Predictive Tracking for Augmented Reality

TR95-007
February 1995

Ronald T. Azuma

Department of Computer Science
CB #3175, Sitterson Hall
UNC-Chapel Hill
Chapel Hill, NC 27599-3175

UNC is an Equal Opportunity/Affirmative Action Institution.

Predictive Tracking for Augmented Reality

by

Ronald Tadao Azuma

A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Computer Science

Chapel Hill

1995

Approved by:

_______________________ Adviser
T. Gary Bishop

_______________________ Reader
Vernon Chi

_______________________ Reader
Frederick P. Brooks, Jr.

ABSTRACT

Ronald Tadao Azuma. Predictive Tracking for Augmented Reality

(Under the direction of T. Gary Bishop.)

In Augmented Reality systems, see-through Head-Mounted Displays (HMDs) superimpose virtual three-dimensional objects on the real world. This technology has the potential to enhance a user's perception of and interaction with the real world. However, many Augmented Reality applications will not be accepted unless virtual objects are accurately registered with their real counterparts. Good registration is difficult, because of the high resolution of the human visual system and its sensitivity to small differences. Registration errors fall into two categories: *static* errors, which occur even when the user remains still, and *dynamic* errors caused by system delays when the user moves. Dynamic errors are usually the largest errors. This dissertation demonstrates that predicting future head locations is an effective approach for significantly reducing dynamic errors.

This demonstration is performed in real time with an operational Augmented Reality system. First, evaluating the effect of prediction requires robust static registration. Therefore, this system uses a custom optoelectronic head-tracking system and three calibration procedures developed to measure the viewing parameters. Second, the system predicts future head positions and orientations with the aid of inertial sensors. Effective use of these sensors requires accurate estimation of the varying

prediction intervals, optimization techniques for determining parameters, and a system built to support real-time processes.

On average, prediction with inertial sensors is 2 to 3 times more accurate than prediction without inertial sensors and 5 to 10 times more accurate than not doing any prediction at all. Prediction is most effective at short prediction intervals, empirically determined to be about 80 milliseconds or less. An analysis of the predictor in the frequency domain shows the predictor magnifies the signal by roughly the square of the angular frequency and the prediction interval. For specified head-motion sequences and prediction intervals, this analytical framework can also estimate the maximum possible time-domain error and the maximum tolerable system delay given a specified maximum time-domain error.

Future steps that may further improve registration are discussed.

ACKNOWLEDGEMENTS

I thank my advisor, Gary Bishop, and my committee members, Frank Biocca, Frederick Brooks, Vern Chi, Henry Fuchs, and Jonathan Marshall, for their advice and guidance in this work.

I would also like to thank the following people:

- Mark Ward, for doing most of the mechanical and electronic design of the optoelectronic tracking system that was critical to this project.
- Brad Bennett and Stefan Gottschalk for writing much of the software for the optoelectronic tracking system.
- Brad Bennett for his help with the low-level software, installation and debugging of the single-board computers and Pixel-Planes 5.
- John Thomas, John Hughes, Kurtis Keller, and Jack Kite for making mechanical parts for this project and expediting the ordering of equipment.
- Vern Chi and Steven Brumback for designing analog circuitry used in this project.
- David Harrison, Brennan Stephens, Elliot Poger, and Peggy Wetzel for their help with video recording and editing.
- Jack Goldfeather and John F. "Spike" Hughes for explaining some of the mathematics to me.
- Russell Taylor and Mark Finch for letting me use equipment from the Scanning Tunneling Microscope project to test our inertial sensors.
- Marc Olano and Jonathan Cohen for creating low-latency rendering code on Pixel-Planes 5.
- Carl Mueller, Marc Olano, and David Ellsworth for their advice on programming Pixel-Planes 5.
- Mike Bajura, Andrei State, Rich Holloway, Jannick Rolland, and Ulrich Neumann for discussions about see-through registration strategies.
- Devesh Bhatnagar, Suresh Balu, and the other Tracker group team members for their general support on the tracking equipment and software.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.