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This paper will discuss an application to provide a sonar operator with a virtual underwater acoustic environment including the design methodology and human factors experiments for testing the system. The technologies used in this application are 3-D modeling software, computer image generation software, 3-D graphics rendering engines, helmet mounted stereoscopic displays, head tracking sensors, 3-D input devices, voice recognition, and a 3-D spatializing sound system.

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WILL ANYTHING USEFUL COME OUT OF VIRTUAL REALITY? EXAMINATION OF A NAVAL APPLICATION

Louise Frantzen Julig
Electrical Engineer

Naval Command, Control and Ocean Surveillance Center
Research, Development, Test and Evaluation Division

NCCOSC RDT&E Div. 442
53355 Ryne Rd. Rm 224
San Diego CA 92152-7252
619/553-7863
fax: 619/553-9229
email: frantzen@nosc.mil

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The term *virtual reality* can encompass varying meanings, but some generally accepted attributes of a virtual environment are that it is immersive, interactive, and intuitive. Integration of many different technologies is necessary in order to produce a system having these attributes. Applications such as molecular modeling, flight simulators, physical rehabilitation, and architectural design and walk through utilize various pieces of the technology, but at present there are few practical applications which are utilizing the broad range of virtual reality technology.

This paper will discuss an application to provide a sonar operator with a virtual underwater acoustic environment including the design methodology and human factors experiments for testing the system. The technologies used in this application are 3-D modeling software, computer image generation software, 3-D graphics rendering engines, helmet mounted stereoscopic displays, head tracking sensors, 3-D input devices, voice recognition, and a 3-D spatializing sound system.

INTRODUCTION
There are many different opinions as to what defines virtual reality (VR) and what elements are essential in creating a virtual environment, but some generally accepted attributes of the environment are that it is immersive, interactive, and intuitive. Some of the basic elements needed to create a virtual environment are computer generated imagery, 3-D input devices, position trackers, and a helmet mounted or monitor based display. New technologies are emerging and evolving almost daily that further the capabilities of VR developers to create these environments. This paper will briefly introduce some of these technologies before describing the Advanced Technology ASW Displays (ATAD) project, its design methodology and system evaluation.

Enabling Technologies
Computing Power
Computing power is the backbone of any VR project, and now specialized graphics computers are able to produce startlingly realistic computer generated images with the aid of lighting models and texture mapping. The Silicon Graphics Reality Engine product line and the Evans & Sutherland ESIG 2000 series computers can generate texture mapped polygons in hardware at update rates more than adequate to accommodate real time movement through an environment. The incorporation of reduced instruction set components (RISC), application specific integrated circuits (ASICs) and multiple processors makes the current generation of graphics computers capable of performance previously the domain of the supercomputer at a fraction of the cost. Even lower end graphics computers are

capable of generating high quality images, with the performance tradeoff being the complexity of the scene versus the speed of the update rate.

Software

The software tools available for graphics computers vary in capability and play an important part in how quickly and easily one can develop a virtual environment. The different objects that appear in a scene can be generated by programming with a graphics library such as the Silicon Graphics GL or a similar graphics library on another platform. This is a tedious process that involves figuring out the geometry of each polygon in x, y, and z coordinates. This can be especially complicated considering that a reasonably realistic model of an object such as a submarine can have a thousand polygons or more. 3-D modeling software products now exist which allow the user to directly draw an object in three dimensions on screen and apply characteristics to the object such as material properties, levels of detail and articulation points, and interactively see the results of changing various properties. Other software tools are available to design user interfaces, serve as simulation managers, import CAD and other 3-D model formats and address other aspects of building a virtual environment.

Position Trackers

A virtual environment needs position trackers and input devices in order to make it interactive. Two of the most widely used position trackers use an electromagnetic field source and sensor, each connected to a control unit, to detect six degrees of freedom: position in x, y, and z from the source, and pitch, roll, and yaw rotations. Mechanical linkages and ultrasonic devices are methods that some other position trackers use. A position tracker enables the graphics to change with relation to the user's head position so the environment behaves just as it would if the person were looking at a scene in real life. The ability to passively track where the person wants to look instead of controlling the scene through a keyboard or mouse adds greatly to the immersiveness and the intuitiveness of the environment, since the user simply does what comes naturally to view a different part of the scene.

Input Devices

In order for the user to have any interaction with the environment, he or she needs input devices, and there are several types available. At least two input devices are based on gloves that have an attachment for an electromagnetic position tracker and use thin fiber optic cables running along the fingers to detect joint bending. The user signifies different commands to perform by way of a set of gestures that is developed for the application. There is also at least one product that is an exoskeleton that fits over the hand and uses robotics technology to measure hand and finger motion. Yet another device is designed as a 2-D or 3-D mouse. The device functions as a regular optical mouse when moved on the mouse pad, and has an electromagnetic sensor inside which enables it to track position when raised off the pad. The user can then use the three buttons for different commands in the 3-D environment. None of these devices is entirely intuitive and the software interfaces are primitive, but an easy to use input device for VR is on the horizon.

Head Mounted Displays

An essential part of any virtual environment is the display. While a head mounted display (HMD) is not essential for VR, it is the one device that is most closely associated with virtual reality. Several options are available in HMDs, generally determined by four factors: color or monochrome, cathode ray tube (CRT) based or liquid crystal display (LCD) based. Small, very high resolution CRTs are widely available in monochrome, but only very recently have color versions become available. Some disadvantages of CRTs are their weight and high power consumption. Small color LCDs that don't have these disadvantages are available, but at present the resolution of an LCD display is much less than what is available in CRTs. Advances in both of these technologies are progressing to the point where it will only be a matter of preference as to which type of HMD to use.

3-D Sound
Another technology that greatly adds to the immersiveness of the environment is 3-D sound technology. A device called the Convolvotron is capable of taking up to four real time analog input sounds and spatializing them through stereo headphones to sound like they are coming from separate, external points in the environment. When combined with a position tracker, the user hears apparently stationary sounds as he or she moves around them. The addition of sound to the environment adds greatly to the feeling of immersion, and is essential to the virtual underwater acoustic environment of the ATAD project.

ATAD Design Methodology

Design Objective
The Advanced Technology ASW Displays project is funded through the Human Factors block of the Manpower, Personnel & Training Office of the Chief of Naval Operations. Its overall mission is to increase the effectiveness of anti-submarine warfare (ASW) operators on all platforms (afloat, airborne, and ashore). The first priority is to improve shipboard sonar operators' performance. The idea is that performance can improve without changing the actual sonar sensors, but by simply modifying the interface to make the system easier for the operator to use. A 3-D system could present the critical tactical information in a far more intuitive and integrated way than the existing 2-D displays, therefore reducing the cognitive interpretation burden and learning time while improving the tactical success rate. The ATAD virtual environment approach aims to provide the operator with a physical representation of the ocean environment with overlaid representations of information such as latitude and longitude lines, thermal layers, and the sonar data from shipboard sensors (Fig. 1).

Designing a virtual environment from the ground up encompasses quite a few challenges. Deciding which hardware will suit the design and budget constraints requires continual research due to the constantly changing market. A difficulty in working with such new technology is integrating the many different components into a cohesive system. With only a small knowledge pool to draw from, much of what is learned is determined from trial and error.

Hardware Components and Integration
The hardware components of the ATAD system are two graphics computers, a 3-D audio system, a data server and audio processing computer, position tracker, head mounted display, speech recognition system and 3-D input devices (Fig 2).

Two Silicon Graphics 4D/310VGX graphics computers are the graphics client hosts, each one dedicated to providing the graphics to one eye of the helmet mounted display. The ATAD project uses SGI systems because of their wide acceptance in the simulator arena, their price and reputation as being among the leaders in the 3-D graphics market. In addition other branches at NCCOSC RDT&E Division (NRaD) have some experience with SGI systems. Each machine has one MIPS R3000 RISC central processing unit (CPU) running at 33 MHz with a capability of 5.1 MFLOPS or million floating point operations per second. Since these systems were purchased in March of 1992 SGI has made significant improvements in processor speed and texture mapping capability.

The Convolvotron 3-D spatializing audio system from Crystal River Engineering runs on a 386 PC with two Spectrum boards using the Texas Instruments TMS320C25 DSP chip. The Convolvotron makes use of research involving head related transfer functions (HRTFs). To determine an HRTF, miniature microphones take measurements from within a subject's ear canals of white noise bursts at different positions in space. The Convolvotron takes real-time sound input and convolves it with the HRTF to make the sound appear as if it is coming from a particular location, and sends the output to stereo headphones. The helmet mounted display incorporates the stereo headphones that receive the output. Other 3-D sound systems exist, but to date the Convolvotron is the only one of its quality that does not rely on multiple speakers to achieve the spatialization. The use of headphones makes it particularly suited for use in a virtual environment where the helmet mounted display encloses the user. The use of 3-D sound greatly enhances the feeling of immersion in the environment and is essential to the ATAD project. The objective is for the sonar operator to be able to selectively listen to multiple beams of spatially accurate incoming sonar information and intuitively know where the sounds are coming from. The Convolvotron includes a Polhemus Isotrack electromagnetic position tracker so the sounds can appear stationary as the user moves his or her head.

An SGI Indigo 24XS is the data server host. The Indigo runs a simulator base that controls the motion of the objects such as surface ships and submarines in the environment. The Indigo sends the simulator update information over Ethernet to each of the graphics clients . An RS-232 connection to the Convolvotron enables the Indigo to tell the Convolvotron where to place the objects that are making sound and reads the position data from the Isotrak. The Indigo sends the head position over Ethernet to the left and right eye clients to reflect the head movements in the graphics. The analog audio output capabilities of the Indigo will play different audio files from disk as the audio input to the Convolvotron; currently the audio input is a four track cassette that is only useful if there are just four stationary objects of interest in the environment.

The head mounted display is a CRT based system that uses the mounting frame, CRTs, and electronics from a teleoperated vehicle program developed at NRaD. The CRT mounting frame is the same as is used for night vision helmet systems. The CRTs are monochrome green NTSC video resolution that is the same as a standard television. The CRT frame mounts onto a bicycle helmet with space cut out to make room for the headphones. A counterbalance in the back of the helmet compensates for the weight of the CRTs. The helmet receives two video channels, one from each graphics client, converted to NTSC resolution by an add on broadcast video option board. Even though the display is monochrome, and about one quarter the resolution of the full screen capability of the SGI 19 inch display, the results are of a fairly good quality.

The ATAD project has acquired two different 3-D input devices to evaluate, one of which will be integrated into the system. The DataGlove by VPL is one of the devices, which uses fiber optic technology to measure joint bending and an Isotrak tracker attached at the wrist to measure position. The other device is the Flying Mouse by SimGraphics that functions as a 2-D mouse on the pad and has an Isotrak inside it to function as a 3-D controller when raised off the pad. In addition a voice recognition system will work together with the input devices. To date very little has been done with 3-D input devices beyond simple demo programs and there are no standard methods of maneuvering in a 3-D environment the way there are with a 2-D mouse on a screen. Human factors research is continuing in this area to determine the best ways for people to interact with a virtual 3-D environment and software tools are being developed to enable easier addition of the user interfaces to 3-D applications.

<u>Software Components & Integration</u>

The software components of the ATAD project consist of a 3-D modeling application, a submarine environment simulator, a high-level interface for controlling the graphics, and system integration code.

MultiGen by Software Systems is the 3-D modeling software package used to generate all of the objects that appear in the scene such as submarine models, marine animals, ocean bottom terrain and representations of the incoming sonar data. It is also used to create representations of such relevant information as thermal layers, sonar coverage zones and latitude and longitude lines that would be of use to the sonar operator. By modeling normally invisible information as something visible in the virtual environment, the operator can absorb more information at an intuitive level. This frees the operator to pay attention to the important tasks of detection and identification.

A submarine environment simulator developed in-house for a different project serves as the foundation for the virtual environment. The simulator provides realistic models of submarine movement and sound propagation in water. The submarines, surface ships and biologics have paths that are scripted in time to follow through the environment. Thus subjects can be tested in different scenarios without undue reprogramming of the simulator by simply changing the scripts. The simulator is written in C and runs on the SGI Indigo data server host.

The Gemini Visual System package (GVS) by Gemini Technology Corporation is a library collection of high-level calls to create dynamic simulations using 3-D models. The library calls are invoked to assign specific 3-D models created in MultiGen to the objects described in the submarine simulator and draw the graphics to reflect the correct motion of all the objects from a specified eye point . Other capabilities exist such as collision detection between objects, the ability to switch eye points to a different perspective, or animate articulated portions of a 3-D model.

Tying all of these pieces together is the system integration code that is generated in-house. The Indigo data server runs a process that communicates through RS-232 with the Convolvotron to send position data for up to four objects in the scene that have sounds associated with them, and receive head position data from the Convolvotron's Isotrak tracker mounted on the helmet. The Indigo then sends the head location information using UNIX sockets over Ethernet to the graphics servers for the left and right eye views.

Evaluation of the System

In order to evaluate the effectiveness of a virtual environment system, human factors experiments need to quantitatively measure performance. One aspect of the sonar problem has been chosen to focus on, namely detection of a target in an active sonar situation. ATAD team members have met with personnel at the Naval ASW school in San Diego to get a good idea of how sonar operators handle the problem currently. A model of the existing displays will be built using the Virtual Prototyping System (VAPS) on an existing Silicon Graphics machine. An experiment is being designed which will present multiple targets in the environment and test the subjects on both systems using the same data sets. This experiment will help to determine if the virtual environment approach does indeed show a performance improvement for at least one segment of the ASW problem. If the results are favorable then the system will be expanded to encompass more aspects of the sonar environment.

As the technology advances and interest in virtual environments expands, a fair amount of research and experimentation is being done on different aspects of virtual reality systems such as stereoscopic displays, 3-D spatialized sound and 3-D input devices. To date few experiments of this kind have been done to measure the effectiveness of an integrated virtual reality system over a conventional display system. Part of the reason may be that the initial applications for virtual reality have been entertainment such as W Industries Virtuality video game system. Universities and R&D centers such as NRaD who have an interest in the human factors aspects may not be able to afford the resources in time and money needed to put together a virtual reality system for testing purposes. The ATAD project aims to show that virtual reality is useful for other applications besides entertainment and can in fact be applied to the problems of today's Navy by helping to solve some of the information overload in the ASW environment.

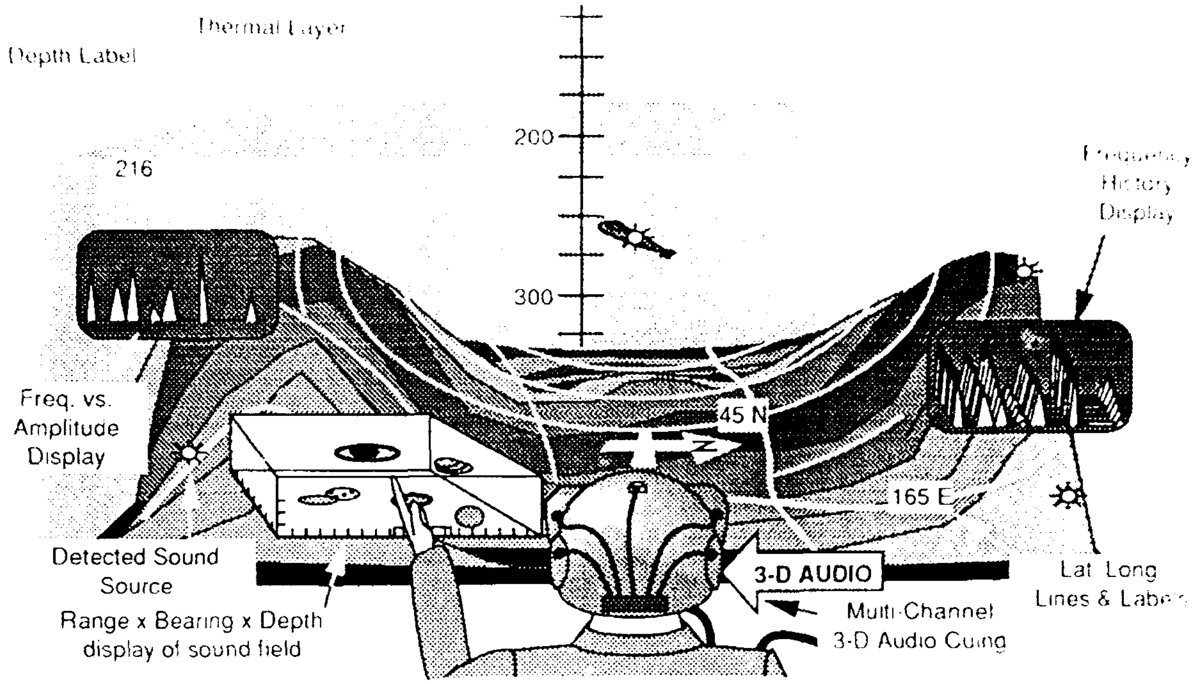

Figure 1 - ATAD Sonar Environment Representation

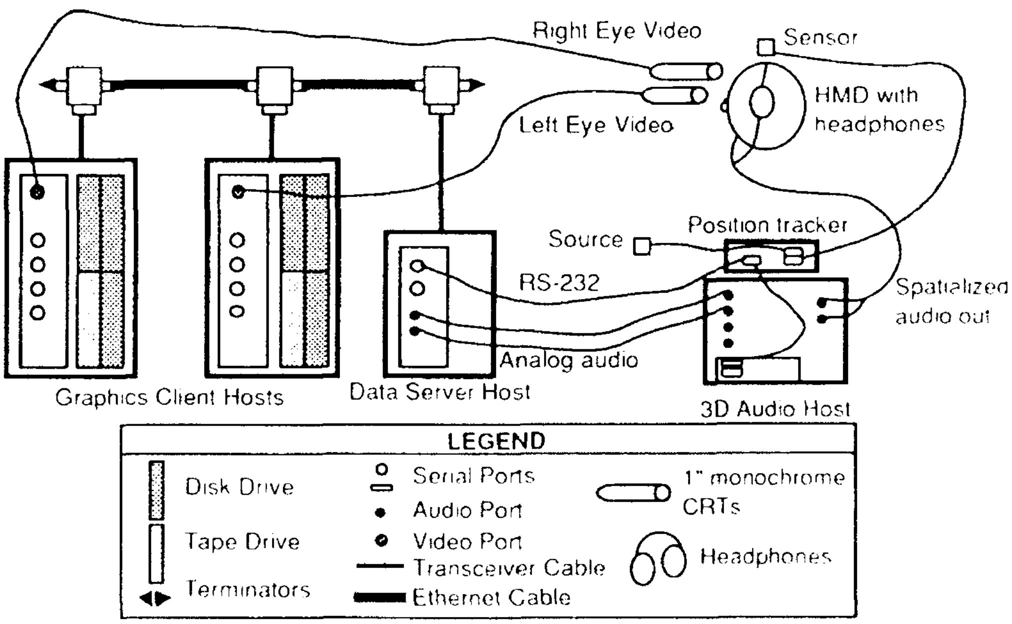

Figure 2 - ATAD System Configuration

BIOGRAPHY

Louise Frantzen Julig has been working in the Information Science and Decision Technology Branch of NRaD for 2 years since graduating from Georgia Tech with a bachelor's degree in electrical engineering. She is active in SWE and currently the San Diego County section president. Louise lives in San Diego with her husband Jim, also an engineer.