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3D Visualization and Imaging in Distributed Collaborative Environments

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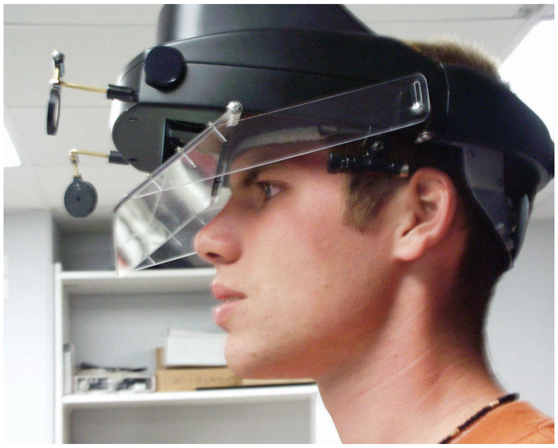
The Optical Diagnostics and Applications Laboratory (ODALab) is investigating methods and technology for 3D visualization and imaging. Specifically, we're integrating and assessing systems driven by real-world applications that can benefit from or enhance distributed collaborative environments. Although optics is at the core of the research program, the research involves extensive knowledge from various science and engineering fields. Students in the ODALab can pursue graduate degrees in optics, engineering, physics, computer science, or modeling and simulation. This article surveys the research the ODALab program is doing in optical system design, fabrication, and assessment of innovative head-mounted displays (HMDs); the design of optical tracking probes for integration in HMDs; the development of mathematical methods and applications for augmented reality (AR); the physics-based modeling of anatomical joint motion and optical special effects for augmented environments; and 3D biomedical optical imaging.

HMD design

We can use see-through HMDs to obtain an enhanced view of a real environment. Optical and video see-through HMDs let users see 3D computer-generated objects superimposed on their real-world view.[1] At ODALab, we've developed a new form of HMD, the Teleportal Head-Mounted Projective Display. An HMPD consists of miniature projection optics mounted on the head and supple, nondistorting, and durable retroreflective material placed strategically in the environment.[2] The teleportal feature lets us capture stereoscopic images of the face of the user wearing the HMPD, via the front mirrors in Figure 1 and miniature video cameras mounted on the side of the helmet, to teleport the user's face via a high-speed network such as Internet2 to a remote environment, as Figure 2 (next page) illustrates.[3]



1 Close view of a user wearing a Teleportal HMPD.

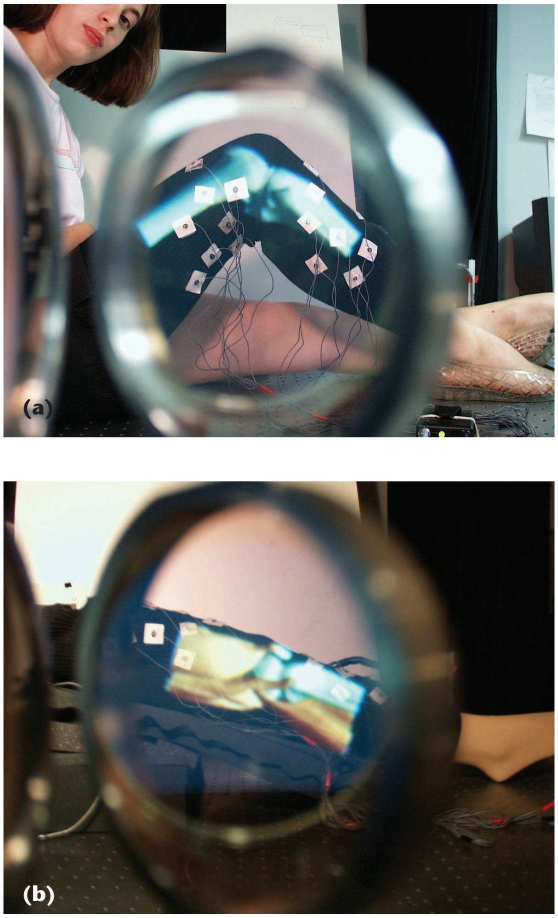
To visualize objects in a virtual environment correctly, we must accurately track the HMD user's head. Based on the Optotrak 3020, a commercially available optical tracking system that acquires the position of individual infrared beacons or the position and orientation of rigid probes made of such beacons, we're developing methods and algorithms for a probe design that equally applies to rigid (for head tracking) and deformable objects (for motion capture). In the near future, we'll also test the methods on a low-cost portable optical tracker.

AR mathematical methods

Generally, AR methods include a calibration followed by a dynamic superimposition procedure to bring virtual objects in register with real objects. The methods we're using assume that a cluster of markers placed on their surfaces defines real objects, and a tracking system provides the markers' individual 3D location in a frame of reference. The calibration procedure occurs in several steps: For each real object in the system, we define a local coordinate frame and compute it based on 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. We then determine the correspondence between real and synthetic objects in the environment based on the registration of common landmarks. Given the synthetic objects' geometry, we apply scaling of the synthetic objects as needed and determine the transformations between real and synthetic objects. Finally, we quantify the system's optical properties.

In the dynamic superimposition procedure, we first measure the global location of at least three markers on each real object. Given the location of these markers in their local coordinate frame obtained during the calibration process, we apply an optimization method based on singular value decomposition to estimate the rotation and translation. When we apply this to the local coordinates, it yields the measured global coordi-

2 A remote collaborative environment with teleportal capability. Users in the local environment perceive a third user's face from a remote site. (Graphics by Stephen Johnson, ODALab-UCF.)



3 Virtual model of a 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.

nates. We manage the local motion of markers on a semideformable object during this step.[4] Next, to account for collision detection and/or motion constraints between linked objects within the environment, we use the transformation matrices, which link the real objects, as an input to a kinematic model of motion. The procedure's last step is the stereoscopic rendering process that combines all the required transformation matrices and defines the connection between the real and synthetic worlds. This final step also corrects for optical distortions.

AR applications

To further drive research in technology and methods, we developed an AR application, the Virtual Reality Dynamic Anatomy (VRDA) Tool, based on preliminary research findings in the ODALab. VRDA is an AR visualization tool for teaching the motion of anatomical joints.[4] The tool lets a user manipulating a subject's anatomical joint (such as a knee) visualize a virtual model of the inner anatomy superimposed on the body. In this teaching tool, the 3D motion of a generic joint's individual components must be fairly accurate on the whole range of motion and for any geometrical model employed. To ensure accurate motion, we used a kinematic model of an anatomical knee joint motion. To produce the superimposition results in Figure 3, we used a conventional see-through bench display and the Optotrak 3020. Next, we plan to integrate the HMPD and a portable optical tracker within the VRDA tool to create a low-cost, easily deployable integrated system.

Another AR application developed at ODALab is Airway Management Visualization and Training for military medics. To open blocked airways, medics often perform an endotracheal intubation procedure, 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. Medics can't easily practice the skills required to intubate a patient, and when they do, the training is costly and their skills deteriorate over time. Current training methods involve videos, printed media, classroom lectures, and training on mannequins.

The US Army Simulation, Training, and Instrumentation Command (STRICOM) has teamed up with the ODALab and 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 AR system that superimposes a 3D model of the upper airway on a METI Human Patient Simulator. This system lets the trainee see the internal interactions of the tracheal tube with the main structures of the upper airways, thus letting trainees visualize what they're feeling while performing the procedure.

Physics-based modeling for augmented environments

Two modeling research efforts at ODALab related to augmented environments are the modeling of kinematic anatomical joint motion and the modeling of special effects to augment static or dynamic images captured in photography and moviemaking.

Modeling anatomical joint motion

Driven by the VRDA tool development, our research focuses on methods that consider the exact motion of a joint produced by the dynamic interaction of its components under no load as opposed to methods that seek to create dynamic, yet anatomically simpler models of anatomical motion under load for animation purposes.

To this end, we've designed a novel automatic modeling algorithm for anatomical joint motion that relies on automatically finding the stable position and orientation of two rigid bodies in contact. The ligaments and contact surfaces produce some kinematic constraints on the joint motion, which is the base of our modeling algorithm. Once a stable position and orientation are achieved via the algorithm for a given attitude of the joint (for example, the value of flexion and extension angle of the joint), the bones' position and orientation are saved 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. We developed this technique as an interface to the VRDA tool for teaching complex anatomical joint motions in situ or via distributed learning collaborative environments.

Optically simulating special effects

Inspired by the Robin Williams movie directed by Vincent Ward, *What Dreams May Come*, which received the 1998 Academy Award for best visual effects, we're trying to create optical painterly effects in a picture or movie camera so we can render such effects at the speed of light. We can then further optically merge the images with other dynamic subjects to create AR worlds.

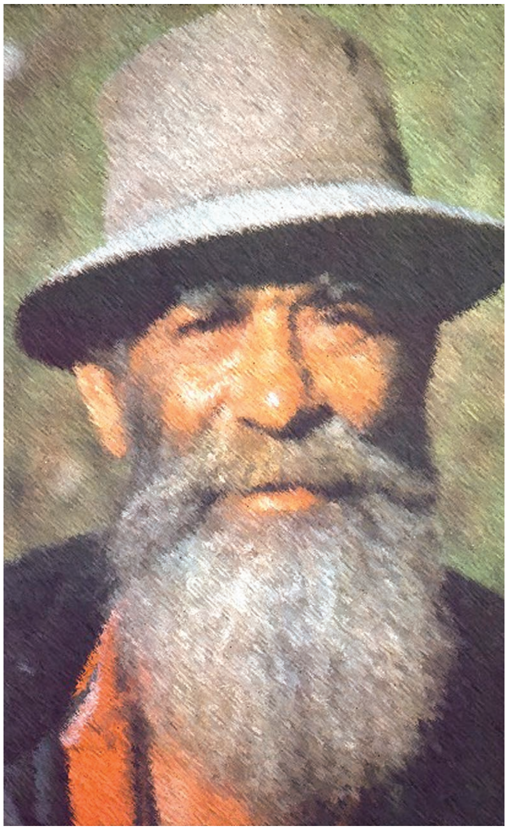
To develop the optical technology to predict and optimize such effects, we're modeling optical imaging based on optical ray tracing, scalar diffraction theory, statistical optics, and combinations of them. Figure 4 shows an example of optical modeling on a portrait via ray tracing and components of statistical optics. Using technology to link art and science can also constitute an effective tool for enhancing curriculum that is best disseminated via distributed learning collaborative environments.

Optical imaging of biomedical data

Optical coherence microscopy (OCM) is a biomedical imaging technique based on low-coherence Michelson interferometry. This technique lets us scan a biological sample in 3D, with a spatial resolution in x,y, and z of 5 to 15 um, depending on the light-source characteristics. We've designed and built a fiber optic interferometer to investigate image quality in OCM as required for cancer diagnosis. Future research also includes developing an interface to Internet2 to create a distributed 3D collaborative environment between the ODALab and a pathology laboratory where HMDs may play a role in explorative visualization of the 3D data acquired.

Conclusion

Since its founding in 1996, ODALab has laid a foundation for research in 3D imaging and visualization in relation to distributed collaborative virtual environments. Future research aims to realize the teleportal application using desktop computers and demonstrate its capability in key biomedical applications such as orthopaedics and oncology. In addition, the technology we're developing will find applications in creative environments and new media for 3D scientific visualization and interpersonal communications. ■



4 **Rendering of a painterly portrait of an old man.**

Acknowledgments

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References

1. J.P. Rolland and H. Fuchs, "Optical Versus Video See-Through Head-Mounted Displays in Medical Visualization," *Presence: Teleoperators and Virtual Environments*, vol. 9, no. 3, 2000, pp. 287-309.
2. H. Hua et al., "Engineering of Head-Mounted Projective Displays," *Applied Optics*, vol. 39. no. 22, 2000, pp. 3814-3824.
3. F. Biocca and J.P. Rolland, "Teleportal Face-to-Face System," patent filed Aug. 2000.
4. Y. Argotti et al., "Dynamic Superimposition on Synthetic Objects on Rigid and Simple-Deformable Real Objects," *Proc. ISAR*, 2001, pp. 5-10.

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