Head-Mounted Projective Displays for Creating Collaborative Environments

J. Rolland,[1,2] L. Davis,[2] Y. Ha,[1] F. Hamza-Lup,[2] B. Del Vento,[2] C. Gao,[3] H. Hua,[3] and F. Biocca[4]

[1]ODALab at the School of Optics/CREOL
[2]School of Electrical Engineering and Computer Science
University of Central Florida

[3]3DVIS Lab at Beckman Institute, University of Illinois at Urbana Champaign

[4]MIND Lab in the Department of Telecommunication, Michigan State University

1. Introduction

In a close distributed collaboration, the ODALab, the 3DVIS Lab, and the MIND Lab are investigating methods and technology for 3D visualization in distributed collaborative environments. The research program embodies the optical system design, fabrication, and assessment of innovative head-mounted displays (HMDs), the design of optical tracking probes for integration in HMDs, and he development of mathematical methods and algorithms for augmented reality and distributed systems.

2. Design of Tracked Head-mounted Displays

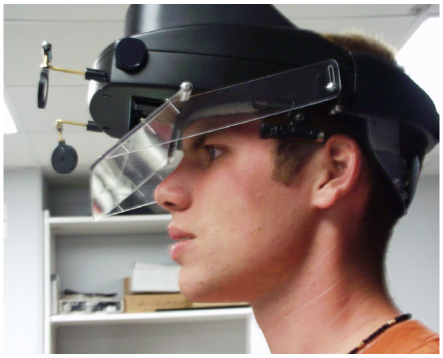

Fig. 1 Close view of one user wearing a Teleportal HMPD.

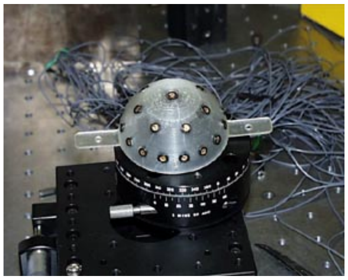

Fig. 3. Marker based head tracking probe.

See-through HMDs can be used to obtain an enhanced view of the real environment. Of the optical or video type, see-through HMDs allow users to see 3D computer-generated objects superimposed on their real-world view.[1]

A new form of head-mounted display is the Teleportal Head-Mounted Projective Display (HMPD). A HMPD consists of miniature projection optics mounted on the head and supple, non-distorting and durable retro-reflective material placed strategically in the environment.[2] The teleportal feature consists of the capability to capture stereoscopic images of the face of the user wearing the HMD, via front mirrors shown in Fig. 1 and miniature video cameras mounted on the side of the helmet, so the face of the user can be teleported via high speed network such as Internet2 to a remote environment as illustrated in Fig. 2.

To correctly visualize objects in a virtual environment, the head of the HMD user must be accurately tracked. Based on the OPTOTRAK 3020, a commercially available optical tracking system, which acquires the position of individual infrared beacons or the position and orientation of rigid probes made of such beacons, we are developing methods and algorithms for probe design applicable equally to rigid (i.e. for head tracking) and deformable objects (i.e. for motion capture described thereafter). A recently design rigid head tracking probe is shown is Fig. 3. Predicted precision in position and orientation are 0.1 mm and 0.16 degree, respectively. The experimental quantification of precision and accuracy of this tracking probe is in progress.

Fig. 2 Illustration of a remote collaborative environment with teleportal capability where a third user's face from a remote site is perceived by each user in the local environment. (*Graphics by Stephen Johnson, ODALab-UCF).*

3. Methods for Augmented Reality

Overall methods for augmented reality include most generally a calibration followed by a dynamic superimposition procedure to bring virtual objects in register with real objects. The methods we employ assume that a cluster of markers placed on their surfaces defines real objects, and a tracking system provides the individual 3D location of the markers in a frame of reference. The calibration procedure occurs in several steps: for each real object in the system, a local coordinate frame is defined and computed based upon the eigenvectors of the dispersion matrix formed by the cluster of markers. Such computation is based on the observation that the eigenvalues are invariant for a rigid body. The correspondence between real and synthetic objects in the environment is then determined based on the registration of common landmarks. Given the synthetic objects geometry, scaling of the synthetic objects is applied as needed and the transformations between real and synthetic objects are determined. Finally, the optical properties of the system are quantified.

In the dynamic superimposition procedure, the global location of at least three markers is first measured on each real object. Given the location of these markers in their local coordinate frame obtained during the calibration process, an optimization method based on singular value decomposition is applied to estimate the rotation and translation which, when applied to the local coordinates, yield the measured global coordinates. The local motion of markers on a semi-deformable object is managed during this step.[3]

Next, to account for collision detection and/or motion constraints between linked objects within the environment, the transformation matrices, which link the real objects, are used as an input to a kinematic model of motion. To this end, we have designed a novel automatic modeling algorithm for anatomical joint motion, which relies on automatically finding the stable position and orientation of two rigid bodies in contact. The ligaments and the contact surfaces produce some kinematic constraints on the joint motion, which is the base of the modeling algorithm described. Once a stable position and orientation are found for a given attitude of joint (e.g. value of flexion/extension angle of the joint), the position and orientation of the bones are recorded in a lookup table indexed by the entry angles. This lookup table is then used during interactive simulation, allowing optical superimposition of internal anatomical models on a live model-patient. Such technique is developed for interfacing to the VRDA tool for teaching of complex anatomical joint motions in situ or via distributed learning collaborative environments.

The last step of the procedure is the stereoscopic rendering process that combines all the required transformation matrices and allows defining the connection between the real and the synthetic worlds. Included in this final step is the correction of optical distortion of the optics.

3. Augmented reality applications

To further drive research in technology and methods, an ODALab augmented reality application is the Virtual Reality Dynamic Anatomy Tool (VRDA), an augmented reality visualization tool for teaching the motion of anatomical joints.[3] The VRDA tool enables a user manipulating an anatomical joint (e.g. the knee) of a subject to visualize a virtual model of the inner anatomy superimposed on the body. In this teaching tool, the 3D motion of the individual components of a generic joint must be fairly accurate on the whole range of motion and for any geometrical model employed. To ensure accurate motion, a kinematic model of anatomical knee joint motion described thereafter was employed. Superimposition results are shown in Fig. 3 using a conventional see-through bench display and the OPTOTRAK 3020. The HMPD and a portable optical tracker will be next integrated within the VRDA tool to create a low cost, portable integrated system.

Fig. 4 Virtual model of knee joint anatomy optically and dynamically superimposed on a real model-patient using an implementation of the VRDA tool (a) bony structures of the knee (b) bony and deformable anatomy of the knee joint.

Another application of augmented reality developed in the ODALab is Airway Management Visualization and Training for military medics described in further detail in a companion paper of this proceeding. To open blocked airways, medics often perform an endotracheal intubation procedure, which consists of inserting a tracheal tube through the mouth into the trachea and then sealing the trachea so all air passes through the tube and oxygenates the lungs. The skills required to intubate a patient are not easily practiced, deteriorate over time, and are costly. Current training methods involve videos, printed media, classroom lectures and training on mannequins to develop the necessary skills. The U.S. Army Simulation, Training, and Instrumentation COMmand (STRICOM) has teamed with the ODALab and with Medical Education Technologies Inc. (METI) to develop a system that combines these training techniques into an integrated system. The heart of the airway visualization effort is an augmented reality system that superimposes a 3D model of the upper airway on a METI Human Patient Simulator. This system allows the trainee to see the internal interactions of the tracheal tube with the main structures of the upper airways, thus allowing trainees to visualize what they are feeling while performing the procedure.

Acknowledgments

We acknowledge Yann Argotti, Valerie Outters, and Yohan Baillot for their early contributions to the development of the VRDA tool and Robert Banks for his assistance in the HMPD assembly. This research is supported by the NIH/NLM 1-R29-LM06322-01A1, the NSF IIS 00-82016 ITR, the NSF EIA-99-86051, STRICOM, and the Florida Education Funds.

References

1. Rolland, J.P., and Henry Fuchs, "Optical versus video see-through head-mounted displays in medical visualization," *Presence: Teleoperators and Virtual Environments (MIT Press),* 9(3), 287-309 (2000).
2. Hua, H., A. Girardot, C. Gao, and J. P. Rolland, "Engineering of head-mounted projective displays, *Applied Optics* 39(22), 3814-3824 (2000).
3. Y. Argotti, L. Davis, V. Outters, and J.P. Rolland, "Dynamic superimposition on synthetic objects on rigid and simple-deformable real objects," *Proc. of IEEE and ACM ISAR'01, 29 October 2001, NY, New York, 5-10* (2001).
4. Baillot, Y., 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).
5. Davis, L., F. Hamza-Lup, J. Daly, Y. Ha, S. Frolich, C. Meyer, G. Martin, J. Norfleet, K. Lin, and Jannick P. Rolland, "Application of Augmented Reality to Visualizing Anatomical Airways," in Proceedings of Aerosense'02, 4711, April1-5th, Orlando FL, 2002. (in press).