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Battlefield Visualization on the Responsive Workbench

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Abstract

In this paper we describe a battlefield visualization system, called Dragon, which we have implemented on a virtual reality responsive workbench. The Dragon system has been successfully deployed as part of two large military exercises: the Hunter Warrior advanced warfighting experiment, in March 1997, and the Joint Counter Mine advanced concept tactical demonstration, in August and September 1997. We describe battlefield visualization, the Dragon system, and the workbench, and we describe our experiences as part of these two real-world deployments, with an emphasis on lessons learned and needed future work.

Keywords: Battlefield Visualization, Responsive Workbench, Virtual Reality, Virtual Environments

1 Introduction

When fighting a battle, commanders must analyze and understand current and future combat situations in order to make good strategic decisions. This problem, which is as old as warfare itself, is referred to as ***command and control***. In addition, commanders must plan and evaluate possible future strategic force movements, an operation referred to as ***planning and shaping***. Currently, both activities are accomplished with paper maps of the battle area placed under sheets of acetate. Technicians receiving intelligence reports from the field depict the changing situation with grease pencils. Commanders may then plan various scenarios by drawing additional symbology on the map.

This is a cumbersome, time consuming process: detailed maps and overlays can take several hours to print and distribute. The fast-changing modern battlefield frequently produces so much time-critical information that the above manual techniques are inadequate for properly visualizing the battlespace. At the Naval Research Laboratory, we have developed a virtual-reality battlefield visualization system, termed ***Dragon***, which is implemented on a virtual reality responsive workbench. We have found the workbench to be an effective virtual reality interface for a battlefield visualization system.

In this paper we briefly discuss the battlefield visualization problem. We describe the workbench and review relevant work done to date. We follow this with a brief discussion of various design issues and tradeoffs we considered as we developed Dragon. We then describe using the system as part of two real-world, large-scale military exercises, and point out many of the lessons learned.

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2 Battlefield Visualization

Despite the advent of computers and sophisticated decision-making software in combat operation centers, the military still undertakes battlefield visualization predominantly with paper maps and acetate overlays. This is a hold-over from the days when reports from the battlefield arrived at the combat operations center exclusively by voice over a radio network. A radio operator at the center received the verbal report, and then translated the information into symbology that was hand-drawn on a paper map. Currently, this same data is sometimes entered by hand into a computer system, where it can be used by computerized battlefield visualization systems. Obviously this is a time-consuming process, with many opportunities for introducing error into the data stream.

New advances in distributed, encrypted digital data links allow combat units to report to the combat operations center using computer networks in place of voice radio links. The intelligence data is now available directly in a digital format. No time or manpower is wasted translating the data from voice report to computer input. Avenues for introducing error are also reduced to just the original reporter in the field. However, current combat operations centers do not take full advantage of this digital data. Time and manpower is spent monitoring this digital data stream and translating it into symbology on a paper map.

3 The Responsive Workbench

The Naval Research Laboratory's virtual reality responsive workbench [6, 10] provides a three-dimensional display for observing and managing battlespace information. The workbench provides a natural metaphor for visualizing and interacting with 3D computer-generated scenes using a familiar tabletop environment. Applications which traditionally require personnel to collaborate around a table are excellent candidates for using the workbench. Since 1994, the Naval Research Laboratory has successfully developed workbench-based prototype systems for medical planning and training [8], simulation based design, and battlefield visualization for planning and shaping as well as command and control [1, 9].

4 The Dragon System

The Dragon battlefield visualization system runs on a virtual reality responsive workbench. The system displays a three-dimensional representation of the battlespace (see Color Plates), which includes a terrain map, entities representing friendly, enemy, unknown, and neutral units, and symbology representing other features such as obstructions or key points in the plan of operations. Entities are represented both by schematic models as well as standard battlefield visualization symbols. Dragon receives electronic intelligence feeds which relate each entity's current status, including such information as position, current speed and heading, current damage condition, and so forth. As these reports are received, Dragon updates the corresponding models on the map. Users can view the battlespace in either monographic or stereographic mode, and navigate to observe the map and entities from any angle and orientation. They can also query and manipulate the entities.

4.1 Interaction Techniques

A fundamental design decision for any virtual environment is how users navigate through the environment and interact with objects in the environment.

4.1.1 The Virtual Laser Pointer

The Naval Research Laboratory has developed three general interaction methods for the workbench: gesture recognition using a pinchglove [7], speech recognition, and a hand-held joystick. We considered using each of these as an input device for the Dragon system. Although an interesting avenue for virtual environment interaction, we deemed the speech recognition technology to be too immature for battlefield visualization. We also found the pinchglove problematic — it is fragile, time-consuming to pass from user to user, and only works for right-handed users whose hands are approximately the same size. In contrast, the hand-held joystick is relatively robust and very quickly handed from user to user, and works for both right- and left-handed users.

For the Dragon system we modified a three-button game joystick by removing it from its base and placing a six degree-of-freedom position sensor inside. The joystick's position and orientation are tracked relative to an emitter located on the front center of the workbench. The interaction metaphor for this joystick is a ***virtual laser pointer***. We imagine that a laser beam comes out of the front of the joystick and enters the virtual environment. Our system renders this beam as another virtual object (see Color Plate 3). Where the beam intersects the terrain or objects, a highlighted marker appears.

4.1.2 Navigation Metaphors Investigated

Using the virtual laser pointer as an interaction device, we implemented and field-tested two virtual environment navigation metaphors.

One metaphor, termed ***map-centric navigation***, was based on how users interact with a real physical map placed on a table surface. Various button combinations produce three navigation modes: pan, zoom, and pitch/yaw. For each mode, the map mimics the motion of the joystick. That is, the map acts as if it were attached to the joystick: a motion along a vector by the joystick causes the map to move by that same vector. For this metaphor the user makes a zero-order control gesture — that is, the magnitude of the user's gesture controls the ***distance*** of the virtual motion. This means that, for example, when panning from one side to the other of a zoomed-in map, the user must make repeated panning gestures, each of which translates the map a distance equivalent to the length of the user's gesture.

The other navigation metaphor we investigated, termed ***user-centric navigation***, was loosely based on the metaphor of a user flying above the map as if in an airplane. Various button combinations again produce three navigation modes: pan/zoom, pitch/yaw, and rotate/zoom. For the user-centric navigation the user makes a first-order control gesture — that is, the magnitude of the user's gesture controls the ***velocity*** of the virtual motion. This means that, for example, the user can fly from one side to the other of a zoomed-in map with a single gesture.

4.1.3 Object Manipulation

The user interacts with all entities on the map with the virtual laser pointer. The user selects an entity simply by pointing at it. Entity selection is denoted by drawing a blue wire frame sphere around the entity (see Color Plate 3). When an entity is selected, a window pops up on the right side of the workbench with all of the known information about that entity gathered from the system. By pressing a button on the joystick, the user can pick up a selected entity and move it around the virtual environment.

4.2 Models and Symbology

We use two different schemes for representing entities on the map (see Color Plates 2 and 3). For some entities we used Intelligence Preparation of the Battlefield (IPB) symbology [5]. This is a military-standard set of symbols representing both force units (e.g. companies of troops) as well as particular areas or locations (e.g. a *named area of interest* or a *targeted area of interest*). Since we needed 3D objects that were visible from oblique angles, we extruded the 2D symbols into cubes, and texture-mapped the symbols onto each face (for example, in Color Plate 2 the boxes marked with blue and red "x's" represent troop squads). For other entities, such as tanks, ships, and planes, we used realistic 3D models, both because we felt that an operator would be able to rapidly identify a realistic model based on shape and coloring, and because the IPB standard lacks symbology for specific pieces of hardware.

When rendered at a real-world size the entities all quickly became invisible as the user zooms away from the map (see Color Plate 1). Therefore, we provided a user-controllable scaling factor for all entities. In addition, most of the entities were represented at multiple levels-of-detail, which increased rendering efficiency. Finally, some entities supported multiple model versions representing variants on the basic chassis, such as a command variant, as well as various levels of damage.

Entity allegiance was multiply encoded using color, shading, and textures. Friendly units were lighter hued or blue in color and contained at least one American flag somewhere on the unit. Enemy units were darker or red in color and flew a skull and cross bones flag. Although to date the exercises where we have used the Dragon system have not required it, it is necessary to develop an additional encoding for unknown, neutral, and civilian units.

4.3 Data Feeds

Currently, the US military typically uses the Global Command and Control System (GCCS) [2] for collecting, storing, visualizing, and interacting with data coming from the field. This data is also occasionally translated into the Distributed Interactive Simulation (DIS) [4] format for use in military simulation systems such as the MODular Synthetic Armed Forces (MODSAF) system [11]. DIS systems are often used to simulate the outcome of a given situation and plan. Both systems provide position and status information for each entity in the battlespace.

Dragon can receive data feeds in both GCCS and DIS formats. Additional information, such as planning symbology, special enumeration of features, and hazards on the battlefield are hand placed by the user, either interactively or through a simple text file.

5 Lessons from the Field

The Dragon system and the workbench have been successfully deployed as a prototype system at two different military operations during the past year: the Hunter Warrior advanced warfighting experiment in March 1997 and the Joint Counter Mine advanced concept tactical demonstration in August and September 1997 [1].

The intent of the Hunter Warrior demonstration was to prove the potential of using a workbench-based battlefield visualization system to provide situational awareness as well as support for conducting planning and shaping operations. The workbench was positioned in the planning and shaping section of the combat operations center and used continuously to brief VIPs, both civilian and military. The commanders were very impressed by the ability to visualize the current operating picture accurately and efficiently on the workbench, especially when compared to the traditional but manpower- and time-intensive technique of using a paper map with acetate overlays.

The intent of the Joint Counter Mine demonstration was to showcase the potential of the workbench to another user community within the military that was concentrating their efforts on command and control of units in a highly congested operation area. For this exercise, the workbench displayed the ongoing simulation of new tactics and equipment for overcoming enemy mines.

5.1 Data Feeds

The GCCS-M system (the Marine variant of GCCS [2]) was used during the Hunter Warrior advanced warfighting experiment. Units in the field created digital report messages on Apple Newton personal data assistants, which in turn were linked back to the combat operations center by a radio wide-area network. The messages were parsed into a form that could be used by GCCS-M. The Dragon system received update reports from GCCS-M at regular intervals or upon user demand. Dragon parsed the GCCS-M data stream for unit type, positional data, and the last textual message sent from the unit (see Color Plate 3). Since the source of the GCCS-M information stream was from units in the field entering data, the data feed on individual entities was very irregular and sparse, resulting in “jerky” entity movements.

The DIS protocol [4] was used at the Joint Counter Mine demonstration. Although the data feed per unit was also irregular, because DIS contains a built-in protocol for dead reckoning, the entity movement was smoother and less distracting than it was at Hunter Warrior. This demonstrated that a workbench-based battlefield visualization system could also effectively provide situational awareness for a simulated military environment.

5.2 Interaction

We initially thought that a battlespace visualization system only required a map-centric navigation metaphor. We based this decision on our observations of how users interact with maps in the combat operations center. In reality, the Dragon system and workbench create a very rich environment in which users can do much more than just move a map. They can actually experience the environment by visually sizing up terrain features, entity placement, fields of fire, lines of sight, etc. Map-centric navigation worked well when globally manipulating the environment and conducting command and control operations on large-scale units. However, when small-scale operations were being examined, the operators wanted to be able to “fly” over the terrain and even get down to a first person viewpoint as if they were a person walking around on the ground. Map-centric navigation did not lend itself to conducting these types of operations in an intuitive way, which encouraged our development of the user-centric navigation metaphor.

The Dragon system lets the user select either a monographic or a stereographic view of the battlespace. In these exercises we observed that users chose the monographic mode much more often than the stereographic mode. We believe there are three main reasons for this: 1) the display technology currently only supports one (or at most two) stereo users, 2) stereo is fatiguing to the user, and 3) the environments for both military exercises were both relatively flat, and thus the improved depth perception from the stereographic mode was not as important as it may become in more geographically varied environments.

5.3 Visualizing the Battlespace

Displaying thousands of entities on a textured terrain map is a difficult visualization problem. In particular, it is difficult for a user to discriminate between various battlefield entities. Mitigating this problem has required experimentation, which has taught us several valuable lessons.

Camouflage: Many of our early 3D entity models had realistic camouflage texturing. Friendly units had lighter camouflage patterns and enemy units had darker camouflage patterns. This was often too subtle of a difference for differentiating between friend and enemy. In addition, the first terrain texture maps chosen contained a significant component of green, thus providing an ideal background for the camouflaged models to blend into. This, combined with the difficulty of picking appropriate model sizes, made it difficult to locate and identify the models on the terrain surface. One solution was to use a gray-scale texture map for the terrain. This highlighted the camouflaged models greatly, but reduced the ability to display terrain information using color as the discriminator.

Model Variation: There are usually multiple variations on a given military hardware entity. For example, an amphibious assault vehicle might come in a troop carrier configuration, a command and control variation, or an attack configuration complete with a light cannon. A battlefield visualization system must be able to visually differentiate between the different configurations of each entity. A related problem is that the ability to differentiate between entities can become difficult if the external appearance between two models is too similar. This calls for more modeling than we provided with Dragon, potentially with a standard model format that supports multiple variations within each model.

Scaling and Aggregation: There are obvious problems with attempting to display every individual entity in the battlespace. One solution is to aggregate individual units into larger hierarchical units [3]. Another solution is to scale the entities up as one zooms out, and down as one zooms in. However, scaling makes the aggregation problem even worse, as even distant entities will eventually intersect if one zooms out far enough. Further, the models will occlude the terrain beneath, and with a large size, it is difficult to ascertain a model’s true position.

These are all very difficult visualization problems for which we do not yet have adequate solutions. Symbology, standard or new, may help with entity identification, scaling, and aggregation. However, it is critical that we do not transfer negative information. Any display metaphors must be thought out in detail and potential problems clearly documented and then understood by the user.

5.4 Impact on Battlefield Visualization

Visualizing the battlefield with the traditional paper map, acetate overlays, and grease pencils has served military commanders well for many years. However, the labor- and time-intensive procedures required to create and maintain these maps translate into expensive and out-of-date information being placed in front of the commander. In addition, the modern battlefield is producing ever more data at an ever-quicker rate. Finally, the modern combat operations center contains too many consoles displaying too much specialized information. The result is both information overload and information fragmentation. Clearly, traditional methods for battlefield visualization need to be improved.

GCCS-M is a partial solution to these problems. This system interfaces with some of the battlespace information gathering systems, and it does have the ability to display its results graphically.

However, the display is two-dimensional and is easily cluttered. We found the general opinion to be that the GCCS-M user interface is cumbersome and difficult to use.

The goal of Dragon is to improve battlefield visualization by using visualization techniques. In pursuing this goal we have extended battlefield visualization into three dimensions, represented entities by both symbolic and realistic three-dimensional models, displayed the results on a responsive workbench, and provided an intuitive interface for navigation and entity manipulation. We have also provided a system that integrates the output from several data feeds into a uniform representation presented on a single display surface. To date our field experiences suggest that Dragon is a superior battlefield visualization platform, compared to both the traditional map-with-overlay method as well as 2D battlefield visualization systems such as GCCS-M.

6 Conclusions and Future Work

Battlefield Visualization in the support of command and control as well as planning and shaping activities is a very difficult problem, but one that has potential for a large payoff. From our experience with Dragon we have come up with a number of areas for future work:

- It is necessary to conduct a formal task analysis to understand what different users in the combat operations center are trying to accomplish, how each task is currently accomplished, and finally how a visualization system can assist in accomplishing the tasks more quickly, with less manpower, and with a greater level of accuracy. A careful task analysis should identify key defaults that can be used to specify everything from how a query result should be displayed to what color scheme should be used.

- It is necessary to conduct user studies to investigate all the usability characteristics of the Dragon system, with an eye towards understanding user preferences and improving the user interface. Such a series of user studies is currently underway, with an emphasis on navigation techniques.

- Any battlefield necessarily deals with ***uncertainty***, and it is necessary to determine ways to represent and encode the confidence level that exists for each piece of battlefield data. For example, as the last reported position of an entity ages, the uncertainty of where the entity is currently located grows.

- Time must also become a part of a battlefield visualization system. This might be used to play back the previous 24 hours or to store and review the plans for the upcoming 24 hours.

- Distributed computing is the direction in which all military systems, but especially the Navy and Marines, are moving. This will include remote collaboration as well as distributing the work load across multiple platforms.

- The system must support more data feeds, including new as well as legacy systems. In the combat operations center there are still too many consoles with specialized users doing very narrowly defined tasks. Military commanders at the exercises we attended made it clear that a system capable of visualizing the output from a multitude of legacy systems in a single, consistent display and interface is desperately needed by today's combat forces.

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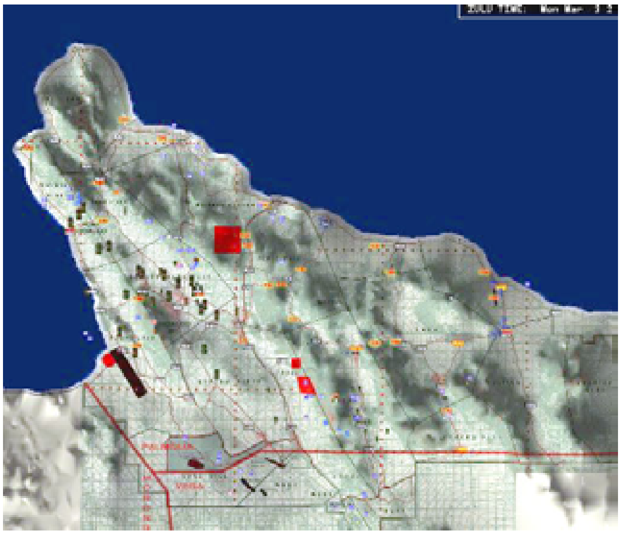

Color Plate 1: An overview of the map.

Color Plate 2: Entities represented as models and symbols.

Color Plate 3: An entity is selected.

Color Plates: Screen Shots from the Dragon Battlefield Visualization System.