Projects in VR

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Shipboard VR: From Damage Control to Design

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Virtual reality efforts in the Information Technology Division of the Naval Research Laboratory (NRL) span mission planning, rehearsal, and execution; simulation-based design; and medicine. We devote much of our work to ship-based applications, presenting two such efforts in this article. One project focuses on experiments in shipboard firefighting to verify the effectiveness of VR as a mission planning tool. The other project involves visualizing a preliminary design of a new Navy ship. Since that work did not extend into the actual design cycle, we can't quantify the results in terms of hours gained or costs saved. However, the design team and the program managers agreed that the VR visualization was worthwhile and provided a better understanding of the design.

Firefighting and damage control

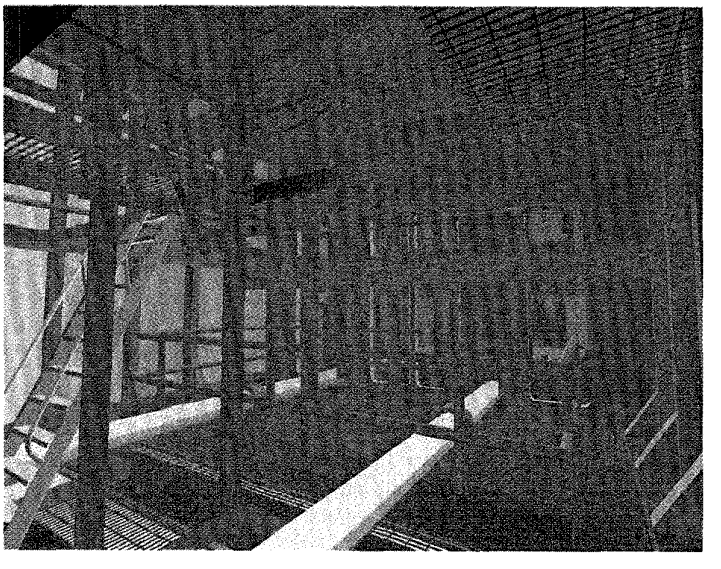
Shipboard fires are a more serious problem for the Navy than the risk of a ship sinking. Such fires can spread very rapidly and generate extremely high temperatures. Shipboard survivability depends on effective firefighting, with a few critical seconds determining success or failure. Training Navy firefighters is expensive and practice opportunities are limited, making VR well suited for the task. By modeling a variety of ships, we can let firefighters familiarize themselves with ships or parts of ships where they have little or no actual experience.

VR training should allow firefighters to concentrate on firefighting rather than on navigating the environment. Inserting virtual fire and smoke into the virtual environment helps to create a virtual environment in which firefighters can practice standard procedures, test tactics, and try out strategies without endangering personnel or property. Since Navy firefighters are trained in firefighting procedures, the virtual environment is less a training tool than a mission preparation aid.

The Navy uses the ex-USS *Shadwell*, a decommissioned ship maintained by NRL off Mobile, Alabama, as its full-scale fire and damage control research, development, test, and evaluation platform. Testing firefighting personnel in real-life scenarios aboard the *Shadwell*, the Navy has demonstrated that successful firefighting depends on familiarity with the neighboring compartments and the ability to operate under limited visibility conditions.[1]

Initial modeling

To demonstrate VR for shipboard firefighting, the VR Lab has modeled several portions of the *Shadwell* used for firefighting experiments. Figure 1 shows the first *Shadwell* section modeled. The entire scene contains approximately 9,000 texture-mapped polygons. We modeled complex objects such as the grated walkways and the linked chains that demarcate them as single texture-mapped polygons. An initial demonstration project let users fly through the ship using a "fly where you look" paradigm, with collision detection limited to the model boundaries.



1 A scene from the virtual walkthrough of the USS *Shadwell*.

We have experimented with physically based realism and sound augmentation within this virtual environment. For example, users can reach out, grab a chain, pull it in 3D, and watch it perform the correct motion. The constraint system for the physical motion is based on earlier work by Barzel et al.[2] This system first describes a set of rigid bodies, a set of forces acting on the bodies (such as gravity), and a set of constraints among the bodies. The constraints may be of three types:

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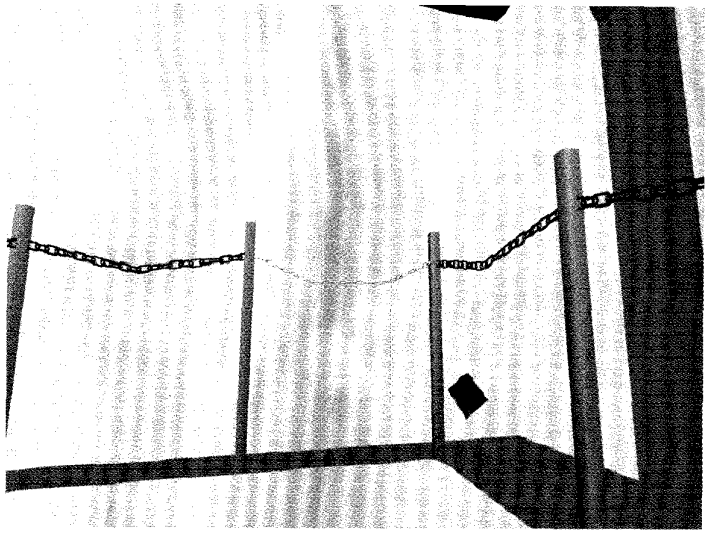
- point-to-point, which attempts to keep a point on one body in contact with a point on another;
- point-to-nail, which attempts to keep a point on one body in contact with a fixed point in space; and
- orientation, which attempts to keep a fixed orientation between two bodies.

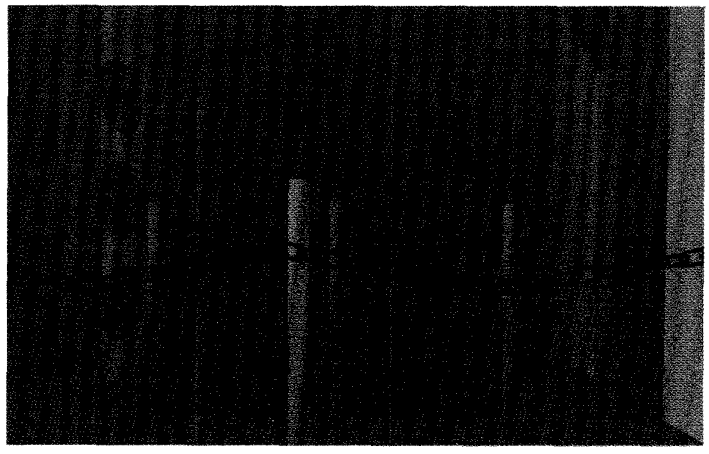
Given the bodies, forces, and constraints, the system then calculates the Newtonian forces necessary to satisfy the constraints at each time step.

Once we implemented the constraint system, we modeled a chain as a set of cylinders connected by point-to-point constraints, with the two endpoints fixed by point-to-nail constraints. To enhance simulation speed, we did not constrain the orientations of the links to prevent interpenetration, and we had each cylinder represent several links. These limitations have only a small visual impact and give a large increase in performance, sufficient to provide near-real-time performance on a Silicon Graphics Onyx computer.

Finally, we added this chain to the virtual ex-USS *Shadwell* environment so that the geometrically modeled chain replaces the texture-mapped chain when the user approaches within a predetermined distance. The user can manipulate the chain by grabbing, pulling, and releasing individual links; the chain responds in a physically realistic manner. We modeled these manipulations by dynamically adding and removing a point-to-point constraint between links and the user's hand. Figure 2 shows a single snapshot as the virtual chain performs its motion.



2 A frame showing the chain deformation as calculated by the constraint algorithms.



3 The *Shadwell* virtual walkthrough with smoke added.

We added 3D sound to the *Shadwell* fire simulation using Crystal Rivers' Acoustetron software. We have found that this helps inexperienced users move rapidly even to a fire they cannot see. Using SGI fog routines, we also added smoke to the environment, as illustrated in Figure 3.

Walkthrough and improvements

In the first *Shadwell* walkthrough, personnel with experience aboard the *Shadwell* felt it gave an accurate representation of "being there." Based on this success, we performed an experiment to evaluate the value of VR for shipboard firefighting. We modeled a second part of the ship, representing an area where a 1995 shipboard experiment with trained Navy firefighters would be performed, with the goal of conducting an experiment with trained firefighting personnel to determine the value of VR in mission rehearsal.

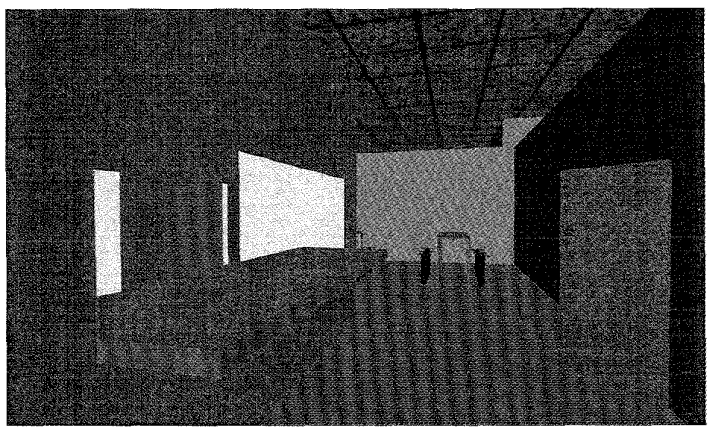
In the new model, we added terrain following and collision detection to restrict users to pathways and have them collide with objects when they walked into a table, locker, wall, or other scene element. A glove avatar allowed users to look around while walking, and navigation followed a "fly where you point" metaphor. Users interactively controlled doors with buttons on a 3D joystick that allowed door motion only when the appropriate button was depressed, thus permitting small movements of the doors.

Accurate 3D models represented many of the shipboard objects, although we used texture mapping for objects such as fire hoses that did not require interaction. A dynamically growing 2D texture-mapped fire simulation provided realistic behavior, and we expanded the smoke model to include distant and nearby effects. Figure 4 shows the fire along with several obstructions.

Statistical analysis of the system

We performed a statistical analysis of these experiments that showed measurable improvement in the per-

4 A view of a simulated fire and obstructions on the *Shadwell* for the shipboard experiment to test the value of VR in mission rehearsal.



5 A section of the arsenal ship as seen through the head-mounted display.

formance of firefighters who used VR for mission rehearsal.[1] In a navigation test, these firefighters performed about 30 seconds faster over a two-minute run to reach a predetermined location. In addition, all members of the traditional training group, given directions to the fire using standard methods, made at least one wrong turn, whereas only one member of the VR training group did so. In a time-critical application such as shipboard firefighting, both traversal time and wrong turns contribute significantly to final success or failure.

The VR training group also performed better on a test involving firefighting tasks. While only a few personnel participated, the combined results indicate that VR provides an environment that lets firefighters familiarize themselves with ships and—with fire, smoke, and physical realism added—practice tactics for firefighting without risking lives and property.

VR for ship design

The Navy is using a fast-track method to develop the arsenal ship, a new ship class that some believe could revolutionize maritime warfare. The Washington Post reports,[3]

> Military officials are pursuing an innovative fast-track method for developing the ship that they hope will save taxpayers money. The Navy is telling the bidder to draw up designs based on bare outlines of the arsenal ship's expected capabilities. The military wants to get the best team by 1998 and get its ship in the water by 2001, a five-year turnaround that is one-third the time needed to develop some Navy ships. In 1992, when the Navy decommissioned its last battleship, the USS Missouri, its 1,700 crewmen cost the Navy $67 million a year in pay and benefits. Thirty sailors on an arsenal ship would cost $1.4 million annually.

Contractors to the Defense Advanced Research Projects Agency (DARPA) will build the ship; Phase One contracts have recently been awarded to competing teams.

The Office of Naval Research (ONR) performed preliminary studies of the ship last year to demonstrate feasibility. As part of this effort, we were asked to take one of the preliminary designs, put it into a virtual environment, and let the designers and the ONR program managers use the resulting VE to visualize the ship. The designers gave us both hull and interior data as Autocad files. The interior of the ship contained rooms only (no detailed machinery, piping, or other features at this stage of design). We thus had only about 4,000 polygons to render for the interior. The hull design contained a larger but still manageable 15,200 polygons.

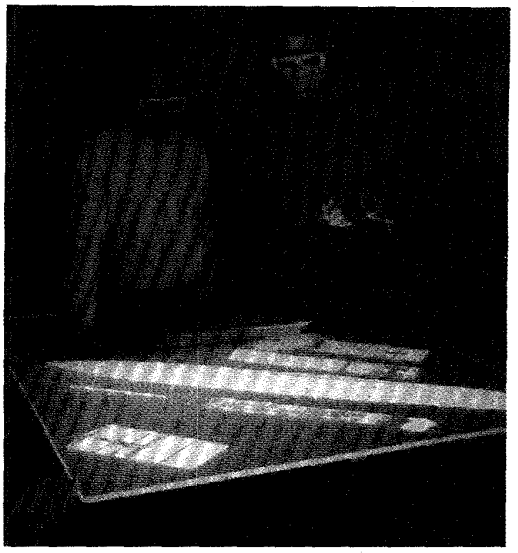
We experienced standard conversion difficulties in going from the design team data to the VE. For readers unfamiliar with the process, typical examples include the following: Line elements did not convert to Wavefront and had to be removed by hand. Our Autocad DXF to Wavefront OBJ file format converter had to be modified to turn line elements with thickness into polygons. For the hull, some normals pointed inward and some outward. Discussion with the design team showed that half of the hull had been treated as a reflection of the other half, but with normals pointing the same way.

We had to edit out repeated objects by hand and add some missing details, such as doors for bulkheads, after consulting with the design team. We also removed overlapping polygons for realistic rendering and added some missing polygons, such as a step in a stairway, after a VR walk-though indicated their absence. Finally, we added graphics attributes (such as color, lighting, and texture maps) to produce the walkthrough. We replicated some polygons, such as walls, to produce two-sided polygons and thus speed up the walkthrough. Figure 5 shows the walkthrough of the arsenal ship, using a head-mounted

display and the paradigms described above.

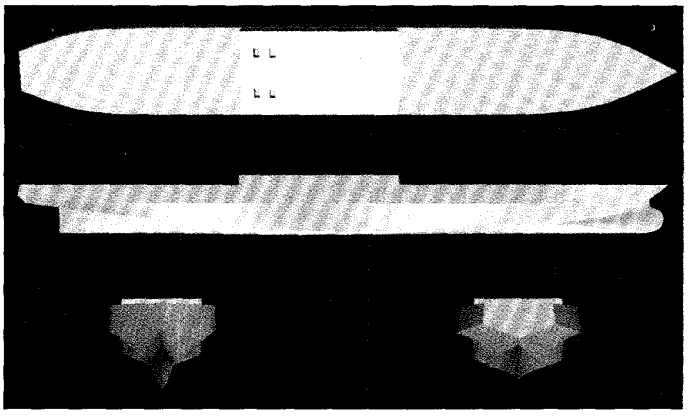
To examine the decks and the hull, we used our lab's Responsive Workbench.[4] This interactive VR environment can support a team of end users such as command and control specialists, designers, engineers, and doctors. The Responsive Workbench matches the real work environment of people who typically work at a table or a workbench as part of their professional routine. For example, a design team could use the Workbench to interactively visualize fluid flow over a ship's hull.

The Responsive Workbench operates by displaying computer-generated stereoscopic images onto a table (workbench) surface. Using stereoscopic shutter glasses, users observe a 3D image displayed above the tabletop. The Responsive Workbench tracks the group leader's head movements to change the view angle. Other group members observe the scene as the group leader manipulates it; this facilitates easy communication about the scene and lets the group help define the leader's future actions. Perhaps the greatest strength of the Responsive Workbench is the ease of natural interaction with virtual objects, including gesture recognition, speech recognition, and a simulated laser pointer to identify and manipulate objects.



6 Analysis of deck structure using NRL's Responsive Workbench. Wearing stereographic glasses and a pinch glove, the user can interactively manipulate the decks in 3D.

Figure 6 shows the Responsive Workbench being used to examine the fit of the decks. Among the observations made was that two abutting decks failed to match. Figure 7 shows the hull shape viewed in 3D on the Responsive Workbench, with rotation and other operations performed by speech recognition. Here, the project managers observed a curvature feature in the hull that they had not previously identified.



7 The arsenal ship hull design. For analysis, the hull is displayed on the Responsive Workbench in 3D.

The projects described here are ongoing. Future firefighting research will extend the modeling, physical reality, and analysis and will evaluate techniques for shipboard navigation. Continuing design research focuses on developing an interactive toolset for Responsive Workbench users, including remote collaboration for multiple workbenches. We also plan to augment our immersive systems with improved input/output techniques, natural language input, and physics-based environment effects. With these and other enhancements, VR should continue to serve the Navy's simulation and training needs well into the next century. ■

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References

1. D. Tate et al., "Virtual Environment Firefighting: Ship Familiarization Tests Aboard the Ex-USS *Shadwell*," NRL Ltr. Report 6180/0672A.1, Oct. 1995, http://www.ait.nrl.navy.mil/DamageControl/VETtest.html.
2. R. Barzel and A. Barr, "A Modeling System Based on Dynamic Constraints," *Computer Graphics* (Proc. Siggraph 88), Vol. 12, No. 4, Aug. 1988, pp. 179-188.
3. J. Mintz, "New Ship Could be Next Wave in Warfare," *Washington Post*, June 23, 1996, pp. 1 and 22.
4. L.J. Rosenblum, S. Bryson, and S.K. Feiner, "Virtual Reality Unbound," *IEEE Computer Graphics and Applications*, Vol. 15, No. 5, Sept. 1995, pp. 19-21.

For more information on this project, or to submit a column or a proposal for one, contact author and department editor Rosenblum by e-mail at the address rosenblum@ait.nrl.navy.mil.