A New Paradigm for Head-Mounted Display Technology: Application to Medical Visualization and Remote Collaborative Environments

J.P. Rolland[1], Y. Ha[1], L. Davis[2,1], H. Hua[3], C. Gao[1], and F. Biocca[4]

1 School of Optics / CREOL, University of Central Florida
2 School of Electrical Engineering and Computer Science
3 Beckman Institute, University of Urbana Champaign
4 Department of Telecommunications, Michigan State University

1 ABSTRACT

Today advanced 3D virtual environments are mostly based on either a technology known as the cave or head-mounted displays. A new type of head-mounted display, which consists of a pair of miniature projection lenses and displays mounted on the helmet and retro-reflective sheeting materials placed strategically in the environment, has been proposed as an alternative to eyepiece optics types of displays. The novel concept and properties of the head-mounted projective display (HMPD) suggests solutions to part of the problems of state-of-art visualization devices and make it extremely suitable for multiple-user collaborative environments. In this paper, we first review the concept of the HMPD and present the latest prototype developed. We then discuss its application to medical visualization and remote collaborative environments.

2 INTRODUCTION

Today advanced 3D virtual environments are essentially based on either a technology known as the cave or head-mounted displays.[1] The cave is basically a room with up to four walls, a ceiling, and a floor.[2] External projection systems are projecting stereo pairs of images on each panel of the room. In such an environment, which is created to immerse one or multiple users in a virtual environment, only one user is presented the 3D information from the correct viewpoint given that only one user can be head-tracked in the cave. The other users will actually perceive a distorted view of the 3D virtual environment. While a cave system provides a sense of immersion in a virtual environment given the large field of view, drawbacks are that it is not easily deployable and calibration can be intensive.

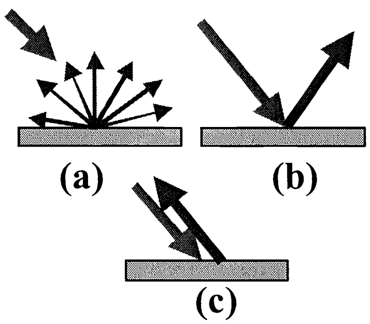
3 HEAD-MOUNTED PROJECTIVE DISPLAYS AS A NEW PARADIGM

An alternative to a cave is to create an immersive virtual environment through a head-mounted display (HMD). While conventional types of head-mounted displays employ eyepiece optics to create the virtual images,[3] an emerging technology known as a head-mounted projective display (HMPD) has fairly recently been demonstrated to yield 3D visualization capability with a large field of view, light weight optics, and low distortions.[4-7]

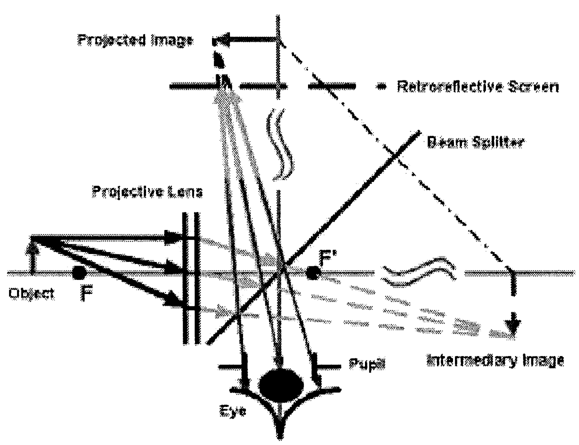
A HMPD, conceptually illustrated in Fig.2 (d), consists of a miniature projection optics mounted on the head and a supple, non-distorting and durable retro-reflective sheeting material placed strategically in the environment.[8] In such a system, a projection lens is used, instead of an eyepiece as used in conventional HMDs, and a retro-reflective screen is used instead of a diffusing projection screen as used by projection systems. A miniature display, located beyond the focal point of the projection lens rather than between the lens and the focal point as in the configuration of a conventional HMD, is used to display a computer-generated image. Through a projection lens, an intermediary image is formed. A beamsplitter is placed after the projection lens at 45 degrees with

Novel Optical Systems Design and Optimization IV, Jose M. Sasian, Paul K. Manhart, Editors,
Proceedings of SPIE Vol. 4442 (2001) © 2001 SPIE · 0277-786X/01/$15.00

respect to the optical axis to bend the rays at 90 degrees as done in an optical see-through HMD, but the attitude of the beamsplitter is perpendicular to that of an optical see-through HMD.



(a) Diffusing surface (b) Reflective surface
(c) Retro-reflective surface



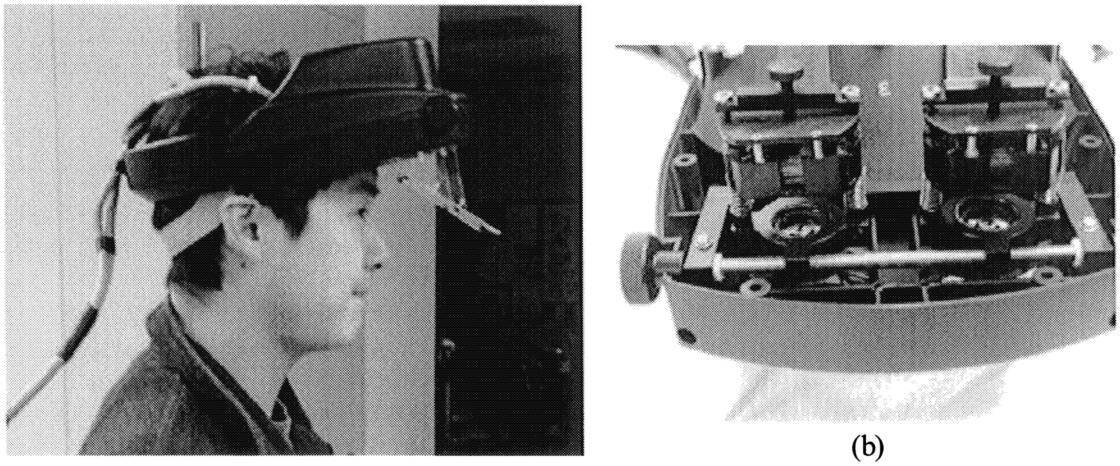
(d)

Fig. 1 (a)-(b) Illustration of different types of reflective surfaces. (d) Schematic of the HMPD imaging.

Meanwhile, a retro-reflective screen is located on either side of the projected image. Because of the special characteristics of retro-reflective materials, the rays hitting the surface are reflected back onto themselves in the opposite direction. A user can perceive the virtual/real projected image at the exit pupil of the optics. Ideally, the location and size of the image is independent of the location and shape of the retro-reflective screen. Furthermore, rays hitting the retro-reflective surface will be reflected independently of the incident angle. The difference between a diffusing surface, a mirror surface and a retro-reflective surface is illustrated in Fig.2 (a)-(c): reflected rays by a diffusing surface (a) can be in all possible directions; reflected rays by a mirror surface (b) are symmetrical to the incident rays with respect to the surface normal; reflected rays by a retro-reflective surface (c) follow the opposites of the incident rays. The optical design of the system was reported elsewhere.[9] The latest prototype recently assembled is shown in Fig. 2 with a look into the optomechanical design of the system. The beam splitter was redesigned from an earlier version and some of the electronics associated to the flat panel display were in part moved to a remove control electronics box.

4 APPLICATION TO MEDICAL VISUALIZATION

The use of head-mounted displays in 3D visualization allows expansion of the technology to other applications besides immersion of users in a virtual environment. With a see-through capability, HMDs can be used to augment reality instead of replacing it. Such capability finds applications in medical visualization where internal anatomy can be optically superimposed on a live patient or model patient. We are also investigating the optical superimposition on a Human Patient Simulator (HPS) produced by Medical Education Technologies Incorporated (METI) for airway management training of medics. The HPS is an integral component to the Army's Combat Trauma Patient Simulation (CTPS). Optical tracking is used to monitor and control the spatial relationships between the user's head, the patient external anatomy being tracked, the 3D image, and the interactive tools such as the intubation tools in the case of the HPS.



(a) (b)

Fig. 2 (a) The HMPD in use (b) Optomechanical design of the HMPD

A demonstration of augmented reality is shown in Fig. 3. In this demonstration, the leg of a real patient is optically tracked using an OPTOTRAK 3020 system. Accuracy and precision of 0.1mm is achieved. From the 3D spatial coordinates of each LED, we apply custom-designed algorithms to optically superimpose the knee-joint anatomy in this case on the leg in motion.[10-12]

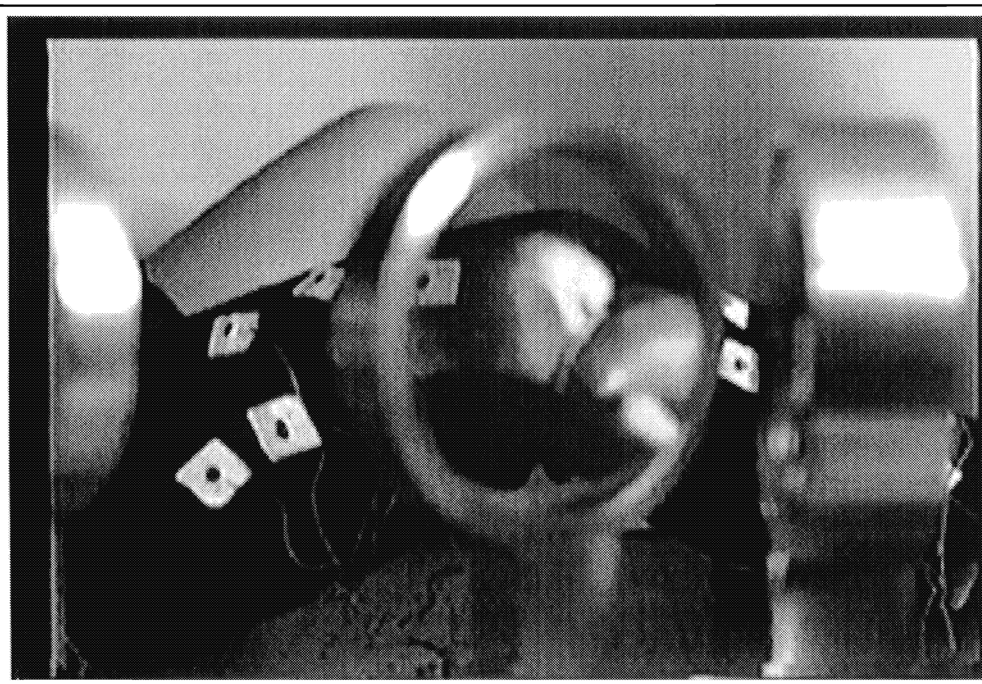


Fig. 3 Optical superimposition of internal knee anatomy on a leg model-patient in motion

5 APPLICATION TO REMOTE COLLABORATIVE ENVIRONMENTS

The basic concept of the HMPD was enhanced to provide the capability to capture the HMD user's face through the HMPD.[13] The stereoscopic views of the face can then be videostreamed via a high speed network such as Internet2, and recombined in another HMPD to simulate the teleportal of the 3D face to a remote location. An illustration of the concept of teleportation via a HMPD is shown in Fig. 4. Two users in an office wearing a HMPD are conversing realtime with a third user remotely located, also wearing a HMPD, whose face has been teleported to the office. Both visual and 3D sounds must be integrated to render the sense of presence of the third user in the virtual environment created. The three users can either visualize some 3D models under investigation together or converse face to face. The remote user can only see one of the two other users at a time, while the users located in the same office can see each other and the third user who has been teleported.

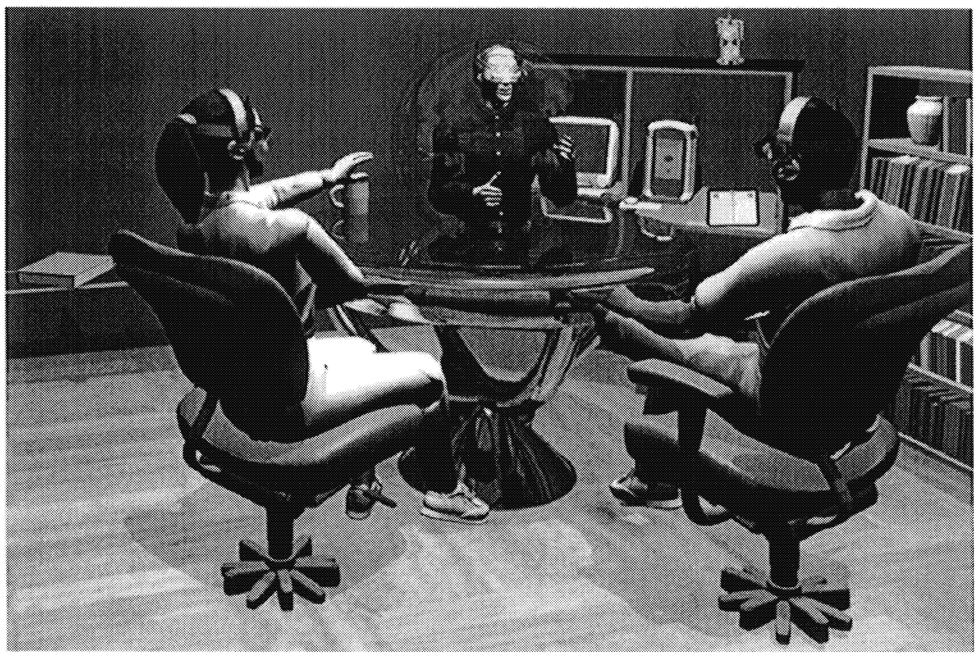


Fig. 4 The HMPD is being developed as a key technology for effective remote collaborative environments. A third party is teleported to a conference room where two HMPD users have gathered.

Graphics by Stephen Johnson, ODALab, School of Optics at UCF.

6 CONCLUSION

In this paper we review the concept of the HMPD and its expansion to allow face to face collaboration at a distance. The unique feature of the HMPD is that it combines the idea of a head-mounted display with the concept of projection optics as utilized in caves. The technology is unique because of its capability to create large field of views with lightweight optics as a consequence of replacing the eyepiece optics in conventional HMDs with projection optics. We have discussed how the technology is applied to 3D medical visualization as well as the creation of remote collaborative environments for face to face teleconferencing connected via high-speed networks.

7 ACKNOWLEDGEMENTS

Different parts of this work are funded by grants from the NIH/NLM 1-R29-LM06322-01A1, the NSF IIS 00-83037 ITR, the NSF IIS 00-82016 ITR, the NSF EIA-99-86051, a STRICOM Award, Lockheed Martin, ELF-Acquitaine Corporation, and Michigan State University.

8 REFERENCES

1. D. Buxton, G W. Fitzmaurice. "HMDs, caves and chameleon: a human-centric analysis of interaction in virtual space". *Computer Graphics (ACM)*, Vol. 32, No. 4, 69-74 (1998).
2. C. Cruz-Neira, Daniel J. Sandin, Thomas A DeFanti. "Surround-screen projection-based virtual reality: the design and implementation of the CAVE", *Proc ACM SIGGRAPH 93 Conf Comput Graphics 1993.* Publ by ACM, New York, NY, USA, 135-142 (1993).
3. J.P. Rolland, and H. Fuchs, "Optical versus video see-through head-mounted displays in medical visualization," *Presence: Teleoperators and Virtual Environments (MIT Press),* 9(3), 287-309 (2000).
4. Ryugo Kijima and Takeo Ojika, "Transition between virtual environment and workstation environment with projective head-mounted display", *Proceedings of IEEE 1997 Virtual Reality Annual International Symposium,* IEEE Comput. Soc. Press. Los Alamitos, CA, USA. 130-137(1997).
5. J. Fergason. "Optical system for head mounted display using retro-reflector and method of displaying an image", U.S. patent 5,621,572. April 15 (1997).
6. J. Parsons, and J. P. Rolland, "A non-intrusive display technique for providing real-time data within a surgeons critical area of interest," *Proceedings of Medicine Meets Virtual Reality98*, 246-251 (1998).
7. J. P. Rolland, J. Parsons, D. Poizat, and D. Hancock, "Conformal optics for 3D visualization," International Optical Design Conference 98 Kona, HI, USA. Proceedings of the SPIE **3482**, 760-764 (1998).
8. H. Hua, A. Girardot, Chunyu Gao, and J. P. Rolland. "Engineering of head-mounted projective displays". *Applied Optics*, 39 (22), 3814-3824 (2000).
9. H. Hua, C. Gao, F. Biocca, and J.P. Rolland, "An Ultra-light and Compact Design and Implementation of Head-Mounted Projective Displays", Proceedings of IEEE-VR, p. 175-182, Yokohama, Japan (2001).
10. Y. Baillot, J.P. Rolland, K. Lin, and D.L. Wright, "Automatic modeling of knee-joint motion for the virtual reality dynamic anatomy (VRDA) tool," *Presence: Teleoperators and Virtual Environments (MIT Press)* 9(3), 223-235 (2000).
11. Y. Argotti, L. Davis, V. Outters, and J.P. Rolland, "Dynamic Superimposition of Synthetic Objects on Rigid and Simple-Deformable Real Objects", In Proceedings of the Second IEEE and ACM International Symposium on Augmented Reality (ISAR '01), IEEE Computer Society, 2001
12. Y. Argotti, V. Outters, L. Davis, A. Sun, and J.P. Rolland, "Technologies for Augmented Reality: Calibration for Real-Time Superimposition on Rigid and Simple-Deformable Real Objects", In Proceedings of the Fourth International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI '01), Springer-Verlag, (2001).
13. F. Biocca and J. Rolland, "Teleportal face-to-face system," *Patent Filed* (1999).