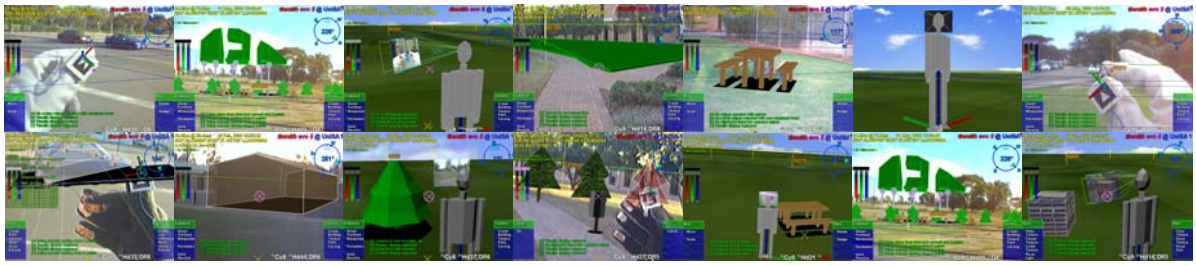
interactive 3d modelling in outdoor augmented reality worlds



Research Thesis for the Degree of Doctor of Philosophy

By Wayne Piekarski

Bachelor of Engineering in Computer Systems Engineering (Hons), University of South Australia

wayne@cs.unisa.edu.au

Supervisor

Dr. Bruce Thomas

Adelaide, South Australia

February 2004

Wearable Computer Lab

School of Computer and Information Science

Division of Information Technology, Engineering, and the Environment

The University of South Australia

Table of Contents

List of Figures

List of Tables

Abbreviations and Definitions

1394	IEEE Standard 1394, also referred to as Firewire or i.Link [IEEE95]
2D	Two Dimensional in XY
3D	Three Dimensional in XYZ
AAAD	Action at a distance, first defined by Mine [MINE95a]
ACRC	Advanced Computing Research Centre at UniSA
AGD66	Australian Geodetic Datum 1966 [ICSM00]
AGD84	Australian Geodetic Datum 1984 [ICSM00]
AR	Augmented Reality
CIS	School of Computer and Information Science at UniSA
COTS	Commercial Off The Shelf
CRT	Cathode Ray Tube (technology used in television and monitor displays)
CSG	Constructive Solid Geometry
DGPS	Differential GPS
DIS	IEEE Standard 1278, the Distributed Interactive Simulation protocol [IEEE93]
DOF	Degrees of Freedom ([X, Y, Z] for position, [θ, ϕ, φ] for orientation)
3DOF	Three degrees of freedom, only three measurements, such as only orientation or position tracker information
6DOF	Six degrees of freedom, information about orientation and position, a complete tracking solution
DSTO	Defence Science Technology Organisation, Adelaide, South Australia
ECEF	Earth-Centred Earth-Fixed Cartesian coordinates, in metres [ICSM00]
Evo	Evolution or version number
FOV	Field of View, the angle of the user's view that a head mounted display or camera can cover
GLONASS	Russian Federation, Global Navigation Satellite System (Global'naya Navigatsionnaya Sputnikovaya Sistema in Russian)
GPS	US Department of Defence, Global Positioning System
HMD	Head Mounted Display
HUD	Heads Up Display
ITD	Information Technology Division (located at DSTO Salisbury, Adelaide)
IPC	Inter-Process Communication
LCD	Liquid Crystal Display

LOD	Land Operations Division (located at DSTO Salisbury, Adelaide)
LLH	Latitude Longitude Height spherical polar coordinates [ICSM00]
LSAP	Land Situational Awareness Picture System
MR	Mixed Reality
NFS	Sun Microsystems' Network File System [SAND85]
OEM	Original Equipment Manufacturer
RPC	Sun Microsystems' Remote Procedure Calls
RTK	Real-Time Kinematic (centimetre grade GPS technology)
SERF	Synthetic Environment Research Facility (located at DSTO Salisbury, Adelaide)
SES	Scientific and Engineering Services (located at DSTO Salisbury, Adelaide)
STL	Standard Template Library (for the C++ language)
SQL	Server Query Language
Tinmith	This Is Not Map In The Hat (named for historical purposes)
UniSA	University of South Australia
USB	Universal Serial Bus
UTM	Universal Transverse Mercator grid coordinates, in metres [ICSM00]
VE	Virtual Environment
VR	Virtual Reality
WCL	Wearable Computer Lab at the University of South Australia
WIM	Worlds in Miniature [STOA95]
WIMP	Windows, Icons, Menus, and Pointer
WGS84	World Geodetic System 1984 [ICSM00]
X	The X Window System
XML	Extensible Mark-up Language

Summary

This dissertation presents interaction techniques for 3D modelling of large structures in outdoor augmented reality environments. Augmented reality is the process of registering projected computer-generated images over a user's view of the physical world. With the use of a mobile computer, augmented reality can also be experienced in an outdoor environment. Working in a mobile outdoor environment introduces new challenges not previously encountered indoors, requiring the development of new user interfaces to interact with the computer. Current AR systems only support limited interactions and so the complexity of applications that can be developed is also limited.

This dissertation describes a number of novel contributions that improve the state of the art in augmented reality technology. Firstly, the augmented reality working planes technique gives the user the ability to create and edit objects at large distances using line of sight and projection techniques. This technique overcomes limitations in a human's ability to perceive depth, and requires simple input devices that are available on mobile computers. A number of techniques that leverage AR working planes are developed, collectively termed construction at a distance: street furniture, bread crumbs, infinite planes, projection carving, projection colouring, surface of revolution, and texture map capture. These techniques can be used to create and capture the geometry of outdoor shapes using a mobile AR system with real-time verification and iterative refinement. To provide an interface for these techniques, a novel AR user interface with cursors and menus was developed. This user interface is based around a pair of pinch gloves for command input, and the use of a custom developed vision tracking system for use in a mobile environment. To develop applications implementing these contributions, a new software architecture was designed to provide a suitable abstraction to make development easier. This architecture is based on an object-oriented data flow approach, uses a special file system notation object repository, and supports distributed objects. The software requires a platform to execute on, and so a custom wearable hardware platform was developed. The hardware is based around a backpack that contains all the equipment required, and uses a novel flexible design that supports simple reconfiguration.

Based on these contributions, a number of modelling applications were developed to demonstrate the usefulness of these techniques. These modelling applications allow users to walk around freely outside, and use proprioception and interactions with the hands to control the task. Construction at a distance allows the user to model objects such as buildings, trees, automobiles, and ground features with minimal effort in real-time, and at any scale and distance beyond the user's reach. These applications have been demonstrated in the field to verify that the techniques can perform as claimed in the dissertation.

Declaration

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university and that to the best of knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text.

_____

Wayne Piekarski

Adelaide, February 2004

_____

Dr Bruce Thomas – Thesis Supervisor

Adelaide, February 2004

Acknowledgements

A dissertation does not just appear out of nowhere, and although it is supposed to be a contribution by one person for a PhD, there are still a lot of people who have helped me out over the years. I have been fortunate enough to have had the support of so many people and without it this would not have been possible. While most people did not help directly on the project, every one of them contributed in some way towards helping me to get where I am today, even things like just being a friend and going out and having fun. Others were responsible for giving me a push in the right direction in life, and for everyone listed here I am eternally grateful for their help.

Firstly there is the Wearable Computer Lab crew. Although I initially started in the lab alone, over the years we have grown to being a major lab at the university, and I have worked with a number of people - Ben Close, Hannah Slay, Aaron Toney, Ben Avery, Ross Smith, Peter Hutterer, Matthias Bauer, Pierre Malbezin, Barrie Mulley, Matthew Schultz, Scott Sheridan, Leonard Teo, John Squires, John Donoghue, Phil DeBondi, and Dan Makovec. Many of us have spent many countless late nights working on projects to meet deadlines and the spirit of our team is truly awesome.

In the CIS department I also have a number of friends apart from those in the WCL who I go to lunch with almost every day, and I also enjoy spending time with them outside of work hours - Grant Wigley, Greg Warner, Malcolm Bowes, Stewart Itzstein, and Toby Richer. I would especially like to thank Grant for his friendship during the PhD program, as we both started at the same time and have helped each other out considerably. On behalf of the lunch crew I would also like to express gratitude to the Brahma Lodge Hotel, for serving up copious amounts of the finest cheesy potatoes on the planet to fuel our lunch time cravings.

In the CIS department I have worked with three heads of school over the years and each have supported me in my endeavours - Andy Koronios, Brenton Dansie, and David Kearney. With their financial and leadership contributions I have been given the resources I need to complete this PhD and also help to develop the WCL into what it is today.

Staff members in the CIS department have also been extremely helpful. The numerous general staff performed the many tasks that are required to keep the department running each day, and were always very happy to help out when required. They helped to organise my teaching trips, the ordering of equipment, and dealing with finances. Greg Warner and Malcolm Bowes ran the department servers and allowed us to perform unorthodox computer networking in the lab. Frank Fursenko and Tony Sobey also discussed with me C++ and

graphics programming on a number of occasions. Millist Vincent assisted by proofreading parts of the thesis and provided technical comments.

The DSTO Land Operations Division with Victor Demczuk and Franco Principe were initially responsible for donating various wearable computers and resources to the department. This was used to start the initial projects in the WCL and would not have existed without them. The Information Technology Division at DSTO has also been instrumental in further research work we have done, giving us a number of large grants for equipment as well as the design of our new backpack. I would especially like to thank Rudi Vernik for his vision in granting this funding to the WCL and it has helped to make our research first class work. The SES group with John Wilson, Paul Zalkauskas, Chris Weckert, and Barry Crook, led by Peter Evdokiou, have to be the finest and most professional group of engineers I have ever met. Together they manufactured the Tinmith-Endeavour backpack design which dazzles people at conferences all over the world.

When I was still growing up in 1993, I had the fortune of using an Internet dial up service run by Mark Newton. He introduced me to the one true operating system Unix, and all its amazing features. I used his machine to learn how to use Unix and the fledgling Internet, and through this I met a number of other people in the area. The late Chris Wood took the time to teach me how to write Makefiles, use Emacs (the one true editor), and how to correct bugs in my first X11 application. These contributions helped to steer my professional development toward Unix development which would come into much use at university. The Linux community has also supported me by inviting me to speak at most of their conferences, allowing me to teach audiences about my research work and to learn from others. The developers who donated their time to the development of drivers for the hardware I use have been most helpful, without these this project would not have been possible.

When I was just starting at university I was fortunate enough to meet Steve Baxter. He had just started up an Internet company called SE Net along with his wife Emily Baxter and friend Chris Foote, and asked me to work as the first employee of the company helping with sales and support. As the company grew I was given the role of Manager of R&D, and given the task of developing the systems that controlled the entire company. Steve trusted in my abilities the future of his entire company. This enabled me to gain a wealth of experience in leadership and design that would never be given to most 18 year olds, and for this I am very grateful. Together we built a company that led the field in a number of areas. As part of the team at SE Net, I have many friends - Matt Altus, David Kuzmak, Richard and Genni Kaye, Robert Gulley, Andrew Xenides, Rebecca Razzano, Lindsay Whitbread, Megan Hehir, Mark

Mills, and Scott Smith. Unfortunately SE Net has now been absorbed by the new owners of the company, and so the fine traditions and spirit from SE Net are no longer around, but exist in our memories forever.

During my travels overseas I have met a number of great people who have been friendly and helpful. I would like to especially thank the Computer Science department at the University of North Carolina at Chapel Hill for allowing me to spend three months performing research there. Sally Stearns and Ray Thomas were kind enough to let me stay at their house for the first few days while I found a place to stay. At UNC I made many friends such as Mark Harris, Scott Cooper, Ken Hoff, Benjamin Lok, Samir Nayak, David Marshburn, Andrew Nashel, and Stefan Sain, as well as the Pi Lambda Phi fraternity and Drink Club crew.

There are also a number of other people who do not work with me but have been friends for many years and I would also like to thank them for their support - David Pridgeon, Trent Greenland, Ghassan Abi Mosleh, Rebecca Brereton, Donna Harvey, Krishianthi Karunarathna, Josie Brenko, Tam Nguyen, Sarah Bolderoff, and Derek Munneke.

The most instrumental person for this dissertation was my supervisor Dr Bruce Thomas. I have worked with Bruce for the last five years first as a final year undergraduate project student, and then as a PhD student. Bruce had the insight to move into wearable computers and augmented reality in the very early days and formed the Wearable Computer Lab we have today. Bruce has helped me to gain an international profile in the AR and wearables community, by generously giving me the funding to travel to numerous places all over the world and to meet other researchers (and obtain a frequent flyer gold card). This international development has strengthened my PhD with experience from a wide range of people and further motivated my research with fresh ideas. I would also like to thank Bruce for the countless hours I have spent with him discussing research, proof reading papers and this dissertation, talking about life in general, and having a beer as friends when travelling.

To achieve a PhD at the University of South Australia, the dissertation must be reviewed by two external experts in the area of research. I was fortunate enough to have Professor Steven Feiner from Columbia University and Associate Professor Mark Billinghurst from HIT Lab New Zealand as reviewers, who are both outstanding researchers in the international community. Each of them carefully read through the hundreds of pages of this dissertation and gave me excellent feedback which has been integrated into this final version. I would like to thank both of them for their time and dedication to reviewing my work and helping to improve it.

Most importantly of all, I would like to thank my mum Kris, dad Spishek, brother Arron, and my grandparents for supporting me for the last 25 years. My family also helped me build some of the early backpack prototypes in the garage, making an important contribution to the project. It is through their encouragement and care that I have made it through all the steps to reach this point in life, and I couldn't have done it without them. When my dad bought me a Commodore 64 when I was a little boy, who would have thought I would have ended up here today? My family has always taken care of me and I love them all very much.

In summary, I would like to thank everyone for putting up with me for the last couple of years. I believe that this dissertation has made a real contribution to the field of computer science and I hope that everyone that reads this dissertation finds it useful in their work. It has been a fun journey so far, and I look forward to catching up with everyone and having lots of fun and good times, because that is the most important thing of all.

Now it is time to catch up on some sleep and have a holiday! (Well, not really - there is still plenty of other work to do now)

Regards,

_____

Wayne Piekarski

Adelaide, February 2004

Inspiration

"Another noteworthy characteristic of this manual is that it doesn't always tell the truth ... The author feels that this technique of deliberate lying will actually make it easier for you to learn the ideas. Once you understand the simple but false rule, it will not be hard to supplement that rule with its exceptions."

Donald Knuth, from the preface to The TeXbook

"If you do choose to use a computer, beware the temptation it offers to let manuscript preparation displace composition. They are two separate activities, best done separately. Hyphenation and exposition are at war with one another. Pagination vies with content. The mind busy fretting over point size has no time left over to consider clarity. If you need a break from the ardors of composition, try the time-honored ones like poking the fire or baking bread. They smell good, and they don't give you any illusion that your paper is making progress while you indulge in them."

Mary-Claire van Leunen