Command and Control in Distributed Mission Training: An Immersive Approach

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ABSTRACT

More than ever before, success in battle depends on effective command and control – but the increasing complexity and speed of modern engagements makes it ever more difficult to develop the comprehensive situational awareness upon which effective command and control depends. In the face of this increase in pace and complexity, developing systems to cost effectively train battle managers and weapons directors, and expose them to the full range and scope of potential conflict situations, is an ever-increasing challenge. This paper presents a distributed immersive command and control visualization system. Based on a JSAF simulation, networked participants, each using one of several different networked immersive devices, visualize and interact with the simulated battlespace from the first-person, tactical or strategic viewpoints. Battle managers interact with simulated and "manned" entities using a mixed mode interface that includes wireless palmtop interaction and gestural interfaces. The system has been developed under the expert guidance of the Iowa National Guard's 133rd Air Control Squadron, which has also cooperated in the evaluation of the system. ISU's Virtual Reality Applications Center (VRAC) is an internationally known VR research facility with a complete range of immersive display devices. Most notable is the C6, a full immersion 10x10x10-foot cube, completely surrounding the user with 3D audio and visual display.

INTRODUCTION

The exhaustive review of prior campaigns, engagements and plans is a staple of military command training. Consider the staff ride, pioneered by Maj. Eben Swift at the turn of the last century [1]. After extensive study of the battle's history and context, instructors and students would physically ride out to a battlefield site to examine the terrain of the field first hand, taking the vantage points of friend and foe, to see for themselves the interplay between ground, objectives and available force that constrain military strategy.

Staff rides and related activities, such as tactical exercises without troops, are time-honored military training aids. Exercises are set by instructors and then students present their solutions for comment and discussion by staff and other students. These techniques help to teach the vital connection between battlefield conditions and tactics.

Modern engagements are no less dependent on a thorough knowledge of the field. However, unlike battles of the Civil War era, where the majority of a battlefield could be envisioned from the highest hill in the county, today's battles are fought over thousands of square miles. The battle landscape is now defined not only by

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natural features, such as mountains and rivers, but by "invisible" features such as friendly and enemy sensors, the threat zones of long range weapons, and the forest of targets which must be struck precisely to minimize loss of life. Creating consistent and complete mental pictures of this complex environment is the task of training, whether as part of pre- and post-mission briefing, or as integral part of command and control of distributed mission training exercises.

Based on recent work at the Iowa State University's Virtual Reality Application's Center, we believe that immersive virtual reality (VR) technologies can be extremely valuable in this context, allowing war fighters to traverse and analyze the complex information landscape that is the modern battlefield, to develop strategies and tactics prior to an exercise or engagement, or develop the common relevant operating picture during an training engagement.

Immersive battlespace visualization has the potential to fuse information about tracks, targets, sensors and threats into a comprehensive picture that can be interpreted more readily than other forms of data presentation. Visualizing engagements in this way can be useful in a wide variety of contexts, from historical mission review, to mission planning, pre-briefing, post-briefing, and command and control of distributed mission scenarios. Immersive battlespace visualization can go beyond flight and vehicle simulation, to provide comprehensive, multi-faceted views of past campaigns, plans, distributed mission training scenarios and even live engagements.

Working with the Air Force Research Lab's Human Effectiveness Directorate and the Iowa National Guard's 133rd Air Control Squadron, a research team at the Iowa State University's Virtual Reality Applications Center have developed an immersive VR system for distributed mission training we call the *Virtual Battlespace*. The Virtual Battlespace is evolving into a useful exercise planning, pre-briefing, and debriefing tool. Additional tools are under development to allow participants to analyze airspaces and develop scenarios, and then analyze the outcomes of scenarios, isolate particular engagements, and allow for alternate paths in a tree-like structure. This paper describes the basic design and implementation of the Virtual Battlespace and some of its applications to date.

SYSTEM DESCRIPTION

The Virtual Battlespace uses virtual reality immersion display technology along with the fusion of multiple data streams to provide a user with a clear representation of the information needed to understand and control a battle. The Virtual Battlespace system connects users to information streams using a display system and a role-based user interface. A general architecture of the system is shown in Figure 1.

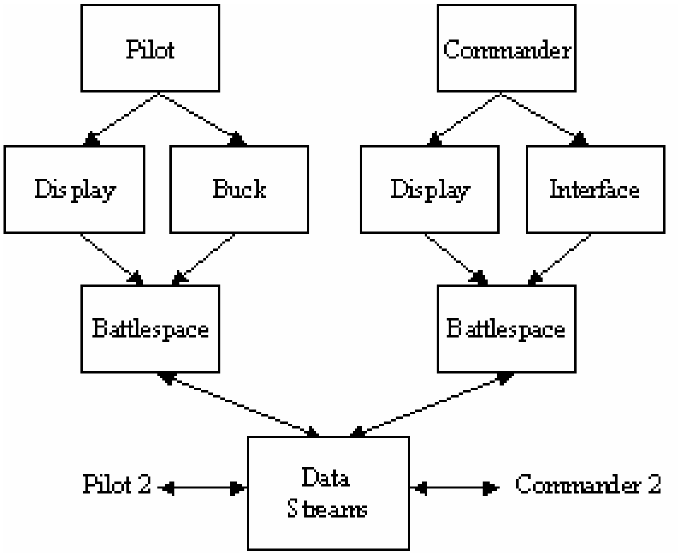


Figure 1: General Architecture.

The Virtual Battlespace visualization system is flexible, to allow it to support multiple end users. Common to most of these end users however is the need to see the entire battlefield or scenario. The goal for the Virtual Battlespace is to provide a comprehensive view of the overall field that can provide additional detail as a user narrows their visual focus to a portion of the space. The battlespace architecture can also accommodate system nodes which generate data streams associated with individual units, such as pilots in a flight simulator. The Virtual Battlespace incorporates these users into a common system, allowing them to interact with one another in a distributed way.

There are many different streams of information that provide support for battle field decision making. Some of these include radar and other sensor feeds, satellite imagery, communication links, and weapons information. The Virtual Battlespace is designed to fuse these multiple information streams and make them centrally available to command and control personnel. The goal of this comprehensive presentation is to improve a user's ability to make effective and intelligent decisions [2][3].

In the Virtual Battlespace, data streams are separated into two main categories: entity based data and battle level information. Entity based information streams deal with the location, attitude, path, weapons, and sensors for a particular weapons system or entity in the battlespace. This information is needed to give the commander an indication of the assets and threats that are present and to paint a global picture of the overall field. Battle level streams include: satellite imagery, video feeds of sectors and munitions, and communication networks among units. In the Virtual Battlespace, these streams are presented graphically to reduce the amount of textual information that the commander must keep track of and allow them to focus more time on critical decisions [4][5].

The information streams are made available to the user of the Virtual Battlespace through the immersive display system. To make the Battlespace useful in the widest possible context, the display system is designed to support the complete range of delivery platforms, from permanent, high-end multi-walled immersive projection theaters to lower cost, deployable systems. With such a design, units with deployable systems in or near the field could be connected with a permanent installation at a central command center to provide a common operating picture.

The user controls the display of information in the Virtual Battlespace with a distributed, cooperative user interface. To avoid information overload, and allow the user to tailor information display to meet individual needs, the Virtual Battlespace allows users to easily interact with the system and focus solely on the information that they need. By decoupling the Virtual Battlepsace's user interface from the underlying application, individual users can simultaneously interact with a common application through interfaces specifically tailored to their roles. Using these decoupled interface tools, users can choose the scale and presentation level of information on a common display to highlight particular aspects of the overall engagement. In this way, the Virtual Battlespace facilitates not only a user's ability to view and understand the battle but also provide a means to control it.

SYSTEM ARCHITECTURE

This section discusses some of the design goals and decisions made in developing the Virtual Battlespace. Figure 2 presents a subsystem level diagram of the system architecture showing the relationships between its major components. In this diagram, the flow of data is from bottom to top. Data streams originate either from a simulator or a mission participant, flow through the data stream managers to the proxies, which are then displayed to the user.

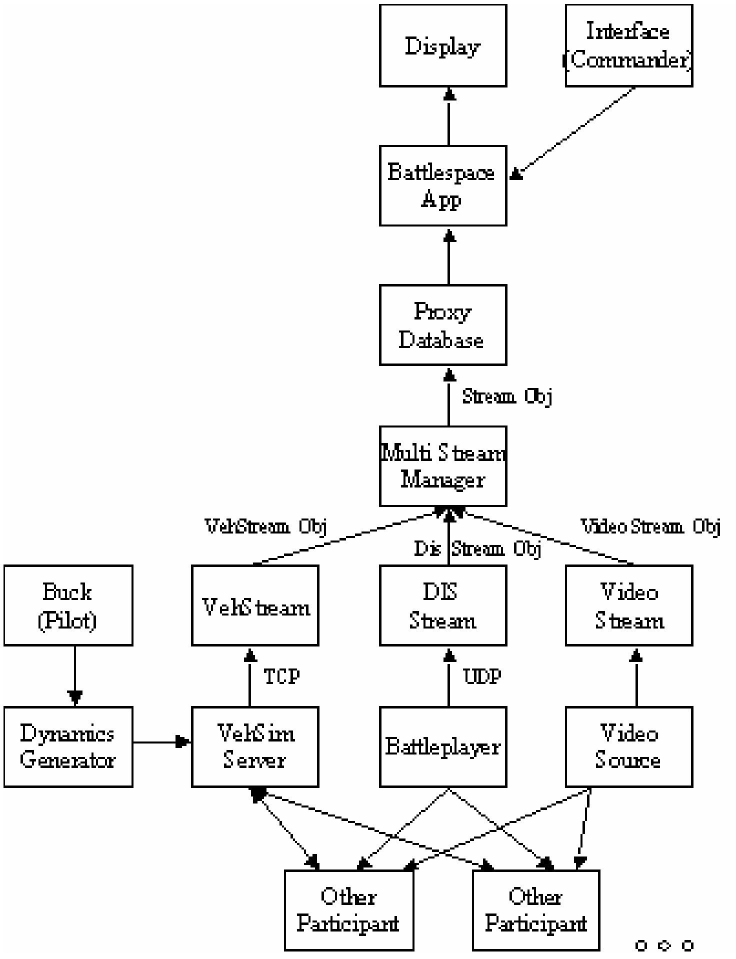


Figure 2: Virtual Battlespace Subsystems.

An individual data stream is a connection to a data source that produces a time-series of data packets. This time series is processed by a stream manager to create time-stamped entries in the proxy database. The data proxies encapsulate common interfaces for data types which are displayable within the battlespace system. New streams of data are incorporated by specializing one of the Virtual Battlespace's defined data proxy interfaces, allowing for stream specific manipulation of entity or battle level data while facilitating its display within the common interaction environment. The proxy interface provides the rest of the system with a common set of object interfaces, that insulate the system at large from specific data stream encodings. This approach allows the system to incorporate disparately defined data streams more easily.

INFORMATION STREAM MANAGEMENT

Central to the Virtual Battlespace is the ability to fuse diverse data streams into an integrated display. This requires a system that allows incorporation of undefined data formats, while simultaneously creating a set of information display tools that can be used to display information from a variety of sources in a common way. In addition to allowing the incorporation of highly flexible, integrated streams such as High-level Architecture (HLA) streams [6], the Virtual Battlespace had as a further design goal, that the addition of non-HLA streams had to be easy and straightforward. This goal is achieved through the implementation of an application-level stream manager responsible for integrating multiple data streams and provide a common set of internal interfaces for data interaction. This critical component, the Multistream manager, manages the process of conversion of raw stream data into stream object data.

A stream of data can be generated by several diverse sources such as a simulated force geneator like Joint Semi-Autonomous Forces (JSAF), or a live sensor such as a radar feed, or a multimedia signal such as audio or video. The streams need not have a common format. The multistream manager is responsible for fusing these disparate, dynamic streams into a coordinated complex of data objects which can be interfaced in a common way by the rest of the application. In the current implementation of the system, a video stream, multiple Distributed Interactive Simulation (DIS) streams [6] and a proprietary vehicle simulation stream (VehSim) [7] are fused by the Multistream manager into a coordinated data feed.

The VehSim stream is the output of a human-in-the-loop vehicle simulation containing a time series of vehicle data including position, acceleration, and orientation. The simulator takes the inputs from the human and uses a dynamics engine to generate time-stamped vehicle data. This data is then sent via TCP/IP as the VehSim stream. The VehSim protocol supports a small number of simultaneous vehicles updated at a high frequency. The opposite of this stream in behavior is the DIS stream. This stream sends DIS packets across a UDP connection and is capable of handling a large number of individual entities, each updated at a low frequency. In the Virtual Battlespace, the DIS stream is generated using a JSAF scenario builder and is used to generate the bulk of the battle participants. The final stream implemented is a simple video feed. The Multistream manager allows a video stream to be integrated into the overall time stream, coordinating when and for how long each frame is played, and where it is to appear. The video stream can be either a live video feed, or a series of stored clips.

PROXY DATABASE

The graphical elements used to display the data streams are a major component of the system. They not only portray the physical attributes of entities in the Virtual Battlespace, such as relative position, orientation, status and speed, they also portray derived attributes such as prior and future paths or sensor and threat ranges. To maintain the system's flexibility with respect to the format of the input streams, the display of the data streams are separated from the management of the streams and from the base application.

Entity proxies provide the application with a uniform interface to individual entities, independent of the data stream the proxies were generated and updated from. This means that a proxy generated from a flight simulator stream can be displayed with the same graphical components as an entity generated from a DIS stream. This approach simplifies the interface not only between the application and the proxies, but also between the user and the entities. The user has no direct knowledge of the number of different information streams are driving the system. All graphical functionality is expressed in terms of a common interface which all entity objects support. This allows entities represented by disparate data streams to be treated uniformly by the remainder of the application.

An example of this approach is in the implementation of the VehSim Proxy and DIS Proxy. The VehSim and DIS streams represent similar information, but at widely differing update rates, referencing distinct coordinate systems. The proxy implementations for each stream encapsulate the transformation of this information into a common representation and common coordinate system. The base implementation of proxy provides methods to support graphical entity display based on the rest of the proxy interface. However, derived proxies can override these basic definitions to define type specific behaviors if need be.

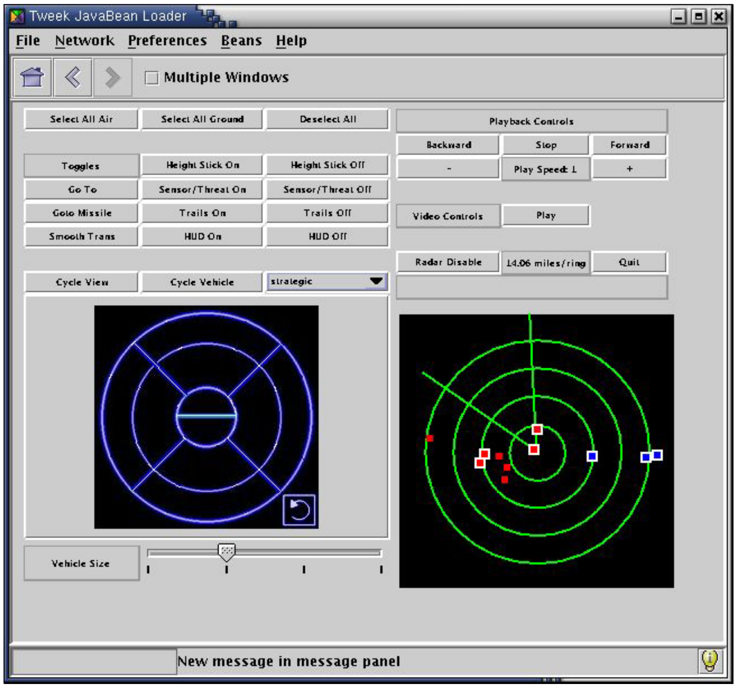
Another important aspect of the proxy database is that it supports the display of aggregate representations of groups of entities. These aggregate objects suppress the individual entity representations to reduce information overload. This allows, for example, flights of aircraft to be displayed as composite entities to simplify a commander's view of a battle. The recursive nature of the proxy model allows aggregation at arbitrary levels by supporting aggregates of aggregates.

USER INTERACTION

The typical approach to user interface in immersive applications is a combination of gestural or positional interaction, combined with graphical display cues such as three dimensional menus and selection rays [8]. These interfaces support illusion of immersion by allowing users to interact directly with virtual objects. However, as the complexity of the application increases, the virtual metaphor must be augmented.

For the Virtual Battlespace to be effective, users must be able to interact with the simulation to accomplish a wide variety of tasks such as navigation, view scale, aggregation, and selective information display. While some of these tasks are compatible with the usual immersive interface methods, many others are not. The Battlespace user needs a wide variety of interaction mechanisms that are intuitive yet provide access to a large number of configurations options. Furthermore, while much of the useful information in a battlespace can be conveyed graphically or iconically, sometimes there is simply no substitute for text. In these cases, immersive displays are handicapped because their display resolution is typically not sufficient to simultaneously display graphics and text.

The Virtual Battlespace system uses a combination of two modes of user input. In addition to the gestural navigation and graphical selection interfaces typical of immersive environments, the Virtual Battlespace allows participants to interact wirelessly with the simulation via personal interface devices (PDAs, tablet computers, or other java-capable devices). This is accomplished via an extension to VRJuggler (see below) known as Tweek. Based on CORBA as a remote procedure call mechanism, Tweek allows Java interfaces running on personal interface devices to communicate with the Virtual Battlespace. The Virtual Battlespace registers an interface that allows two-way communication between these devices and the application. Using this interface Java applications can give remote commands to drive the Virtual Battlespace application or issue queries to obtain status information. Because the interface is decoupled from the application, it is straightforward to provide custom simultaneous interfaces for multiple participants. Figure 3 shows a picture of a Virtual Battlespace's Java interface implemented on a tablet PC via Tweek.



New message in message panel

Figure 3: Virtual Battlespace User Interface.

With this interface, users can navigate through space, select entities via the interactive radar screen, and perform actions on those entities such as toggling graphical features. Some of these graphical features include height sticks, sensor sweeps, threat zones and heads up displays. This interface not only provides the user the ability to interact with the application but it also provides information to the commander about the Virtual Battlespace. The java-based interface complements the typical immersive interface well. The display devices are portable and non-intrusive yet provide crisp display of detailed information. The java-based interface can support much greater complexity and yet remain very intuitive to a user because it uses familiar paradigms displayed on a device familiar to the user.

SYSTEM IMPLEMENTATION

The Virtual Battlespace is a VRJuggler application [9]. VRJuggler is a platform for the development of virtual reality applications that provides developers with the ability to use a single source code base to support a broad range of VR devices, from desktops and head-mounted displays to Powerwalls and Caves. VRJuggler abstracts I/O devise to allow the applications developer to focus the application and not the VR device configuration. VRJuggler is offered under an open source license.

Since it is built on VRJuggler, the Virtual Battlespace supports all of the immersive display devices found at the Virtual Reality Applications Center (VRAC) at Iowa State University. In addition to desktop and head-mounted displays, VRAC has several large scale immersive environments which have been used as testbeds for the Virtual Battlespace.

VRAC most immersive device is the C6 (Figure 4), a 10’ x 10’ x 10’ room on which stereo images can be projected on all four walls, and the floor and ceiling. The result is a totally immersive 360 degree field of view. The C6 is driven by a SGI InfiniteReality2 system and achieves a frame rate of approximately 40 Hz. Users inside of the C6 are tracked by a wirelesss Ascension Flock-of-Birds tracking system. The wireless tracking system leaves the user free to move about untethered.

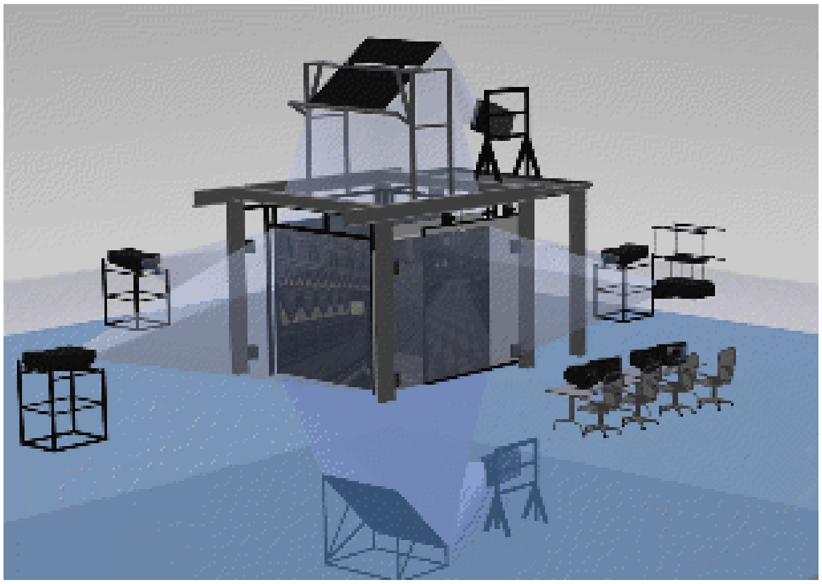


Figure 4: C6 Immersive Display Device.

The sister system of the C6 is the C4 (Figure 5). The C4 has four display surfaces measuring 12’ x 12’ x 10’ and is driven by an SGI InfiniteReality system. It is a flexible system that can be configured so that the walls may open to form a 36’ Powerwall or close to form a traditional Cave configuration. Both of these systems were developed for VRAC by Mechdyne [10].

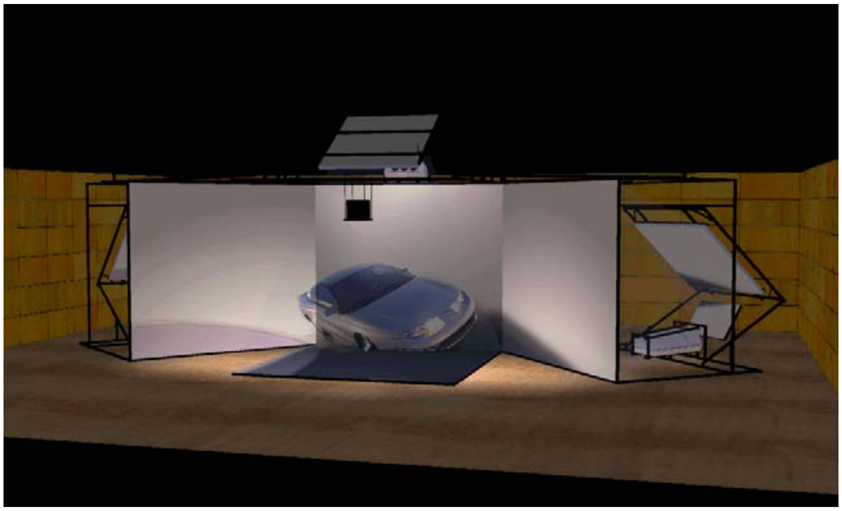


Figure 5: C4 Immersive Display Device.

A third Cave device (Figure 6) at Iowa State employs three display surfaces measuring 8’ x 8’ x 8’. These surfaces are a center wall and two side walls angled at 30 degrees. This cave is driven by a cluster of six Dell PCs running RedHat Linux.

Figure 6: “Baby” Cave.

In addition to the image generation resources required by the Virtual Battlespace are the networked computing resources which generate the various streams of incoming data. For example, VehSim streams representing individual ground vehicles and aircraft are generated by Windows-based vehicle dynamics engines, while the JSAF forces may be simulated on either Linux or Irix resources. The Virtual Battlespace supports a wide range of input devices including, for example:

- a Microsoft Sidewinder Steering wheel and pedals for ground vehicles,
- a Microsoft Joystick for air vehicles,
- a variety of physical bucks for ground or air vehicles,
- several wireless-enabled personal interface devices (PDAs and Tablet PCs).

FEATURES

Consider a scenario involving an engagement between Red team and Blue team. Blue team is tasked with destroying Red team’s headquarters located in Nellis Air Force range in Nevada. The Red team headquarters is defended by two SAM sites and five squadrons of fighter aircraft. Blue force consists of seven groups of aircraft. When the engagement is viewed strategically, these groups of aircraft are shown as aggregate entities and are scaled greatly to be visible from a long distance. The aircraft aggregates appear as symbolic entities but are placed in the space at the correct position height.

When the application starts, the user is presented with a view that encompasses the entire engagement. In addition to the terrain and the units engaged, the user is also presented with an information “billboard” – so called because it appears across the top of the display no matter where the user navigates (see Figure 7).

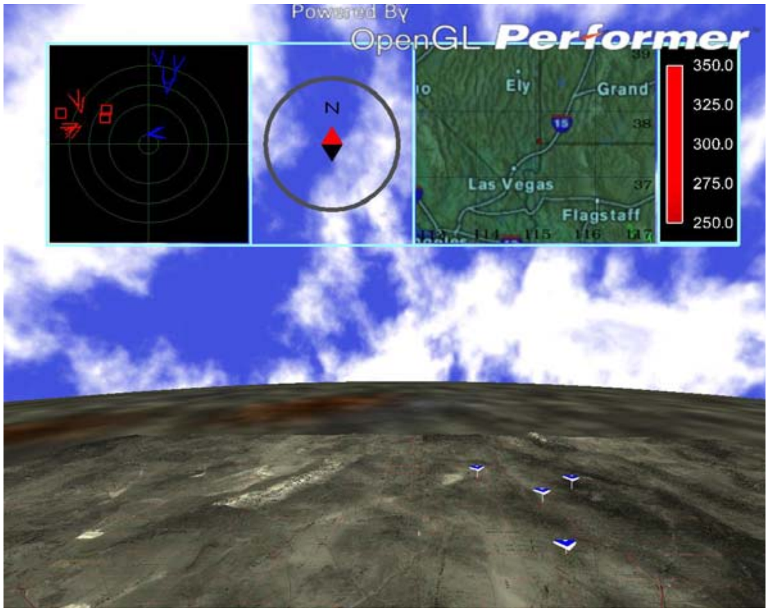


Figure 7: Billboard Battle Information Display.

The billboard allows for the presentation of multiple simultaneous information channels. These may include symbolic views of the battlespace, such as synthetic “radar” screens, maps indicating additional features of the battlespace not contained in the main terrain display, orientation aides, and graphical keys.

The individual entities use a variety of graphical methods to display information about their status. For example, in addition to position, orientation, and velocity, entities in the space can also leave a colored trail indicating where they have been or where they may be targeted to go. The configuration of these additional display mechanisms is controlled by one or more users through the decoupled java-based interface. Using this interface, the user is able to navigate through the battle and focus on areas of interest. The interface can also be used to select entities by position, call sign, or type, and reconfigured to display additional attributes. For example, as shown in Figure 8, the Blue team lead sensor sweep reveals which Red team units are within the range of the Blue team’s “vision”.

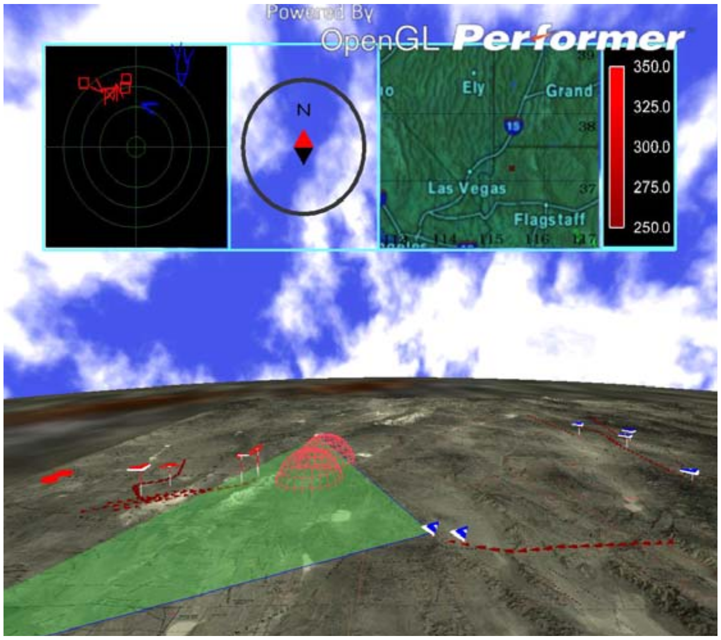


Figure 8: Sensor Sweep.

The virtual Battlespace incorporates a variety of points of view to allow users to gain useful perspectives on simulated engagements. Figures 7 and 8 depicted the battle from a long range (or strategic) point of view. Units are displayed symbolically at size consistent with the unit's importance, rather than its physical distance. Figure 9 shows an alternative view that combines a realistic first-person entity perspective with symbolic, but physically accurate representations of ranges of threat. This allows a user to adopt a tactical perspective combining the participant's first-person view with battle-level sensor information or other abstractions.

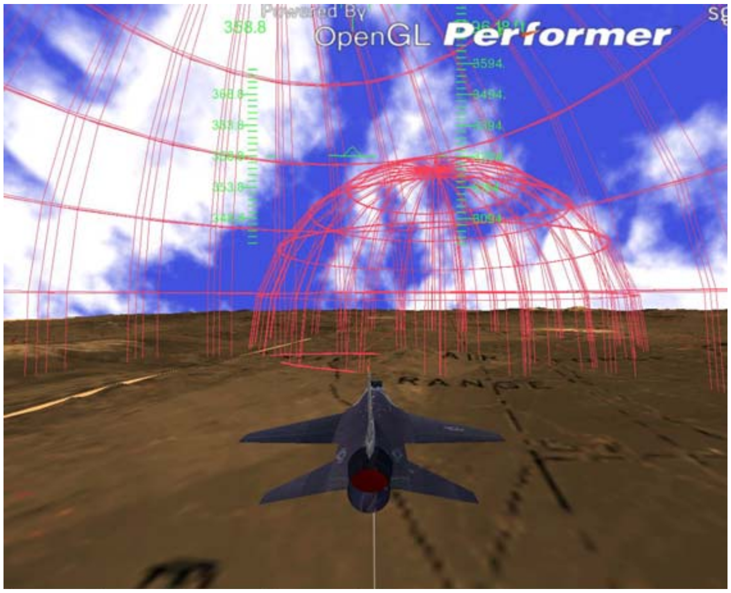


Figure 9: First Person.

The position and status of ordinance can also be tracked either globally or individually. The results of weapon-based video feeds can be displayed in the billboard while simultaneously displayed as battlespace graphics in the virtual depiction.

Because all the data streams accessed by the Virtual Battlespace pass through the Multi-stream manager, recordings of the engagement are easily made. These recordings can be replayed through the Virtual Battlespace with a VCR-style interface allowing the user to replay portions of the engagement at any speed. Unlike a video recording, the playback is fully flexible, allowing the user to reconfigure in real time all aspects of the information displayed.

FUTURE WORK

We plan to continue development of the Virtual Battlespace along several lines: to increase deployability, broaden its applicability, and enhance display quality.

While the technologies underlying the Virtual Battlespace have been carefully chosen to facilitate the application's portability, the computational complexity of the display, the size of the data streams and the time demands of the system make deploying the system on commodity level hardware a challenge. To address this challenge we are focusing on the development of a Linux-based implementation of the system that uses a cluster of commodity PC's as image generators and simulation engines. This work is based on recent extensions to the VR Juggler platform that simplify some of the complexities of synchronizing multiple image generators with simultaneous, time critical input sources [11]. With the cooperation of the 133rd ACS , we look forward to integrating a more deployable version with their MCS control module to allow immersive visualization of a combination of live and simulated sensor feeds.

To broaden the system's applicability, we will be incorporating a wider array of data input streams, including additional sensor streams as well as more sophisticated voice and video streams. Part of this work will be devoted to integrating these streams with the Multi-stream manager, but the larger effort will be the extension of the display and user interface systems to effectively integrate these information streams into the overall system to add to the user experience without cluttering the display or otherwise overwhelming the user. Among the data streams we are considering are additional sensor streams and weather information such as temperature and wind conditions.

We also plan to continue to enhance the visual quality of the display, by experimenting with new ways to represent units, terrain, sensors and threats at various levels of detail. We are continuing to enhance the graphics to add realism to first-person views and explore other visual enhancements that improve upon the immersive character of the application.

We are also interested in experimenting with the Virtual Battlespace as an interface for real-time command and control of simulated, automated and even live units. The ability to command and control units in real time will greatly enhance the Virtual Battlespace as a tool for training, command and scenario planning. The vision is to empower a user to communicate to any entity on the battlefield, whether computer generated or human controlled.

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