REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	3 May 1999	Final Report, 3/1/97–5/1/99

4. TITLE AND SUBTITLE
Enhancing a CAVE with Eye Tracking Systems for Human-Computer Interaction Research in 3D Visualization

5. FUNDING NUMBERS
G N00014 97 10395

6. AUTHOR(S)
Deborah Hix

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Virginia Tech
Department of Computer Science
600 McBryde Hall
Blacksburg, VA 24061

8. PERFORMING ORGANIZATION REPORT NUMBER
Not Applicable

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research, Code 1141SB
800 N. Quincy Street
Arlington, VA 22217

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
Not Applicable

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The objective of this award was to purchase and install two *ISCAN Inc. Eye Tracking Systems* and associated equipment to create a unique set-up for research in fully immersive virtual environments (VEs), specifically a CAVE. To our knowledge, the Virginia Tech installation is the first CAVE in the world to have eye-tracking technology incorporated into it. We purchased two ISCAN Inc. Eye Tracking Systems, including calibrator, headband-mounted eye imaging system, dual video monitors, line of sight scene imaging system, magnetic head tracker, and appropriate software.

The Eye Tracking Systems collect three-dimensional measurements of a user's eye inside the CAVE. These measurements are performed by calculating the direction of a line called the line-of-sight, which originates from a user's eye and extends into the environment in the direction of the pupil's gaze. Intersections between the line-of-sight and visible objects in the VE are computed, and the results are stored to a log file on disk.

This work has the potential to lead to strong analytical assessment methodologies for VEs (see Conclusions above) that can reduce the effort and costs of usability evaluations of VEs.

14. SUBJECT TERMS	15. NUMBER OF PAGES
eye-tracking, CAVE, usability engineering, human-computer interaction, visualization	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

GRANT #: N000149719395

Principal Investigator: Dr. Deborah Hix

Institution: Virginia Tech

Grant Title: Enhancing a CAVE with Eye-Tracking Systems for Human-Computer Interaction Research in 3D Visualization.

Award Period: 3/1/97 - 5/1/99

Objective:
To purchase and install two *ISCAN Inc. Eye Tracking Systems* and associated equipment to create a unique set-up for research in fully immersive virtual environments (VEs), specifically a CAVE. To our knowledge, the Virginia Tech installation is the first CAVE in the world to have eye-tracking technology incorporated into it.

Approach:
Virginia Tech's funding to acquire a CAVE came from the National Science Foundation. The instrumentation funded by this DURIP is creating and studying human-computer interaction (HCI) in a CAVE, especially new aspects such as cognitive, physical, behavioral, and psychophysical issues. We purchased two ISCAN Inc. Eye Tracking Systems, including calibrator, headband-mounted eye imaging system, dual video monitors, line of sight scene imaging system, magnetic head tracker, and appropriate software.

The Eye Tracking Systems collect three-dimensional measurements of a user's eye inside the CAVE. These measurements are performed by calculating the direction of a line called the line-of-sight, which originates from a user's eye and extends into the environment in the direction of the pupil's gaze. Intersections between the line-of-sight and visible objects in the VE are computed, and the results are stored to a log file on disk.

There are three general steps to use the Eye Tracking Systems in the CAVE:
1. to add functionality to a new or existing CAVE application's source code to accommodate for the eye trackers and collect data
2. to set up the Eye Tracking Systems and calibrate them with a user wearing the appropriate headset, to accommodate for slight physiological differences in users' eyes
3. to perform an evaluation session in the CAVE with a user to collect data about a user's eye movements, which are stored to a log file.

Although this ONR grant officially began in 1997, we did not order the eye-trackers right away because there were numerous unexpected delays in acquiring space for setting up our CAVE. It finally became fully functional in early 1998. Soon after that we began installation of the ISCAN Eye Tracking Systems. This proved to be technically much more difficult than anticipated. Despite ISCAN's best efforts to help us, there were many unforeseen challenges with installing the

Eye Tracking Systems in the CAVE. Finally by early 1999, the systems were installed and ready to collect data related to HCI and usability of VEs. Initial data files were small and somewhat non-informative. In summer 1999, we have a GRA (funded by a large Naval research project) who will add some enhancements on the serial aspects of the Eye Tracking Systems and will begin collecting larger volumes of data for analysis in terms of HCI and usability issues for designing VEs. We also hope to have an undergraduate student performing an independent study to complete a literature review of eye tracking research, and to propose the next steps in our research program with the Eye Tracking Systems.

Space for all this equipment will eventually be provided in the Advanced Communications and Information Technology Center (ACITC), a $25 million building currently being constructed on the Virginia Tech campus, and ready to occupy in Summer 2000. The ACITC will serve both on-campus and related regional off-campus information technology programs. Human-computer interaction and scientific visualization have both been targeted by Virginia Tech in its long-term strategic plans for the ACITC.

Accomplishments:
Installation of, we believe, the first Eye Tracking Systems in a CAVE. Collection of eye tracking data for a medical information system, a molecular structure, and a couple of other small VE applications.

Conclusions:
Eye tracking for graphical user interfaces (GUIs) led to varying levels of information in terms of usability and design of GUIs. Much of the eye tracking data for GUIs has not been found to be particularly effective for usability and design. However, we believe this is in large part because of the small screen size for most GUIs; a user's eyes move only a small distance even if they move a lot around the screen. In contrast, in a VE such as a CAVE, a user's eyes typically will move much greater distances. So we believe that when we have collected and analyzed more eye tracking data, we will find that there are some aspects of eye tracking that can be useful in helping assess usability of VEs. A very simple example would be a task thread in which a VE user's eyes moved frequently from the upper front wall of the CAVE to the lower right wall of the CAVE. Finding that this kind of major eye movement is prevalent in a CAVE application would surely be an indication that the layout of objects on the various CAVE walls should be re-examined.

Further, as VEs become more complicated, we are convinced that analytical assessment methodologies for VE usability will become more important, so that as many problems as possible can be found before empirical assessment methodologies (i.e., bringing representative users into the VE application) are applied. Analytical methods that do not involve users directly will be much more cost-effective and rapid than empirical methods that do involve users. While we do not believe analytical methods can or should replace the empirical methods with users, analytical methods such as those that can be supported by eye tracking data can potentially help reduce the overall cost of usability evaluations of VEs.

Significance:
This work has the potential to lead to strong analytical assessment methodologies for VEs (see Conclusions above) that can reduce the effort and costs of usability evaluations of VEs.

Patent Information: None

Award Information:
VR'99 Conference, Houston Texas, March 1999. First paper listed below was awarded Best Technical Paper at this conference, the premiere international conference in virtual environments. After Dr. Hix presented this paper, Dr. Fred Brooks, keynote speaker at the conference, stated in the question and answer period following her talk: " I want to commend you on a very important piece of work. I learned more per hour from your talk than at any time in the past 6 months." Dr. Brooks was the father of OS/360 (the architectural concept, the hardware development, and the operating system), and was the CS department chair for many (15+) years at UNC-Chapel Hill. This Best Technical paper award, made by popular vote of conference attendees, carried a $1000.00 reward which the authors donated to the Virginia Tech Computer Science Department.

Publications and Abstracts:
Hix, Deborah, Edward Swan, Joseph Gabbard, Mike McGee, Jim Durbin, and Tony King, "User-Centered Design and Evaluation of a Real-Time Battlefield Visualization Virtual Environment." In *Proc. IEEE Virtual Reality '99*, Houston, TX (March 1999).

Gabbard, Joseph, Kent Swartz, Kevin Richie, and Deborah Hix, "Usability Evaluation Techniques: A Novel Method for Assessing the Usability of an Immersive Medical VE." In *Proc. Virtual Worlds and Simulation Conference (VWSIM'99)*, San Francisco CA (January 1999).

Swartz, Kent, Umesh Thakkar, Deborah Hix, and Rachael Brady, " Evaluating the Usability of Crumbs: A Case Study for VE Usability Methods," In *Proc. Third International Immersive Projection Technology Conference*, Stuttgart, Germany (May 1999).

Richie, Kevin, and Deborah Hix, "Eye Motion Tracking in the CAVE," Virginia Tech Department of Computer Science Internal Report (1999).