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Applying Virtual Reality and Human Figure Modeling Tools to Explore Crew Manning Configurations of the U.S. Navy DDG Class Bridge

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Abstract

This report describes a portion of the modeling and simulation work performed by the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) in support of the manpower assessment technologies (MAT) project. Funding for this project was through the Naval Surface Warfare Center, Carderock Division (NSWCCD).

For this effort, virtual reality (VR) technology and human figure modeling tools were applied to achieve some of the objectives of the MAT project. The discussion that follows in this report focuses on two software tools in particular, Jack™ and the Naval Postgraduate School Networking Software (NPSNET), and how each was used to demonstrate a proof-of-concept capability for examining crew manning configurations on U.S. Navy ships.

In the future, U.S. Navy ships will need to be automated to a sufficient degree in order to realize significant manpower reductions in engineering, combat systems, ship support and Condition III watch-standing requirements.

The use of VR technology and human figure modeling tools to graphically visualize concepts for Navy ships on the computer and to examine manning requirements before building physical prototypes, shows great promise in the future for saving time and reducing development cost.

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APPLYING VIRTUAL REALITY AND HUMAN FIGURE MODELING TOOLS TO EXPLORE CREW MANNING CONFIGURATIONS OF THE U.S. NAVY DDG CLASS BRIDGE

BACKGROUND

With the downsizing of the U.S. military, defense agencies are exploring methods for handling shrinking budgets and smaller funding levels for future acquisitions. A major factor driving the cost of any future system is the number of personnel needed to operate and maintain that system. The Navy, for example, has started to take a more integrated approach toward future ship design to significantly reduce crew size. One of the technologies that the Navy is exploring in order to accomplish these goals is computer modeling and simulation.

The manpower assessment technologies (MAT) project, sponsored by the Advanced Research Projects Agency (ARPA) Marine Systems Technology Office (MSTO), is an effort to help the Navy improve the ship design process and meet its reduced manning requirements. The objective of the MAT project was to develop a suite of simulation-based design tools and technologies that incorporate human factors elements into the ship design process. This simulation-based design approach is an engineering tool that can facilitate the decision makers' ability to understand the options early in the conceptual development phase of ship design. Additionally, these tools can provide a virtual training environment to train the future crews that will be manning these ships (Walman, 1995). Two of the tools selected to accomplish the objectives of the MAT project were Jack™, a human figure performance modeling program, and the Naval Postgraduate School Networking Software (NPSNET), software for constructing and navigating through virtual environments. These tools give the designer or engineer the ability to simulate humans interacting with equipment or other objects within a three-dimensional (3D) modeled environment.

GOAL

The primary goal of this portion of the MAT project was as a proof of principle to demonstrate the feasibility of using 3D modeling and simulation-based tools such as NPSNET and Jack™, for optimizing manning on U.S. Navy ships through "front end" design consideration of human factors and manpower requirements. The scope of the effort was limited by time (approximately 3 months) and resources available.

METHOD

This modeling and simulation effort combined the interaction of two human figure performance tools, Jack™ and NPSNET, with 3D computer-aided design (CAD) models of both current and future bridge configurations of the Navy's DDG class guided missile destroyer. The current bridge model was based on the DDG-52, while the future bridge model was based on the Sperry Marine Vision 2100 integrated bridge concept for the DDG-83. The current bridge was modeled using Condition I, manning with 14 crew positions represented, while the future bridge with the additional automation and integrated bridge consoles was modeled with three crew positions represented.

Athough both the NPSNET and Jack™ software tools allow the user to display and interact with human figure models in a simulated 3D environment, these tools were used in two different ways for this project. NPSNET was used to demonstrate a technology for performing distributive interactive simulations (DIS). Each NPSNET workstation can control an individual crewman on the bridge and interact with the other crewmen in a common simulated environment. NPSNET gives the user the option to position the camera view directly in back of the figure that they are controlling so that the figure can be seen as it is moving through the environment or a view from the figure's eyes can be selected instead.

The Jack™ software was used to demonstrate a technology for performing human engineering analysis. The human figures could be sized to represent the full range of Navy crewmen. Evaluations such as fit, reach, and vision can be performed on the placement of equipment on the bridge. The motions of the individual figures in the simulated bridge can be controlled by task workload modeling data or through a library of motion data that represent typical tasks such as "view radar screen" or "call engine room."

Software and Equipment

This project used a combination of several different hardware components and software packages.

The NPSNET system consisted of NPSNET IV.7 software (version 8 was received during the final month of this effort). NPSNET is public domain software that is undergoing development by the Computer Science Department of the Naval Postgraduate School. The software is used to provide a test bed for virtual reality research (see Figure 1). NPSNET incorporates the Jack™ human figure code and the Jack™ motion library (provided by the

University of Pennsylvania) to display and maneuver human entities in a virtual 3D environment. NPSNET provides a framework for creating virtual reality simulations geared toward military systems and environments. The software allows the user to specify many attributes of the simulation such as terrain database, input control device (keyboard, joystick, motion platform, etc.), display type (monitor, helmet-mounted display [HMD], wide integrated screen, etc.), and simulated entity (human, tank, aircraft, ship, etc.). Other environmental effects such as sound, smoke, fog, and lighting can also be provided. A key feature of NPSNET is that it can operate as a distributed simulation in which entities from multiple networked machines can interact simultaneously sharing the same virtual environment. NPSNET uses the network standard DIS protocol for network communications and thus can be run with any other DIS standard protocol simulator. DIS is a network standard that was developed from simulation network (SIMNET), a DIS standard developed by the Defense Advanced Research Projects Agency (DARPA) in 1985 (Locke, 1994).

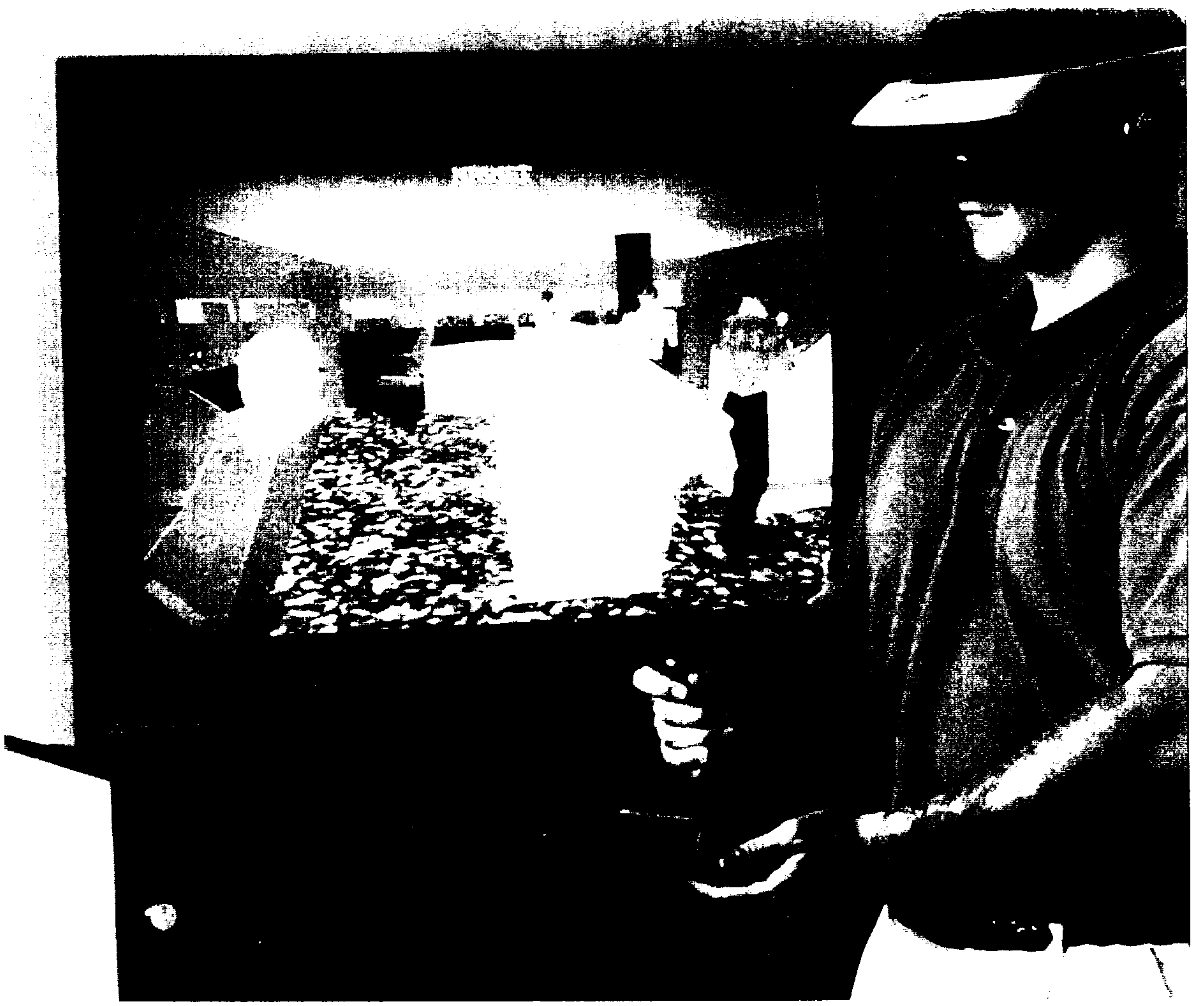

Figure 1. NPSNET system.

Hardware used with the NPSNET system included

a) A Silicon Graphics dual processor Onyx Reality Engine II system (see Figure 2).

b) An HMD made by Kaiser Electro-Optics, Inc. (see Figure 3).

c) A Polhemus 6 degree-of-freedom head position tracker which was used with the HMD.

d) A ThrustMaster flight control system (FCS) which was used to control walking direction and velocity of the human figure in the simulated environment (see Figure 4).

Figure 2. Silicon Graphics Onyx reality engine II system.

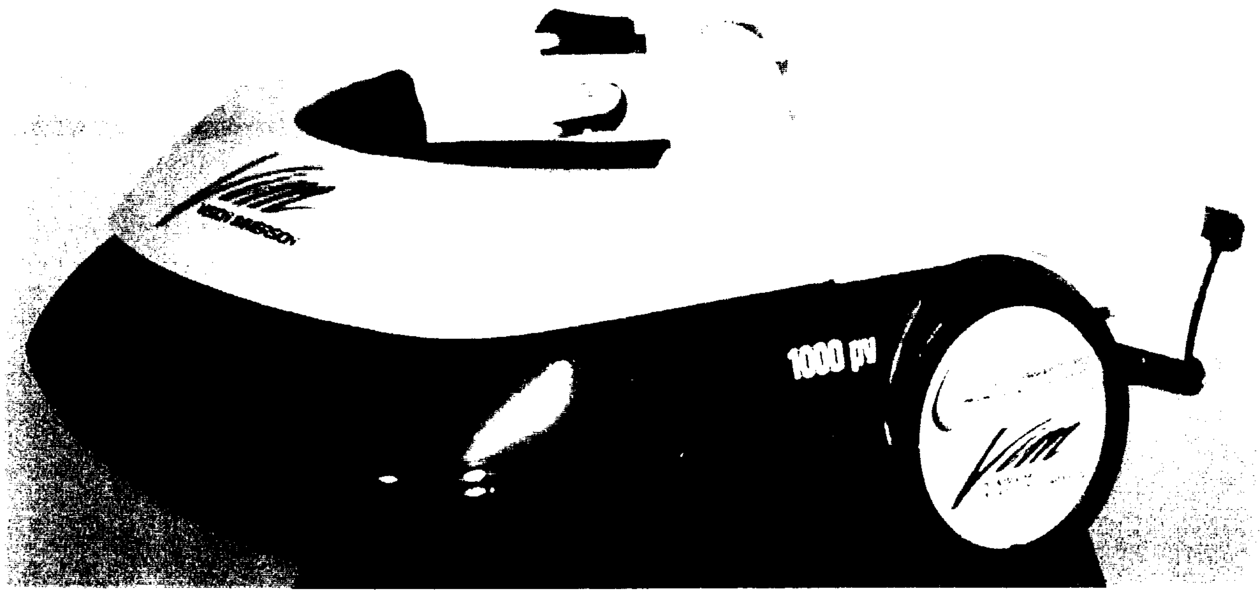

Figure 3. The Kaiser electro-optics helmet-mounted display.

Figure 4. The ThrustMaster flight control system.

The only built-in file loader for 3D CAD models contained within both versions of NPSNET used for this project was for ModelGen format files. ModelGen software, by MultiGen, Inc., is a CAD package used to develop 3D models optimized for real-time simulation applications. To display objects within an NPSNET environment, they must be constructed in ModelGen, or an existing CAD file would have to be converted to the ModelGen file format before it can be loaded. For this project, ModelGen version 14.2 running on a Silicon Graphics Indigo Elan workstation was used. A ModelGen screen with a wire frame view of the DDG52 bridge model is shown in Figure 5.

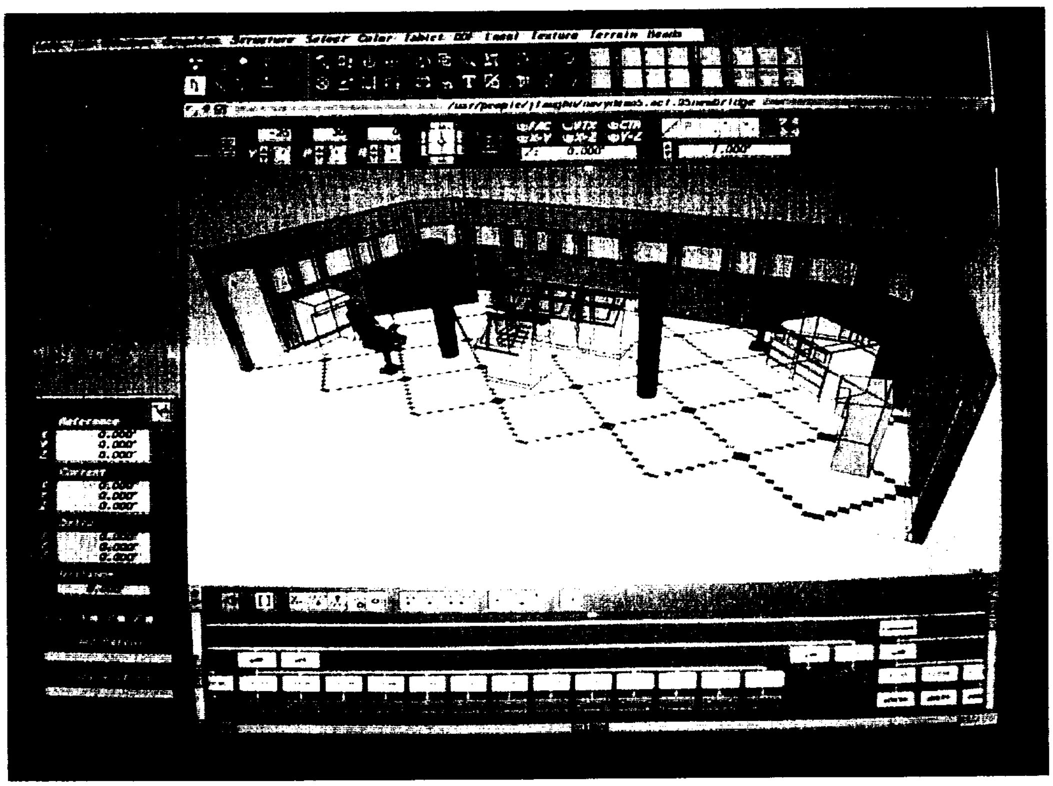

Figure 5. ModelGen user interface with a wire frame model of the DDG52 bridge.

The Jack™ system consisted of a modified version of Jack™ 5.9. The Jack™ software, which was developed at the University of Pennsylvania Center for Human Modeling and Simulation (CHMS), is a system that provides an interactive platform for modeling, manipulating, and analyzing human and other 3D articulated geometric figures (Badler, Phillips, & Webber, 1993).

Jack™, however, is most widely used to define and create human figure models to perform human engineering analysis of 3D CAD models. The default human figure, shown in Figure 6, has 74 rigid body segments and 74 joints including a 17-vertebrae spine and fully fingered hands. A feature called the spreadsheet anthropometric scaling system (SASS) contained within Jack™, allows the user to generate human figures based on anthropometric data from any population or database (Azoula, 1995). Physical dimensions, joint limits, center of mass, and strength data can be entered and modified for any body segment using SASS. The default population measurement database for the Jack™ human figures is derived from the U.S. Army 1988 anthropometric survey (Gordon et al., 1989).

Figure 6. A male poly-body Jack™ human figure model.

The primary mode of operation for Jack™ is as a 3D interactive environment where the user imports the geometry for a workplace design from an external CAD system, adds one or more human figures to the scene, and then performs a variety of fit, reach, movement, strength, and view analyses. Although initially developed as a human factors tool, the interactive nature of the Jack™ software has also made it suitable for virtual reality applications. A modified version of Jack™ 5.9 with software drivers to support the Kaiser HMD, "flock of Birds®" (FOB) body position tracker, and ThrustMaster FCS was used for this project.

Hardware used with the Jack™ system was similar to that used for the NPSNET part of the project and included

a) A Silicon Graphics Crimson Reality Engine I system.

b) An HMD made by Kaiser Electro-Optics Inc.

c) An FOB 6 degree-of-freedom head position tracker by Ascension Technology.

d) A ThrustMaster FCS that was used to control the camera view in the bridge model.

e) A Microtek color scanner that was used to develop the texture maps applied to the bridge models.

Additionally, several CAD translators were used in this modeling effort. The ModelGen "dxf translator" was used to import AutoCAD files into NPSNET. The "pf2jack translator" was used to import the ModelGen files into Jack™, and the "dxf2jack" translator was used to import AutoCAD files into Jack™. AutoCAD software is a widely used CAD package among architects and designers for creating both 2D drawings and 3D models. Because of its widespread use, many other CAD packages both import and export files in the AutoCAD .dxf file format.

Data Collection

Current Bridge Model Data

The initial task of this project was to develop a 3D CAD model of the DDG Class bridge deck for both current and future configurations. Sources for existing CAD files or blueprint drawings were unknown at the start of this project. While a search for these data had begun, the first approach to obtaining the required dimensions was to go aboard the DDG52 (USS Barry), docked in Annapolis, Maryland, May 29 through 31, 1995. (See Figure 7 for a photograph of the ship.) During this visit, several hundred measurements of the pilot house, port and starboard wings as well as dimensions of the operational station equipment were taken (see Figure 8). In addition to the measurements, 25 minutes of video footage and more than 100 photographs were taken of the bridge deck to use as a layout and equipment placement reference for constructing the 3D CAD model.

Figure 7. The USS Barry guided missile destroyer.

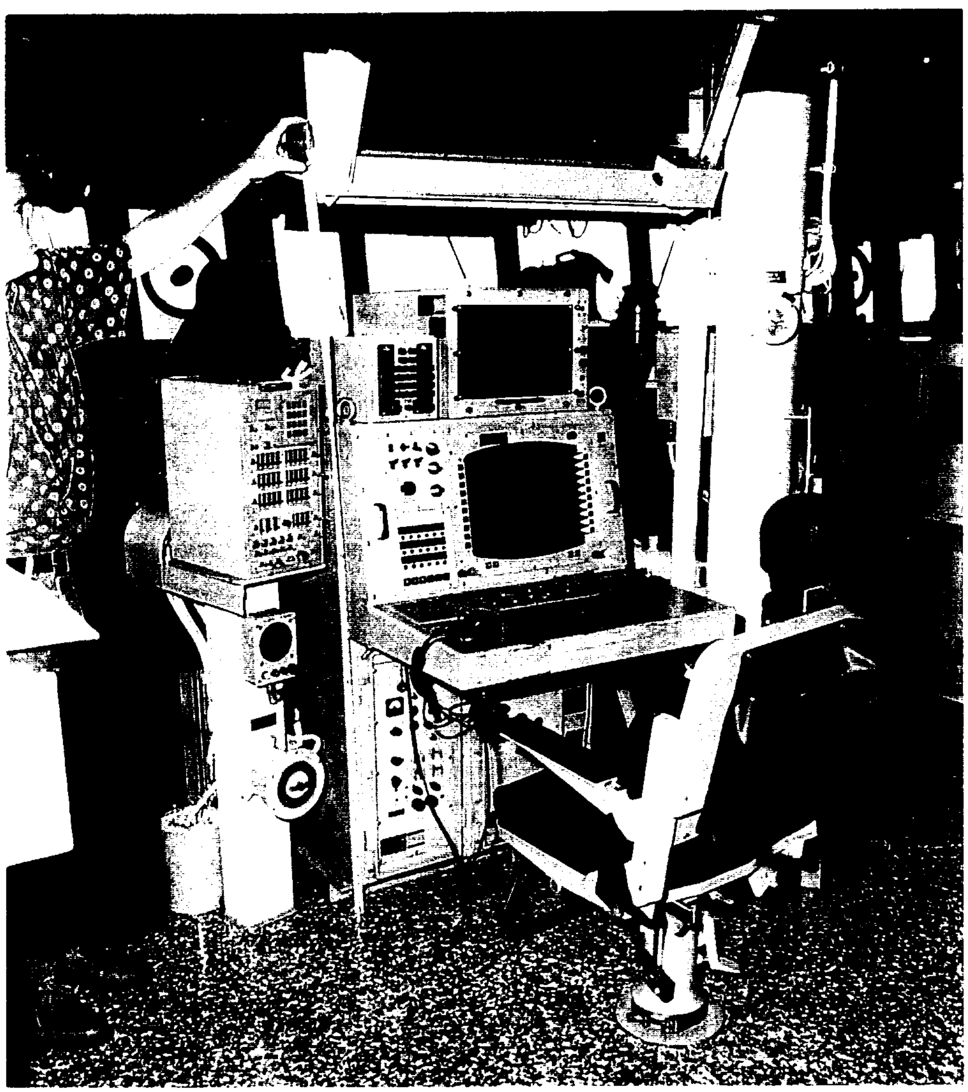

Figure 8. Measuring USS Barry bridge equipment.

On June 16, 1995, while the USS Barry was docked in Norfolk, Virginia, additional measurements were taken of the pilot house windows, door openings, surface radar controller console, navigation table, and seats. Photographs of the bridge instrumentation, suitable for texture mapping the CAD model, were also taken. The texture maps were used to add realistic detail to the modeled bridge equipment, such as displays, gauges, switches, and lamps. The use of texture mapping helped to reduce the number of polygons for the bridge model that would otherwise have been needed to construct these additional details in 3D geometry. Keeping the polygon count to a minimum helped to improve the frame rate speed of the graphics display, and this in turn helped to make "fly-throughs" of the bridge model and human figure movements run faster.

Future Bridge Model Data

The future CAD model of the DDG Class bridge was based on the integrated bridge concept developed by the Sperry Marine Company, a developer and manufacturer of marine navigation, control, and communications systems. The Sperry integrated bridge is a command and control system that incorporates state-of-the-art computer navigational controls and has been used by commercial ship owners for several years, reducing the manning on the bridge of these ships, in some instances to just three crewmen (see Figure 9).

Figure 9. Sperry marine integrated bridge console equipment.

On July 26, 1995, a meeting was held at the Sperry Marine headquarters in Charlottesville, Virginia, for discussions about upgrades for the DDG class ships and reduced crew bridges. During this visit, Sperry Marine provided 3D CAD files of the integrated bridge consoles that had been modeled with AutoCAD software. These CAD files were received in ".dxf" format and then translated into ModelGen format. The files were then loaded into NPSNET and were also translated from ModelGen format into Jack™.

Modeling the DDG Class Hull

A 3D model of both the current and future bridges was completed by the third week of August 1995. To complete the modeling task, the bridge models now needed to be integrated into a hull model of the DDG class ship. This would allow the Jack™ or NPSNET user to get a realistic view when looking out of the windows of the modeled bridge. Investigations into sources for existing 3D CAD models or blueprint drawings of this ship led to contacts at the Bath Iron Works (BIW) Corporation, builder of the DDG class ships for the U.S. Navy.

On 24 August, a meeting was held at BIW's Washington, DC, office to discuss modeling data for the DDG class ship hull. The Flight IIA CAD Manager for BIW explained that the ships are built in modular sections called "blocks." However, only a few of these blocks had 3D CAD models developed for them. The other blocks are in 2D drawings only. BIW used a CAD package from Computervision to construct the existing 3D models.

On 30 August, BIW sent two 3D CAD files as a test case to see if they could be successfully translated into Jack™ and NPSNET. A Computervision-to-Jack data translator "cv2jack" was used to attempt this translation, but the data could not be read by this translator. Several alternate data formats such as the initial graphic exchange specification (IGES), or ".dxf" could have been attempted for the translation of these files, but with only 2 weeks remaining before a scheduled dry run of this demonstration, the decision was made to substitute another hull model that was available at the time. A 3D hull model of the CG52 ship was located within the NPSNET version 8 software. The bridge models were integrated onto this hull and used for the demonstration.

RESULTS

The goal of this demonstration was to show how tools such as NPSNET and Jack™ could be used to compare and contrast manning strategies for the current and future bridges through front end design analysis. Through the use of these human figure modeling tools, it was successfully demonstrated that one could maneuver around in the simulated bridges and interact with other objects in the environment such as doors, control levers, and valves. Consequently, it was possible to demonstrate the concept of how a task and its associated manning requirement would be performed on the current bridge as compared to performing that same task on the future bridge, containing the newer integrated console equipment and added automation. Several different configurations for the placement of the future bridge console equipment were developed based on reach envelopes, space claims, and view analysis of the human figures representing each crew member. The goal for this demonstration, however, was to show how these human figure modeling tools could be applied to examine manning strategies in the simulated bridge environments, not to recommend any specific equipment layout or manning strategy.

Several obstacles were encountered in attempting to use both the NPSNET and Jack™ systems during the course of this project. The current bridge model was to be simulated during Condition I manning requirements. This called for a total of 14 crew positions to be represented within the pilot house and bridge wings. Figure 10 shows the simulated bridge with Condition I manning. The future bridge model required three crewmen to man the pilot house. Even though only one human figure at a time could be controlled by a NPSNET workstation, the goal was to represent all crew positions on the bridge models. The NPSNET software, however, could only display a single crewman under the control of an individual NPSNET workstation and could not display any other crewmen unless they were being controlled by another workstation. Also, colors, textures, and other material properties of the objects displayed in NPSNET were defined by the ModelGen software. Some of the colors and material properties changed when these objects were loaded into NPSNET. For example, when the CG52 hull was loaded, the hull color was pink instead of gray and was transparent instead of solid shaded. Both the ability to display additional crewmen and the problem with correct object properties have since been remedied in subsequent versions of NPSNET.

The ThrustMaster FCS is one method that can be used with NPSNET to control motion and direction of the human figures. This works well when moving the figures over a large open terrain environment but proved to be difficult for controlling the motion of the figure in a smaller confined space such as the pilot house. For this demonstration, the use of the keyboard arrow keys was substituted as the method for controlling the human figure motion in place of the ThrustMaster FCS.

For the Jack™ system, the full crew was represented on both the current and future bridges. In order to perform a smooth "fly-through" of both bridge models, the ThrustMaster FCS driver software was added to Jack™ 5.9. The ThrustMaster FCS was to be used to move

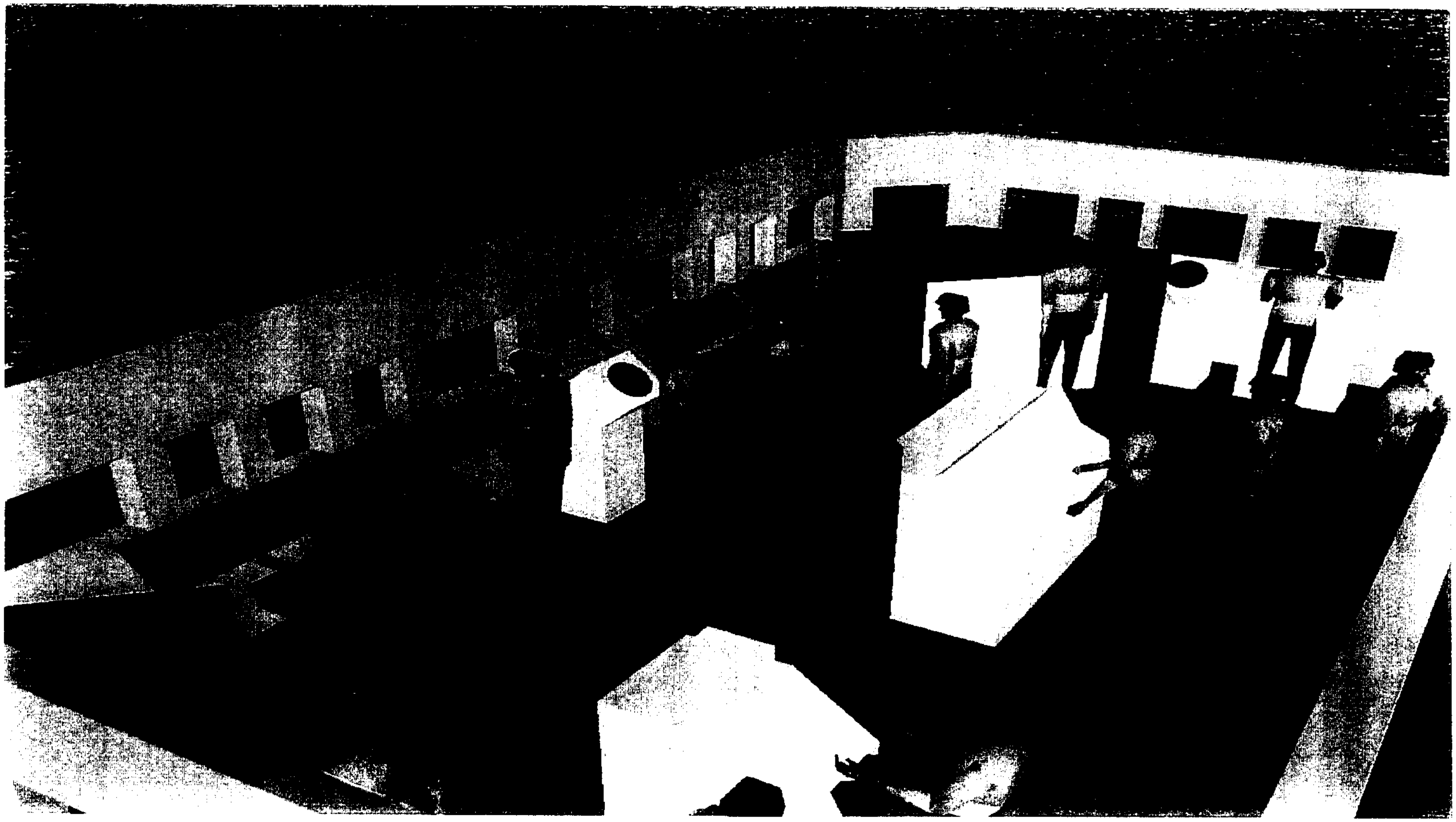

Figure 10. Jack model of the DDG52 bridge with low resolution human figure models in Condition I manning crew positions.

and control the camera view in the simulated environments. However, shortly after this software was added, the ThrustMaster FCS developed an electronic failure and another FCS could not be obtained in time for the demonstration. A three-button mouse was substituted for the ThrustMaster FCS to control movement of the camera view. This method was effective for moving the camera view but did not produce a desirable, smooth "fly-through" effect. Also, for added immersion into the simulated environments, software to support the Kaiser HMD and the FOB head position tracker was added to Jack™. A bug was discovered with the FOB code that caused the view seen from the HMD to be slanted as the user's head moved. This bug could not be fixed in time for the demonstration, and the simulations were displayed on a high resolution 37-inch Mitsubishi monitor in place of the HMD. A limited task motion library was developed for some of the crew positions on the current and future bridges to demonstrate the concept of how the human figures could interact with objects within the modeled bridge environment. This method would allow these motions to be executed only one time before having to reinitialize the motion sequence, however. A more sophisticated method using channel sets and a Lisp interpreter now allows the user to build more complex motions that can be repeated over a specified time interval.

RECOMMENDATIONS

Human figure modeling and simulation tools such as the Jack™ and NPSNET software used for this MAT demonstration should play a more significant role in examining crew manning requirements and equipment placement aboard future Navy ships. These tools can help designers and engineers avoid costly design changes later in the program by considering human factors and crew manning requirements early in the design cycle. The ability to analyze 3D CAD models early in the design cycle will help to reduce or eliminate the need for physical prototypes, by being able to make a better "first cut" of the design on the computer.

Some of the problems encountered during the course of constructing this demonstration have been addressed with subsequent releases of NPSNET and Jack™ software since then. Aside from correcting some of these problems, additional methods could be employed to improve this demonstration.

NPSNET has a limited motion library that can be used to place the human figures into a few infantry-type postures such as walking, running, crawling, and aiming a weapon, for example. To exercise more control over the movements of these human figures, a body position sensor suit could be worn or a set of Polhemus trackers could be positioned on the body of an individual who could control the real-time motions of the human figures through the movements of their own arms and legs. A full body sensor suit is currently being integrated with NPSNET. However, a separate workstation would still be required to drive each figure in the simulated environment.

To increase the immersion effect into the virtual environment, some type of motion platform could be used to navigate the human figures through the environment instead of using the ThrustMaster FCS, keyboard, or mouse. Some of the devices currently used with NPSNET are unicycle-type devices, treadmills, and stair-steppers.

A more extensive library of task motion data could be constructed within the Jack™ software for all crew positions on both the current and future bridge models. A 3D CAD model of the DDG class ship hull should be integrated with the bridge models that were developed. Given additional time, a source for this model could be located or one could be built from blueprint drawings that could be obtained from the BIW Corporation.

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13. ABSTRACT *(Maximum 200 words)*

This report describes a portion of the modeling and simulation work performed by the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) in support of the manpower assessment technologies (MAT) project. Funding for this project was through the Naval Surface Warfare Center, Carderock Division (NSWCCD).

For this effort, virtual reality (VR) technology and human figure modeling tools were applied to achieve some of the objectives of the MAT project. The discussion that follows in this report focuses on two software tools in particular, Jack™ and the Naval Postgraduate School Networking Software (NPSNET), and how each was used to demonstrate a proof-of-concept capability for examining crew manning configurations on U.S. Navy ships.

In the future, U.S. Navy ships will need to be automated to a sufficient degree in order to realize significant manpower reductions in engineering, combat systems, ship support and Condition III watch-standing requirements.

The use of VR technology and human figure modeling tools to graphically visualize concepts for Navy ships on the computer and to examine manning requirements before building physical prototypes, shows great promise in the future for saving time and reducing development cost.

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