VIRTUAL REALITY FOR SMALL COLLEGES*

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ABSTRACT

The popularity of Virtual Reality (VR) display systems has increased dramatically in recent years. VR applications are characterized by a virtual world into which users are immersed, providing interactivity and sensory feedback [1]. These superior sensory environments make virtual reality a popular medium for many types of applications, ranging from exploration of severe thunderstorm and tornado data [2], to architecture from ancient times [5]. Proponents of virtual reality feel that the VR experience enhances learning, since participants utilize more of their senses than with typical computer applications. VR systems generally provide displays to users in stereo projection that give a sense of 3D viewing. Traditionally, the cost of implementing virtual reality environment has been very high, limiting VR to only those institutions with large research budgets. However, with recent advances in commodity hardware capabilities and the reduction in cost of typical LCD projectors, a low cost VR system can now be constructed at any institution, even those with significant budget restrictions. This paper discusses our experiences with the construction of a stereo projection display environment at Hanover College, and some projects my students and I have done with this system. Several potential research projects in virtual reality, which could be done with little funding, are also proposed.

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1. INTRODUCTION

Virtual Reality (VR) display systems have become increasing popular in recent times. Sherman and Craig [1] describe four defining components of virtual reality: a virtual world, immersion, sensory feedback, and interactivity. Virtual worlds can take on many forms. They may attempt to represent reality, or they can be a product of someone's imagination. From a science standpoint, virtual worlds are often constructed to help us learn about environments that we may have trouble visiting in real life. For example, say we want to teach students about the surface of Mars. Since travel to the red planet is not yet feasible for humans, an application could be constructed from known data about Mars, and we could "in a sense" visit mars through the realization of this data in a VR program. The immersive nature of virtual reality applications is often accomplished by presenting images in 3D and surrounding users with display screens. This gives the users a greater sense of presence and realism, as they visit the virtual world. Incorporating sensory feedback (such as sound and touch) in virtual reality applications adds to the illusion, and makes participants more likely to "believe" they are really in the virtual place. For the illusions to be truly effective, users must be able to interact with the virtual environment in real time, receiving nearly constant feedback as they move about. Proponents of virtual reality feel that the VR experience enhances learning, since the participants utilize more of their senses than in a typical computer application.

Virtual reality systems have become extremely popular for teaching and training in today's high tech world. The U.S. Department of Defense used "virtual fly-throughs" to train pilots about the terrain they would encounter over Afghanistan in October of 2001 [3]. Johnson, et al [4], discuss using virtual reality to teach elementary age students about science, while Cruz-Neira reports on applications that allow users to explore architecture from ancient times [5]. Potential uses of virtual reality for teaching Computer Science concepts have even been discussed in the Journal of Computing Sciences in Colleges [6]. Virtual environments are often cheaper, safer, and/or more feasible than training in the "real world", which explains their growing popularity. The 3D (or stereo viewing) effect typical of virtual reality applications helps to captivate the interest of the audience and holds their attention throughout the VR experience. Hollywood has even seemed to "rediscover" the appeal of stereo viewing, releasing several 3D movies recently [7].

The primary obstacle preventing VR from becoming part of the mainstream is not the technology; in fact, VR technology has been around for decades. The real problem of virtual reality has been its excessive cost. Virtual 3D displays are typically provided through one of two means: Head Mounted Displays (HMDs) or large screen projection systems. The HMDs are single user devices that are worn and provide access to a virtual world [8]. While a single HMD is not terribly expensive (a quality device can be purchased for $1000-$4000), buying enough for large groups of people to collaborate simultaneously on the same application can be. Large screen systems can provide access to a virtual world for several users and are often the preferred method for building virtual reality systems in academia. The CAVE [9] environment and software libraries developed at the Electronics Visualization Laboratory are the state of the art for developing these types of applications. In a CAVE system, display screens that show multiple views into the same scene surround the participants. Users of the CAVE wear special "shutter" glasses that help them to see the stereo (or 3D) images. Stereo viewing is accomplished by providing slightly different images to each eye, which correspond to the difference views our eyes actually perceive of the real world. The Silicon Graphics Incorporated (SGI) Onyx 2 typically used to support these types of display environments is very expensive (prices can exceed one million dollars). This amount makes the equipment infeasible for all but the top research institutions and has fostered the perception that virtual reality is not for smaller institutions.

In his book entitled "Virtual Reality" from 1991, Harold Rheingold states that when the cost for virtual reality systems drop sufficiently, the "homebrew (VR) revolution will take off" [10]. It seems as if the "revolution" has begun. Recognizing that the problem of cost drives most institutions away from virtual reality, the creators of the CAVE system (and others) have begun investigation into alternative, less expensive architectures based on PCs [11, 12, 13]. The systems these groups have devised run Linux, are connected with dedicated Ethernet networks, and use light polarization techniques to produce the stereo viewing (3D) displays. The estimated cost for these systems is between $10,000 and $60,000. There is even a consortium now for those interested in single screen passive stereo systems (the Geowall Consortium [14]), which is largely a collection of those in the earth sciences who are interested in visualization and virtual reality.

The purpose of this paper is to attempt to dispel the myth that virtual reality can only be done at large universities with big budgets, by describing our experiences with VR at Hanover College. While it is true that much of the high tech VR equipment for haptics and head tracking can be very expensive, the equipment required to build a system with the essentials for teaching and demonstrating VR is not. In this paper, we will first discuss the basics of stereo projection (the heart of a virtual reality display system). Next, techniques for generating stereo pair images will be covered. Some of our activities with virtual reality at Hanover College will be presented, and then we will conclude by discussing several VR projects that could be undertaken at any small college or university.

2. STEREO VIEWING SYSTEMS

As humans, we are able to perceive depth because each eye actually observes the world from a slightly different perspective. To convince yourself of this, try holding your finger a few inches from your face. Now, alternate looking at your finger with one eye open at a time. You should notice that each eye sees a different view of your finger. Our brain fuses these images into one to give a sense of depth. To create 3D (or stereo) images, we must present a different view to each eye that corresponds to the views they would actually see in the real world. The three commonly accepted techniques for performing stereo viewing are discussed in the following subsections.

2.1 Anaglyphs

The cheapest (but lowest quality) technique is called anaglyphs, and is based on the simple principle that if you view an image through a certain color filter, that filter's color will disappear in the image. Thus, if we project left and right displays in separate red and blue channels, and then users wear appropriate glasses with the same red and blue filters, each eye will perceive a different image. The advantage with this technique is that the left and right images can be blended into one, and a single projector can be used [7]. The drawback with anaglyphs is that the color spectrum for each eye is drastically reduced.

2.2 Light Polarization

For this technique, two projectors are used to project images for the left and right eyes, respectively. Opposite polarizing light filters are placed over the lens of each projector [15]. Users then wear special glasses with the corresponding polarizing filters as lenses, which allow each eye to see only the correct image. Both linear and circular polarization can be used. Linear polarizers are cheaper than their circular counterparts, but suffer from severe "crosstalking" when users hold their head at a 45° angle to the screen. Circular polarization has little to no "crosstalk" but eliminates more light as it passes through the filter resulting in darker images. A "silver" projection screen is also needed to preserve the polarization effect. The standard white matte projection screens common today have diffuse surfaces that scatter the light evenly in all directions, destroying the polarization of the light. This technique has become the preferred method for low cost virtual reality systems because it produces superior images to anaglyphs, for a much lower cost than active stereo (discussed in section 2.3).

Figure 1 shows the linearly polarized stereo projection system we built over the summer of 2003. Notice that the projected image on the left appears blurry. Without the glasses, both images are visible to each eye producing a display that appears out of focus.

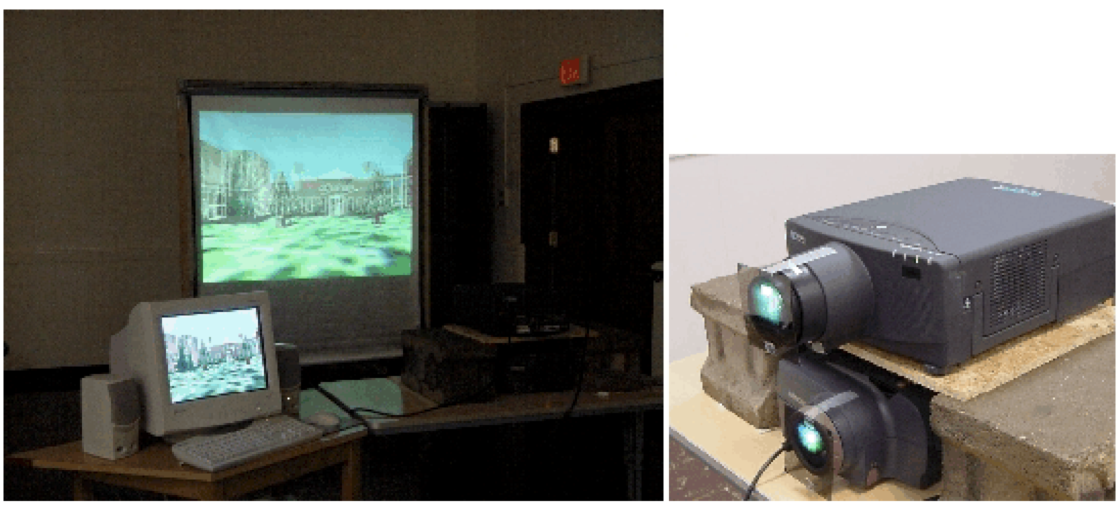

Figure 1 - LEFT) A single screen passive stereo system built at Hanover College during the summer of 2003. RIGHT) The projector "stack" - each projector has an opposing polarizing light filter taped to the lens.

2.3 Active Stereo

Cave systems [9] use an active stereo approach for projecting the left and right eye images. The display alternates in coordination with special LCD shutter glasses worn by the users. When the left lens is open, the display for the left eye is on the screen. Then the left lens closes and right one opens while the right eye image is on the screen. Our brain once again fuses these images producing a 3D display. This process must take place approximately 120 times per second, or users will see a "flicker" in the image. The LCD glasses themselves can cost as much as $500 per pair, and the CRT projectors needed to achieve such high refresh rates can cost over $10,000. Obviously, this approach to stereo projection is out of the price range for most institutions.

3. GENERATING STEREO PAIR IMAGES

One of the most difficult aspects of creating a virtual reality system is learning how to program applications for the system. Stereo pair images must be generated and sent to the appropriate projector(s). The following section describes the process of generating stereo pairs.

Figure 2 shows the basics of a stereo viewing system. Modern day graphics APIs like OpenGL [16] use a camera analogy when determining the viewing position. The camera orientation is based on three parameters: the eye position, the aim point, and the up direction. Generating stereo pairs simply involves shifting the eye position to the location of the left eye, calculating an image, then doing the same for the right eye. The

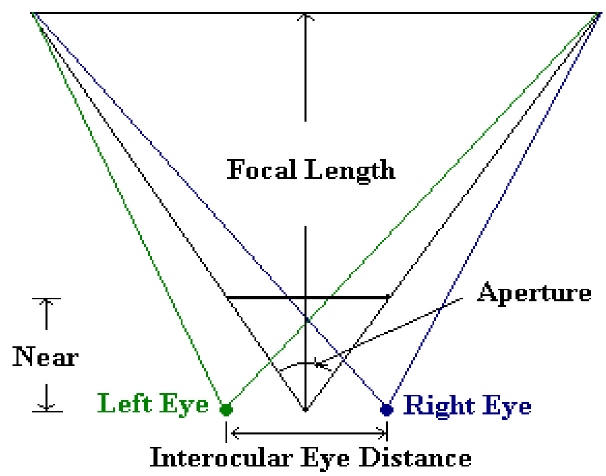

Figure 2 - Top down view of a stereo viewing system. Objects in the scene at the Focal Length will appear to be at the depth of the screen. Object closer than the Focal Length will appear to "pop out" of the screen.

distance between the eyes is known as the interocular eye distance, and this amount should be expressed proportional to the units used in modeling the scene. The focal length is the distance at which the eyes focus on an object. The net effect will be that objects closer than the focal length will appear to "pop out" of the screen, while those further away will appear to be beyond the screen. The aperture is the angle of view (60° is a common choice) and defines how much of the scene will be visible on the screen. A complete description of the mechanics of stereo projection is outside the scope of this paper. Interested readers are referred to Paul Bourke's excellent web tutorial on "Calculating Stereo Pairs" [17]. If still stereo images are desired, then one could simply

Item	Where it was purchased	Cost
2 - used NEC 830 LCD projectors	Inventory Solutions, Inc.	$500 (each)
Da-Lite 40x40" Silver Pacer Projection Screen	Ebay	$50
4"x4" linear polarizer squares	Berezin Stereo Photography Products	$25
5 - plastic polarized glasses	Berezin Stereo Photography Products	$2.75 (each)
3 - GeForce 4 MX 440 graphics cards	Pricewatch.com	$50 (each)

Figure 3 - Equipment required for a stereo projection system that utilizes linear light polarization.

take left and right eye pictures with digital cameras that are offset from each other by a distance equal to the interocular eye distance.

To streamline the process of calculating the left and right eye images, we have modified an in house multi-monitor programming API [18] to generate displays. The system depicted in figure 1 uses a 1.4 Ghz Windows PC with three GeForce 4 MX 440 [19] graphics cards. Windows allows us to configure the desktop with multiple displays and our API enumerates them so we can easily send appropriate images to each. We attached a monitor to the primary display (which contains the Window's icons), and the other graphics cards are attached to the left and right eye projectors. Our virtual reality application code is exactly the same as a typical multi-monitor graphics application, except when we need to set the viewing parameters for each eye. OpenGL itself has a command gluLookAt(eye, aim, up), which establishes the camera analogy for the scene. Our API has analogous commands for each eye that take the same parameters, and from them generate appropriate calls to the OpenGL routines that set the view frustum and camera orientation correctly based on figure 2 and described in [17].

4. OUR EXPERIENCES WITH VIRTUAL REALITY

As mentioned previously, during the summer of 2003 a student and I constructed a low cost stereo projection system based on light polarization techniques. We were able to borrow two LCD projectors already owned by the college and make use of a PC we had been using for multi-monitor applications. When the summer ended, the need for the projectors around campus by other departments increased significantly, so we have since purchased our own projectors that are dedicated to this project. Figure 3 shows the items needed for a similar type system, costs of the items, and where we purchased our equipment. As you can see, a complete, single screen system can easily be built for less than $1500.

The obvious piece of equipment that was omitted from the table is a computer. We assume that most Computer Science departments can get their hands on one. Any Pentium IV machine will have sufficient power to drive two displays at 800x600 resolution. We also saved a great deal of money by purchasing used equipment (particularly with the projectors). The NEC MT830 models that we purchased have half their bulb life left, and are certainly adequate for our purposes. Before you go out and buy a silver screen, make sure you check all the AV closets at your institution. All projection screens were silver about 20 years ago, so you may have some stashed away somewhere that no one knows about. After buying our own screen, we discovered two that were unused hanging in faculty offices.

The most difficult part of system setup is aligning the projectors. Ideally, the corners of each projected image will match up. This is easier said than done, however. To get both images on the same screen, it is usually necessary to stack the projectors (see figure 1) and then tilt one or both projectors until the pictures align. This makes the projected image subject to a keystone effect. If the projectors have digital keystone correction, then the images can be adjusted until they are aligned. If no digital keystone correction is available, then you will have to live with getting the images as close as you can. We have found that the stereo image is "workable" even without the keystone correction, but some users may experience eyestrain after a several minutes of viewing. The NEC MT830 projectors we have now do have digital keystone correction.

Aligning the color intensities of both projectors is also important. When we started this project, we were using different model projectors and it was very difficult to get the colors to "match up". The experience was visually disturbing when our eyes perceived different colors from the same scene. If two projectors of the same model are available, then it is definitely advantageous to utilize them. If it is necessary to use different models, then adjust the colors as best you can and make sure the brightness is the same for both images. We found that the most visually disturbing phenomenon was when each eye perceived different levels of light intensity.

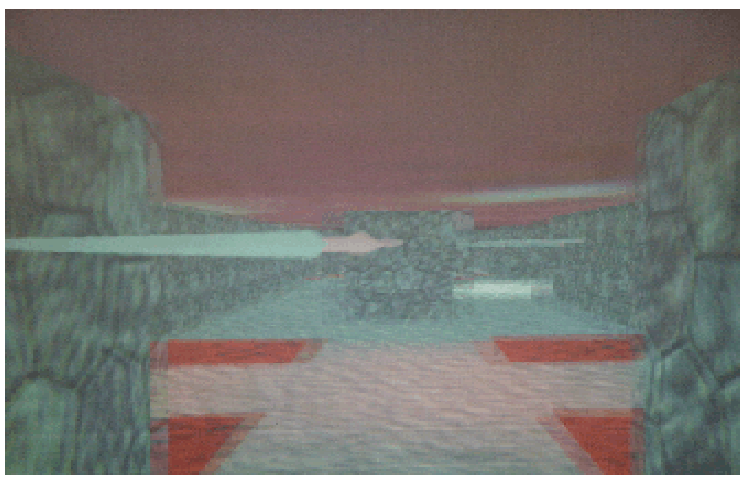

Figure 4 - Virtual Hunt the Wumpus. Notice the blurry image caused by both left and right eye views being projected on the same screen.

We have developed three pilot virtual reality applications: a virtual tour of our campus (shown in figure 1), an dungeon crawler game based on the old "Hunt the Wumpus" artificial intelligence problem (figure 4), and a virtual tour of the Solar System (figure 5). In October of 2003, our local ACM student chapter held a "Computer Science Camp" for elementary age children as a fundraiser for the group. One of the workshops at the camps was a virtual reality course during which we demonstrated each of these applications to the camp participants.

One of our goals for the VR course was to determine the effectiveness of virtual reality as a teaching tool. We hypothesized that VR could increase the amount of information the students retained when compared to a traditional lecture. We divided the 16 participants into two groups: one group learned basic concepts about the solar system in a lecture format, while the other group was presented with the same material through an interactive tour of the solar system in virtual reality. We then gave both groups a short 12-question quiz based on the information they had been taught. The virtual reality students had a quiz average of 9.8 questions correct while the lecture group averaged 8.9 correct responses. We then presented the lecture group with the material in VR and allowed them to retake the quiz. They raised their quiz average to 10 on the second try. While these results are far from conclusive (we would need many more students and a greater disparity in results), there does seem to be evidence that virtual reality can be effective for teaching. As qualitative support, the students who were taught the concepts in VR were more attentive and seemed to enjoy the learning experience more than those in the lecture.

Figure 5 - Students viewing the "Virtual Solar System" application we demonstrated at our Computer Science camps in October of 2003

5. FUTURE WORK

While much of the leading research in virtual reality does involve very expensive, sophisticated equipment, there are many interesting projects that could be undertaken at small institutions with systems similar to the one described in this paper. This section describes a few ideas for future directions of this work.

5.1 Uses of Virtual Reality in Education

I think it would be very interesting to perform a much more thorough study of the effectiveness of virtual reality as a teaching medium in education, particularly for the K-6 grades. While there are several works that propose the use of VR in education [4,6], very little research has been done to date analyzing the improvement (if any) that VR provides in teaching over traditional methods. We would like to develop additional virtual environments that could be demonstrated to students at local elementary schools and study their effectiveness in explaining concepts. Perhaps a partnership with local teachers to incorporate VR into their classroom over an entire semester, then comparing the performance of students to those of past years (or different sections the same year) would make an interesting study. To this end, there are practically an unlimited number of potential applications that could be developed. Our "Solar System" program, for example, could certainly be improved to teach more sophisticated concepts like the cause of an eclipse or the size of the galaxy. In other applications, students could visit far off places, or underwater worlds. The possibilities are endless.

5.2 Immersive Virtual Reality Systems

The best virtual reality systems allow users to feel completely immersed in the application by surrounding them with displays screens and giving them the freedom to physically move around. Unfortunately, this is not possible with front projection systems, because users cast shadows on the display when they stand in front of the screen. In immersive systems, rear projection is commonplace. Here, the projectors are positioned on the side of the screen opposite the user, and a special screen material is used that allows the image to filter through. The advantage with rear projection is that users can walk all the way up to the screen without casting a shadow. This makes applications seemingly more interactive. Unfortunately, the cost of rear projection screen materials that preserve light polarization is usually prohibitive for small departments. A single 6-foot by 4-foot screen will cost at least $450. To create a more immersive system with front projection, we plan to place the projectors behind the screen facing up towards the ceiling. Two mirrors will then be used to reflect the projection over and then onto the front of the screen, so images are visible to the users. This technique should allow for users to get fairly close to the screen without blocking the projection. Keystone adjustments on the projectors can be used to align the images appropriately on the screen. Each screen requires two projectors (one for each eye), so a three-screen system would need a total of six projectors. We are in the process of purchasing the needed projectors and plan to build the proposed system in 2004.

5.3 A Virtual Reality PC Cluster

While a single PC approach to a virtual reality system is certainly cheaper and easier to build, the processing power is much less than that of a cluster of PCs. Another interesting project would be to explore the differences in performance between a dedicated PC cluster and a fairly high performance PC (say 2.8 GHz or higher), particularly as the number of display screens increases. In general, when several computers work on a well-distributed problem, they can outperform a single computer - even if the sum total of the single computer's processing power is greater than that of the individual computers. Ultimately, we would like to go to a cluster for our virtual reality environment. One of my students has already expressed interest in taking part of this work on as a senior project. Building a cluster would also require development of an appropriate API for programming VR applications with the cluster.

5.4 Digital Camera Based Motion Tracking

Most CAVE [9] systems are equipped with head tracking capabilities that allow displays to be automatically adjusted as the user physically moves around. Changes in the display, with our system, can only be done through use of an input device such as a mouse or joystick. Sophisticated head tracking systems can cost over $10,000, so they are not typically part of a low cost VR environment. There has been some work in recent years to build motion-tracking systems based on digital image processing - most notably, the "C-Wall" project at the Electronics Visualization Laboratory [20]. A simplistic version of this motion tracking approach could be attempted using several cheap digital cameras positioned a various angles around the user. Tracking the differences in user locations from image to image could provide adequate information to make appropriate adjustments in the displays for the user.

6. CONCLUSION

Virtual reality continues to increase in popularity both in the sciences and in mainstream culture. While it is true that virtual reality systems are often very expensive, it is possible to build a low cost system at a small college or university. This paper describes our experiences in constructing a stereo projection system and the development of several prototype VR applications. We evaluated the effectiveness of virtual reality as a teaching medium and found that it could be helpful for presenting concepts to young children. Several potential projects in virtual reality were discussed, which could be performed at institutions with limited budgets. The excuse that VR is too expensive to teach at smaller institutions is a myth. Virtual Reality deserves consideration for inclusion in the computer science curriculum, and as a research topic at schools of all sizes.

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8. REFERENCES

[1] Sherman, W., Craig, A., *Understanding Virtual Reality, Interface, Application, and Design*. San Francisco, California: Morgan Kaufman, 2003.

[2] Jaswal, V., CAVEvis: Distributed Real-Time Visualization of Time-Varying Scalar and Vector Fields Using the CAVE Virtual Reality Theatre. In *Proceedings of the IEEE Conference on Visualization*, pages 301-308, 1997.

[3] Macedonia, M., Games Soldiers Play, IEEE Spectrum, March, 2002.

[4] Johnson, A., Moher, T., Cho, Y., Lin, Y., Haas, D., Kim, J., Augmenting Elementary School Education with VR, *IEEE Computer Graphics and Applications*, Vol. 22, No. 2, 2002.

[5] Cruz-Neira, C., Computational Humanities: The New Challenge for VR. *IEEE Computer Graphics and Applications,* May/June, 2003.

[6] Neubauer, B., Harris, J., Immersive Visual Modeling: Potential use of Virtual Reality in Teaching Software Design. *The Journal of Computing Sciences in Colleges*, Vol. 18, No. 6, 2003.

[7] Porter, S., Video Goes Stereo. *Computer Graphics World*, August, 2003.

[8] Dumas, J., Novobilski, A., Ellis, D., Paschal, M., VR on a Budget: Developing A Flight Simulator in a Small Institution with Off-The-Shelf Hardware and Open Source Software. *The Journal of Computing Sciences in Colleges*, Vol. 18, No. 2, 2003.

[9] Cruz-Neira, C., Sandin, D., DeFanti, T., Kenyon, R., Hart, J., The CAVE: Audio Visual Experience Automatic Virtual Environment. *Communications of the ACM*, vol. 35, no. 6, 1992.

[10] Rheingold, H., *Virtual Reality*. New York, New York: Summit Books, 1991.

[11] Pape, D., Anstey, J., Dawe, G., A Low-Cost Projection Based Virtual Reality Display. *The Engineering Reality of Virtual Reality 2002 SPIE Electronic Imaging: Science and Technology.* San Jose, CA, 2002.

[12] Pair, J., Jensen, C., Flores, J., Wilson, J., Hodges, L., Gotz, D., The NAVE: Design and Implementation of a Non-Expensive Immersive Virtual Environment. *SIGGRAPH 2002 Sketches and Applications*, 2000.

[13] Belleman, R., Stolk, B., de Vries, R., Immersive Virtual Reality on Commodity Hardware. *ASCI* 2001.

[14] The GeoWall Consortium, http://geowall.geo.lsa.umich.edu/.

[15] Bennett, D., Farrell, P., Lee, M., Ruttan, A., A Low Cost Commodity Based System for Group Viewing of 3D Images. *Proceedings of Visualization Development Environments*, 2000.

[16] OpenGL Architectural Review Board, *OpenGL Programming Guide*. Reading, Massachusetts: Addison Wesley, 1993.

[17] Bourke, P., Calculating Stereo Pairs, http://astronomy.swin.edu.au/~pbourke/stereographics/stereorender/, 1999.

[18] Cliburn, D., GLUMM: An Application Programming Interface for Multi-Screen Programming in a Windows Environment. *The Journal of Computing Sciences in Colleges*, Vol. 18, No. 4, 2003.

[19] nVIDIA GeForce4 MX, http://www.nvidia.com/view.asp?PAGE=geforce4mx.

[20] "C-Wall", http://www.evl.uic.edu/research/res_project.php3?indi=234.