on the technical ability to correlate both physical and virtual environments, therefore indicating the Veldt system has successfully overcome this issue.

On participants' ability to meet training objectives due to their experience in the Veldt, a large majority (84%) reported *Moderate* or *Vast Improvement*. Similarly, 75% reported *Moderate* or *Vast Improvement* on their ability to make quick decisions in a stressful environment and 67% of participants reported *Moderate Improvement* on their ability to identify and evaluation challenges in complex situations. These data indicate a DSS LVC training system, such as the Veldt, can provide real-life training benefit for the dismounted warfighter.

On the involvement of the experience, participants all agree, either *Agree Somewhat* or *Agree Completely*, that the visual aspects of the Veldt environment involved them. Despite issues mentioned previously with sound, 83% of participants agreed their senses were completely engaged, 84% of participants agreed they felt involved in the virtual environment and 67% of participants agreed their interactions seemed natural or true to life.

These survey data suggest the Veldt is an truly immersive system that can compare to experiences within pure physical training systems such as MOUT.

In interviews conducted with the participants by RISE staff, participants provided their perceptions of the benefits of the Veldt system and also proposed suggestions for improvement. From these interviews, participants reaffirmed some of the conclusions drawn from the survey data on the usefulness of DSS LVC training systems, such as the Veldt, for training:

- Participants commented that LVC training technologies can be effective for decision-making, rules of engagement and shoot-don't-shoot situations.
- A number of participants mentioned the reconfigurability of the Veldt would make it easier to train in multiple types of scenarios, despite not directly demonstrating this capability.
- Participants felt training in these types of LVC systems prior to combat would improve their decision-making ability, especially when non-combatants are present.
- Participants reported one particularly effective use of LVC training was the ability to track and record trainee movements for feedback.

Trainees also addressed areas of improvement for the Veldt system. Several suggestions for improving sound within the system involved adding more "friction" sounds, such as gunfire and ambient noise. Physical suggestions for the Veldt involved adding obstacles and furniture, changing flooring and/or ceiling texture, and modifying walls with holes to make the environment more realistic. Other suggestions for improving the Veldt experience involved providing ambiguous directions and technical improvements to tracking and weapon characteristics. These improvements will be addressed in Chapter 5.

Lastly, recorded AAR data provided quantitative data to compare with qualitative survey and interview data sources. Analysis of AAR data provided three key findings: Experience was an important factor in predicting scenario completion time, team completion speed greatly improved after the first exercise, and weapon accuracy was generally poor. The importance of experience was shown when the team with previous combat experience completed the scenario in less time than any other group with far fewer shots fired. In addition, considerable improvement was shown by all teams except for the team with previous combat experience, where all other teams often reduced scenario time by half on their second training run. Lastly, poor accuracy was often a result of technical tracking issues as most shots were fired at close range and would have hit opposing forces.

INTERSERVICE BOMB DEFUSAL SCENARIO DEMONSTRATION

The interservice bomb defusal scenario tested three components of the Veldt system:

- Flexibility of the system to add new simulations and tracking systems
- The protocol independent network architecture
- Latency within the distributed system and network architecture

Aside from the Veldt system, a high resolution, six sided cave automatic virtual environment (CAVE) system known as the C6 was also utilized. The C6 displayed an application in stereo with head tracking and required serialization of that application across its 96 node graphics cluster. Scenario interservice capability was offered through the command and control application for semi-autonomous unmanned aerial vehicles (UAVs) known as Battlespace [68][69]. The Battlespace application was developed at Iowa State University to enable operators to control a large area combat simulation through simultaneous control of multiple UAVs through semi-autonomous path planning. In addition to UAV planning, Battlespace can provide a global commander perspective of the entire ground scenario or the ability to magnify a location within that environment such as the location of the Veldt environment.

The demonstration involved many other components spread between three locations at Iowa State University with three live, four virtual, and eight constructive entities described as:

- Two tracked live soldiers in the Veldt, configured with three deltaJug nodes running various displays
- One tracked live semi-autonomous ground vehicle (packbot) and virtual vehicle operator external to the Veldt, shown in Figure 11.
- One virtual ground commander in VBS2
- One virtual UAV controller in VBS2
- One virtual UAV command and control (C2) officer in a 96 node virtual environment
- Multiple constructive dismounted and ground vehicle entities

Equipment involved in this exercise included: three tracking systems, multiple instances of two game engines, and two clustered virtual environments. Both Veldt and UAV virtual environment computer cluster nodes were synchronized through the same swap locking mechanism present within VRJuggler.

The physical Veldt was configured in the *Checkpoint* scenario with two live trainees reporting to a co-located virtual ground commander within VBS2 and physically present within the Veldt. The Veldt ground commander communicated with the command and control center at the C6 location via Skype. The ranking commander in the scenario was immersed within the C6 Battlespace environment with a VBS2 UAV operator nearby and video feeds from an semi-autonomous ground vehicle displayed on a large screen in the room for viewing. The command and control room, the C6 and the UAV and packbot screens are shown in Figure 12. The physical packbot and its operator were present in a third location with a tracking system to calculate the packbot's location. All virtual and constructive forces in VBS2, live forces within the Veldt, and the semi-autonomous ground vehicle were

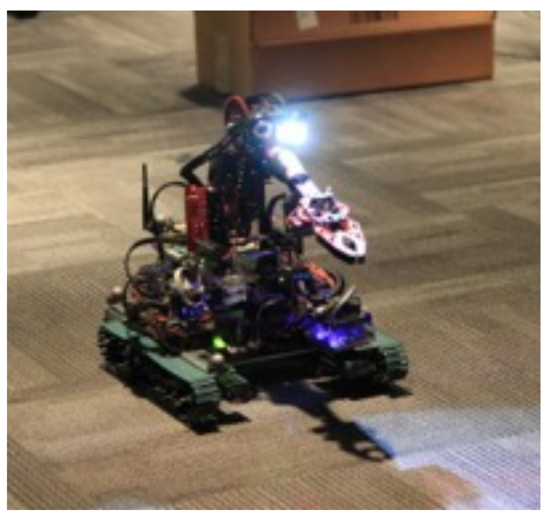

Figure 11. Tracked packbot

visualized with Veldt, VBS2 and C6 displays. VBS2, Battlespace and Veldt components communicated through the communication server using distributed interactive simulation (DIS) protocol while the packbot tracking system information was communicated through a independently defined protocol. All systems used user datagram protocol (UDP) connections due to the high frequency of component updates and to minimize latency.

The scenario began with normal traffic behavior down the road from the Veldt checkpoint, and normal UAV paths, road traffic near the Veldt was visualized on the physical Veldt's displays. After a short amount of time a truck approaches the checkpoint at a high rate of speed and a military-aged male exists the vehicle and disappears behind a parked panel van. To add confusion another military-aged male runs past the checkpoint while the first male remains unseen. Finally, the male behind the van returns to his truck and quickly drives away. The ground commander first requests a UAV to track the fleeing truck from the ranking commander within the C6. The ranking commander observes this situation locally within the C6 and communicates with the VBS2 UAV operator to track the truck. Next, the ground commander requests a packbot to investigate the area behind the van, first instructing this squad to take cover in case of a planted improvised explosive device (IED), shown in Figure 13. The ground commander then communicates with the packbot operator

Figure 12. Ranking commander outside of C6 Battlespace environment within command and control room

to identify the location of interest. Within the third physical location the packbot is physically moving toward an area while its progress is being visualized on the C6 and Veldt displays. Meanwhile the ranking commander checks in with the VBS2 UAV operator on the location of the vehicle that fled the checkpoint. The ground commander is alerted by the packbot operator that an IED is present and then informs his squad to prepare for potential explosion. The scenario ends when the packbot operator informs all commanders the IED was disarmed. A complete script for the scenario can be found in Appendix C.

Throughout this 10-15 minute scenario, network speed, software delays, and hardware differences were not identified as an issue for latency. This exercise occurred in real-time on a high-speed internal network with multiple entity updates a second for all components, and all component information transported through the communication server. While this qualitative assessment of latency provided a great initial evaluation of latency within the communication server architecture, a detailed quantitative should be completed in future work. This demonstration further emphasizes the abilities of the Veldt system to successfully correlate physical and virtual worlds for a flexible environment that can accommodate new components quickly and throughout multiple scenarios of a

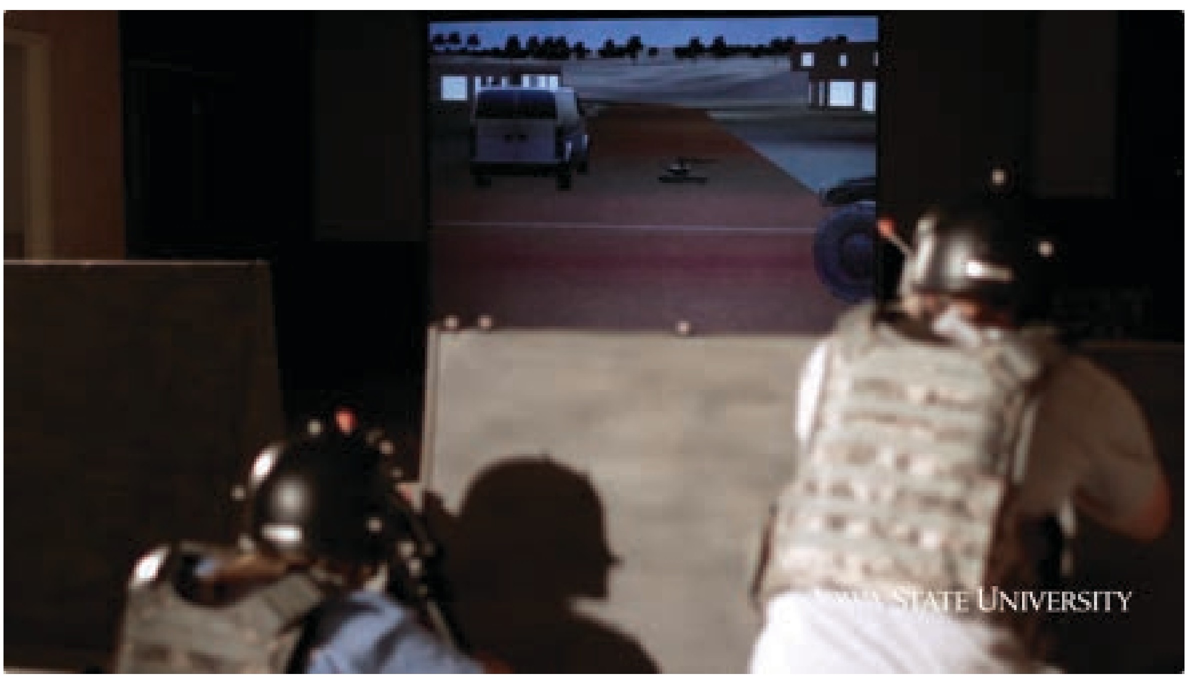

Figure 13. Live Veldt BLUEFOR taking cover while packbot investigates IED

reconfigurable system. The exercise also demonstrated the ability of the network architecture to connect live, virtual and constructive entities across a distributed system involving multiple protocols in real-time with negligible latency.

The scenario for the interservice exercise was designed by David Prater and implemented by David Prater and Brice Pollock. Packbot tracking and video feed software was developed by Ken Kopecky and the packbot tracking system was connected to the Veldt communication server by Brice Pollock. Battlespace development for configuration and integration with the Veldt system was accomplished by Brice Pollock. Lastly, other Battlespace development was completed by Joe Holub and a team of developers at the Virtual Reality Application Center.

CHAPTER 5. CONCLUSIONS & FUTURE WORK

In summary, the questions addressed by this research were how to correlate virtual and physical worlds for joint scenario flexibility and reconfigurability and whether it was feasible to connect LVC entities across a DSS involving multiple protocols. Solving these challenges would make the mixed reality Veldt environment the first large reconfigurable LVC DSS for the dismounted warfighter and impart the ability to flexibly accommodate new simulations, game engines, and other components regardless of communication protocol.

Protocol Independent Network Architecture for DSS

Systems typically utilize one-way gateways between connected components that institute differing communication protocols. However, appropriate LVC interaction across distributed components requires two-way communication for a realistic and immersive experience. Additionally, this two-way communication architecture should be easily extended to include other protocols and components due to the game engine, simulator, and protocol diversity in the military simulation industry. A central communication structure architecture was designed by Christian Noon and implemented by Brice Pollock within the Veldt which received information from one source in its native protocol, converted it to a world state, and then for all interested components, converts the world state into a component’s native protocol and sends the information. This concept was initially proven by positive participant feedback from the RISE evaluation. which indicated this architecture succeeded for standard DIS protocol communication between two systems with a limited number of entities as no issues with entity networking to lead to reduced experience for trainees. The architecture was more appropriately evaluated throughout an interservice bomb defusal scenario demonstration involving three live, four virtual and eight constructive entities from three physical locations utilizing two different protocols for communication. The demonstration was executed in real-time and latency was found to be negligible for all LVC entities and components. This proved the central communication server implementation as an affective architecture for connecting LVC entities across a DSS involving multiple protocols.

Physical-Virtual Correlation with Joint Flexibility and Reconfigurability

The correlation of physical and virtual worlds was achieved through a combination of network design, configuration, and workflow pipelines. A central communication server provided the network architecture for components to flexibly add components to the systems and transporting position, orientation, fire and other information quickly between components. This network architecture therefore enabled component-based interaction as if all entities were native.

A key challenge to physical-virtual correlation is the separate and sometimes proprietary model databases for the connected game engines and simulations. This situation impedes effective collaboration and synchronous interaction in scenarios regardless of interaction, as models must be visually indistinguishable between components. As a solution, a central database could be created from which models are generated in each component's format, however this approach is costly in flexibility, time, and resources. A model-matching approach was thusly employed within the Veldt system by Brice Pollock, utilizing local databased within these components for a constrained set of model entities. Model-matching produces less extensive, non-identical databases when compared with a generation approach. However, model differences between databases are often negligible and model-matching requires less time and resources and is more easily scalable when adding components.

The large terrains often utilized in LVC training systems can range from a few blocks to several square miles, however they also require high detail from the dismounted warfighter perspective to be used effectively within immersive environments. Moreover, geo-specific terrains are typically gathered external to simulation systems, often do not provide adequate detail, and require generation for both open and proprietary formats. Differences between terrain formats generated by the same source often occur when using separate generation tools. These terrain differences between connected components can cause issues with collaboration and fair fight, creating a non-beneficial and unrealistic training environment. Therefore, a single generation workflow must be constructed for highly detailed and identical terrains across multiple game engines and simulations. For the Veldt, a repeatable procedural terrain modeling framework was implemented by Travis Engelhaupt and Brice Pollock to rapidly generate large terrains in open and proprietary formats while maintaining warfighter level detail.

Data from an evaluation conducted by RISE staff involving the *Clear A Room* scenario reported participant high ratings of the Veldt's involvement, interaction, and immersion. Alternatively, a complex scenario involving diverse game engines and simulations for the *Checkpoint* demonstrated the ability of participants to effectively collaborate from distributed and different components. These results indicate successful implementation of physical-virtual correlation within a flexible and reconfigurable system across diverse user interfaces and scenarios.

With both these correlation and communication issues addressed, the Veldt presents an example of the low cost, efficient and flexible LVC systems for the dismounted warfighter. The U.S. military needs such a system to replace the current standalone trainers which produce large expenditures in maintenance and quickly become legacy systems in an industry where technological innovation is driven by the commercial industry.

Future Work

The current state of this research has shown successful implementations for physical-virtual correlation and protocol independent communication. However, several challenges remain for the Veldt system to completely operate as an immersive LVC training system. While most of this future work involves the physical Veldt environment and not the system presented within the methodology of this thesis, the environment's deficiencies inhibit the interaction allowed by the system architecture and therefore were included.

From the RISE evaluation of the Veldt in 2010, several technical challenges remain with the physical Veldt. Sound was found to be a key deficiency of the system, detracting from both realism when participants attempted to use auditory cues to locate sources of fire. Since the time of the study large speakers in the corners of the Veldt have been installed, however no such plan of enacting friction or ambient sounds have emerged as of yet. Utilizing the large corner speakers for these ambient sounds in conjunction with spatial or 3D sound within the Veldt would most likely provide the noisy and auditory rich environment expected by trainees.

A detailed quantitative evaluation of latency within the communication server architecture needs to be performed. This evaluation could provide more accurate analysis of how much latency this architecture produces and how it scales with additional components. This evaluation should be conducted with various network speeds, number of components and types of protocols.

Tracking issues greatly affected the ability of participants to fire their weapons throughout the RISE evaluation. While tracking has improved since the time of the study by working with the tracking camera vender Motion Analysis, serious testing has not yet determined whether it has reached the fidelity necessary for accurate and reliable engagement with opposing forces. If upon testing tracking has not reach high enough fidelity additional tracking systems could be employed to improve tracking. In addition, camera configurations could be moved to create scenario specific tracking configurations. However, tracking configurations unique to each scenario would seriously affect reconfigurability of the system by adding additional steps of moving the ceiling cameras and recalibrating. Because this could potentially add hours onto the current thirty minute reconfiguration time, other options should be pursued first.

Veldt display configurations currently utilize static viewports with the center of projection assigned as the average positions of areas where trainees are most likely to view the display. This situation is an inaccurate portrayal of what a trainee should see rendered on these displays. In order to allow live-virtual fair fight, each trainee must see a view individual to their location. Consider looking through a window. As a person changes their position relative to the window they see a new view through that window. For mixed reality training in the Veldt, displays should also be treated as windows into the virtual world in order for live trainees to manipulate their physical position to gain a better view of a virtual object around a corner for example. Currently with static viewports, a live trainee could manipulate their position to see an opposing force around a corner, however the display image does not change in response. Meanwhile, a virtual trainee around that corner is now able to see the live trainee's representation in the virtual environment due to this change in position. In this situation, fair-fight and realism is violated as the virtual entity can see a live entity, however a the live entity cannot see the virtual entity. Research is being conducted on how to allow this type of interaction for all squad members for stereo displays. With technical or software solutions alone unable to scale and maintain the immersion of a display, studies are being conducted as to the affects of static viewports when viewed by others at alternative locations.

Finally, for a system such as the Veldt to be integrated within the U.S. Army's training structure, further studies should be conducted to help discover possible limitations. One such study could involve a large population of over 100 trainees in two and four squad groups repeatedly running through differently configured scenarios to provide more accurate data on the time for reconfiguration as well as providing more data as to weaknesses of the system. Another such study could involve region-wide or nationwide components to test system latency and flexibility.

ACKNOWLEDGEMENTS

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Thank you to my major professor Dr. Eliot Winer who saw something in a 19 year-old man that made him think I would be a good fit for his group. Thank you for all of the professional opportunities you have provided over the last three years and supporting me in all my professional pursuits. Thank you to Dr. Stephen Gilbert who was primary investigator for the U.S. Army project and gave me the opportunity to be a part of some really interesting work. Julio de la Cruz and Hector Gonzalez from U.S. Army RDECOM - STTC, thank you for supporting the U.S. Army grant which funded my research.

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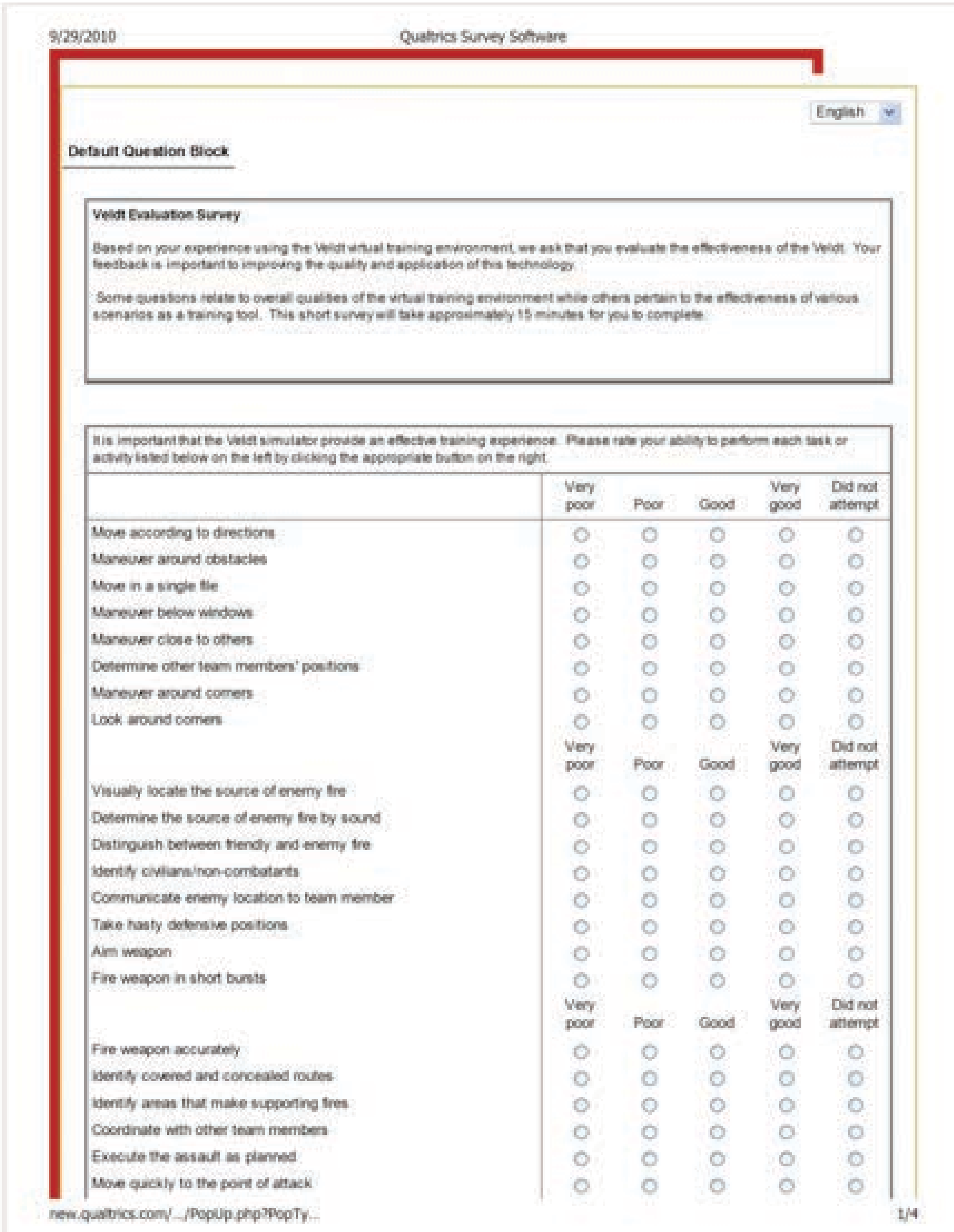
APPENDIX A. RISE VELDT EVALUATION SURVEY & SURVEY RESULTS [58]



9/29/2010 Qualtrics Survey Software

English

Default Question Block

Veldt Evaluation Survey

Based on your experience using the Veldt virtual training environment, we ask that you evaluate the effectiveness of the Veldt. Your feedback is important to improving the quality and application of this technology.

Some questions relate to overall qualities of the virtual training environment while others pertain to the effectiveness of various scenarios as a training tool. This short survey will take approximately 15 minutes for you to complete.

It is important that the Veldt simulator provide an effective training experience. Please rate your ability to perform each task or activity listed below on the left by clicking the appropriate button on the right.

	Very poor	Poor	Good	Very good	Did not attempt
Move according to directions	○	○	○	○	○
Maneuver around obstacles	○	○	○	○	○
Move in a single file	○	○	○	○	○
Maneuver below windows	○	○	○	○	○
Maneuver close to others	○	○	○	○	○
Determine other team members' positions	○	○	○	○	○
Maneuver around corners	○	○	○	○	○
Look around corners	○	○	○	○	○
	Very poor	Poor	Good	Very good	Did not attempt
Visually locate the source of enemy fire	○	○	○	○	○
Determine the source of enemy fire by sound	○	○	○	○	○
Distinguish between friendly and enemy fire	○	○	○	○	○
Identify civilians/non-combatants	○	○	○	○	○
Communicate enemy location to team member	○	○	○	○	○
Take hasty defensive positions	○	○	○	○	○
Aim weapon	○	○	○	○	○
Fire weapon in short bursts	○	○	○	○	○
	Very poor	Poor	Good	Very good	Did not attempt
Fire weapon accurately	○	○	○	○	○
Identify covered and concealed routes	○	○	○	○	○
Identify areas that make supporting fires	○	○	○	○	○
Coordinate with other team members	○	○	○	○	○
Execute the assault as planned	○	○	○	○	○
Move quickly to the point of attack	○	○	○	○	○

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Figure 14. RISE Veldt evaluation survey questions 1/4

9/29/2010 Qualtrics Survey Software

Assume defensive positions	○	○	○	○	○
Identify safe and dangerous areas	○	○	○	○	○
	Very poor	Poor	Good	Very good	Did not attempt
Take position to one side of a doorway	○	○	○	○	○
Move quickly through doorways	○	○	○	○	○
Take a tactical position while within a room	○	○	○	○	○
Scan the room quickly for hostile combatants	○	○	○	○	○
Engage targets within a room	○	○	○	○	○
Identify non-combatants within a room	○	○	○	○	○
Identify non-combatants in scenario	○	○	○	○	○
Move past furniture in a room	○	○	○	○	○
	Very poor	Poor	Good	Very good	Did not attempt
Understand verbal commands	○	○	○	○	○
Move close to walls	○	○	○	○	○
Scan from side to side	○	○	○	○	○
Scan up and down	○	○	○	○	○
Identify enemy combatants	○	○	○	○	○
Estimate distances from self to a distant object	○	○	○	○	○
Locate enemy combatants inside buildings firing at your unit	○	○	○	○	○
Determine direction of enemy rounds	○	○	○	○	○

Consider the three scenarios used for your training in the Veldt. Based on your experience, please click the response that best indicates how your ability to meet the following training objectives has changed.

Scenario: Clear a Room

	No improvement	Slight improvement	Moderate improvement	Vast improvement	Not applicable/Did not attempt
Effectively communicate with other team members	○	○	○	○	○
Make quick decisions in a stressful environment	○	○	○	○	○
Engage enemy combatants	○	○	○	○	○
Distinguish between shoot and don't shoot situations	○	○	○	○	○
Identify challenges in evaluating complex situations quickly	○	○	○	○	○
Improve marksmanship	○	○	○	○	○
Recognize potential life-threatening circumstances (e.g., trip-wires, sniper fire, IEDs)	○	○	○	○	○
Understand rules of engagement (ROE)	○	○	○	○	○

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Figure 15. RISE Veldt evaluation survey questions 2/4

9/29/2010 Qualtrics Survey Software

Use other weapons to engage enemy combatants	○	○	○	○	○

Indicate how much you DISAGREE or AGREE with each of the following statements, based on your use of the Veldt.

	Disagree completely	Disagree somewhat	Agree somewhat	Agree completely	Not applicable
I was able to control events.	○	○	○	○	○
The environment was responsive to actions I performed/initiated.	○	○	○	○	○
My interactions with the environment seemed natural or true to life.	○	○	○	○	○
The visual aspects of the environment involved me.	○	○	○	○	○
The auditory aspect of the environment involved me.	○	○	○	○	○
I was able to actively search the environment using vision.	○	○	○	○	○
	Disagree completely	Disagree somewhat	Agree somewhat	Agree completely	Not applicable
My experience in the virtual environment were consistent with my real world experiences.	○	○	○	○	○
I could identify sounds.	○	○	○	○	○
I could localize sounds, or tell where sounds were coming from.	○	○	○	○	○
The visual display quality distracted me from performing my assigned tasks.	○	○	○	○	○
I could actively search the environment using touch.	○	○	○	○	○
I had a sense of moving around inside the virtual environment.	○	○	○	○	○
	Disagree completely	Disagree somewhat	Agree somewhat	Agree completely	Not applicable
I was able to examine objects from multiple viewpoints.	○	○	○	○	○
I felt involved in the virtual environment.	○	○	○	○	○
I was able to adjust quickly to the virtual environment experience.	○	○	○	○	○
By the end of the experience, I felt proficient in moving around and interacting with the virtual environment.	○	○	○	○	○
The visual display quality interfered with my ability to perform the assigned tasks.	○	○	○	○	○
My senses were completely engaged by this experience.	○	○	○	○	○

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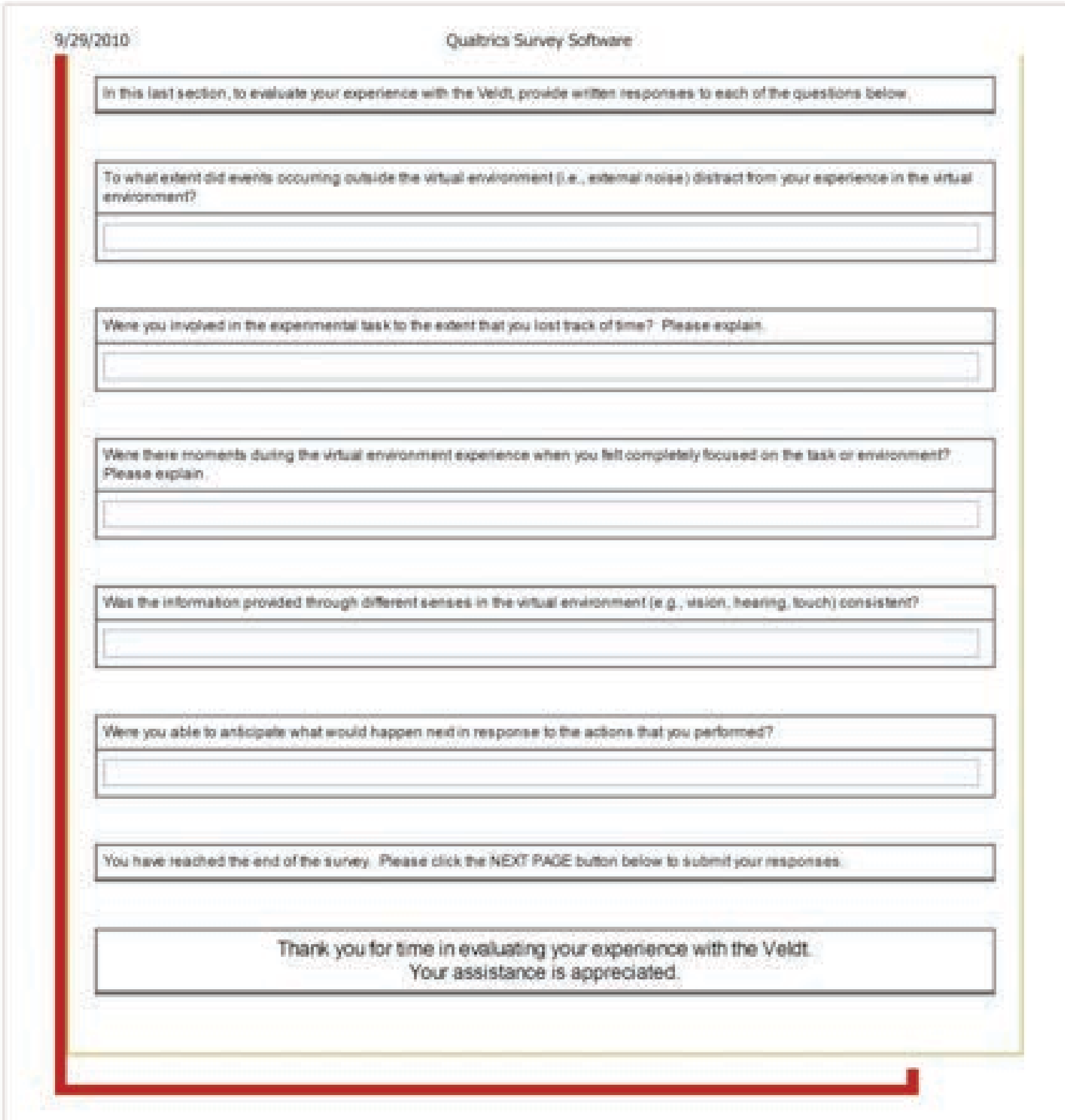
Figure 16. RISE Veldt evaluation survey questions 3/4



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In this last section, to evaluate your experience with the Veldt, provide written responses to each of the questions below.

To what extent did events occuring outside the virtual environment (i.e., external noise) distract from your experience in the virtual environment?

Were you involved in the experimental task to the extent that you lost track of time? Please explain.

Were there moments during the virtual environment experience when you felt completely focused on the task or environment? Please explain.

Was the information provided through different senses in the virtual environment (e.g., vision, hearing, touch) consistent?

Were you able to anticipate what would happen next in response to the actions that you performed?

You have reached the end of the survey. Please click the NEXT PAGE button below to submit your responses.

Thank you for time in evaluating your experience with the Veldt.
Your assistance is appreciated.

Figure 17. RISE Veldt evaluation survey questions 4/4

Table 2. RISE Veldt evaluation survey results 1/8

Item	n	"Not applicable" responses dropped				
		n	Mean	SD	Min	Max
Scan from side to side	12	12	3.92	0.29	3	4
Identify enemy combatants	12	12	3.92	0.29	3	4
Maneuver around obstacles	12	12	3.75	0.45	3	4
Fire weapon in short bursts	12	12	3.75	0.45	3	4
Maneuver around corners	12	12	3.67	0.49	3	4
Look around corners	12	12	3.67	0.49	3	4
Move quickly through doorways	12	12	3.67	0.49	3	4
Take position to one side of a doorway	11	11	3.64	0.50	3	4
Communicate enemy location to team member	12	10	3.60	0.52	3	4
Understand verbal commands	12	10	3.60	0.52	3	4
Move according to directions	12	12	3.58	0.51	3	4
Determine other team members' positions	12	12	3.58	0.51	3	4
Move quickly to the point of attack	12	12	3.58	0.51	3	4
Engage targets within a room	12	12	3.58	0.51	3	4
Move close to walls	12	12	3.58	0.51	3	4
Scan up and down	12	12	3.58	0.67	2	4
Move in a single file	12	11	3.55	0.52	3	4
Scan the room quickly for hostile combatants	12	12	3.50	0.52	3	4
Maneuver close to others	12	12	3.42	0.51	3	4

Table 3. RISE Veldt evaluation survey results 2/8

Item	n	"Not Applicable" responses dropped				
		n	Mean	SD	Min	Max
Coordinate with other team members	12	12	3.42	0.51	3	4
Execute the assault as planned	12	12	3.42	0.51	3	4
Locate enemy combatants inside buildings firing at your unit	12	10	3.40	0.70	2	4
Assume defensive positions	12	8	3.25	0.71	2	4
Take a tactical position while within a room	12	12	3.25	0.75	2	4
Identify non-combatants within a room	12	4	3.25	0.50	3	4
Maneuver below windows	12	9	3.22	0.67	2	4
Take hasty defensive positions	12	9	3.22	0.44	3	4
Aim weapon	12	12	3.17	1.19	1	4
Identify covered and concealed routes	12	7	3.14	0.38	3	4
Identify safe and dangerous areas	12	8	3.13	0.83	2	4
Identify non-combatants in scenario	12	3	3.00	0.00	3	3
Estimate distances from self to a distant object	12	12	3.00	0.74	2	4
Visually locate the source of enemy fire	12	10	2.90	0.74	2	4
Identify areas that make supporting fires	12	10	2.80	0.63	2	4
Distinguish between friendly and enemy fire	12	7	2.14	0.69	1	3
Identify civilians/non-combatants	12	3	2.00	1.00	1	3
Determine direction of enemy rounds	12	8	1.88	0.64	1	3
Determine the source of enemy fire by sound	12	8	1.75	0.46	1	2
Fire weapon accurately	12	12	1.25	0.45	1	2
Move past furniture in a room	12	0	.	.	.	.

Items listed by mean in descending order

Research Institute for Studies in Education (RISE), Iowa State University

Table 4: RISE Veldt evaluation survey results 3/8

Item	Very poor	Poor	Good	Very good	G + VG	Did not attempt	n
Scan from side to side	.	.	8%	92%	100%	.	12
Identify enemy combatants	.	.	8%	92%	100%	.	12
Maneuver around obstacles	.	.	25%	75%	100%	.	12
Fire weapon in short bursts	.	.	25%	75%	100%	.	12
Maneuver around corners	.	.	33%	67%	100%	.	12
Look around corners	.	.	33%	67%	100%	.	12
Move quickly through doorways	.	.	33%	67%	100%	.	12
Take position to one side of a doorway	.	.	36%	64%	100%	.	11
Move according to directions	.	.	42%	58%	100%	.	12
Move quickly to the point of attack	.	.	42%	58%	100%	.	12
Engage targets within a room	.	.	42%	58%	100%	.	12
Move close to walls	.	.	42%	58%	100%	.	12
Scan the room quickly for hostile combatants	.	.	50%	50%	100%	.	12
Maneuver close to others	.	.	58%	42%	100%	.	12
Coordinate with other team members	.	.	58%	42%	100%	.	12
Execute the assault as planned	.	.	58%	42%	100%	.	12
Determine other team members' positions	.	.	42%	58%	100%	.	12
Scan up and down	.	8%	25%	67%	92%	.	12
Move in a single file	.	.	42%	50%	92%	8%	12
Take a tactical position while within a room	.	17%	42%	42%	83%	.	12
Communicate enemy location to team member	.	.	33%	50%	83%	17%	12
Understand verbal commands	.	.	33%	50%	83%	17%	12

Table 5: RISE Veldt evaluation survey results 4/8

Item	Very poor	Poor	Good	Very good	G + VG	Did not attempt	n
Aim weapon	17%	8%	17%	58%	75%	.	12
Locate enemy combatants inside buildings firing at your unit	.	8%	33%	42%	75%	17%	12
Estimate distances from self to a distant object	.	25%	50%	25%	75%	.	12
Take hasty defensive positions	.	.	58%	17%	75%	25%	12
Maneuver below windows	.	8%	42%	25%	67%	25%	12
Visually locate the source of enemy fire	25%	.	42%	17%	58%	17%	12
Assume defensive positions	.	8%	33%	25%	58%	33%	12
Identify covered and concealed routes	.	.	50%	8%	58%	42%	12
Identify areas that make supporting fires	.	25%	50%	8%	58%	17%	12
Identify safe and dangerous areas	.	17%	25%	25%	50%	33%	12
Identify non-combatants within a room	.	.	25%	8%	33%	67%	12
Identify non-combatants in scenario	.	.	25%	.	25%	75%	12
Distinguish between friendly and enemy fire	8%	33%	17%	.	17%	42%	12
Identify civilians/non-combatants	8%	8%	8%	.	8%	75%	12
Determine direction of enemy rounds	17%	42%	8%	.	8%	33%	12
Determine the source of enemy fire by sound	17%	50%	.	.	0%	33%	12
Fire weapon accurately	75%	25%	.	.	0%	.	12
Move past furniture in a room	.	.	.	.	0%	100%	12

Items listed by frequency of Good + Very Good in descending order

Research Institute for Studies in Education (RISE), Iowa State University

Table 6: RISE Veldt evaluation survey results 5/8

Item	n	"Not applicable" responses dropped				
		n	Mean	SD	Min	Max
Distinguish between shoot and don't shoot situations	12	6	3.00	1.10	1	4
Engage enemy combatants	12	12	2.92	0.79	1	4
Make quick decisions in a stressful environment	12	11	2.91	0.83	1	4
Communicate with other team members	12	12	2.75	0.62	2	4
Identify challenges in evaluating complex situations quickly	12	12	2.67	0.49	2	3
Recognize potential life-threatening circumstances	12	4	2.50	1.29	1	4
Understand rules of engagement (ROE)	12	6	2.50	0.84	1	3
Use other weapons to engage enemy combatants	12	4	2.00	1.15	1	3
Improve marksmanship	12	10	1.60	1.26	1	4

Items listed by mean in descending order

Research Institute for Studies in Education (RISE), Iowa State University

Table 7: RISE Veldt evaluation survey results 6/8

Item	No improvement	Slight improvement	Moderate improvement	Vast improvement	NA / Did not attempt	n
Engage enemy combatants	8%	8%	67%	17%	.	12
Make quick decisions in a stressful environment	8%	8%	58%	17%	8%	12
Identify challenges in evaluating complex situations quickly	.	33%	67%	.	.	12
Communicate with other team members	.	33%	58%	8%	.	12
Distinguish between shoot and don't shoot situations	8%	.	25%	17%	50%	12
Understand rules of engagement (ROE)	8%	8%	33%	.	50%	12
Use other weapons to engage enemy combatants	17%	.	17%	.	67%	12
Improve marksmanship	67%	.	.	17%	17%	12
Recognize potential life-threatening circumstances	8%	8%	8%	8%	67%	12

Items listed by frequency of Moderate improvement + Vast Improvement in descending order

Research Institute for Studies in Education (RISE), Iowa State University

Table 8: RISE Veldt evaluation survey results 7/8

Item	n	"Not Applicable" responses dropped				
		n	**Mean**	**SD**	**Min**	**Max**
I was able to actively search the environment using vision	12	12	3.75	0.62	2	4
I was able to adjust quickly to the virtual environment experience	12	12	3.42	0.51	3	4
The visual aspects of the environment involved me	12	12	3.33	0.49	3	4
I had a sense of moving around inside the virtual environment	12	12	3.33	0.89	2	4
I could actively search the environment using touch	12	10	3.10	0.57	2	4
I was able to examine objects from multiple viewpoints	12	12	3.00	0.43	2	4
I felt involved in the virtual environment	12	12	3.00	0.60	2	4
By the end of the experience, I felt proficient in moving around and interacting	12	12	3.00	0.95	1	4
My senses were completely engaged by this experience	12	12	3.00	0.85	1	4
My interactions with the environment seemed natural or true to life	12	12	2.83	0.72	2	4
I was able to control events	12	12	2.58	0.67	2	4
My experience in the virtual environment were consistent with my real world experiences	12	10	2.50	0.71	1	3
The visual display quality interfered with my ability to perform the assigned task	12	12	2.50	1.09	1	4
The auditory aspect of the environment involved me	12	11	2.45	1.04	1	4
The environment was responsive to actions I performed/initiated	12	12	2.42	0.67	1	3
The visual display quality distracted me from performing my assigned tasks	12	12	1.83	0.83	1	3
I could identify sounds	12	9	1.78	0.67	1	3
I could localize sounds, or tell where sounds were coming from	12	9	1.44	0.53	1	2

Items listed by mean in descending order

Research Institute for Studies in Education (RISE), Iowa State University

Table 9. RISE Veldt evaluation survey results 8/8

Item	Disagree completely	Disagree somewhat	Agree somewhat	Agree completely	Agree	Not applicable	n
I was able to adjust quickly to the virtual environment experience	.	.	58%	42%	100%	.	12
The visual aspects of the environment involved me	.	.	67%	33%	100%	.	12
I was able to actively search the environment using vision	.	8%	8%	83%	91%	.	12
I was able to examine objects from multiple viewpoints	.	8%	83%	8%	91%	.	12
I felt involved in the virtual environment	.	17%	67%	17%	84%	.	12
My senses were completely engaged by this experience	8%	8%	58%	25%	83%	.	12
I had a sense of moving around inside the virtual environment	.	25%	17%	58%	75%	.	12
By the end of the experience, I felt proficient in moving around and interacting	8%	17%	42%	33%	75%	.	12
I could actively search the environment using touch	.	8%	58%	17%	75%	.	12
My interactions with the environment seemed natural or true to life	.	33%	50%	17%	67%	.	12
The environment was responsive to actions I performed/initiated	8%	42%	50%	.	50%	.	12
My experience in the virtual environment were consistent with my real world experiences	8%	25%	50%	.	50%	17%	12
I was able to control events	.	50%	42%	8%	50%	.	12
The visual display quality interfered with my ability to perform the assigned task	17%	42%	17%	25%	42%	.	12
The auditory aspect of the environment involved me	17%	33%	25%	17%	42%	8%	12
The visual display quality distracted me from performing my assigned tasks	42%	33%	25%	.	25%	.	12
I could identify sounds	25%	42%	8%	.	8%	25%	12
I could localize sounds, or tell where sounds were coming from	42%	33%	.	.	0%	25%	12

Items listed by frequency of Agree somewhat + Agree completely in descending order

Research Institute for Studies in Education (RISE), Iowa State University

APPENDIX B. RISE VELDT EVALUATION INTERVIEW QUESTIONS AND RESPONSES [58]

1) What stands out to you regarding your experience in the live-virtual environment?

- Actual movement was real
- Realistic kicking in doors, rooms were very realistic
- Technical issues were a negative
- Unrealistic was lack of sound, recoil on the weapon
- Entire layout was well-built, very real-life
- Being in close quarters, having an alley way and windows made it seem more real
- No sound made it hard to know if we were being fired at
- The one room we cleared was small, realistically they are bigger, have furniture. Things were condensed.
- Tracking issues, unable to hit what was shot at
- Wanted to use more of the weapon, sight

2) Could scenarios, such as the one you experienced here, be used in this type of environment to practice decision-making skills? Please explain.

- Especially if non-combatants were involved. We were briefed that there were three bad people.
- It was straightforward but adding defensive positioning might be help
- Depends on what the real life situation is – first time you go through you need to think on your feet. If we hadn't received the tour beforehand, things would've been slightly different. We would've needed more communication.
- Ceilings would be nice, holes in walls
- For someone who has never been in a combat situation this gets them accustomed to what they might encounter
- Yes, especially with worrying about shooting "blue on blue"/friendly incidents and identifying friend and foe.
- No, with regard to tactics because the rooms are really small but you might run into that in the real world though
- Seeing the layout ahead of time and knowing which doors and such probably detracted away from the experience—for the most part you'll get a topographical map and know that it's a building.
- A lot more "friction" would be needed to make it more realistic—anything that would get in the way of the participants from making decisions (sights, sounds, longer scenarios).
- It would've been neat to see reactions without knowing that there was a live insurgent. All that is known is that there are three insurgents.

To what extent did events occurring outside the virtual environment distract from your experience in the virtual environment?

- There was no outside noise, as soon as he was down, that was it.
- There wasn't any sound coming from the other operators
- Maybe a drape over the computer area, near the barricade would've been nice.
- A lot of it was distracting – were in a big room, there was virtual reality equipment all around, the flooring wasn't realistic. These little things made it hard to focus completely.
- Didn't notice the cameraman at all – accidentally shot him

Were there moments during the virtual environment experience when you felt completely focused on the task or environment?

- The first room clearing and having an actual real person there.
- Kicking down the door was a focused moment…maybe by adding some ambiance, like mosque music, gunfire sound. Stuff that makes you really focus.

Do you think this type of environment could be beneficial if you were training for military activities, such as practicing Rules of Engagement, making decisions in a stressful environment, and practicing shoot/don't shoot situations?

- Yes especially those because of the large operation you'll need a huge area.
- If they incorporated civilians and have the actual bad guys move even on the screen
- Ambient noise/noise from actual combatants (gunfire)
- Just being able to move and interact can be extremely helpful and could make it so much more confusing—a lot of things you could work into the situation.
- Could make things as realistically as possible without having to hurt people
- There are times when you'll need to know when to shoot – we did not encounter any friendly but those surprises are nice to know who is thinking on their feet and who is going through the motions.
- Yes, definitely dealing with civilian populace and rules of engagement especially as they change.

APPENDIX C. INTERSERVICE BOMB DEFUSAL SCENARIO DEMONSTRATION SCRIPT

<u>C6</u>

Bravo 2-6, Battlespace Commander

Bravo 2-2, Tech Operator

Bravo 2-3, Tech Operator

<u>Veldt</u>

Golf 4-6, Ground Commander

Golf 4-1, Ground Soldier

Golf 4-2, Ground Soldier

Checkpoint Scenario Script:

(first vehicle begins to approach checkpoint)

Golf 4-1: (Local to Golf 4-2) Heads up. Incoming truck...Alright, he's turning around, nevermind.

(second vehicle approaches checkpoint)

Golf 4-1: (Local to Golf 4-2) Another white truck, approaching fast.

Golf 4-2: (Local to Golf 4-1) Let's see what he's doing…

Golf 4-2: (Local to Golf 4-6) Hey, Sir, we've got a suspicious military aged male, just exited that vehicle and ran behind that panel van. (Golf 4-1 and Golf 4-2 raise weapons, speech is more urgent)

Golf 4-6: (Local to Golf 4-2) Can you see what he's doing. Is he digging? Was he carrying anything?

Golf 4-2: (Local to Golf 4-6) No visual.

(second foot mobile appears suddenly)

Golf 4-1: (Local to all) Second military aged male! (give description)(shouting)

Golf 4-6: (Local to all) Is he armed?

Golf 4-1: (Local to Golf 4-6) Negative!

Golf 4-2: (Local to screen) Get on the ground! Get down! Get down!(shouting, repeat commands several times until man runs away)

(second foot mobile runs off, first foot mobile goes back to truck)

Golf 4-6: (Local to all) He's taking off. I'll keep eyes on the second guy. What's the situation with the guy from the truck?

Golf 4-1: (Local to all) He's running back to his truck. What should I do?

Golf 4-6: (Local to all) Hold your fire.

Golf 4-1: (Local to Golf 4-6) Sir, he's on the move!

Golf 4-6: (Local to Golf 4-1) Roger that…. I'll call in for the UAV to track him.

Golf 4-2: (Local to Golf 4-6) Requesting to check out the area near the van.

Golf 4-6: (Local to Golf 4-2) Negative, we'll send the bot.

Golf 4-6: (Radio) Bravo 2, this is Golf 4-6. Over.

Bravo 2-2: (Radio) This is Bravo 2-2. Send. Over.

Golf 4-6: (Radio) Requesting UAV surveillance at grid five niner zero zero -- zero five three zero. Break… …Target is a military aged male in a white pickup truck. Over.

Bravo 2-2: (Radio) Roger, Golf 4-6. Searching now. Over.

Golf 4-6: (Radio) Roger that, Bravo 2-2. Out.

Golf 4-6: (Radio) Bravo, this is Golf 4-6. Over.

Bravo 2-3: (Radio) This is Bravo 2-3. Send it. Over.

Golf 4-6: (Radio) Requesting remote operation of our UGV to investigate a possible IED. Over.

Bravo 2-3: (Radio) Roger. Connecting now. Can you describe the area of interest? Over.

Golf 4-6: (Radio) Area of interest is approximately 50 feet due south of the rover's current position. Break. Then 10 feet due east, on the ground near the front of a white panel van. Over.

Bravo 2-3: (Radio) Copy that. Deploying UGV. Over.

Golf 4-6: (Radio) Roger, Bravo 2-3. Over.

Bravo 2-3: (Radio) Golf 4-6, I am moving toward a white van, is that the vehicle of interest? Over.

Golf 4-6: (Radio) Affirmative, Bravo 2-3, continue forward 25 more feet. Over.

Bravo 2-3: (Radio) Roger, Golf 4-6. Over.

Golf 4-6: (Radio) Golf 4-6, Out.

Golf 4-6: (Local to all) Bravo is gonna check this out. Keep your eyes open.

Bravo 2-6: (Radio) What's the situation on those unmanned vehicles in the village?

Bravo 2-2: (Radio) Got a positive ID on the suspect. Suspect exited his vehicle and entered a building to the southeast of the checkpoint. Bravo 2-3, do we have a visual on the package?

Bravo 2-3: (Radio) I've got visual on a package that may have been left by the suspect. Looks like an IED.

Bravo 2-6: (Radio) I need you to confirm that.

Bravo 2-3: (Radio) Yes, sir. (uses Virgil to look in the box) Ok, I see wires and a cellphone attached to some kind of artillery shell. Definitely an explosive device.

Bravo 2-6: (Radio) Can you disarm it?

Bravo 2-3: (Radio) Yes, sir. It's a pretty basic setup. I can just cut these wires.

Bravo 2-6: (Radio) Ok. Tell Golf 4 to take cover as a precaution. (Bravo 2-6 goes back to monitoring other UAVs.)

Bravo 2-3: (Radio) Golf 4-6 this is Bravo 2-3. Over.

Golf 4-6: (Radio) Golf 4-6. Go ahead. Over.

Bravo 2-3: (Radio) We confirmed the presence of explosives. Will attempt to disarm from the bot. Recommend that you take cover. Out.

Golf 4-6: (Local to all) Just heard from Bravo. There was an IED in front of that van. Good eyes. The UGV is gonna attempt to disarm the explosive, now. Take cover until we get the all-clear.

(Golf 4-6 watches Robot feed to monitor the disarming of the bomb)

Golf 4-6: (Radio) IED disarmed, good work everyone.

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