COMPARISON OF US AND CANADIAN VIRTUAL REALITY SHIPHANDLING

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A comparison of the Virtual Environment Training Technology (VETT) shiphandling simulation at the Naval Air Warfare Center Training Systems Division (NAWCTSD) in Orlando, FL with the Maritime Surface/Subsurface Virtual Reality Simulator (MARS VRS) development system at the Defence and Civil Institute of Environmental Medicine (DCIEM) in Ontario, Canada found similarities in the technology used by the systems. The basis for these similarities is the natural interaction immersive technology provides for shiphandling. Both systems use a comparable head mounted display (HMD) for the visual scene, however head movements are tracked with dissimilar technology. VETT hardware includes an inertial tracker so that it can meet the requirement for shipboard use. MARS uses a magnetic tracker, allowing for 6 DOF to accommodate for movement used in real world performance. This hardware difference is compared. Necessary environmental fidelity is directly related to training objectives. Both systems create an environment to develop "seaman’s eye", a perceptual skill used by shiphandlers. However, due to the differences in the specific shiphandling exercises used in the simulations, the fidelity requirements of environmental cues are different. VETT implements an underway replenishment (UNREP) maneuver, an exercise in which ships operated in close proximity, requiring detailed environmental cues such as waves and wakes. MARS VRS is used for performing training maneuvers completed at safe distances, precluding the necessity of high fidelity wakes. These differences are compared. VETT represents navigational information in numeric/abstract format on an HMD for voice call-up by the student. MARS uses high fidelity and real world representation of actual navigational instruments. The navigational information displays are compared. Unique to VETT is the collection of automatic performance metrics for correlation with subject matter expert (SME) ratings. Some preliminary findings are discussed. Conclusions are drawn regarding the differences in the systems and the implication for design of operational shiphandling training systems using virtual reality HMDs.

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INTRODUCTION

The United States and Canadian defense laboratories have applied virtual environment (VE) technology to develop shiphandling simulation and analysis applications for training seaman's eye, a perceptual shiphandling skill. Seaman's eye is the ability to control and predict a ship's movement by synthesizing general ship dynamics knowledge with perceptual input (Crenshaw, 1975). The focus of this paper is to compare examples of this technology from each country, specifically, (1) the US Virtual Environment Training Technology (VETT) testbed and (2) the Canadian Maritime Surface/Subsurface Virtual Reality Simulator (MARS VRS). US and Canadian team members conducted a comparison of the two simulators in the fall of 1998.

BACKGROUND INFORMATION

The simulators were developed during separate time periods. The VETT simulation is currently undergoing investigation while MARS was field tested in 1993 and 1994. The two projects were conceived for different purposes. The VETT simulation was created to provide a research tool to explore the application of VE technology for military training. A shiphandling application was selected due to interest of the US Navy's Surface Warfare Officers School (SWOS). The MARS simulator was developed to fulfill the Canadian's Chief of Maritime Doctrine and Operations (CMDO) appeal for a simulator for shiphandling training (Magee, 1997).

The skills required to perform shiphandling maneuvers include the ability to estimate distance, speed, and turning rate (i.e. seaman's eye). In order to develop seaman's eye, the student must be able to see all around the environment, such as the panoramic visual displays common to traditional bridge simulators (Magee, 1997), requiring a visual interface with an unlimited field of regard and a wide field of view. Both organizations converged on the applications of VE technology with an HMD interface as a more effective and less expensive alternative to the existing bridge simulator technology.

The selection of the shiphandling maneuvers employed by the VETT and MARS simulations were guided by requests from their respective customers. VETT employs the underway replenishment (UNREP) maneuver while MARS uses formation maneuvers. UNREP is a shiphandling maneuver which requires close quarter maneuvering between ships (i.e. ranges less than 200 feet) while formation maneuvers are generally performed at greater distances (i.e. ranges 350 yards or greater). The simulations used different ship classes for the student's vessel and were chosen based upon relevance to the target task. The VETT student vessel was a CG-47, and the MARS student vessel was a Bay Class training vessel. Additionally, both simulations involved other ship classes. The VETT simulation modeled a Wichita Class AOR for the receiving vessel, and the MARS simulation has the flexibility to support several different ship types.

VETT

The UNREP simulation was constructed through an iterative development process (see Martin et. al., 1998), which began with a literature review (Crenshaw, 1975; US Navy, NWP-14) and interviews with subject matter experts (SME's). A basic UNREP simulation was developed from information obtained through the literature and SME's interviews. The SME's performed an UNREP utilizing this basic simulation in conjunction with a verbal protocol. The sessions were video taped and reviewed by the researchers and the SME's to obtain comments on the simulation and explanations of the verbal protocol responses. Subsequent modifications were made to the scenario, and the steps were repeated until the SME's indicated that the simulation adequately modeled a real world UNREP.

MARS

The MARS team used an iterative approach for the simulation development, employing Naval Officer Training Centre (NOTC) SME input. By comparing students trained with MARS to students trained with the existing NOTC bridge simulator, they hoped to assess real world training effectiveness. The results of the training effectiveness evaluation demonstrated that training with the MARS simulator resulted in learning and that the skills developed during the MARS training sessions improved real world performance of shiphandling maneuvers (Magee, 1997).

SIMULATORS

The following section describes the various hardware, software, and simulation properties of the two simulators.

VETT

The VETT shiphandling simulator has two primary components: a student interface and an instructor/operator station (see Fig. 1). The simulation environment is an open ocean that is populated with receiving vessel (the student's ship), the supply vessel, and four vessels used to populate the environment with additional contacts. The simulation is run on an Octane with two MIPS R10000 processors, MXI Graphics, Octane Channel Option, by *Silicon Graphics, Inc.*, and modeled with dvReality software, by *Division, Inc.* Paradigm Simulation, Inc renders the ocean graphics with VEGA Marine software.

Figure 1. VETT Hardware during operation

The student interface enables the student to interact as the conning officer on the receiving vessel. The student uses a VR4 Head Mounted Display (HMD) by *Virtual Research,* to view the environment with head movements tracked by an IS600 Inertial Tracker, by *Intersence*. The student's view is from the port bridgewing of the receiving vessel, but can be switched to an alternative viewpoint. A customized independent speech recognition system enables the student to control the movement of the receiving vessel by issuing verbal commands and requesting navigational information in the manner a conning officer would perform the task in the real world. The student speaks into a SM10A microphone, by *Shure,* while depressing a button on a *Division, Inc.* 3-D mouse. The independent customized speech models, constructed with *Entropic* software (see Cope et. al., 1998), perform the speech recognition functions. The speech input is digitally converted and then handled as if data were entered via keyboard strokes. Pre-recorded audio responses are used to simulate the standard engine room and helmsman responses that inform the student that his command has been recognized and executed. Navigational information is presented visually in either a heads-up digital display or a heads-up representation of the real world instrument. Navigational information displays for both simulators will be addressed in a later section.

The instructor/operator station (IOS) is supported by an Indigo^2 Impact MIPS R10000 by *Silicon Graphics, Inc.* The IOS consists of two monitors: an interface monitor and an observation monitor. The interface is comprised of UNIX shells and a graphical user interface (GUI). The simulation is "turned on" through a series of UNIX commands and the actual scenario is controlled with the GUI. The interface monitor provides the instructor/operator with a view of the simulation minus the ocean graphics. The instructor's visual display of the simulation allows the instructor to manipulate his viewpoint and observe the student and the environment while the scenario is being conducted. This display is enhanced by visual tracks, which represent the receiving and supply vessels' movement, and a visual representation of the student's line of sight. The GUI enables the instructor/operator to manipulate the environment, and control the simulation to a limited extent during the performance or replay of a scenario. The instructor/operator may also input the commands issued by the student via the keyboard in lieu of the speech recognition interface.

MARS

The MARS simulator has three components: an interface for the student, an instructional station, and a simulated bridge team (Magee, 1997). The simulation environment is the open sea, which can be populated with several ships, and is run on an Indigo 2 with Extreme Graphics, by *Silicon Graphics, Inc*. The shiphandling exercises that MARS executes are formation maneuvers traditionally taught during the at sea training conducted at NOTC. The Bay Class minor war class vessel, the ship used for training at NOTC, is the primary hydrodynamic model used in MARS.

However, the design has the extendibility to implement other ship models (see Fig. 2).

Figure 2. MARS Hardware during operation

The student is positioned on the bridge and views the environment with a MRG 2 HMD, by *Liquid Image Corporation,* with head movement tracked by a Fastrack motion tracker, by *Polhemus*. A speech recognition system enables the student to perform OOW duties as on a real ship, meaning that he issues verbal commands to control the ship and receives audio replies and status reports from a simulated bridge team. The MR8 speech recognizer, by *Marconi,* is used to synthesize the speech input and a Model MS20S speaker (35 Watt), by *Yamaha,* emits the simulated bridge team's responses. The student obtains navigational information by observing the environment or viewing navigational instruments. The navigational displays are visible when the student looks up or down, so that they do not obscure the student's view of the environment while allowing the instructor to determine when the student uses the navigational instruments (Magee, 1997).

The instructor station is run on an Indigo 2 with XZ Graphics by *Silicon Graphics, Inc.* The IOS enables lesson planning, facilitation of the training exercise, and debriefing. Similar to VETT, the IOS consists of two monitors, one for the interface and one for observation. The instructor interface consists of a GUI and an observation monitor, which provides the instructor with a view of the environment. The instructor can select the vantage point to be either the student's point of view, which enables him observe the students head movements and use of navigational instruments, or a third person view, which provides a view of the entire formation. The third person perspective is enhanced with trails of the ships to mark the course the student takes during the exercise and a track, which represents the course of the standard solution for the maneuver.

OBSERVATION

The comparison was conducted at the MARS lab in the Human Factors Division of the Defence and Civil Institute of Environmental Medicine (DCIEM) located in Toronto, Canada. The Canadian team members were Lochlan Magee, Ph.D., Program Manager, Stuart Grant, Ph.D., Research Psychologist, Donald Turner, Training Specialist, and Ralph Kuehnel, Lead Engineer. The United States team members were Elizabeth Sheldon, Research Engineer, and William Walker, Visual Engineer of the Naval Air Warfare Center Training Systems Division in Orlando, Florida. The VETT simulator was transported to Canada so that the two simulators could be compared "side by side", and the investigation took place over a two-day span. The process involved demonstrations of the simulations and a series of question and answer sessions.

The side by side comparison enabled the researchers to observe the subtle differences in functionality. These differences were a product of the specific task requirements, technological evolution, and cost. The VETT team desired a flexible tool to support exploratory research, while the MARS team built a training simulator. The IOS, auditory displays, navigational information displays, scenario generation, and performance measurement techniques had different capabilities primarily due to the functional requirements of the end users. The VETT system was generally operated by experienced computer programmers and not intended for widespread use, whereas MARS was developed as a training simulator to be used by Canadian naval instructors.

The VETT system did not have a formal IOS; the operator initialized the system through a series of UNIX commands. After the simulation was initialized, the operator could access a pull-down menu, a visual display of the scenario, and a message window. The pull-down menu was a generic graphical user interface (GUI) generated by the *Division* application. The operator used this menu to run the specific scenario. The GUI could be used to close the operators visual window of the environment, but the simulation and speech processes could only be closed by performing the "CTRL, C" function in the respective UNIX shells. Data from each run of the exercise could be saved, however, the data files had to be renamed in UNIX prior to restarting the simulator to prevent the data files from being overwritten.

The MARS IOS was a windows interface comprised of pull down menus and visual displays controlled with point and click actions and keyboard input. The operator was able to easily turn on the simulator, construct and conduct shiphandling exercises, save data, review exercises, and shut down the simulator. Additionally, there was an instruction manual, enhanced with pictures and examples, to assist the user with the interface.

There were no auditory enhancements other than the verbal replies to the student's orders available on the VETT simulation. The audio enhancements by MARS provided an additional modality to perceive the environment and contributed to a sense of realism. The auditory enhancements were engine noise and foghorns that had been digitally recorded in the real world setting. A single speaker was used to emit the audio recordings (Magee, 1997).

Navigational information was provided in two visual formats by the VETT simulation: a digital heads-up display, and a heads-up representation of real world navigational instruments. Range, speed, RPM, course, and bearing information were displayed digitally, unless the user specifically requested a navigational instrument, such as a rudder angle indicator or compass. A radar display was developed in anticipation of examination of other shiphandling maneuvers, but was not used for UNREP tasks due to the close range of the vessels. It is important to note that range and bearing information was only available in reference to the supply vessel. Additionally, ranges and bearings were calculated from center points of the vessels, whereas ranges and bearings would have been calculated from receiving vessel's bridge to the closest point on the supply ship in the real world. MARS presented navigational information via representations of real world navigational instruments used by the OOW. The instruments were in a heads-up format and visible when the student looked up or down. This method of representation enabled the instructor to determine when the student was using the instrument and prevented the instrument from obstructing the student's view of the dynamic seascape (Magee, 1997). The display types were: compass, peloris, rudder angle indicator, and clock. A surrogate team provided range and bearing information as well as relative velocity solutions.

The VETT simulation ran a pre-scripted UNREP scenario, but did not have the capability for on-line scenario generation. Any modifications to the scenario would require editing the code or writing new code.
A feature of the MARS IOS provided quick and easy scenario generation, in which the instructor was able to specify the number of ships involved, designate ship control to students or automation, create a training evolution, position ships in the formation, and label the ship icons in the display.

A focus of the VETT research has been the development of automatic performance measurement techniques. At the time of the comparison, a text data file containing the attributes and events of ownship (i.e. position and movement of receiving vessel, student input, etc) was available for analysis immediately following completion of an UNREP. Additionally, a two dimensional graph could be generated using a statistical software package to provide the student with visual feedback of his track. To date, regression techniques have been used to analyze the relationship between the physical output of ownship and objective performance ratings provided by SME's (Patrey et. al, to appear). In contrast, the philosophy of the MARS development team was that automatic performance measurements could result in the misdiagnosis of a problem and lack the robustness of a human instructor's evaluation. Therefore, MARS used NOTC evaluation sheets, which were completed by the instructor for evaluating performance in the simulator. Student performance was measured on five different criteria: planning, performance of the task, ability to maintain station, bridgemanship, and safety (Magee, 1997).

The close proximity of the systems during the side by side comparison accentuated the differences in the technological components. MARS had completed field testing three years prior to the start of VETT development. The technologies available during the two development periods were different due to the rapid advancements in VE technology. This factor was most evident in the HMD, head tracking, graphics, and speech recognition systems.

In the past few years, HMD technological advances have improved comfort and display quality. The VR 4 HMD used by the VETT simulation was smaller, and lighter than the MRG 2 HMD used by MARS. However, despite the technological advances, the MRG 2 HMD used by MARS had a 65 degree high and 80 degree wide field of view (Magee, 1997), while the VR4 used by VETT only had a field of view of 60 degrees high and 60 degrees wide.

The VETT simulation originally used a Polhemus (magnetic) tracking system similar to the MARS head tracking system. However, the VETT project was required to fulfill a future requirement of shipboard training. Faced with the dilemma of using a magnetic tracker on a metal ship, the development team chose an inertial tracking system. The inertial tracking system's ability to function in a ship environment was demonstrated during a pilot experiment conducted aboard the USS YORKTOWN.

The fidelity of ocean graphics for each system provided the environment cues needed to perform the specific maneuver (see Table 1). The VETT ocean environment included detailed bow and wake effects specific to close quarter maneuvering. SME reports indicated that the wavetrain of the receiving vessel was used to determine lateral separation during the approach, and the bow and wake effects were used to monitor lateral separation while the vessels were alongside. While the maneuvers performed in the MARS simulator did not require high fidelity bow wakes and wavetrains, there were ocean effects not applicable to UNREP that were essential for learning to perform formation maneuvers. Therefore, the MARS ocean environment included knuckles and rudder swirls effects.

VETT used a custom independent speech recognition system, while MARS used a dependent speech recognition system. The VETT speech system was user independent because it was built with application specific speech models. Data samples, consisting of a series of pre-scripted commands specific to the domain were recorded by SME's and used to build the models. The Hidden Markov Model theory, in which the system matched an individual's utterance to the phonemic structure of the utterances (Cope et. al., 1998), was the methodology used to construct the speech models. The MARS speech system was user dependent because the user had to "train" the system to understand his voice. This was accomplished by having the user create a template, a process in which the user makes a verbal recording of a series of pre-scripted commands and took approximately 20 minutes. Additionally, custom independent speech recognition systems had not evolved at the time of MARS' development.

Despite the differences in functional requirements and available technological resources, the two simulations had many similar features unique to immersive environments. The convergence on similar applications of VE technology suggests that the features provide a sense of natural interaction for shiphandling tasks. Additionally, the implementation of these features is supported by Gabbard and Hix's suggestions for VE interactions (Gabbard & Hix, 1997).

Both teams investigated applications of viewpoint manipulation. It was suggested that the capability to alter the viewpoint increases the user's development of spatial knowledge (Gabbard & Hix, 1997). Additionally, viewing the dynamic visual scene from different orientations was attributed as a method of advancing perceptual skill development (Breaux et. al., 1998). One study (Knerr et. al., 1998) demonstrated

	✓Environment
VETT	**The close quarters maneuvering of UNREP requires detailed environmental cues such as waves and wakes**
MARS VRS	**High fidelity of waves and wakes was not required to meet the training objectives of MARS**
	✓Navigational Instruments
VETT	**Navigational information is represented in numeric/abstract format on an HMD with the sole objective of providing navigational data in an easy to use format.**
MARS VRS	**High fidelity and real world representation of actual navigational instruments was required to meet the training objectives.**

Table 1. Comparison of Environment & Navigation

that the user's degree of interaction within the VE positively correlates with the development of the user's spatial knowledge within the VE. However, the functional operation of this tool differed between the two simulators. The capability to change the user's point of view was implemented in the VETT simulation, but its effectiveness has not yet been studied. Viewpoint manipulations were used to immediately change the vantage point to three other locations on the receiving vessel; the middle of the bridge, starboard bridgewing, and stern as well as the "above" position, approximately 10 feet directly over the receiving vessel, and a bird's eye perspective. The operator was able to interactively manipulate his viewpoint to the student's perspective or a third person view when using the visual display of the IOS. The MARS team supported the use of a third person perspective in the IOS so that the instructor could view the entire formation simultaneously. However, the philosophy of the MARS development team was that OOW student use of viewpoint manipulation would lead to negative transfer.

Record and replay functions were available on both systems to enhance debrief and review sessions. During the replay mode, the scenario was viewed from a third person perspective. Additionally, the VETT replay function permitted the scenario to be replayed from the user's perspective. The replay function also enabled the scenario to be viewed in a fast forward and rewind mode, in both systems. However, the MARS version allowed the instructor (or student) to immediately advance to a specific part of the exercise.

CONCLUSIONS

Three important issues regarding training system design emerged during this exercise, (1) considering the objectives of the task, (2) determining the fidelity requirements, and (3) planning for the continual advancement of technology. The comparison revealed a convergence on the application of immersive environments for perceptual skill development. The parallelism between the designs provides additional evidence that the development of perceptual skills, such as seaman's eye, is enriched with the use of virtual environment technology.

The developers also recognized the importance of matching the fidelity of the system with the requirements of the end user. The fidelity of the ocean environment was a product of cost, availability of graphics technology, and the visual requirements of the training applications. The ocean graphics of both systems provided the environment cues required for the development of seaman's eye as applied to the specific maneuver being trained. Neither team had performed a formalized requirements test, however, the lessons learned from this exercise could be applied to the development of a protocol for determing the fidelity level of the environment. Future experimentation could investigate which portions of the environment contribute to task performance and which portions are being filtered out of the perceptual process. Rassumssen (1986) has posed a theory of abstraction hierarchy, which suggests that elements of a process are stored at a level of abstraction relative to their impact on the process. For instance, what if performance of the task was not at all related to fidelity of the ships? What if the ships need only be represented at a level of abstraction such as a box? Additionally, the notion of filtering out non-essential perceptual input was addressed by Hill's (1999) exploration of filtering perceptual input to reduce the computational load on a SOAR SAF application.

Lastly, this investigation underscored the rapid evolution of state of the art technology. The developer should not only design his system depending on the resources currently available, but also for expanded capabilities as improved hardware or software becomes available. In addition to planning for the future, the developer should study the results of similar projects. This study is an example of two organizations converging on similar technology to address similar issues. It also demonstrated the benefits of communicating with colleagues and comparing design issues. The knowledge gained by both parties and continued collaboration could lead to the development of an improved training system and advances in the understanding of the training benefits of VE technology.

REFERENCES

Bradley, S. & Watters, R. (1998). Examination of Surface Warfare Officers School (SWOS) (Technical Report 98-014). Orlando, Florida: Naval Air Warfare Training Systems Division.

Breaux, R., Martin, M., & Jones, S. (2 – 6 March 1998). Cognitive precursors to virtual reality applications. Proceeding of SimTecT '98, Adelaide, South Australia, pages 21 – 26.

Cope, R., Boemler, S., Kotick, D. (December 1998). Developing speech recognition models for use in training devices. Proceedings to '98 I/ITSEC Conference, Orlando, Florida.

Crenshaw, R.S., Jr., CAPT, U.S. Navy (Retired). (1975). Naval Shiphandling. Annapolis, Maryland: Naval Institute Press.

Davidson, S. (1997a). Design of an Open Water Shiphandling Software Testbed (Technical Report 97-007). Orlando, FL: Naval Air Warfare Center Training Systems Division.

Davidson, S. (1997b). Development of a virtual environment software testbed using commercial off the shelf software components. In, Proceedings to NATO VR Conference, (December 1997), Orlando, FL.

Gabbard, J. & Hix, D. (1997). A Taxonomy of Usability Characteristics in Virtual Environments.

Hill, R. (1999). Modeling perceptual attention in virtual humans. In, Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation, pages 563 - 574.

Knerr, B., Lampton, D., Singer, M., & Witmer, B. (1998). Recommendations for enhancing the effectiveness of virtual environments for dismounted soldier training and performance.

Magee, L. (1997). Virtual reality simulator (VRS) for training ship handling skills. Seidel, R (Ed.) & Chatelier, P. (Ed), Virtual Reality: Training's Future? New York: Plenum Press. Pages 19 – 29.

Martin, M.K., Sheldon, E., Kass, S., Mead, A., Jones, S., & Breaux, R. (1998). Using a virtual environment to elicit shiphandling knowledge. Proceedings to '98 I/ITSEC Conference, Orlando, Florida.

Patrey, J., Sheldon, E., Breaux, R., & Mead, A. (to appear). Predicting performance in a dynamic shiphandling perceptual-action task from spatial moments.

Rassumussen, J. (1986). Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering. New York, NewYork: Elsevier Science Publishing Company, Inc.