Proof of Graphic Concepts for Limited Visibility Piloting

PB98-121940

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sponsored by the

Southwest University Transportation Center
Texas A&M University
Texas Transportation Institute
College Station, Texas

Project No. 467407

October 1997

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SWUTC/98/467407-1		

4. Title and Subtitle
PROOF OF GRAPHIC CONCEPTS FOR LIMITED VISIBILITY PILOTING

5. Report Date
October 1997

6. Performing Organization Code

7. Author(s)
Vandana Konda, Stephen F. Ford, Harlow C. Landphair and Terry R. Larsen

8. Performing Organization Report No.
Report 467407-1

9. Performing Organization Name and Address
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
10727

12. Sponsoring Agency Name and Address
Southwest Region University Transportation Center
Texas Transportation Institute
The Texas A&M University System
College Station, TX 77843-3135

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
Supported by general revenues from the State of Texas.

16. Abstract

Recent developments in the field of Computer Graphics have resulted in real time simulations that successfully mimic the real world and enhance our perception of it. An important use of this technology lies in creating realistically simulated environments which allow us to study and understand existing conditions to make safe decisions for future courses of action. The closer the simulated environment is to reality, the greater is one's confidence in making these decisions.

This paper is to describes an Augmented Reality application intended to aid ship navigation in conditions of low visibility. A modeled view of the real world surrounding the ship is projected onto a screen to simulate the view from the bridge of a ship. The movement of the ship is controlled by voice commands, visibility conditions are simulated by manipulating the level of "fog." A special see-through head mounted display is used to project a wireframe model, augmented world, that overlays the real world. The user's head movements are tracked to ensure the proper registration of the two worlds. The degree of accuracy of the overlap of both worlds is sufficient to allow the user to establish his orientation and confidently make navigation decisions.

This provides a description of Augmented Reality and its application to this project, a description of the "real-world" simulator, a discussion of the problems associated with Augmented Reality such as calibration, registration, and system latency. The preliminary results obtained from a series of tests are described.

17. Key Words
Piloting, Visibility, Augmented Reality,

18. Distribution Statement
No restrictions. This document is available to the public through NTIS:
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	34	

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This paper is to describes an Augmented Reality application intended to aid ship navigation in conditions of low visibility. A modeled view of the real world surrounding the ship is projected onto a screen to simulate the view from the bridge of a ship. The movement of the ship is controlled by voice commands, visibility conditions are simulated by manipulating the level of "fog." A special see-through head mounted display is used to project a wireframe model, augmented world, that overlays the real world. The user's head movements are tracked to ensure the proper registration of the two worlds. The degree of accuracy of the overlap of both worlds is sufficient to allow the user to establish his orientation and confidently make navigation decisions.

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ACKNOWLEDGMENT

This publication was developed as part of the University Transportation Centers Program which is funded 50% with general revenue funds from the State of Texas.

EXECUTIVE SUMMARY

PROOF OF GRAPHIC PRINCIPLES FOR LOW VISIBILITY PILOTING

Introduction

Fog and other atmospheric conditions that impair visibility, frequently delay ship traffic in and out of major ports. It is estimated that the costs resulting from delays at the Port of Houston are on the order of the $6,000 per hour per vessel. These costs result from underutilized port facilities, loss of perishable commodities and costs associated with resulting delays in the intermodal connectors. The ability to maintain port traffic in all visibility conditions could result in significant savings in transportation costs across the entire transportation network.

A system combining Augmented Reality Computer Graphics and Differential Global Positioning System (DGPS) navigation technology, appear to offer a framework that could lead to a piloting system allowing safe movement of vessels in very low visibility conditions in confined channels. Augmented reality is a form of virtual reality graphics. It allows the viewer full view of the immediate surroundings by projecting supplemental graphic information on a "see-through" medium. This is a similar to the "heads-up" technology used in combat aircraft.

The Texas Transportation Institute with support from the Southwest Region University Transportation Center (SWUTC) has initiated an effort to develop a workable system. The first phase of the project was to prove the graphic concepts for the use of an augmented reality display. This project was limited to proving only the graphic principles involved in developing a working prototype. The technology involves the latest technological advances in high speed computer graphics engines, augmented reality displays and voice control devices.

Graphic Principles for Low Visibility Navigation

The graphics concepts of the augmented reality display for piloting in low visibility conditions as currently envisioned involves the integration of a highspeed graphics engine, a head mounted augmented reality display, and a head tracking device. The head tracking device sends information on the position of the viewers head in relation to the real world. This information is used by the graphics engine to generate a wire-frame view of the world which is projected on the see-through medium of the head mounted display. By tracking the viewers head the computer is able to generate a world view that will register with the real world.

Proving the graphic principles was divided into tasks of equipment evaluation and selection, identification of significant graphic problems and resolution of problems, and verification of principles.

The equipment needed for a practical navigation aid must be light weight, portable, and durable. At this time the weight and portability and durability requirements can be met for the augmented reality head mounted display. Head tracking devices present a more difficult problem. At this time the most portable type of device will not likely be suitable in an operating prototype because it limits movement and can be disturbed by magnetic fields. However, the technology is developing rapidly and several other options are available. Computer technology is available now that can meet the graphic demands. Continued improvements in hardware and software will only increase the speed and quality of the imagery.

Graphic Issues to be Resolved

The graphics problems that must be overcome to make the system workable are related to issues of graphic registration and system latency. Registration is being sure that the computer generated view properly overlays the view of the real world. System latency has to do with the time it takes for the computer to update the imagery when the viewer changes the line of sight.

The lag in head movement and generating the proper world view is annoying and can result in motion sickness in users. The problems of latency are easily overcome with increased computing power and processor speed. At the current rate of development there is every reason to believe that the computing power exists to overcome any problems.

Issues of registration are more troublesome. With current head tracking equipment good image registration was achieved so long as the viewers station point was constant. If the viewer moved, as in the case of a pilot needing to move to a wing of the bridge to observe tug activity, registration would be lost. With current off the shelf technology it would be difficult to over come this problem. Nevertheless, there are research and development efforts underway in head tracking that promise a solution to the registration issues.

Evaluation of the Concept

To verify the workability of the concept a computer model of the Galveston ship channel was developed and two graphics engines were used represent the real world and augmented world. One graphics machine generated imagery that represented the real world view which was projected on a screen. The atmospheric conditions of the real world display could be changed from clear to fog that obscured 95 percent of normal vision. The second machine generated the augmented display graphics which were sent to the head mounted augmented reality display. A head tracking device was attached to the head mounted display to tell the augmented graphics machine what view to generate.

Two experienced ships masters used the display to navigate the Galveston channel. The tests suggest that the graphic principles are workable and can be refined with further development efforts. Key issues that would have to be overcome are improved head tracking so that movement is not restricted and greater portability of the head mounted display and head tracking mechanism.

Conclusions and Need for Further Development

The work successfully demonstrated that it is possible to achieve image and real world view registration. On going research also suggests that current problems that restrict movement will be overcome as the basic technology of head tracking and processor power improves.

The next step in the development process is to develop the DGPS links to the graphics engines to determine if the information provided by the DGPS receivers is sufficiently accurate to be used. There are several questions that need to be resolved in this next step.

- Can computer models be built that a accurate enough to represent the real world? Many pilots and masters are not convinced that the accuracy of current navigation aids are sufficiently accurate.

- Adding DGPS to the equation adds a second source of system latency. The links from the DGPS navigation system to the augmented imagery engine will have to be carefully designed in order to minimize the time lag in generating the appropriate views.

- Finally there is the issue of building pilot confidence. An extended period of use will probably be required to generate the level of confidence necessary for the maritime industry to adopt the technology.

TABLE OF CONTENTS

LIST OF FIGURES

Introduction

Computer generated Graphics Imagery (CGI) has become commonplace, in such diverse fields as scientific research and entertainment. One of its major applications lies in enhancing visual perception and awareness of one's environment. Through real time simulations, knowledge of the surrounding environment is increased.

Fog and other atmospheric conditions that impair visibility frequently delay ship traffic in and out of major ports. It is estimated that the costs resulting from delays at the Port of Houston are on the order of the $6,000 per hour per vessel. These costs result from underutilized port facilities, loss of perishable commodities and costs associated with resulting delays in the intermodal connectors. Clearly the ability to maintain port traffic in all visibility conditions could result in significant savings in transportation costs accross the entire transportation network.

The use of Augmented Reality computer graphics linked to a Global Positioning System (GPS) navigation technology appear to offer a framework that could lead to a piloting system that would allow safe movement of vessels in very low visibility conditions. The Texas Transportation Institute with support from the Southwest Region University Transportation Center (SWUTC) has initiated an effort to develop a workable system. The first phase of the project was to prove the graphic concepts for the use of an augmented reality display to aid navigation in restricted visibility conditions.

This project is limited only to developing graphic principles involved in the project. It makes use of the latest technological advances which include high speed graphics engines, augmented reality displays and voice control devices.

This report is divided into several sections. The first three sections introduce the basic technologies and explain the graphics concepts. Section four covers major problems encountered in the application of augmented reality and their relevance to this project. Section five presents preliminary results of tests performed on the system, along with alternatives for possible solutions. Section 6 discusses the conclusions and suggests directions for future research.

PROOF OF GRAPHIC CONCEPTS

Ship Piloting

Ship piloting is primarily a visual task. The pilot relies on visual clues such as landmarks, range towers and buoys as a means of judging the position and behavior of the ship [6]. Using these navigational aids, the pilot identifies the vessels position and orientation within the channel. The line-of-sight between two landmarks allows the pilot to detect deviations and or rates from the desired path and commands are given to the steersman to correct the direction of travel. Visual clues are also used to judge the speed of the ship. The constant change in apparent size, shape, texture and position of landmarks provide the pilot with a constant stream of information that are used to safely guide the vessel to port.

Radar and electronic charts provide supplemental information during normal conditions, which includes night and inclement weather. Pilots are unwilling to rely totally on these navigation aids unless supplemented by line-of-sight data.

Augmented Reality

Augmented Reality is a potentially useful technology that can be employed to enhance the pilot's visual perception of his surroundings during low visibility conditions. Such an approach offers minimum deviation from the natural process of ship piloting. The landmarks that are used as visual navigation aids can be compiled into computer graphics models. These models can be projected onto a "heads up" display so that they match all the real world visual aspects. When low visibility conditions prevail, the augmented graphics provide the missing visual clues pilots use for navigation.

Project Tasks

The proof of graphic concepts phase of development was accomplished in three tasks.

Task 1: Implement an Appropriate Augmented Reality Display

This task involved the identification and acquisition of an appropriate augmented reality display and linking it to the graphics engines and head tracking device. Head tracking movements, are critical to generating mathematically accurate, real time graphics to augment the view of the real world environment.

Task 2: Develop Link to Real World Simulator

Since this phase of the overall project works only with graphic principles it was necessary to develop a simulated "real world." This is accomplished by using a ship bridge simulator to traverse a simulated ship channel. The simulator provides the simulated "real world"visual "environment" within which an augmented reality technique could be used to aid navigation.

The augmented reality graphics engine generates a second set of wire frame graphics which are displayed in a head mounted display (HMD). By tracking the observers head real time graphics are generated that overlay the view being generated by the simulator.

Task 3: Develop a Ship Channel Model for Testing the Augmented Reality Concepts

The third task was the development of a mathematical model of a regional port channel to be used for demonstration and evaluation. The channel selected was the Galveston Island Ship Channel. The model includes all navigational aids and landmarks used by harbor pilots for negotiating the channel. This channel is adjacent to the Texas A&M University campus at Galveston and will be used for all development research.

AUGMENTED REALITY AND ITS APPLICATION TO NAVIGATION

Augmented Reality (AR) is a technology which allows the user to see the real world overlaid with computer generated graphics to enhance his understanding of the world around him. AR has its applications in medical imaging, manufacturing and maintenance systems. In this project it is applied to conditions of restricted visibility, enabling a ships pilot to see navigation references that would be obscured.

An augmented reality navigation aide would use a computer model of the channel and surroundings to be navigated by the ship. The objects chosen for the model include navigation obstructions, buildings, landmarks, ranges and buoys used by pilots as visual clues for operation. The pilot, when equipped with an AR display, sees the immediate environs supplemented by the computer graphics in the heads up display. Head movements are accurately tracked so that the real and augmented graphics align in position, size and orientation. This is especially important in restricted visibility conditions, if augmented graphics are to correctly inform the pilot of the vessels location, orientation, and speed, as well any obstructions in the immediate surroundings. The AR system is used only to enhance the real world and not to replace it. Therefore, the pilot would see what he would naturally see through the fog plus an overlay of the augmented graphics that fall in his field of view.

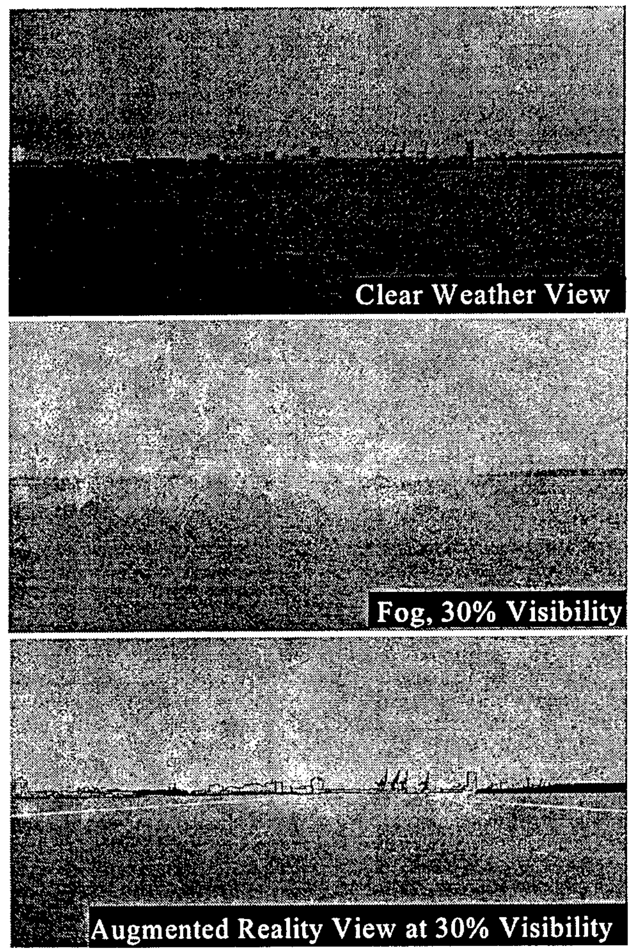

Figure 1: Principles of Navigation Using Augmented Reality

The picture sequence in Figure 1 demonstrate the principle of augmented reality applied to ship piloting and navigation. The first frame shows shows the view as would be seen on a clear day. The second frame shows the same scene on a foggy day, approximately 30% visibility. The last frame shows a AR overlay provided by projecting a wireframe model of the local landmarks to a HMD. The power of the AR display is that the head movement of the individual wearing the HMD is tracked so that as the user changes the direction of viewing the AR display changes to match the viewers sight line.

THE AR SYSTEM AND THE REAL WORLD SIMULATOR

The AR Display System

The use of augmented reality is relatively new to domestic markets. For this reason there are few commercial products available. The cost of the available displays and their functionality ranges from $500 to $130,000. Cost depends on the resolution and field of view. Available displays may be broadly classified as either see-through displays or monitor-based displays.

See-through Displays

See-through displays are immersive head mounted displays. Graphics are displayed on a transparent panel while allowing an unobstructed view of the surroundings. Figure 2 shows two views of a see-through panel placed in front of the real world object. The second view is a head-on view, demonstrating how the augmented view superimposes the real world view. These devices are also referred to as "Panel Mounted Displays" or "Head Mounted Displays (HMD)".

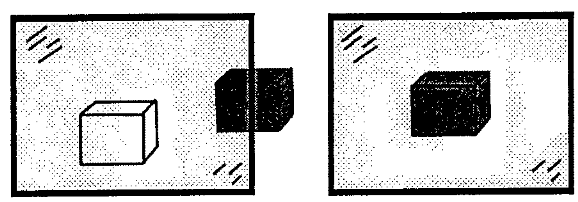

Figure 2: Principle of a See-through Display

Augmented reality HMDs differ from virtual reality HMDs due to their see-through nature. They use reflective mirrors to superimpose computer generated graphics optically onto a see-through display panel. A HMD provides the advantage of being immersive and head tracking can be tailored to the specific user. It maintains the simplicity of the application by requiring head tracking only for a single user. However, like virtual reality headsets, they can be cumbersome, and depending on the sophistication of the display may decrease the available field of view. In some individuals the display can cause eye strain, nausea and headaches.

Monitor-Based or Panel Mounted Displays

A panel mounted display, allows the user to move freely and the display can be seen by multiple users. However, with the current state of technology, each user would see the same perspective view as the person whose head movements are being tracked.

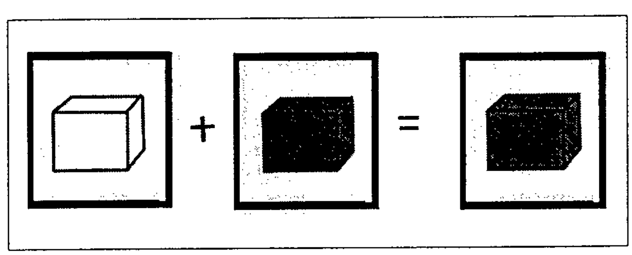

Figure 3: Principle of Monitor or Panel Mounted Displays

Panel mounted displays are non-immersive. Computer generated graphics are overlaid on live or analog, or digitally stored video images. As shown in Figure 3, two images are generated, one of the augmented view (wireframe) and another of the real world view. The two images are then composited to generate the image displayed on the screen. These types of displays find their application in telerobotic systems and in hazardous environments where the user cannot be in physical contact with the real world. The disadvantages of monitor-based displays are that they are not immersive and require real-time video compositing.

Display Selected for Navigation Project

For Phase I, of this project a see-through, head mounted display, provides the following advantages

- HMDs are commercially available products at reasonable cost;
- HMDs are very portable;
- HMDs do not require special design specifications for different scenarios;
- Head tracking is required only for the user of the HMD.

A simulation of the real world outside the ship is projected onto a projection screen. When this screen is viewed using the see-through HMD, augmented graphics overlay the real world. Another reason for using a head mounted display for this project is that the harbor pilot, who is intimately familiar with the channel to be traversed, has the primary responsibility for navigation decisions. Only the ships master would require a complementary display.

The chosen head mounted display is the Datavisor VGA manufactured by "n-Vision, Inc." It is a see-through HMD and provides an image resolution of 640x480 and a field of view ranging from 52 degrees to 78 degrees (depending on the amount of stereo overlap). It uses reflective collimated windows and corrective relay lenses to achieve optical tolerances, within standards established by the US Air Force Armstrong Aerospace Medical Research Laboratory.

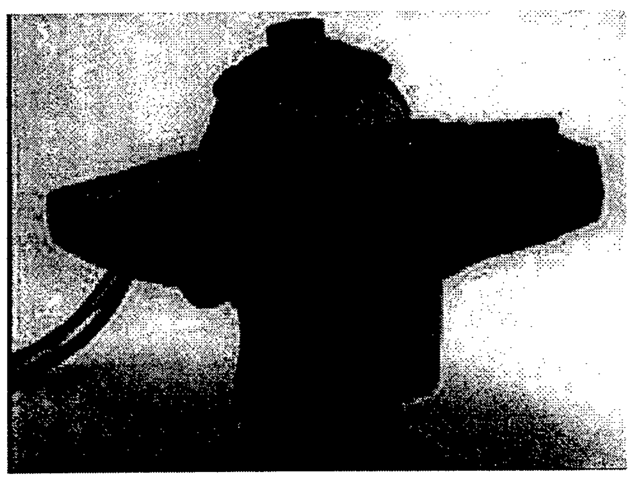

Figure 4: n-Vision Head Mounted Display

The input to the HMD is standard VGA at 60 Hz horizontal frequency, which it converts into a color field sequential signal [10]. The unit is shown in Figure 6. Even though the HMD appears bulky, it provides a system center of gravity within one centimeter of the head's natural center of gravity, keeping the moment of inertia close to the head and allowing easy head movements.

The Tracking Device:

Head orientation is tracked with an Ascension Flock of Birds (FOB) tracker, which is a six degree-of-freedom electro-magnetic tracking device. The reasons for choosing this product are:

- Freedom of Movement
- High tracking accuracy
- Electro-magnetic tracking is unobstructed by objects in the path of the transmitter and receiver
- Low Cost

The tracking device, Figure 5, consists of a transmitter, (the cube-like object), the Ascension Bird electronic unit, (the rectangular box), and the receiver (the small cube attached to the end of the chord). The HMD is fitted with a receiver to track the user's head movements. The receiver is capable of making up to 144 measurements per second of its position and orientation when it is located within a 3 ft. radius centered on the transmitter. The Ascension Flock of Birds (FOB), tracking unit offers an angular range of 180° azimuth and roll. The FOB has the capacity to track up to thirty receivers using a single transmitter. Position and orientation is determined by the FOB by transmitting a pulsed DC magnetic field that is measured by the receiver. Using the measured magnetic field, the receiver computes its position and orientation and passes these values to the host computer [7].

The FOB has several limitations that would prevent its use in the final prototype system. The short 3 ft. transmitter radius limits the freedom of movement which would not be acceptable on a large ship bridge. Because it is a magnetic device it may also be effected by large metal objects present in the vicinity of the tracking transmitter. However, the FOB is being used initially because the receiver is small, portable, unobtrusive and has the line-of-sight limitations of optical devices.

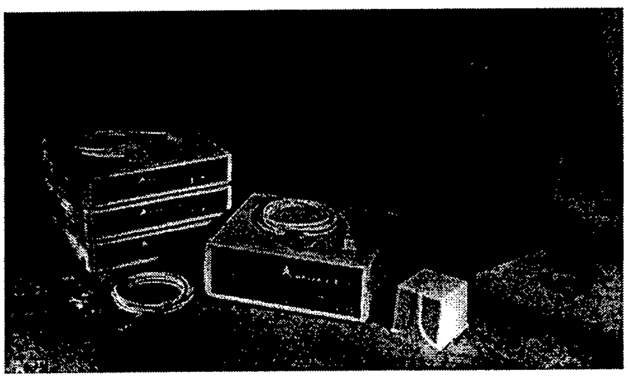

Figure 5: Head Tracking Device

There are several other options that could be used in a final prototype. Options include mechanical, inertial, acoustic and optical trackers [3]. Mechanical trackers have a physical link between a fixed reference point and the mobile entity. The position and orientation of the target is calculated by sensors at pivot points of the physical link. They provide very good accuracy and update rates, but impose movement and portability constraints. Inertial trackers use miniature gyroscopes to measure changes in orientation through the conservation of angular momentum in the spinning masses. Their main disadvantage is that, like all gyroscopic instruments, they are subject to accumulated drift from the actual orientation. Acoustic trackers employ several ultrasonic emitters and sensors that would not likely be practical, since variation in sound propagation speed causes inconsistencies.

At this point it appears that an optical tracking system would be the most practical for the final prototype. Optical trackers are built with optical emitters and sensors to compute position and orientation. In this case, the environment must be structured so that the emitters and sensors are visible to one another. This line-of-sight restriction could be problematic if there are displays or equipment suspended from the ceiling of the bridge that could interrupt the line-of-sight.

The Real World Simulator:

This phase of development is focused only on the graphic principles involving the use of an augmented environment display as a navigation aide. For this reason the real world views are computer generated imagery. The real world simulator generates a view as seen from the bridge of a ship. The real world simulator uses a model of the Galveston ship channel which was constructed using Microstation. Graphic output is generated by RIB (RenderMan Interface Bytestream).

The simulator reads the RIB and converts it into an OpenGL model. A displacement file is input as an argument to the simulator software to position the center of the model at the global origin. The simulator reads a frame file to generate future positions of the ship. The frame file consists of a series of pre-determined positions and orientations for the ship, to allow navigation along a fixed path. Alternatively, it can consist of values defining only the starting point. This implies that the ship would move only through ship maneuvering commands issued by the pilot and not along any pre-defined path. The positions and orientations are specified as a set of points defining the viewer's position, the point he is looking at and the Up Vector.

For this project, a single position frame file has been used. The view as seen from the current ship position is projected onto a screen. The projection screen represents the windscreen of the bridge of a ship, providing a view of the channel outside. Ship control is simulated by issuing voice commands that are translated into geometric transformations that are added to the current position of the frame file. Voice control is a feature that has been incorporated by integrating a commercially available voice recognition software called "IN CUBE Voice Command", manufactured by Command Corp. Inc. The simulator generates low visibility conditions by providing various degrees of fogginess, through an OpenGL software library function.

Client Server Model

The AR system is built on a client-server model, Figure 6. There are two servers. The first server generates the view to be projected onto the projection screen for the real world simulation. It receives ship position and orientation data from the pilot. This view remains static until the pilot issues a voice command to move the ship. Low visibility conditions are simulated in this view by using the percentage of fog data from the client.

The second server generates the wireframe model of the augmented view that is projected onto the pilot's HMD unit. It receives the ship's position and orientation data and the pilot's head tracking information from the client. The augmented view depends on both the ship's orientation and position in the channel as well as the pilot's head orientation. When the pilot looks directly at the projection screen, he sees the simulated real world overlaid with the augmented graphics of his HMD. When the head is turned the pilot sees the landmarks that would be visible to the port and starboard sides of the channel. The head tracking information received from the client adjusts the augmented view to display the landmarks in the pilot's line-of-sight.

The client collects the voice commands issued for ship maneuvering, the head position information and calibration information. The system must be calibrated to ensure that the augmented and real world views accurately register. Calibration is the process of aligning the real and augmented views so that they match in position, orientation and scale during the initial setup process. It is achieved by adjusting the camera parameters for the augmented view. Calibration information is passed from the client to the server generating the augmented view, to allow for camera positioning in the augmented view until the two worlds match. Voice commands can be issued to re-orient the ship to achieve calibration from different view points. The necessity for multiple viewpoint calibration is discussed in the next section. The client also provides the option to quit the program.

The Order of Operation:

The sequence of events between the servers, as depicted in Figure 6, are summarized below:

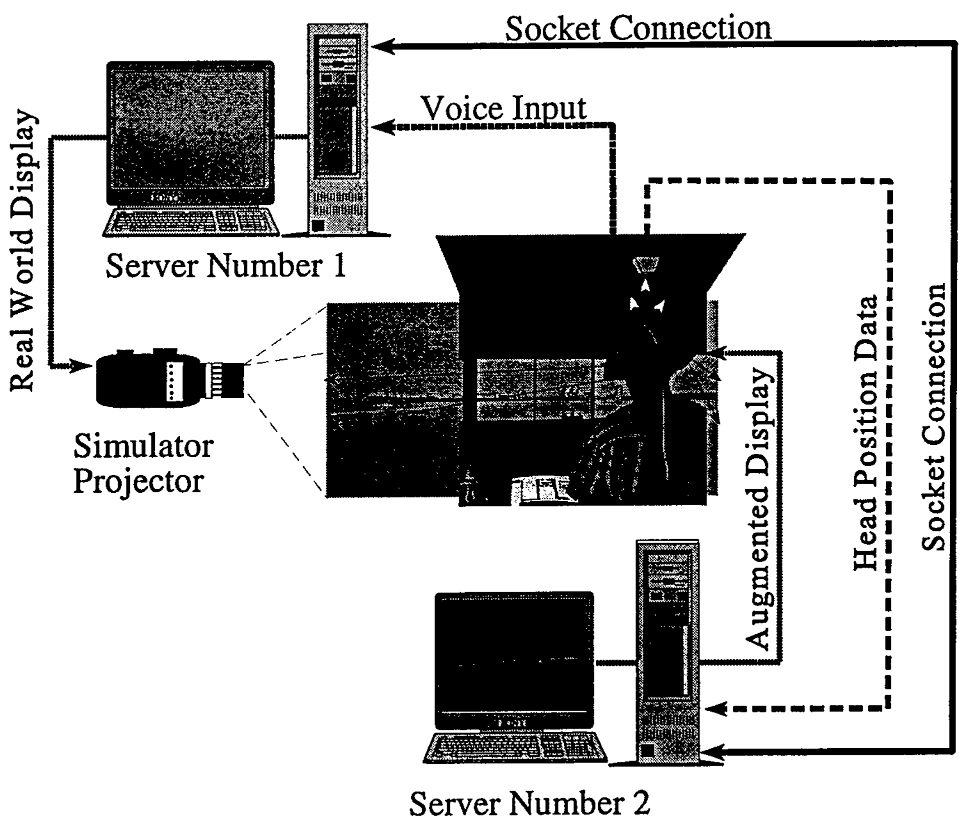

Figure 6: Diagram of the Client Server Model Used for Testing Graphic Concepts

1. The view of the ship channel model, with respect to the current ship location and orientation, is projected onto the projection screen by the real world simulator.
2. The head position is tracked, using the FOB.
3. Through the HMD, the user sees a wireframe of this model (AR world) overlaying the view on the screen (simulated real world). The server that controls the augmented display is responsible for the update of the wireframe view.

4. The system is interactively calibrated by the user until the two worlds register. This is done only once at the beginning, before any voice commands are issued for ship navigation.
5. Based on the head position, a view of the augmented display is superimposed on the HMD screen.
6. After evaluating the surroundings through the augmented display, the user issues a voice command, such as "full ahead", to move and/or re-orient the ship.
7. The simulator recognizes this voice command and executes an update of the projected view on the screen.
8. The augmented view is also updated to reflect the change in view due to the movement of the ship.
9. The user may once again move his head to evaluate the updated scene. His head is tracked and the augmented view is updated accordingly.

Steps 1-4 are one-time operations that are part of the simulator setup process. Steps 5-9 are repeated several times during the course of the simulation.

AUGMENTED REALITY PROBLEMS IN NAVIGATION

Introduction

Typical problems that are encountered in augmented reality systems include calibration, registration and system latency. Each of these issues must be addressed successfully if an augmented reality system is to be used as a navigation aide. Other problems more specific to this project are also presented.

In virtual reality applications, the user is fully immersed in the computer generated world, whereas in augmented reality applications, the real and virtual worlds co-exist. The human eye is very sensitive to changes in view with head movement. Therefore, in order to make this co-existence believable, when the user moves his head, the virtual view should update along with the real world view, maintaining accurate registration.

Registration

Registration is the alignment of augmented graphics with their real world counterparts, in proportion, position and orientation. There are two kinds of registration errors, static errors and dynamic errors [2]. Static registration errors are induced by several characteristics related to head tracking and the output display. Static registration errors can be induce by low resolution HMDs, mechanical misalignments within the HMD, improper adjustments of the viewing parameters such as field of view (FOV), inter-pupillary distance (IPD), and eye-to-receiver correspondence. Static inaccuracies can also be the result of errors in the head tracking system. Dynamic registration errors, are caused by system latency and are not noticeable until the user changes the line-of-sight.

Static Registration

Static registration is achieved by calibrating the system properly so that the real world objects and virtual world objects align accurately in size, orientation and position. When stereoscopic graphics overlay real world objects, their scale is required to match in all directions. A method of camera calibration with a virtual pointer is described in [4]. Another method of calibration is performing object matching from different viewpoints around the object [2].

This second alternative is the approach taken for this project. Augmented graphics on the headset are made to align with the simulated real world graphics on the projection screen by moving the headset's camera position until the perspective views of both worlds match. Voice commands issued to change the ship's orientation and position allow for different viewpoint checks when calibrating.

Calibration is necessary because an object may appear to present perfect registration from one viewpoint, but may in fact be off by a considerable amount from a different viewpoint. Figure 7a shows a head-on view of a box where the axis appear to align perfectly with the top left corner of the box. However, the same model when viewed from the left side, as in Figure 7b [2], clearly shows that the axis are offset from the corner by a few inches.

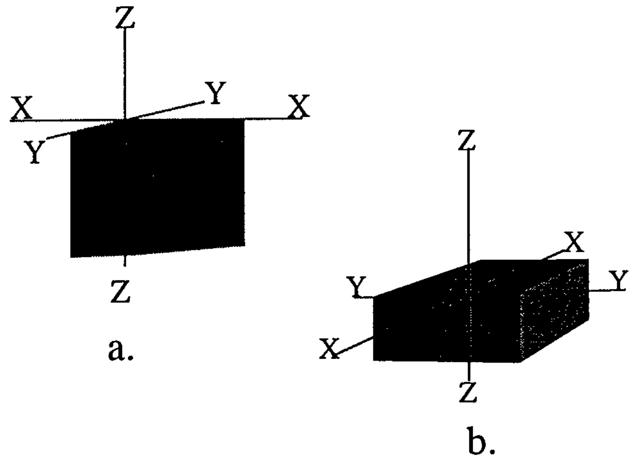

Figure 7: Registration

Equipment related issues of static registration will improve with technological advances. As HMD optics improve and tracking units become more sensitive static registration will improve.

Dynamic Registration

Dynamic registration is essential to ensure that the virtual objects remain aligned with their real world counterparts during the course of the user's head movements. The user's head position needs accurate and real time tracking to affect changes in both world views simultaneously. When the user's head is in motion, the augmented objects must move with the real objects so that they do not appear to be floating in mid-air.

Figure 8 demonstrates the difference between imperfect registration, Figure 8a, and perfect registration, Figure 8 b, when the user's head is in motion.

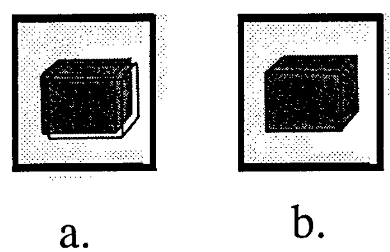

Figure 8: Dynamic Registration

To achieve dynamic registration, real-time generation of updated views is necessary. However, there is a time difference between the instance when the head position is tracked and the instance when the graphics are displayed on the HMD. This causes the display of the world objects to lag behind the real world objects. This dynamic registration problem is reduced by predicting future head locations, using inertial sensors. Future head positions are then used to draw the updated view instead of waiting for the actual head position computation to take place.

Dynamic registration improves by 2-3 times with inertial sensors over other prediction mechanisms and by 5-10 times over not using any prediction at all [2]. However, inertial trackers lose accuracy with time due to accumulated drift. Tracker performance can be improved by combining existing tracker technologies [3]. For example, inertial trackers can be kept in check by timely updates from more precise short-range trackers. Tracker information can also be time stamped to use the most recent information when drawing the augmented view.

One technological advancement that would aid calibration is "wide-area tracking." This would allow the user to minimize errors, by calibrating the system from several viewpoints far away from the initial viewpoint. The University of North Carolina, Tracker Research Group, has developed an optoelectronic tracking system which maintains registration errors under 2 mm and 0.2 degrees. It is also the only known scaleable tracking system, currently covering a 16 x 18 square feet area [3].

System Latency

Another factor effecting registration is system latency. Factors that affect system latency are delays in client-server communications, generation of graphics displays and processing of voice commands. Client-server communications can be improved by increasing network speed. The graphics are rendered using OpenGL display lists which are designed to optimize performance, particularly over networks. The use of fast graphics engines and simple models improve rendering performance considerably.

Voice recognition time can be reduced by keeping the vocabulary small and simple. While system latency is not as important for ship maneuvering as for aircraft or automobile maneuvering, it is important to have reasonable update times for the pilot's head movements so that he is able to visually gauge speed and heading.

Head Mounted Display Issues

Technical issues, related to the HMD, that require attention are achieving a stereoscopic display and optimal lighting conditions in the AR environment. Stereoscopic displays provide two views, one from the perspective of each eye. The advantages of using stereoscopic displays are binocular depth clues (i.e. eye convergence), as well as monocular depth clues (i.e. texture gradient) are retained [8]. It is difficult to estimate absolute sizes with a monoscopic display.

The headset allows only a portion of the natural light in the room to reach the eye, and the remaining percentage of light is made up by the displayed augmented graphics. When the light intensity in the room is increased, the AR graphics display becomes dimmer and vice versa. The colors used for the augmented display also make a difference since some colors such as red and cyan are visible even in fairly bright environments. Though it would be ideal for the light in the surrounding environment to be a controlled parameter, it may not be possible during the actual implementation of phase II. The acceptable limits for the above problems are presented in the next section, along with the actual values obtained from the system tests.

SYSTEM TESTS

The augmented reality system can only be put to a final test only when a ship pilot, familiar with the test channel, has a chance to experience the system first hand. Upon the initial developme3nt of the simulator, a number of tests were conducted in order to evaluate various parameters of the system's performance. The current state of the system is as follows.

Static Registration Issues Related to Equipment

Resolution of the Datavisor VGA is 640 x 480 at 60 Hz horizontal frequency. This is the minimum resolution required for reasonable static registration in augmented reality applications. Commercial products that offer higher resolutions (up to 1280 x 1024) are at least twice as expensive.

Inaccuracies in the tracking system is another cause for static registration errors. The Ascension Flock of Birds tracking unit offers a static positional accuracy of 0.1" RMS averaged over the transitional range and an angular resolution of 0.1° RMS @ 12" [7]. Metal present in the vicinity interferes with the tracking system and can cause inconsistencies when recording the receiver's position.

The normal field of view for a human being, including peripheral vision, is 180 degrees in the horizontal direction and 130 degrees in the vertical direction. The Datavisor VGA is configured to a factory set stereo overlap of 100 percent. This provides a diagonal FOV of 52 degrees. The horizontal FOV can be increased up to 78 degrees by compromising on 50 percent of the stereo overlap. For this test, 52 degrees diagonal FOV and 100 percent stereo overlap is found to be acceptable.

The inter-pupillary distance is adjusted by moving the mirrors on the headset. This affects the convergence of the stereo images for both eyes. Controls are provided on the HMD to adjust the IPD and focus. These settings vary from person to person and are essential to the initial setup process.

Incorrect eye-to-receiver correspondence causes visual inconsistencies. The camera is calibrated according to visual perception. Although all tracking is done with respect to the receiver mounted on the HMD, it has been found that the eye-to-receiver separation has not caused any noticeable inconsistencies. The receiver is fixed on a special mount provided on top of the HMD. However, the Datavisor VGA's mount is not sturdy and care should be taken to ensure that the wires are not tugging on the receiver.

Calibration

Since both the real world an HMD view were computer controlled and generated, calibration could have been automated. However, to explore the problems associated with calibration, a decision was made to perform calibration manually in a manner similar to that required on board ship.

Calibration is done by adjusting the camera position for the augmented view until both the real and augmented world attain acceptable static registration. The client provides controls to translate and rotate the camera affecting the augmented view. This process is tedious and is prone to several inconsistencies.

Because the augmented view is updated based only on head rotations, the system can be calibrated for just one position. Once the system is calibrated, any translation in the user's head position causes static registration problems. All calibration is user-dependent and is restricted by the user's visual capacity.

Dynamic Registration and System Latency

System latency is measured with respect to delays caused by low system speed, and lags in network communications and voice commands. The system requires time for client-server communications and for the generation of graphics. This aspect of system latency is measured as the average time taken from the time a command is issued for updating the graphical display to the time the updated display is rendered. Rendering times improve with lower polygon count models. The current test model has 4,148 polygons.

The system latency is measured as the average round-trip network delay between the client and each server, the average time taken by each server to render a single frame and the average time taken by the client to collect the head tracking data.

The client is a Sun SPARC station 2. Server 1 is a Sun SPARC station 10, equipped with an Evans & Sutherland Freedom 3000 Graphics Accelerator and is used to generate the flat shaded real world view. The network connecting the client to server 1 and server 2 is slow and transfers only 10MBit/sec. It has been observed that the average round-trip network delay between the client and server 1 is 140,389.55 microseconds and is represented graphically in Figure 9.

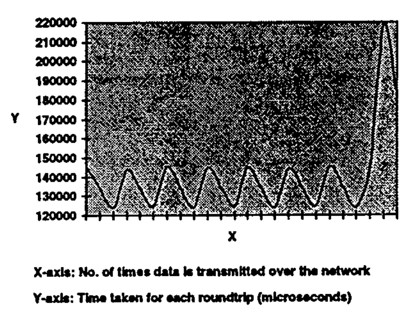

Figure 9: Average Round Trip Network Delay Between Client and Server 1

Server 2 is an SGI Indigo2 Extreme and is used to generate the wireframe display for the augmented world view. The average round-trip network delay between the client and server 2 is 135,877.64 microseconds and is represented graphically in Figure 10.

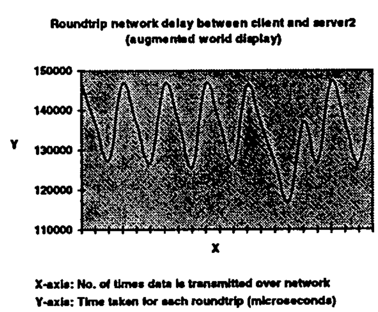

Figure 10: Round Trip Network Delay Between Clint and Server 2

The average time taken to render each frame on Server 1 (real world display) is 30315.54 microseconds. This is shown in the graph of Figure 11.

The average time taken to render each frame on Server 2 (augmented world display) is 439.75 microseconds. This is shown in the graph of Figure 12.

The average time taken by the client to track the user's head movements and compute the new head position is 67,296.79 microseconds. The graph depicting this is shown in Figure 13.

Overall, the network delay has been observed to be relatively high. A possible solution is to eliminate the machine used by the client and use the SGI to run both the client and the server 1. Network speed may also be improved by moving to a faster network. Another option is to directly connect the machines and pass information through their serial ports.

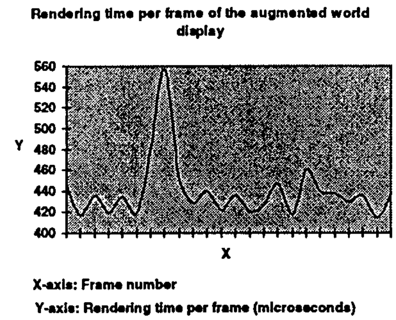

Figure 11: Rendering Time Per Frame on Server 1, Real World Simulator

The voice recognition software takes time to recognize words. It depends on the size of the vocabulary, consistency in pronunciation and how easily the words can be distinguished from one another. It was observed that some words need to be repeated over 10 times before they were recognized. Figure 14 shows a list of the voice commands used for this project.

Surrounding Light and Drawing Color

The change in lighting conditions of the room makes a very noticeable impact on the display. However, a normal office environment provides sufficiently clear visibility of both real and augmented worlds. The brightness provided by the Datavisor VGA is greater than 10 fL.
Drawing color also makes a difference in the visibility of the augmented display. Black is the color that is least visible and provides the highest degree of transparency. It is used for the parts where the display is required to be completely transparent, such as the background. From display tests that were conducted, objects drawn in red appeared to provide the maximum visibility in different lighting conditions.

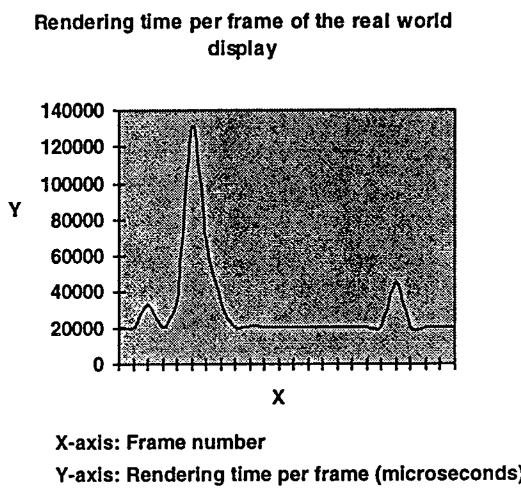

Figure 12: Average Render Time Per Frame Server 2, Augmented World

System Test By Ship Pilots

All tests have been performed using the real world simulator, which is designed to meet the minimal requirements to demonstrate the principle of Augmented Reality. The simulator does not make use of real update times. So far, the study only involves testing for system latency, calibration accuracy, lighting conditions and equipment limitations. The true test of the system lies in obtaining the approval for real world implementation by harbor pilots and other ship channel experts. Their familiarity with normal ship maneuvering practices is needed to evaluate whether or not the current system's latency, resolution, registration,

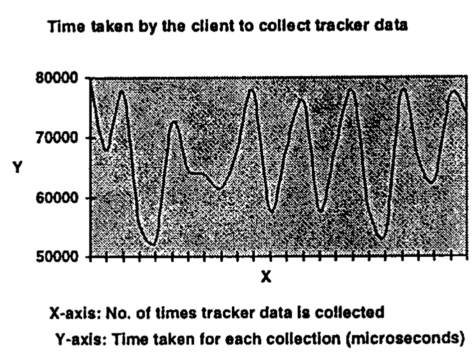

Figure 13:Average Head Tracking Time

calibration and nature of equipment is acceptable for further trials aboard ship.

Conclusion

Of the tests conducted, system latency proved to be a greater problem then originally anticipated. The update rate of 1-2 frames per second is too low fro any practical application. The major cause appears to be the result of communication time between the client and the servers over the network. This is a problem with the simulation, however, and not the concept. The use of the SPARC 2 as the client operated on SUN OS 4.1.3 an old operating system and communication with the TCP/IP stack on the world view server running Solaris 2.4 and the HMD server running IRIX 5.3 appears to be particularly slow. The lack of software to run the Flock of Birds (FOB) on Solaris necessitated this decision. Moving the client to a more favorable machine world dramatically reduce system latency and improve the system response.

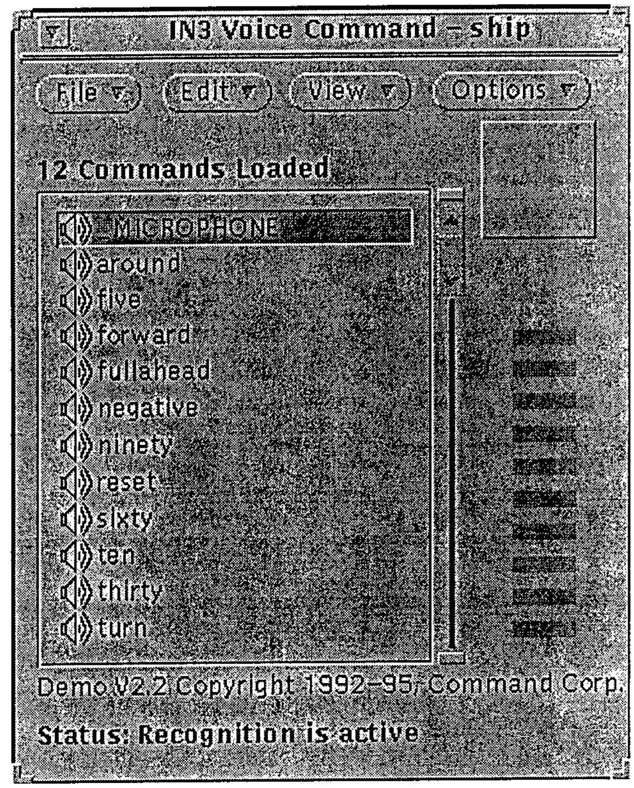

Figure 14: Library of Voice Commands Used in Demonstration

The overlay of a synthetic world view of a real world view is possible with commercially available equipment and computing resources. However, acceptability and trust in the system will involve field trials with a prototype system on an actual ship bridge. The issue of equipment and system confidence is potentially a major issue in an operational environment. While the registration and calibration procedures employed in this system proved adequate for these tests, they did raise questions about the techniques and methods that would be required in the field to instill confidence in the user. Any inaccuracy in these procedures over the course of the ships movement could be subtle enough as not to be perceptible to the pilot. Some form of periodic/automatic re-calibration needs to be performed. With the use of DGFS, this procedure appears feasible but was not explored.

Applications of Augmented Reality technology are still very young and the cost of implementation is high by comparison to other computer based graphic applications. The availability of "off-the -shelf" resources is also limited. This initial phase of the project was conducted using a minimum level of resources to determine whether the graphic issues involved in the development of an operating system could be addressed satisfactorily to warrant further development.

The results of demonstrations with experienced pilots was not particularly conclusive. At this point only pilots that have an understanding of and an interest in, augmented technologies have examined the system. They are excited about the possibilities of continued development but are cautious about how pilots less familiar with the technology and its potential may react to a demonstration in its current format. It is somewhat like showing a prospective client a freehand sketch of a building on the back of an envelope. The may or may not understand what the final product will do.

Rendering speed and efficiency can easily be improved with more powerful graphics engines. Issues of resolution can be overcome with more expensive headsets that provide higher resolution and wider fields of view. Other issues related to head tracking and freedom of movement can also be overcome with commercially available equipment.

During demonstrations there have also been questions about the lack of hydrodynamic behavior of the real world model. The concerns were that the "own-ship" or real world view did not behave as might be expected under the influences of current, wind and effects of waves. This a valid concern but was not a part of this project phase. In order to prove this portion of the project it is necessary place the graphic equipment of an actual ship bridge and link it to input from Differential Global Positioning System (DGPS) receivers. This input will provide the ship behavior information and "feel of the ship" so important to the real piloting experience.

Future Work

The augmented reality system needs to be ported to the bridge of an actual ship. The use of DGPS technology to provide ship behavior input must be linked to the graphic engine to provide the hydrodynamic and ship behavior input. The navigation technology must also be employed to accurately map the channel and landmarks involved in the piloting and ship maneuvers. Anticipated problems such as registration and system latency will have to be addressed and more sophisticated graphic techniques developed to maintain registration.

Issues of appropriate head tracking systems need to be investigated further in this second phase. The need for wide area tracking and the need for use of line-of-sight sensors must be explored in the context of numerous bridge layouts. At this point registration of the real world and the augmented world depend on the pilot remaining in the position used for calibration.

Many of the equipment based problems will be solved by continuous improvements in equipment and computer resources.

Other issues that must be addressed in developing the prototype system will be a means to account for "stray objects." This includes other ships and debris which cannot be included in the computer generated model. Means to account for these objects and render them as part of the augmented view must also be explored.

Finally, all equipment must be made robust enough to survive the rough waters of the channel and high moisture conditions, yet it should be portable and easy to use.

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