Tracking for Interactive Computer Graphics

Department of Computer Science | University of North Carolina at Chapel Hill | February 2002

Highlights

- **Technology and algorithms for *wide-area* tracking for virtual and augmented-reality systems.**
- **Sensor systems (acoustic, optical, inertial, etc.) and algorithms for *unobtrusive* tracking.**

The Challenge

Head-mounted displays, projector systems, and conventional monitors are used to provide a user with the impression of being immersed in a simulated three-dimensional *virtual* environment, or to *augment* a user's natural view of the real world with computer-generated imagery. To achieve this effect, the computer must constantly receive precise information about the position and orientation or *pose* of the user's head, and it must adjust rapidly the displayed images to reflect the changing head pose. Additionally the computer might make use of information about the pose of hands, arms, legs, and feet. Such real-time pose information comes from a *tracking system*.

Building accurate, real-time tracking systems for computer graphics is a difficult task. Our group has built head-tracking systems that cover room-sized environments with accuracy on the order of 1/2 millimeter and 0.03 of a degree. One of our long-term goals involves tracking with reduced supporting infrastructure in the environment—for, for example, in ordinary rooms and outdoors. This presents new challenges because without external infrastructure the available sensing modalities become relatively limited. In particular, one is limited to sensing external forces or physical properties in a self-contained fashion. The problem is further compounded as these forces or properties are typically sparsely available and/or provide limited information. A related goal is head and limb tracking with reduced user-worn components. This presents a significant challenge because, in general, a reduction in device size corresponds to a reduction in signal strength. In addition, small components on users' limbs are likely to be hidden or occluded as the user interacts with a virtual or augmented environment.

Previous Work

In 1991, we demonstrated a working scalable electro-optical head-tracking system in the Tomorrow's Realities gallery at that year's ACM SIGGRAPH conference. The system used four head-worn optical sensors that looked upward at a regular array of infrared LEDs installed in precisely machined ceiling panels. A user-worn backpack contained electronics that digitized and communicated the photo-coordinates of the sighted LEDs. The system was groundbreaking in that it was unaffected by ferromagnetic and conductive materials in the environment, and in that the working volume of the system was determined solely by the number of ceiling panels.

In the late 1990s, we completed work on a second-generation system we call the *HiBall Tracking System*. As a result of significant improvements in hardware and software this HiBall system offers unprecedented speed, resolution, accuracy, robustness, and flexibility. The bulky/heavy sensors and backpack of the previous system have been replaced by

The HiBall Tracker.

Graduate student Dorian Miller experiments with a novel optical sensor for the Latency Meter project.

a five-ounce, six-camera sensor module that we call the HiBall. In addition, the precisely machined LED ceiling panels of the previous system have been replaced by looser-tolerance panels that are relatively inexpensive to make and simple to install. Finally, we are using an unusual Kalman-filter-based approach we call *single-constraint-at-a-time*, or SCAAT, tracking that generates very accurate pose estimates at a high rate with low latency, and simultaneously self-calibrates the system. Currently, the system generates estimates at greater than 1,500 Hz, with accuracy on the order of 1/2 millimeter and 0.03 of a degree, all over a 500 square foot area. The system is now being manufactured and sold by 3rdTech, Inc. (www.3rdtech.com).

Current Research

We are working on novel technologies and algorithms aimed at both tracking with reduced environmental infrastructure, and tracking with unobtrusive user-worn components. Graduate students Danette Allen and Marcel Prastawa are developing a mathematical and graphical framework for exploring and assessing the design space of proposed tracking systems. Such a framework will enable designers to find sensors and configurations that optimally trade off component size, configuration, and performance. Graduate student Dorian Miller is investigating small, fast, one-dimensional optical sensors for unobtrusive tracking in office-sized environments. Dorian is also exploring the related development of something we call the *Latency Meter*, an unobtrusive optical device form measuring end-to-end graphics system latency. Finally, graduate student Nick Vallidis is working on a dissertation introducing an approach that uses spread-spectrum acoustic techniques to achieve full-body (limb) tracking with very small user-worn devices.

Project Leaders

Gary Bishop, associate professor
Leandra Vicci, lecturer and director of the Microelectronic Systems Laboratory
Gregory F. Welch, research associate professor

Other Investigators

Stephen Brumback, research electrical engineer
Henry Fuchs, Federico Gil professor
Kurtis Keller, research engineer
John Thomas, research associate and manager of the Microelectronic Systems Laboratory

Graduate Research Assistants

Danette Allen, Dorian Miller, Marcel Prastawa, Nicholas Vallidis

Research Sponsors

Current Sponsorship

National Science Foundation Science and Technology Center for Graphics (Cooperative Agreement ASC-8920219)
Office of Naval Research (Contract N00014-01-1-0064)

Past Sponsorship

Defense Advanced Research Projects Agency (DARPA) (Contract N00019-97-C-2013)
DARPA (Contract DABT 63-93-C-0048)

Selected Publications

Miller D., and G. Bishop. "Latency Meter: a Device for Easily Monitoring VE Delay," *Proc. SPIE Engineering Reality of Virtual Reality*, San Jose, Calif., January 2002.

Welch, G., G. Bishop, L. Vicci, S. Brumback, K. Keller, and D. Colucci. "High-Performance Wide-Area Optical Tracking—The HiBall Tracking System," *Presence: Teleoperators and Virtual Environments*, 10(1), 2001.

Welch, G., and G. Bishop. "SCAAT: Incremental Tracking with Incomplete Information," *Computer Graphics: Proc. ACM SIGGRAPH '97*, Los Angeles, Calif., 3–8 August 1997.

Azuma, R., and G. Bishop. "A Frequency-Domain Analysis of Head-Motion Prediction," *Computer Graphics: Proc. ACM SIGGRAPH '95*, Los Angeles, Calif., 6–11 August 1995, 401–408.

Azuma, R., and G. Bishop. "Improving Static and Dynamic Registration in an Optical See-Through HMD," *Computer Graphics: Proc. ACM SIGGRAPH '94*, Orlando, Fla., 24–29 July 1994, 197–204.

Gottschalk, S., and J. F. Hughes. "Autocalibration for Virtual Environments Tracking Hardware," *Computer Graphics: Proc. ACM SIGGRAPH '93*, Anaheim, Calif., 1–6 August 1993, 65–72.

Azuma, R. "Tracking Requirements for Augmented Reality," *Communications of the ACM*, 36(7), July 1993, 50–51.

Ward, M., R. Azuma, B. Bennett, S. Gottschalk, and H. Fuchs. "A Demonstrated Optical Tracker with Scalable Work Area for Head-Mounted Display Systems," *Computer Graphics: Proc. 1992 Symposium on Interactive 3D Graphics*, Cambridge, Mass., 29 March–1 April 1992, 43–52.

Bishop, G., and H. Fuchs. "The Self-Tracker: A Smart Optical Sensor on Silicon," *Proc. Conference on Advanced Research in VLSI at MIT*, 23–25 January 1984, 65–73.

Key Words

Three-dimensional graphics; Virtual Reality; head tracking; autonomous navigation; Kalman filter; sensor fusion.

For More Information

Dr. Greg Welch or Dr. Gary Bishop
Department of Computer Science
University of North Carolina at Chapel Hill
CB#3175, Sitterson Hall
Chapel Hill, NC 27599-3175
Phone: (919) 962-1819 or (919) 962-1886
Fax: (919) 962-1799
E-mail: welch@cs.unc.edu or gb@cs.unc.edu