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## Army Research Institute Virtual Environment Research Testbed : Final Report

Glenn A. Martin

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Army Research Institute  
Virtual Environment Research Testbed

CONTRACT N61339-99-K-0003  
CDRL A001  
April 7, 2000

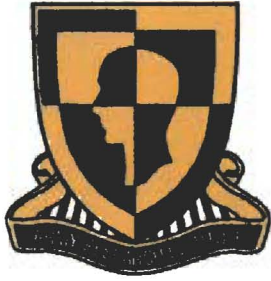


FINAL REPORT



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Army Research Institute  
Virtual Environment Research Testbed

Final Report

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April 7, 2000

**Institute for Simulation and Training**  
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**Virtual Environment Research Testbed**

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CDRL A001 – Final Report

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# Army Research Institute Virtual Environment Research Testbed

## Final Report

Written By:

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April 7, 2000

### **Abstract**

The principal purpose of the IST Army Research Institute Virtual Environment Research Testbed is to provide a flexible and adaptive mechanism which can be used to conduct behavioral research on factors which affect the acquisition of skills in a virtual environment and the transfer of those skills to the real world.

Research conducted at IST under contract with the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) has been successful in identifying virtual environment interface requirements for training applications, documenting the effectiveness of virtual environments as a training medium, and researching the transfer of skills acquired in a virtual environment to the real world.

This report describes the ARI Virtual Environment Testbed project and the work specifically conducted under contract N61339-99-K-0003 for the period of performance from April 1999 to March 2000.



# 1. Introduction

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The U. S. Department of Defense has made a major commitment to the use of networked real-time simulators for combat training. A principal component missing from today's training simulations on the electronic battlefield, however, is the dismounted soldier. Little is known about the effective use of these virtual environments for training infantrymen. To address this issue, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) and the University of Central Florida Institute for Simulation and Training (IST) have established the ARI Virtual Environment Research Testbed at IST's Visual Systems Laboratory. The goal of the Testbed is to investigate the use of virtual environment technology for Army training and develop training strategies and performance measures to make virtual simulations an effective training medium for dismounted soldiers.

The ARI Virtual Environment Research Testbed, established in the summer of 1992, has been successfully designed and developed for purposes of research and experimentation in the application of virtual environments to military tasks for the dismounted soldier.

The Testbed provides a flexible and adaptive mechanism, which can be used to conduct behavioral research on factors that affect the acquisition of skills in a virtual environment and the transfer of those skills to the real world. Working together, ARI research psychologists plan, design and conduct the experiments and analyze the data, and IST researchers, mostly software and hardware engineers, develop the necessary models, hardware, and software simulation components.

IST performed work in support of two experiments under contract N61339-99-K-0003. This support consisted of the development of models and databases, the development of control, data capture and reduction software, the provision and special configuration of physical facilities, and the general operation of the research facility.

This report will first provide an overview of the research program, followed by a description of the two experiments conducted in 1999. A separate section will then describe some specific software developments.





## 2. The Army Research Institute Research Program

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The tasks developed for each experiment are selected to be similar to what soldiers would do in a virtual environment. Participants are tested in a formal and controlled experimental environment. Each experiment has a specific set of tasks and objectives. Data is captured and later analyzed by ARI personnel to evaluate participant performance.

Each unique experiment resides within a standard framework. Participants are required to fill out initial forms and questionnaires. They are given preliminary demonstrations showing some of the details about the experiment such as how to put on the gear, how to maneuver within the virtual environment (walk forward, back up, and turn around, for example), and how to use any special interactive input devices particular to their tasks. Some hands-on training is usually administered to allow the participants a chance to get familiar with the environment so they can focus more directly on the tasks at hand during the actual experiments.

During the experiment, participants are closely observed for indications of simulator sickness. The Simulator Sickness Questionnaire (SSQ) developed by Essex Corporation [1] is used to assess simulator sickness. This is a 16-item questionnaire which participants report their symptoms on vision problems (eyestrain, difficulty focusing, blurred vision, headache), disorientation (dizziness, vertigo) and nausea (nausea, stomach awareness, salivation, burping). A four-point scale (none, slight, moderate, or severe) is used to measure some of the symptoms; an indication of being present or absent is used for others.

At the outset of this project, in 1992, an initial analysis of the task requirements for dismounted soldier training was conducted and a review of the previous research in the use of virtual environment technology for training was performed. The research program was then developed and divided into a series of experimental phases.

### **Phase I. Perceiving, Performing & Reacting**

In the first phase, experiments were conducted to evaluate the participant's ability to perform simple tasks in a virtual environment. A battery of tasks and performance measures were developed to assess human performance and effects of immersion in a virtual environment. Variables investigated using the battery of tasks included such things as displays (helmet-mounted display, boom, monitor), control devices (joystick, spaceball) and stereoscopic versus monoscopic immersive displays. Six experiments have been completed under

this phase of research – five were conducted under previous ARI contracts; one was conducted under the current contract and is discussed in this final report in a future section.

### **Phase II. Interior Spaces**

The second phase of experiments addressed the use of virtual environments to effectively teach configuration of, and routes through, large and complex buildings. A model of a real-world office building was developed. Participants in these experiments were required to learn a particular route in the virtual building and then walk that route in the real-world building. Two experiments were conducted under this phase of research – both were completed under an earlier contract with ARI.

### **Phase III. Exterior Spaces**

The third phase addressed the use of virtual environments to teach land navigation skills and, similar to the previous indoor experiment, addressed the issues of transfer of knowledge from the virtual world to the real world. A small area of Fort Benning, Georgia was modeled – participants (which had never been exposed to the real-world area they were being tested in) were required to navigate the Fort Benning virtual model to acquire knowledge of the landscape and then navigate the real-world counterpart. Two experiments were conducted under this phase – both were completed under an earlier ARI contract.

### **Phase IV. Distance Estimations**

The fourth phase investigates an individual's ability to accurately estimate distances in a virtual environment. This suite was not in the original research plan, but results from previous experiments suggested that distance estimations in the virtual environments may impede effective training. Four experiments from this suite were completed under previous contracts. Under the current contract, one experiment was completed — this is discussed in a future section in this report.

### **Phase V. Body versus No Body**

The fifth phase addresses the issues of body (avatar) presence. These experiments compare the effects of having one's own body visible in an immersive virtual environment. Experiment 5.2 from this suite is discussed below.

### **Phase VI. Team Situational Awareness**

The sixth phase addresses the issues of multi-player, networked environments for training team situational awareness and collaborative team tasks. The second experiment from this phase is discussed below.



### 3. Experiments Conducted Under Contract N61339-99-K-0003

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Two experiments were conducted in 1999 to support the ARI Virtual Environment Research Testbed under contract N61339-99-K-0003. These experiments (currently in data collection) are described in the sections below.

#### **3.1 Experiment 5.2 -- The Effect of Restricted Field of View on Locomotion Tasks, Head Movements, and Motion Sickness**

The purpose of this experiment is to investigate the effects that a restricted field of view has on head movements, locomotion tasks, and motion sickness in both virtual and real world environments.

##### The Virtual Environment

A four-room virtual world configuration was created. The virtual rooms were modeled after a coffee room and three adjacent conference rooms located at the IST facility. The coffee room is used for a practice session. The conference rooms were modeled to contain empty boxes as well as typical office furniture and materials, e.g., desks, chairs, etc. which were placed in such a way as to create both narrow and relatively wide passageways. Two targets (e.g., trashcans) were placed on the floor next to furniture in the last two conference rooms. One target was placed in the coffee room for the practice session. Participants will be required to drop a ball into each basket in a specified order.



**The Virtual IST Conference Room C  
With Boxes**

Participants view the VE through a Virtual Research V8 helmet-mounted display (HMD). An Ascension Flock of Birds™ six-sensor tracker provides position tracking for the participant's head, orientation, dominant hand/arm, and feet.

Participants begin with a short session to practice target acquisition and to allow for familiarization of body and viewpoint movement in the virtual world. After the practice session, participants will move from the coffee room into the first



conference room. In this room, participants are required to perform a guided movement task. This task requires the participant to move through the room as quickly and accurately as possible, while minimizing the number of collisions with the boxes, walls, and furniture. Paper arrows are placed at strategic locations along the floor of this room to delineate the path that the participant must follow. The participant then moves to conference rooms two and three to perform a search task. The search task in these rooms requires that participants search for targets as quickly and accurately as possible while minimizing the number of collisions with boxes, walls and furniture. Two waste cans are used, each with a number assigned to them (1 or 2). The participant's task is to locate the first target and drop a ball into it, then locate the second target and drop a ball into it.

### The Real World Environment

The coffee room and three adjacent conference rooms located at the IST facility are used for the real world configuration. These are the same rooms that are modeled for the virtual world environment discussed above.

The helmet was built to mimic the feel and weight distribution of the HMD used for the virtual environment. A resolution mask will be placed in front of the participant's eyes that mimics the resolution of the virtual-world HMD. A field-of-view restriction shield is attached to the HMD to allow for adjustable field-of-view parameters.

In order to track the orientation of the participant's head an accelerometer and inclinometer is used. The picture on the right shows a person wearing the helmet. The tracking system is attached on top of the helmet and is fed to a data collection device attached to a backpack that the person is wearing. The data collection device stores orientation data for later analysis.



**The Helmet with Tracking System**



**IST Conference Room C Configured to Run the Experiment**

Cardboard boxes, as well as real office furniture, are used in each room. Cardboard boxes are used to help reduce the possibility of injury occurring if a participant bumps into an object. All objects in the real world will be placed exactly as they are in the virtual world.

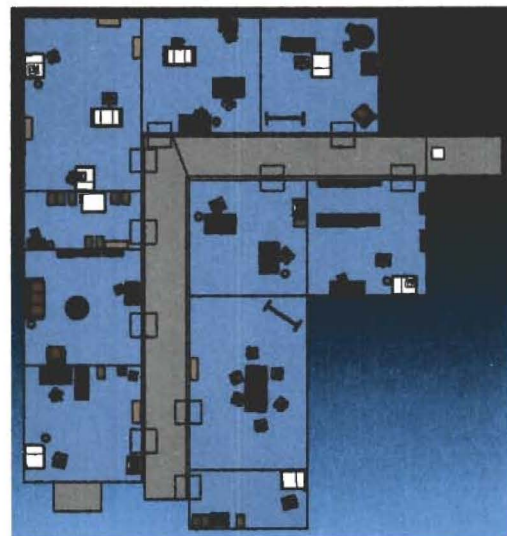
The picture on the left shows one of the IST conference rooms, as it is arranged for an experiment.

As in the virtual environment, participants practice in the coffee room. They then move into the first conference room, performing the same tasks as those found in the virtual environment. They then perform the search tasks in the second and third conference rooms.

### **3.2 Experiment 6.2 -- Distributed Team Training: Communication and Team Performance**

The IST Virtual Environment (VE) Team Training System, developed at IST over the past several years, has been brought to a sophisticated level. This system can support local and distributed team players. It can support a broad range of input devices, output devices, tools, trackers, etc. Experiment 6.2 is described below.

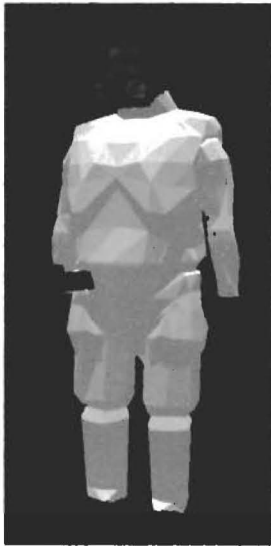
The training scenario for Experiment 6.2 is a building search exercise with a two-person team under resource, time, and environmental constraints. The trainees are a team leader and an equipment specialist. The building is searched for targets (chemical canisters) that have to be neutralized within a certain time. The building has normal complex rooms and areas that serve to conceal the targets. The scenario also has opposing forces that can act to distract the trainees and increase the complexity of the scenario.



**Typical 10-Room Building**

A typical 10-room building floor plan is pictured to the right.





**Team Member Avatar**

Each of the two simulated team members wear protective clothing, a clock that shows the remaining airtime in the simulation, and a breathing apparatus to prevent exposure to the toxins. See picture of avatar wearing chemical suit with gear to the left.

The physical confinements of wearing immersive VR gear (helmets, tethers, etc.) actually enhances the immersion value of the situation since the protective gear similarly limits vision, locomotion, and audition.

The team must deal with the computer-generated enemies, innocent bystanders, and leaking gas canisters as they move through the building.

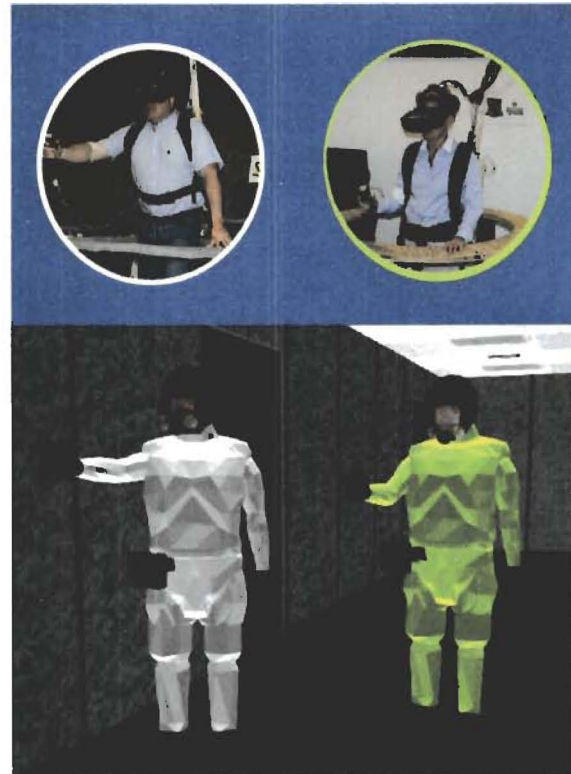
In addition, the team leader and equipment specialist must cooperate and communicate to efficiently search for gas canisters, detect and identify opponents as quickly as possible, and search the maximum area within the timeframe of the exercise.

The bottom portion of the picture to the right shows the two-player team in the virtual environment. The top portion shows the two corresponding live players.

The simulation requires a system of sensors for each team member, a head mounted display with stereo view, and a joystick device placed in the right hand that allowed the players to change their tools and trigger them.

The system also uses a simulated radio net that allows the team members to communicate with each other and the mission commander.

Audio cues like grenades, gun shots, and doors opening are used in the simulation to help the team members feel more immersed.



**Two Player Team**

To accomplish this, six tracking sensors are used to track each trainee's position and orientation in the environment.

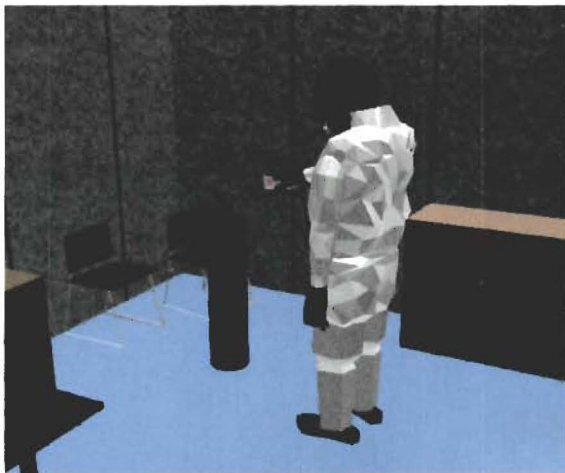
- A sensor mounted to a backpack controls body orientation.
- A sensor on each leg allows forward movement through a natural marching movement and backward movement by taking a step back.
- A sensor mounted to the helmet controls the view displayed inside the head-mounted display so a player can look around.
- A sensor placed at the elbow of the right arm and on the hand-held device allows a player to gesture, aim and fire weapons, and operates equipment in the virtual environment.

Using these sensors, the simulated system is able to fully articulate each player in the virtual environment.

All mission activity, including sounds and communications, are recorded during the live mission runs. The entire mission can be viewed flat-screen using a VCR-like control to allow real-time playback as well as frame-by-frame, fast-forward, rewind, or slow motion.

The system supports running local teams as well as remotely distributed teams. Communication for remote teams is handled over ISDN.

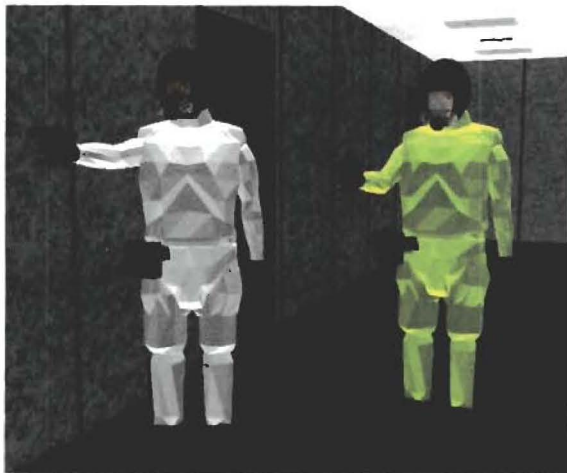
Stealth views are supported to allow others to view the scenario from a flat-screen. During the actual scenario described above, one additional player, the Commander, uses a stealth viewer to oversee the mission as it is taking place.



**Equipment Specialist using Canister  
Detection Device**



**Team Approaching Enemy**



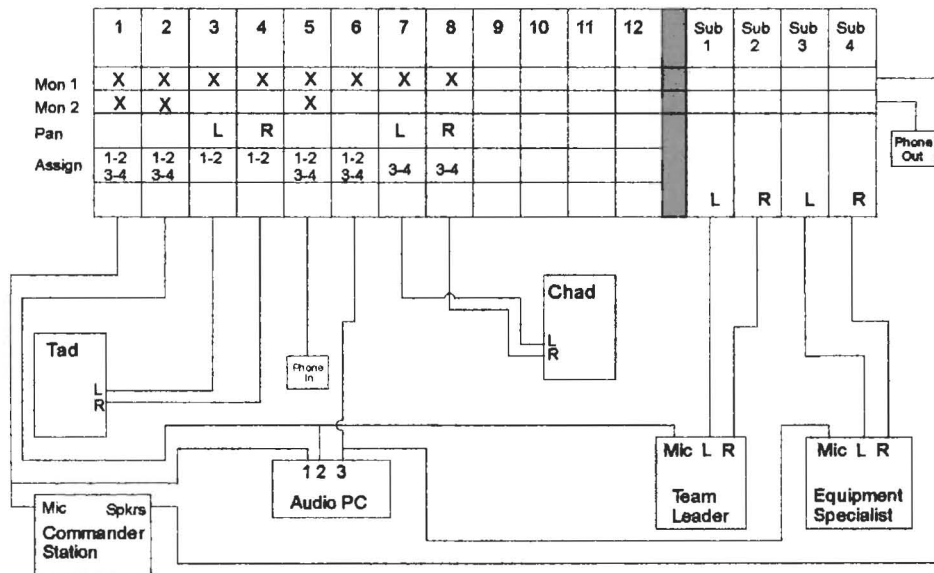
**Team Stacking Procedure  
in Hallway**



**Stealth/Commander View**

Lastly, to facilitate the communication between sites involved in the distributed training phase, a combination of ISDN lines and regular phone lines are used. The ISDN lines carry network traffic involved in broadcasting states of entities and event information using an Ascent Communications Pipeline 50 ISDN Router connected to the private sub-net within the testbed at IST. The phone lines are used to pass voice communication back and forth between the Team Leader, Equipment Specialist and the Mission Commander using a mixer. This is more complicated than it sounds as shown in the following audio wiring diagram:

**Audio Configuration  
IST Site**







## 4. Major Software Developments

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To support the two experiments executed during this contract period, several new software capabilities needed to be developed by IST. These are discussed below.

### 4.1 Magnetometer/Inclinometer Support (Experiment 5.2)

For Experiment 5.2, data collection was trivial for the group tested in the virtual environment since the subject's gaze and orientation could be measured directly from the motion tracker data. However, this was not the case for the group tested in the real world condition. To overcome this, an apparatus was designed and worn by the subjects during the experimental run. The core of the apparatus consisted of a Precision Navigation TCM2-50 electronic compass and inclinometer module. This device measures the earth's magnetic field to determine the orientation and corrects for pitch and roll using a fluid-based inclinometer. The magnetometer measures a full 360 degrees of heading and the inclinometer measures up to 100 degrees of pitch and roll (50 degrees positive and negative).

This device was mounted onto a plastic helmet, which was then weighted to approximate the weight distribution of the head-mounted display worn by the virtual environment group. The device is then connected to a wearable computer via RS-232C serial port. The data collection software was adapted from the module used in the virtual environment condition and produces nearly identical orientation output.

Two limitations of this device are its sensitivity to metallic distortion and its rate of measurement. The device is designed for use in automobiles, aircraft, and watercraft, not indoors. The rooms used for the real-world condition of the experiment showed a noticeable amount of metallic distortion. The device can be calibrated for such distortion, but because of the construction of the room, the distortion is oriented differently in different areas. This distortion will cause a small amount of error in the heading measurements. Secondly, the device's rate of measurement is significantly slower than the tracking system used for the virtual environment group. Measurements were taken every tenth of a second in the virtual environment condition, but the device used in the real-world condition is only capable of generating a measurement every eighth of a second.

## **4.2 Collision Detection (Experiment 5.2)**

A new data-driven approach to collision detection was developed for Experiment 5.2 (FOV), allowing users to maneuver easily in the restrictive environment of Experiment 6.1, and facilitate collision detection for scalable avatars. This method builds on the collision detection of previous experiments in that it works on the methodology of projecting a number of collision vectors from points relative to the avatar's current position and orientation. The user's movement is then restricted based upon how far away these vectors intersect.

In previous experiments, the origin of the collision vectors was relative to a fixed distance from a point at which the user was standing in the virtual environment. One of the requirements of Experiment 6.1 was to have avatars that were scalable to the user's body size. Having the origins of the vectors at a fixed distance from a point on the avatar would not allow for the collision detection to scale with the avatar. The new approach was to have the collision vectors defined within the model so that they scale with the model. In order to define the vectors within the model, the modeler placed the collision vector origin and orientation in the model in the form of a Degree of Freedom Node. When the model is loaded, this information is translated into a collision vector for the collision algorithm to use.

The second aspect of the collision detection that was changed was in how the vectors interact with the environment to keep the user from walking through walls and other objects. The manner in which this was accomplished previously worked fine for the more open environments of previous experiments, but it was not designed for the more cramped environment of Experiment 6.1. The user can now move through much tighter areas.

In the future, collision detection may use bounding boxes. There are technical difficulties in using them, but there are ways around these difficulties. Another approach would be to make a 2-dimensional map of the environment with areas marked where the user cannot walk.

## **4.3 Multiple Audio Streams (Experiment 6.2)**

The Audio Capture System from Experiment 6.1 had to be changed to accommodate multiple sound cards for capturing multiple audio streams to support the voice analysis requirement (i.e. who said what) of the experiment. In addition, the system was also written to respond to network commands, as opposed to serial port commands to make the system more robust and easier to install at remote sites. Other miscellaneous features were added.

#### **4.4 Changes to After-Action Review System (Experiment 6.2)**

The After-Action Review System was very similar to the Experiment 6.1 version, but numerous features were added to support the extensive set of Experiment 6.2 training tasks, as well as the new tool set. Second, the revised bullet hole/paint splat algorithm was integrated into the AAR system. Third, the extended capabilities of the Audio Capture/Playback system warranted the removal of the audio control code to its own class. Finally, the AAR system was made capable of responding to commands from the Experiment 6.2 menu system for automated operation during training modes, automated remote operation during mission reviews, and the standard interactive operation for other purposes.

#### **4.5 Changes to Data Capture System (Experiment 6.2)**

The modifications to the Data Capture System were relatively few in number compared to the other systems. However, support for the additional PDUs needed in the experiment was added as well as Ethernet connectivity to the Audio Capture System.

#### **4.6 Computer Generated Entities Server (Experiment 6.2)**

In Experiment 6.2, the two-member team must interact with each other in order to accomplish their assigned mission. However, the two participants must also interact with the environment around them. The Computer Generated Entities Server takes care of animating the dynamic portions of the environment. The Computer Generated Entities Server has three main types of objects it must control within the virtual environment: OpFors, CoFors, and gas canisters.

##### OpFors

The OpFors, short for Opposition Forces, are the hostile and neutral entities that the team members encounter within the simulation. The Opfors are designed to keep the subjects alert and aware of their situation. Opfors can be configured to be hostile or neutral. Hostile Opfors are given weapons and set to attack the first player that they see. Neutral Opfors are generally equipped with gun-like objects, such as drills, but do not react to the player's presence. The objective is to get the players to react to the hostile opfors' reactions and intentions, not simply what they may be carrying.

Opfors can be configured in a variety of ways. They may be set to stand at a particular point and simply monitor a particular area, or may be given a sentry path, which they follow until a player is discovered. An opfor can also be told to stand in place until an event occurs, such as a door opening or a time limit expiring, before starting on a sentry patrol. In addition, the opfors can be

configured with varying amounts of marksmanship and awareness of their surroundings.

### CoFors

The CoFors, short for Cooperative Forces, are the friendly counterparts to the Opfors. The Cofors generally do not appear during the actual mission runs but are more used during the training scenarios when the various tools and tasks are being introduced to the participants. Since these training tasks are for use only by a single player at a time, the Cofors take the place of the other player in tasks that generally require both team members to be present.

The Cofors can be programmed with scripts that allow them to simulate the typical actions of the team member that they are emulating. Typical actions for a Cofor include moving to specific locations, interacting with gas canisters, disabling hostile Opfors, and reciting prerecorded speech audio files. The experimenter, sitting at the simulation console, can control when the Cofors continue on each leg of their scripted routine, in order to make sure that their movements and actions stay synchronized with the subject's.

### Gas Canisters

These tall green gas cylinders form the basis for the mission that the two-member team members must embark upon. The gas canisters are generally either found closed and inert, or open and leaking poisonous fumes into the air. In addition, some canisters have black bomb devices attached to them, set to explode if the canister is tampered with.

Whenever the team's equipment specialist brings his detector tool near a canister, the canister sends out information stating whether the canister is leaking gas, and if it has an active bomb or not. If the equipment specialist pulls the trigger on the detector, the canister initiates its countdown and broadcasts its disarming code. Attempting to cap the leaking canister with the bomb still active causes the canister to explode. However, after the team leader sends it the correct disarm code, the canister becomes relatively harmless and can be sealed normally.

## **4.7 Additional Tools (Experiment 6.2)**

In order to allow the subjects in the experiment to better interact with their environment, the subjects are each provided with a set of 'tools', objects which can be held in the right hand and allow the subjects to affect the simulation. Each subject has a specified set of tools, dependent on the role that subject has in the mission, that allow the subject to perform his assigned tasks. Only one such tool can be held at a time, and switching between these tools is a simple matter of pressing one button on the subject's hand device.



During the experiment, participants hold a joystick-handle device in their right hand. This device has a magnetic tracker mounted on it to allow the computer to determine where the participants are pointing. The devices also have two buttons on them; a trigger button for activating tools and a thumb button for switching between tools. The effect of the trigger button varies depending on which tool that the player is currently holding.

Each subject has a particular set of tools, specified by configuration files within the system. Each tool has a different appearance and function, though all are needed for the team to complete its assigned mission. The different tools are described in the following subsections (the Door Opener, Disarming, Locking Cap, and Grenade tools are all new for Experiment 6.2; in addition, the Detector tool was altered as well).

#### Gun Tool

This tool satisfies the need for the players to be able to respond to hostile threats while completing their mission. Any opposing force shot by a player's gun tool instantly falls to the ground and doesn't move for the remainder of the simulation. The gun tool also has a red 'aiming laser' coming out of its barrel to denote where it will hit when fired. Both participants are armed with these weapons.

#### Paint Gun Tool

This tool allows the team leader to mark areas or objects with bright green painted 'X's. The main purpose of this is to allow the team leader to mark the entrance area of rooms that have already been searched and cleared. Each pull of the trigger creates one such 'X'. The paint gun has an aiming laser similar to the regular gun that tells the leader where the paint mark will occur.

#### Door Opener Tool

This 'tool' actually has the appearance of an empty hand... it is classified as a tool to make it easier to integrate into the system. Whenever a player brings their hand near any door's doorknob and pulls the trigger, that door opens. Both players are equipped with this capability.

#### Detector Tool (Delta2)

The equipment specialist uses the detector tool in order to "scan" any discovered gas canister for gas leaks and active bomb devices. The detector tool has a large color light display for indicating to the specialist what type of canister hazard is present, as well as two numerical readouts for display of bomb information. A pull of the trigger on this tool causes it to interrogate the closest canister bomb device for its disarming code; unfortunately, this also initiates a countdown for bomb detonation. The time remaining before detonation is also displayed on this tool.

#### Disarming Tool (Delta1)

The team leader uses the disarming tool to defuse a ticking canister bomb. Once the equipment specialist scans a bomb for its disarm code, he relays that



information to the team leader, who then uses the code and this tool to stop the bomb countdown and make it inert. This tool also has a laser sight similar to the gun tools; this sight is required because the team leader must aim the disarming tool at the correct communications port on the bomb for the disarm code to be accepted. Pulling the trigger when the tool is not pointed at a canister bomb box causes the displayed disarm code to cycle. In order to disarm the canister bomb, The team leader must cycle the code until the correct one is displayed.

#### Locking Cap Tool

This tool is used after a canister bomb device has been disarmed or is otherwise determined to be inactive (or not present). This tool takes the shape of a large hexagonal nut that is installed at the valve area of any leaking gas canister in order to seal the leak. To use this tool, the locking cap must be placed approximately on top of the canister and the trigger pulled; if the placement is correct the cap will move from the subject's hand onto the top of the canister and change color to indicate that it has been successfully installed. Both players are equipped with this tool.

#### Grenade Tool

This tool is used to disable opposing forces within a particular room. Rather than doing actual damage, this grenade explodes with a bright flash five seconds after it is released. The flash stuns any hostiles and neutrals (as well as any players) looking in the direction of the grenade when it detonates. This tool also has an aiming laser pointing out of it to indicate the general direction the grenade will travel when thrown. When the trigger is pulled, the grenade leaves the player's hand with a set arc and travels until it hits the ground, stopping forward movement when it hits a wall. Only the equipment specialist is given this weapon.

### **4.8 Sticker Support (Experiment 6.2)**

In Experiment 6.1 minimal support for a "splat" feature was available. The team leader could mark a room by using a Splat Gun that would leave a mark on the floor. This was implemented by placing a texture of an "X" in the world at the location that was hit by the team leader. However, this posed a problem for moving objects such as the other player. If the team leader hit the equipment specialist, the splat would appear at the specialist's location, but if the specialist then moved, the splat was left behind hanging in space.

For Experiment 6.2 the splat support has been changed to allow splats to be directly attached to objects. This was necessary since Experiment 6.2 allowed for moving Opfors as well as other players. In addition, marks for the regular gun and grenade explosions were also added. All of this functionality was collected together into what was called the sticker manager (the generic term "sticker" was used to refer to all the marks possible in Experiment 6.2, not just splats). Now if a roaming Opfor or another player gets hit (either by the regular gun or the splat

gun), a mark is made directly on him at the location of the hit and will continue to be there as the player or Opfor moves around).

#### **4.9 Post Processing System (Experiment 6.2)**

In Experiment 6.2, information concerning the states of the two subjects as well as the various environmental hazards, flows freely across the computer network joining the entire experiment together. This information is interpreted instantly by each machine involved, providing feedback to the players, experimenter, and computer generated entities. This networked information is also captured and stored for later use in network packet files.

The two data postprocessing applications designed for this experiment take the network packet files and process them in such a manner that enables the experimenter to quantitatively evaluate the subjects' performances. The intermediate postprocessing program is designed to provide output that goes along with the subject's after-action review, where the subjects are given feedback about correct and incorrect action during the mission. The final postprocessor is more designed for the experimenter after the day is finished; it provides more detailed information about the subjects' activities in the virtual environment.

##### Intermediate Postprocessor (AARDVARK)

The intermediate postprocessing program is designed to take a saved network data stream and create an analysis of the subjects' actions during the recorded experiment. The output from this program is generally used to assist the experimenter during the after-action review process. The output from the processor is separated into "pages", one page for each room that the subjects entered. These pages of data point out the correct and incorrect actions that the subjects made during the mission. The experimenter can then use the after-action mission playback application to actually show the subjects what they were doing and why it was right or wrong, using the data from the intermediate postprocessor to direct the playback application to the correct point in the mission.

Each "page" of data generated by the processor contains information about the activities of both team members for the particular room that that data page represents. The data page contains information on the time of entry and exit of the room in question and the time of performance of certain required tasks, such as opening the room door or throwing a flash grenade. The pages also contain initial line-of-sight time information for each important object or person in the room. Additionally, the data page contains statistics about the shots fired by the team members, as well as statistics concerning their performance regarding disarming of leaking or armed gas canisters.

### Final Processor

The final postprocessing application is used when the session has ended for the day and the experimenters wish to more thoroughly examine the subjects' actions and performances. Where the intermediate processor generates a page of data for each room in the simulation visited, the final processor creates a line of data for every second that elapsed during the mission. Each line of data contains information about the subject's current actions. Two of these output files are generated for each experiment run: one for each team member. Taken as a whole, these output data files describe the actions of each subject throughout the experiment.

Each line of the output files from the final processor describes a subject's actions within the span of one second. Each line contains the location of the subject within the virtual environment during that second. It contains information about the tool(s) that the subject was holding and using during that second. It also tells if the player was shot or who he was shooting, and who the target was. Lastly, it states if the player was speaking at that time and which speech file (stored internally somewhere else) contains that player's words for that moment.

### **4.10 ISDN Networking Support (Experiment 6.2)**

To support the distributed condition of Experiment 6.2, it was necessary to connect directly to each site through an ISDN line in order to limit variables relating to network latency. The general-purpose ISDN lines (i.e. those usually installed) support only 128-kilobit of bandwidth. However, upon an analysis of the Experiment 6.1 traffic, it was found that it used approximately 1,000-kilobits of bandwidth. Hence, a reduction of a factor of 10 was necessary.

To achieve the bandwidth reduction necessary, a number of steps were performed. First, dead reckoning of the avatars was used. Since Experiment 6.1 had no real bandwidth requirements (other than the IST network), dead reckoning was not used in order to give the best view of the actual data that existed. However, this was not possible for Experiment 6.2 so dead reckoning was used to reduce the number of packets sent per second. As part of this task, much work was spent minimizing the use of dead reckoning (the more estimation in use, the more potential error) while maintaining an appropriate bandwidth. Second, alterations to the Entity Service (IST/VSL's DIS service) were performed to reduce the number of data sent when it was sent. Instead of sending angles for all 15 joints every time, only the angles that changed a significant amount were changed. Receiving clients assumed all others had not changed. This is a further change from DIS, but this alteration was particularly important because the articulated angles formed almost 90% of the entity state traffic evident in Experiment 6.1.

Once the bandwidth use was reduced to an adequate level, there was still the problem of connecting two sites. We purchased an ISDN Router from Ascend

Communications for use during the experiment. When connecting two different networks, there are two possible methods: routing and bridging. However, since we were using DIS, which is broadcast-based, only bridging was an available option (you cannot route broadcast protocols). Actually, routing would have been an option if we simply connected all the machines in a series of host-to-host connections; however, doing so would have simply increased the bandwidth use by a factor equivalent to the number of machines involved in the experiment.

With the installation of the ISDN line and router and the modifications required to the Entity Service, the Virtual Environment Research Testbed now has the ability to perform distributed team training between sites using an albeit modified DIS protocol.

## **CONCLUSIONS**

Over the past several years, the Army Research Institute Virtual Environment Research Testbed has yielded a wealth of research information on the development of complex virtual environments. The development of the experiments has helped to determine the path of future research. They have resulted in tangible benefits in the form of a grand arsenal of simulation code that has been used to develop many Department of Defense funded projects at IST.

The research efforts put forth to develop and maintain the ARI VE Research Testbed address much of the real science and feasibility of the realistic and purposeful use of virtual environment technology for training.

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