UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

META PLATFORMS, INC.,
Petitioner,

v.

MULLEN INDUSTRIES LLC,
Patent Owner.

Case IPR2025-00737
Patent 8,585,476 B2
Issue Date: November 19, 2013

Title: LOCATION-BASED GAMES AND AUGMENTED REALITY SYSTEMS

DECLARATION OF INGRID HSIEH-YEE, PH.D.

I. INTRODUCTION AND QUALIFICATIONS 4
A. Qualifications and Professional Experience 4
II. BACKGROUND OF LIBRARY CATALOGING....5
A. Machine-Readable Cataloging ("MARC")....5
B. Library Online Catalogs....8
C. Scope of this Declaration 12
D. Evidence Considered in Forming My Opinion....15
III. AUTHENTICITY AND PUBLIC AVAILABILITY OF *PIEKARSKI 1999* (EX1004) 15
A. Authentication 15
B. Records of Linda Hall Library 17
C. MARC Record of Brown University Library 20
D. Copyright Registration Record....22
E. IEEE Metadata Record 23
F. Webpage of "tinmith research papers"....26
G. Usage Records 28
H. Summary of My Opinion on *Piekarski 1999*....28
IV. AUTHENTICATION AND PUBLIC AVAILABILITY OF *PIEKARSKI 2001* (EX1009) 30
A. Authentication 30
B. Internet Archive Records 32
C. Usage Records 34
D. Summary of My Opinion on *Piekarski 2001*....34
V. AUTHENTICITY AND PUBLIC AVAILABILITY OF *MILGRAM* (EX1010) 35
A. Authentication 35
B. Records of Linda Hall Library 36
C. Usage Records 40
D. Summary of My Opinion on *Milgram*....40

VI. AUTHENTICATION AND PUBLIC AVAILABILITY OF *ROLLAND* (EX1013) 41
A. Authentication 41
B. Records of Linda Hall Library 43
C. Copyright Registration Record 47
D. Usage Records 48
E. Summary of My Opinion on *Rolland* 48
VII. AUTHENTICITY AND PUBLIC AVAILABILITY OF *STRATTON* (EX1014) 49
A. Authentication 49
B. Record of Library of Congress 51
C. Internet Archive Record 54
D. Summary of My Opinion on *Stratton* 55
VIII. CONCLUSION 56

I, Ingrid Hsieh-Yee, declare as follows:

I. INTRODUCTION AND QUALIFICATIONS

1. I am over the age of eighteen and otherwise competent to make this declaration.

2. I have been retained by counsel for Petitioner to provide my expert opinion in connection with the above-captioned proceeding ("IPR") regarding the public availability of a certain prior art references in relation to U.S. Patent No. 8,585,476 B2 ("Challenged Patent").

3. I am being compensated for my time in connection with this IPR at my current consulting rate. I am also being reimbursed for any reasonable expenses associated with my work and testimony in this investigation. My compensation is not contingent on the results of my study, the substance of my opinions, or the outcome of this matter.

A. Qualifications and Professional Experience

4. My complete qualifications and professional experience are described in my academic curriculum vitae (**Appendix A**). The following is a brief summary of my relevant qualifications and professional experience.

5. I was a professor in the Department of Library and Information Science at the Catholic University of America for 32 years and was conferred the title of Professor Emerita in December 2022. I have experience working in an academic

library, a medical library, and a legislative library. I hold a Ph.D. and a Masters in Library and Information Studies from the University of Wisconsin-Madison.

6. I am an expert on library cataloging and classification and have published two editions on this subject, *Organizing Audiovisual and Electronic Resources for Access: A Cataloging Guide* (2000 and 2006). I taught a variety of courses, including Cataloging and Classification, Advanced Cataloging and Classification, Organization of Internet Resources, Organization of Information, Metadata, Digital Content Creation and Management, Internet Searches and Web Design, Information Literacy Instruction, Advanced Information Retrieval and Analysis Strategies, and The Information Professions in Society. I am familiar with metadata schema design and implementation. In my teaching, I covered the design and implementation of metadata in databases, search engines, digital repositories, digital libraries, and digital archives. I also covered how information organization affects the discovery and access to digital resources on the Internet. My research interests cover cataloging and classification, information organization, metadata, information retrieval, information architecture, digital collections, scholarly communication, social media, user interaction with information systems, and others

II. BACKGROUND OF LIBRARY CATALOGING

A. Machine-Readable Cataloging ("MARC")

7. I am very familiar with a library cataloging encoding standard known

as the "Machine-Readable Cataloging" standard, also known as "MARC," which became the national standard for sharing bibliographic data in the United States by 1971 and the international standard by 1973. MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries. Experts in my field reasonably rely upon MARC records when forming their opinions.

8. A MARC record consists of several fields, each of which contains specific data about the work. Each field is identified by a standardized, unique, three-digit code corresponding to the type of data that follows. **Appendix B** is a true and correct copy of Parts VII to X of "Understanding MARC Bibliographic: Machine-Readable Cataloging" (https://www.loc.gov/marc/umb/um07to10.html), a brief description and tutorial published by the Library of Congress in 2009 that explains commonly used MARC fields. For example, the personal author of a work is recorded in Field 100, the title is recorded in Field 245, publisher information is recorded in Field 260, the physical volume and characteristics of a publication are recorded in Field 300, and topical subjects are recorded in Fields 650. More details of MARC21 format for Bibliographic Data are available on the Library of Congress website at https://www.loc.gov/marc/bibliographic/.

9. I am very familiar with library cataloging and processing practices and the relationships between OCLC (Online Computer Library Center) and library catalogs, and how libraries create and share their records to help the public discover

and access information.

10. OCLC is the largest bibliographic network of the world, and its WorldCat database contains more than 559 million records from thousands of member institutions (many of which are libraries of some type) in more than 100 countries. OCLC was founded in 1967 to promote and support library cooperation. According to the third article of the "Amended Articles of Incorporation of OCLC [Online Computer Library Center], Inc.," OCLC was created "to establish, maintain, and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary, and educational knowledge and information" (source: https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf).

11. OCLC members can contribute original cataloging records in MARC to the system or derive cataloging records from existing records, an activity referred to as "copy cataloging." When an OCLC participating institution acquires a work, it can create an original MARC record for the work in OCLC's Connexion system (a system for catalogers to create and share MARC records), and the system will

automatically generate a code for the date of record creation in the yymmdd format, and the creating library's OCLC symbol is recorded in subfield "a" of the 040 field. Once the MARC record is in Connexion, it becomes available to other OCLC members for adoption to their local online catalogs (*i.e.*, copy cataloging).

12. After a MARC record is created in Connexion, it also becomes searchable and viewable on WorldCat.org, which is a free web portal for users to explore more than 10,000 libraries worldwide. Records in WorldCat.org, however, are not presented in MARC fields. Instead, the data elements are labeled to help users interpret the records. Thus, the information stored in MARC records in Connexion is available to the interested public through the user-friendly WorldCat web portal. WorldCat records can also be searched on OCLC FirstSearch, a subscription-based search system that provides access to many proprietary databases, including the WorldCat database.

B. Library Online Catalogs

13. Library online catalogs gained acceptance in the early 1980s and many libraries migrated their systems to the World Wide Web in the mid-1990s. Library online catalogs are based on MARC records that represent their collections in order to help the public understand what materials are publicly accessible in those libraries. Most libraries with online catalogs have made their catalogs freely available on the Web. These online catalogs offer user-friendly search interfaces. Strong user interest

in keyword searches and the popularity of Google have led to the "googlization" of library search systems. As a result, many library catalogs nowadays provide a single search box for users to conduct keyword searches, with additional support for searches by author, title, subject terms, and other data elements such as ISBN (International Standard Book Number). Library catalogs these days also offer features for users to narrow their search results by language, year, format, and other elements. Many libraries display MARC records on their online catalogs with labels for the data elements to help the public interpret MARC records. Many libraries also offer the option to display MARC records in MARC fields.

14. Libraries create MARC records for works they acquire, including books, serials, motion pictures, and publications in other formats. Monograph cataloging is fairly common in libraries, and most libraries make a newly cataloged monograph available to the public soon after the cataloging work is completed, usually within a week. Libraries can create original cataloging records or use an existing record in the OCLC WorldCat database to create a copy cataloging record. As soon as the cataloging record is completed, it is added to the library's online catalog for users. If the record is an original record, it is also entered into the OCLC system. If it is a copy cataloging record, the library's holding symbol is attached to the existing original record in the OCLC system to facilitate searching and interlibrary loan.

15. The cataloging of serials and the serial check-in process are discussed here to show how libraries usually provide access to newly received serial issues. According to the glossary of the *RDA: Resource Description and Access* cataloging standard, a serial is "a mode of issuance of a manifestation issued in successive parts, usually bearing numbering, that has no predetermined conclusion. A serial includes a periodical, monographic series, newspaper, etc." (RDA Glossary at https://original.rdatoolkit.org/rdagloss_rdaregistry.info-termList-ModeIssue-1003_1.html (subscription required for access); cited in https://www.ccslib.org/Catalogers/index.php/Category:Serials). Because the publisher of a serial makes new issues of the serial available successively, a customary cataloging practice is to create one bibliographic record for the serial, and the serial record (encoded in MARC) typically provides information on the beginning date and frequency of the serial, not the dates of individual issues. In other words, libraries typically do not create MARC records for individual issues of a serial. Instead, they rely on a serial check-in system to track the receipt of new issues. A common check-in practice is to date stamp a new issue when it arrives. This practice has become automated since the late 1990s, and libraries now vary in how they share the receipt date of a new serial issue with the public. Some libraries use a date stamp, some affix a label to indicate the receipt date, some pencil in the receipt date, and some do not provide the information to the public.

16. The serial check-in process usually takes less than an hour, and one of the steps involves placing a date stamp on the new issue to document the date the issue is checked in. After that, the holdings information of the serial is updated in the library's catalog so that users know which issues are available for request or access. After serial check-in is completed, the new issue is placed on the shelf with the previous issues of the serial. Libraries with a public periodical room typically place new issues in the periodical room for easy user access. Because information presented in serials often reflects latest discovery, a general practice of libraries is to make new issues of serials available for user access soon after they are checked in, usually within a week.

17. I am personally familiar with many online catalogs, databases, and search engines. In preparing for this declaration, I used the following authoritative information systems to search for records:

- Google Scholar (https://scholar.google.com/)
- Internet Archive (https://archive.org/)
- Libraries.org, a directory of libraries throughout the world (https://librarytechnology.org/libraries/)
- Online catalog of the Brown University Library (https://library.brown.edu/catalogs/)
- Online catalog of the Library of Congress (https://catalog.loc.gov/)

- Online catalog of the Linda Hall Library (https://catalog.lindahall.org/discovery/search?vid=01LINDAHALL_INST:LHL)
- Public catalog of the US Copyright Office (https://cocatalog.loc.gov/cgi-bin/Pwebrecon.cgi?DB=local&PAGE=First)
- WorldCat.org (https://search.worldcat.org/)

C. Scope of this Declaration

18. I have been asked to offer an opinion on the public availability dateS of the following documents:

- Piekarski, W., Gunther, B., & Thomas, B. (1999, October). Integrating virtual and augmented realities in an outdoor application, in *Proceedings 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99)*, pp. 45-54, **EX1004** ("*Piekarski 1999*");
- Piekarski, W., & Thomas, B. (2001, January). Augmented reality with wearable computers running Linux, in 2nd Australian Linux Conference (Sydney), 14 unnumbered pages, **EX1009** ("*Piekarski 2001*");
- Milgram, P., & Kishino, F. (1994, December). A taxonomy of mixed reality visual displays, *IEICE Transactions on Information and Systems*, Vol. E77-D, No. 12, 1321-1329, **EX1010** ("*Milgram*");

- Rolland, J. P., Holloway, R. L., & Fuchs, H. (1995, December). Comparison of optical and video see-through, head-mounted displays, in *Telemanipulator and Telepresence Technologies : 31 October-1 November 1994, Boston, Massachusetts*, Proceedings of SPIE vol. 2351, pp. 293-307, **EX1013** ("*Rolland*"); and
- Excerpts of *The Legend of Zelda : A Link to the Past : Prima's Official Strategy Guide* by Bryan Stratton and Stephen Stratton (2002), obtained from the Library of Congress, **EX1014** ("*Stratton*").

19. I am informed by counsel and. Understand that a given reference is "published" upon a satisfactory showing that such a document has been disseminated or otherwise made publicly available to the extent that persons interested and ordinarily skilled in the subject matter or art could locate it exercising reasonable diligence and obtain the document. I have also been informed by counsel and understand that materials available in a library constitute "printed publications" if they are catalogued and indexed according to general library practices and protocols that make the references available and accessible to members of the interested public.

20. I have been informed by counsel that the Challenged Patent claims November 16, 2004, as its earliest priority date. I have assessed public accessibility of the documents referenced below as of this claimed priority date.

21. I have been informed by counsel that the subject matter of this

proceeding generally relates to virtual and augmented reality computing systems.

22. I have been informed by counsel that a "person of ordinary skill in the art at the time of the invention" (POSA) is a hypothetical person who is presumed to be familiar with the relevant field and its literature at the time of the inventions. I have been informed by counsel that this hypothetical person is also a person of ordinary creativity, capable of understanding the scientific principles and literature applicable to the pertinent field.

23. I have been informed by counsel that a person of ordinary skill in the art as of November 16, 2004, would have knowledge of the scientific literature and have skills relating to virtual and augmented reality computing systems. A person of ordinary skill would have possessed a bachelor's degree in electrical engineering, computer science, or similar field, with two years combined experience in designing and/or developing interactive location-based computer systems/software, such as video games or other simulations incorporating location information (such as GPS information associated with a user's physical location), and in designing and/or developing computer systems/software involving graphical virtual and/or augmented reality. A person could also have qualified as a person of ordinary skill in the art with some combination of (1) more formal education (such as a master's of science degree) and less technical experience, or (2) less formal education and more technical or professional experience.

24. It is my opinion that such a person would have been actively engaged in learning about the field, possibly through formal instruction and through bibliographic resources. By at least November 16, 2004, such a person would have had access to a vast array of print and electronic resources, including at least the documents referenced below.

D. Evidence Considered in Forming My Opinion

25. In the preparation of this declaration, I have reviewed **EX1004**, **EX1009**, **EX1010**, **EX1013**, and **EX1014** referenced in paragraph 18 above, and any other documents I reference herein. Each of these is a type of material that experts in my field would reasonably rely upon when forming their opinions. I provided a further description of materials I considered in **Appendix C**.

III. Authenticity and Public Availability of *Piekarski 1999* (EX1004)

A. Authentication

26. **Exhibit 1004** is a true and correct copy of "Integrating virtual and augmented realities in an outdoor application," ("*Piekarski 1999*"), by W. Piekarski, B. Gunther, and B. Thomas, in *Proceedings 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99)*, pp. 45-54, that I obtained from the Linda Hall Library. This copy is presented as **EX1004** in this declaration.

27. Page 1 is the cover that shows the conference name, dates, location, sponsors, and publisher. Page 2 is the title page that shows the same information as

the cover and also shows the names of four sponsors, and the location of the publisher. Page 3 is the copyright page that shows a "1999" copyright date and The Institute of Electrical and Electronics Engineers, Inc. as the copyright holder. The top of the page shows a hand-written call number of "T385 .I48 1999." This page shows "PRO0359" as the IEEE Computer Society order number for this work, "99-64284" as the Library of Congress Catalog Number for the library record for this work, and "0-7659-0359-4" and "0-7659-0361-6" (for microfiche) as the ISBNs (International Standard Book Numbers). Page 4 (internal page v) is the table of contents that carries a library stamp and shows *Piekarski 1999* is in "Session 2: Mobility + Displays" and begins on internal page 45. The left side of this page shows a date annotation of "12-8-99" (*i.e.*, December 8, 1999) that indicates the Linda Hall Library added this work to their collections on this date. The knowledge of this date annotation practice is based on my personal knowledge and experience with the Linda Hall Library and its collections. Pages 6 to 15 are the full text of this article. **EX1004** shows *Piekarski 1999* has a total of ten pages, including eight figures and 18 references.

28. To authenticate **EX1004**, I located a metadata record for *Piekarski 1999* from IEEE Xplore at https://ieeexplore.ieee.org/abstract/document/803805 and used it to obtain a PDF of this article. This IEEE copy is presented as **EX1004A** in this declaration. **EX1004A** shows this article has a total of ten pages, including eight figures and 18 references. I have closely compared the Linda Hall Library copy

(**EX1004**) with the IEEE copy (**EX1004A**), and found them to contain the same content for *Piekarski 1999*.

29. **EX1004** is in a condition that raises no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, and there are no visible alterations to the document. Furthermore, this library copy has the same content as the IEEE copy (**EX1004A**) and is held by a well-known public research library. Based on my review and analysis, it is my opinion that **EX1004** is authentic.

B. Records of Linda Hall Library

30. To determine the public availability date of *IWAR'99* that contains *Piekarski 1999* at libraries, I obtained records for this work from the online catalog of the Linda Hall Library. **EX1004B** is a true and correct copy of the bibliographic and MARC records for this work. I personally located, identified, and obtained these records. They are the type of records experts in my field would reasonably rely upon when forming their opinions.

31. Pages 1 to 3 of **EX1004B** are the bibliographic record and Page 4 is a copy of the MARC record. Page 1 shows "conference proceeding" is the format of this work, and it is cataloged as a book and available at "Linda Hall Library Books – 2nd Floor (T385 .I48 1999)." The record details include the title, subtitles, a variant title ("IWAR'99"), two contributors, subjects, identifiers, publisher, creation date ("c1999"), physical description, and a note on bibliographic references and author

index. The title, variant title, contributors, two 10-digit ISBNs, and publisher information match the information presented in **EX1004**, confirming this record represents *IWAR'99* that contains *Piekarski 1999*.

32. Page 4 is a copy of the MARC record. The first six digits of Field 008 show the record was created on "991209" (*i.e.*, December 9, 1999). Subfields 'a" and "c" of Field 040 show "LHL" created the original record and entered it into the OCLC WorldCat database. According to the *Directory of OCLC Members* (https://www.oclc.org/en/contacts/libraries.html), "LHL" is the OCLC library symbol for the Linda Hall Library. Based on the data in Fields 008 and 040, it is my opinion that the Linda Hall Library created the original record for the conference proceedings containing *Piekarski 1999* on December 9, 1999, making this work discoverable in their online catalog from that date on. A customary library practice is to process a newly cataloged monograph promptly for public access, usually within a week after the cataloging work is completed. It is therefore my opinion that, after processing, the physical copy of *IWAR'99* that contains *Piekarski 1999* became publicly accessible at the Linda Hall Library by December 16, 1999.

33. Field 010 shows the Library of Congress card number, Field 020 shows the 13-digit and 10-digit ISBNs, Field 111 shows the conference name, Field 245 shows the title, subtitles, and statement of responsibility, Field 246 shows a variant title, and Field 260 shows the publisher and copyright date. Field 504 shows a note

for bibliographic references and author index, and Field 710 shows the Task Force on Human-Centered Information Systems of the IEEE Computer Society is included to help users discover this work.

34. Interested users could also conduct subject searches to discover this conference proceedings, because the MARC record contains subject representations. Field 090 shows a Library of Congress Classification number ("T385") that represents "General works" on "Computer-assisted drafting. Computer graphics" (source: Library of Congress Classification Schedule T at https://www.loc.gov/aba/publications/FreeLCC/LCC_T2019TEXT.pdf), and Fields 650 show three Library of Congress subject headings, with "Computer graphics," "Virtual reality," and "Visualization" as the main topics, each followed by "Congresses" as a form subheading encoded in subfield "v" to indicate the main topics are treated at a conference.

35. The MARC record (**EX1004B**) shows that the Linda Hall Library created their original cataloging record for *IWAR'99* on December 9, 1999, making this work discoverable in their online catalog from that date on. As of that date, interested users could discover this work by the conference name, title, variant title, and sponsor. They could also conduct subject searches to discover this conference proceedings that contains *Piekarski 1999*.

36. As evidence that the Linda Hall Library had an online catalog in

operation in December 1999 when the library's MARC record for *IWAR'99* that contains *Piekarski 1999* was completed, I obtained a profile of the library at https://librarytechnology.org/library/2294 from libraries.org, a directory of libraries throughout the world. I personally located, identified, and obtained this profile. This is the type of record experts in my field would reasonably rely upon when forming their opinions. This profile is presented as **EX1004C** in this declaration.

37. The Technology Profile on page 2 of **EX1004C** shows the Linda Hall Library began using Horizon as their online catalog in 1994, and changed to Voyager in 2010. These dates mean that in December 1999 interested users were able to use the Horizon system to search for the conference proceedings containing *Piekarski 1999* and access this article at the Linda Hall Library.

C. MARC Record of Brown University Library

38. As further evidence that *IWAR'99* was publicly available in late 1999 and early 2000, I obtained the MARC record for this work from the Brown University Library. I personally located, identified, and obtained this record from the library's online catalog. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

39. **EX1004D** is a true and correct copy of the MARC record for *IWAR'99* that contains *Piekarski 1999*. The first six digits of Field 008 show the record was created on "991209" (*i.e.*, December 9, 1999). Subfields "a" and "c" of Field 040

show the record was created by "LHL" and subfield "d" shows "RBL" modified the record later. According to the *Directory of OCLC Members* (https://www.oclc.org/en/contacts/libraries.html), "LHL" is the OCLC library symbol for Linda Hall Library, and "RBL" is the OCLC library symbol for the Brown University Library. Field 005 is a machine-generated field that automatically record the last date the Brown University Library modified this record, and their last record modification date was "20000110093057" (*i.e.*, January 10, 2000, at 9 a.m., 30 minutes and 57 seconds). Record modification can be made for various reasons such as correcting typos and updating record encoding practice. The record modification date in Field 005 is usually the same or later than the record creation date in Field 008, because a record needs to be created before it can be modified. Fields 008, 040, and 005 inform my opinion that the Linda Hall Library created the original record on December 9, 1999, and the Brown University Library used the Linda Hall Library MARC record for copy cataloging and their copy cataloging record was last modified on January 10, 2000, meaning *IWAR'99* was discoverable in the online catalog of the Brown University Library by January 10, 2000.

40. Since **EX1004D** is a copy cataloging record based on the Linda Hall MARC record (**EX1004B**), it is logical that the two records have many data elements in common, including the Library of Congress card number (Field 010), ten-digit ISBNs (Fields 020), conference name (Field 111), title (Field 245), publisher and

copyright date (Field 260), physical description (Field 300), note on references and index (Field 504), and the first sponsor (Field 710). These two records also have the same subject representations in Field 090 and Fields 650. One difference is that Field 245 of the Brown University Library record begins with "Proceedings" while the Linda Hall Library record places "proceedings" in subfield "b" as a subtitle. The conference date, location, and name of the first sponsor are the same in both records. Another difference is the Brown University Library record includes six variant titles in Field 246 and includes the second and third sponsors in Field 710. These additional fields provide more data elements for interested users to discover *IWAR'99* at this library.

41. **EX1004D** informs my opinion that by January 10, 2000, interested users would be able to discover *IWAR'99* in the online catalog of the Brown University Library. They would be able to discover this work by the Library of Congress card number, the ISBNs, the conference name, title, variant titles, and three sponsors. They would also be able to conduct subject searches because of the Library of Congress Classification number in Field 090 and the Library of Congress subject headings in Fields 650 in their MARC record.

D. Copyright Registration Record

42. **EX1004E** is a true and correct copy of the copyright registration record for *IWAR'99* that contains *Piekarski 1999*. I personally located, identified, and

obtained this record from the public catalog of the US Copyright Office. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

43. The title, subtitles, other title, and copyright claimant match the information presented in **EX1004**, confirming this record represents *IWAR'99* that contains *Piekarski 1999*. The "Date of Publication" field shows this work was published on "1999-06-28" (*i.e.*, June 28, 1999). This date aligns well with the "12-8-99" date annotation in **EX1004** that shows the Linda hall Library added this work to their collections on December 8, 1999. The publication date also aligns well with the December 9, 1999 MARC record creation date at the Linda Hall Library, and with the January 10, 2000 copy cataloging record modification date at the Brown University Library.

E. IEEE Metadata Record

44. **EX1004F** is a true and correct copy of the metadata record for *Piekarski 1999* from IEEE Xplore, the IEEE Digital Library. I personally located, identified, and obtained this record from https://ieeexplore.ieee.org/abstract/document/803805. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

45. Page 1 shows the title, authors, publisher and abstract. It shows *Piekarski 1999* was published in "Proceedings 2nd IEEE and ACM International

Workshop on Augmented Reality (IWAR'99)" whose ISBN is "0-7695-0359-4" and the conference took place on "20-21 October 1999" in San Francisco, CA, USA. The "Date Added to IEEE Xplore" field shows this metadata record was added to the system on "06 August 2002." Since the general public can search IEEE Xplore free of charge, it is my opinion that *Piekarski 1999* became publicly discoverable in IEEE Xplore on August 6, 2002. Users affiliated with institutional subscribers to this system would be able to access the full paper from this record. Users without such affiliation could use the PDF link to purchase the article online from IEEE.

46. As evidence that IEEE Xplore was in operation in August 2002 when the metadata record for *Piekarski 1999* was added to the system, I obtained a copy of the system's website from Internet Archive. **EX1004G** is a true and correct copy of the website of IEEE Xplore. I personally located, identified, and obtained this record. It is the type of record experts in my field would reasonably rely upon when forming their opinions.

47. Internet Archive is a digital library that archives scholarly materials, cultural artifacts, and other web resources on the Internet and provides the public with free access to its collections. I have used the Internet Archive in the past and am familiar with their practice of assigning an extended URL to an archived resource in the format of http://www.archive.org/web/[Year in yyyy][Month in mm][Day in dd][Time code in hh:mm:ss]/[Archived URL] to show the point of time the archived

file was captured. Since Internet Archive usually does not archive web resources the moment they appear on the Internet, and a web resource must be available first before it can be archived, the archive date of a file captured by the Internet Archive is typically later than the date when the file first became publicly accessible. In other words, the archive date means the archived file was typically available before, and definitely no later than, the archive date.

48. Page 1 of **EX1004G** is a screen capture of a Wayback Machine calendar that shows the IEEE Xplore website (http://ieeexplore.ieee.org/lpdocs/epic03/) was archived 115 times between "7 Apr 2000" and "2 Dec 2024" and this particular copy was archived on "FEB 07 2001" and available at https://web.archive.org/web/20010207003457/http://ieeexplore.ieee.org/lpdocs/epic03/. Page 2 is the PDF of this archived copy that explains that "IEEE Xplore provides full-text access to IEEE transactions, journals, magazines and conference proceedings published since 1988 and all current IEEE standards." Under "Free to All," the archived copy shows the general public can have "[a]ccess to tables of contents of IEEE transactions, journals, magazines, conference proceedings and standards." The archived copy also explains that users affiliated with corporate, government and university subscribers "can search and access abstract/citation records, and full-text documents of the IEEE online publications to which" the institutions subscribe.

49. **EX1004G** informs my opinion that IEEE Xplore was available to the general public for searching since at least 2001, and individual subscribers and users affiliated with institutional subscribers have been able to access full text of documents freely. Non-subscribers have been able to purchase the full text of documents after they have identified abstract/citation records in IEEE Xplore.

F. Webpage of "tinmith research papers"

50. As evidence that *Piekarski 1999* is publicly available on the Internet, I obtained the webpage of "tinsmith research papers" and an archived of *Piekarski 1999* from Internet Archive. I personally located, identified, and obtained these copies. They are the type of material experts in my field would reasonably rely upon when forming their opinions.

51. **EX1004H** is a true and correct copy of the webpage of "tinsmith research papers" and a true and correct copy of *PieKarski 1999*. Page 1 is a screen capture of a Wayback Machine calendar that shows this webpage was archived 79 times between "9 Aug 2002" and "1 Mar 2025" and this particular copy was archived on "AUG 09 2002" and available at https://web.archive.org/web/20020809170822/http:/www.tinmith.net/research.htm. Pages 2 and 3 are the PDF version of this archived copy that includes a link to a paper presented at "IWAR99" and described as "our work with making Tinmith communicate using the DIS simulation protocol to collaborate with remote software."

This link leads to a copy of *Piekarski 1999*. The end of page 3 shows the archived webpage was last updated on "17 July 2002," which means the webpage was publicly available on the Internet on July 17, 2002, before the "AUG 09 2002" archive date of this archived webpage.

52. Page 4 shows a screen capture of a Wayback Machine calendar that shows *Piekarski 1999* was archived 26 times between "18 Jul 2003" and "23 Apr 2024" and this particular copy was archived on "JUL 18 2003" and available at https://web.archive.org/web/20030718234001/http://www.tinmith.net/papers/piekarski-iwar-1999.pdf. Pages 5 to 14 are the full text of *Piekarski 1999*. I have closely compared **EX1004** with this archived copy and found them to have the same content for *Piekarski 1999*. A difference between these two copies is that pages of the archived copy are not numbered and the first page shows a note "In IWAR 1999 – 2nd International Workshop on Augmented Reality October 20-21, 2001 – San Francisco, Ca, USA – Copyright © 1999 IEEE Please visit http://www.tinmith.net for more information." The "October 20-21, 2001" appears to be a typo because IWAR'99 took place from October 20 to 21 of 1999 in San Francisco, California. The archived copy does not include the ISBN of the conference proceedings containing *Piekarski 1999*, as shown in **EX1004**.

53. **EX1004H** informs my opinion that the webpage for "tinmith research papers" was publicly available on the Internet by July 17, 2002, and the webpage

includes a link to a copy of *Piekarski 1999* archived on July 18, 2003. As discussed earlier, Internet Archive usually does not archive web files as soon as they are posted, so the archive date of a web file does not mean the file becomes available on that date. Instead, the archive date shows the archived web file was available before, and definitely not after, the archive date. It is therefore my opinion that *Piekarski 1999* was publicly available on the Internet by July 17, 2002, if not earlier.

G. Usage Records

54. Actual usage of a publication is reflected by other publications that make reference to it. I have reviewed citations to *Piekarski 1999* on Google Scholar to compile a list of early citations. **EX1004I** presents five citations from 2000 that cited this article. **EX1004I** shows the earliest citation appeared in March 2000, supporting my opinion that this article was publicly accessible at the Linda Hall Library by December 16, 1999, and publicly discoverable at the Brown University Library by January 10, 2000.

H. Summary of My Opinion on *Piekarski 1999*

55. The copyright registration record for *IWAR'99* that contains *Piekarski 1999* (**EX1004E**) shows this work was published on June 28, 1999. The date annotation on **EX1004** shows Linda Hall Library added this work to their collections on December 8, 1999, and the MARC record (**EX1004B**) shows their cataloging record was completed on December 9, 1999, making this work discoverable in their

online catalog of the Linda Hall Library from that date on. The MARC record of the Brown University Library (**EX1004D**) shows *IWAR'99* became discoverable in their online catalog by January 10, 2000.

56. IEEE metadata record (**EX1004F**) shows *Piekarski 1999* became discoverable in IEEE Xplore on August 6, 2002, and interested users affiliated with institutions that subscribed to IEEE Xplore would be able to access the full text of this article from the record. Interested users not affiliated with institutional subscribers would be able to use the PDF link in the record to purchase this article online from IEEE.

57. The archived webpage of "tinsmith research papers" and the archived copy of *Piekarski 1999* (**EX1004H**) show that this webpage of articles was publicly discoverable by July 17, 2002, and interested users could use it to access *Piekarski 1999*. Citations published in 2000 (**EX1004I**) show the earliest citation to this article appeared in March 2000.

58. Based on the records and documents that I have reviewed and analyzed, it is my opinion that *IWAR'99* that contains *Piekarski 1999* was publicly discoverable at the Linda Hall Library on December 9, 1999, when the MARC record was created. The physical copy, after processing, would become publicly accessible by December 16, 1999. *IWAR'99* became discoverable at the Brown University Library by January 10, 2000. *Piekarski 1999* became discoverable and accessible on IEEE Xplore on

August 6, 2002. By July 17, 2002, interested users could discover the webpage for tinsmith research papers and followed the "IWAR99" link to access this article.

IV. AUTHENTICATION AND PUBLIC AVAILABILITY OF *PIEKARSKI 2001* (EX1009)

A. Authentication

59. **Exhibit 1009** is a true and correct copy of "Augmented reality with wearable computers running Linux," ("*Piekarski 2001*"), by W. Piekarski and B. Thomas, in *2nd Australian Linux Conference (Sydney)*, 14 unnumbered pages, that I obtained from the Internet Archive at https://web.archive.org/web/20030719115835/http://www.tinmith.net/papers/piekarski-linuxconf-2001.pdf. This copy is presented as **EX1009** in this declaration.

60. Pages 1 to 14 are the full text of *Piekarski 2001*. Page 1 shows the title, authors, and abstract, and the bottom of the page shows a note "In Linux Conf Au 2001 – 2nd Australian Linux Conference, January, 2001 – Sydney, NSW, Australia – Copyright ©2001 Linux Australia. Please visit http://www.tinmith.net for more information." The area above the article title shows "Tinmith evolution 5." Page 15 is a screen capture of a Wayback Machine calendar that shows this paper was archived 23 times between "19 Jul 2003" and "1 Jun 2023" and this particular copy was archived on July 19, 2003. **EX1009** shows this paper has a total of 14 unnumbered pages, including 14 numbered figures, five unnumbered figures, and 16 references.

61. To authenticate **EX1009**, I searched Google Scholar for copies of *Piekarski 2001* and found seven copies posted on various sites. I selected the CiteSeerX copy at https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=17b8a38955940 1112a3e826b9393c44588534bc7 for file comparison. CiteSeerX is a digital library and search engine for scientific literature in computer and information science established in 1997 and hosted at the College of Information Sciences and Technology of the Pennsylvania State University. The CiteSeerX copy is presented as **EX1009A** in this declaration.

62. **EX1009A** shows the full text of *Piekarski 2001*. Page 1 shows the title, authors, and abstract. The area above the article title shows "Tinmith evolution 5." The bottom of page 1 shows a note of "In Linux Conf Au 2001 – 2nd Australian Linux Conference, January, 2001 – Sydney, NSW, Australia – Copyright ©2001 Linux Australia. Please visit http://www.tinmith.net for more information." **EX1009A** shows this article has a total of 14 unnumbered pages, including 14 numbered figures, five unnumbered figures, and 16 references. I have closely compared **EX1009** with **EX1009A** and found them to be the same.

63. **EX1009** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, and there are no visible alterations to the document. Furthermore, the archived copy from

Internet Archive (**EX1009**) has the same content as the CiteSeerX copy (**EX1009A**).

B. Internet Archive Records

64. To determine when *Piekarski 2001* became publicly discoverable and accessible on the Internet, I obtained an archived copy of the webpage of "tinsmith research papers" from Internet Archive. I personally located, identified, and obtained this copy. It is the type of material experts in my field would reasonably rely upon when forming their opinions.

65. When I visited http://www.tinmith.net to learn more about the tinmith project, I discovered a webpage for reports and publications from the tinmith project at http://www.tinmith.net/research.htm. **EX1009B** is a true and correct copy of the webpage of "tinsmith research papers" archived by Internet Archive. Page 1 is a screen capture of a Wayback Machine calendar that shows this webpage was archived 79 times between "9 Aug 2002" and "1 Mar 2025" and this particular copy was archived on "AUG 09 2002" and available at https://web.archive.org/web/20020809170822/http:/www.tinmith.net/research.htm. Pages 2 and 3 are the PDF version of this archived copy that includes a link to a paper presented at "LINUX01" and described as "[a] very easy to understand paper describing the hardware used when constructing outdoor augmented reality systems, written for Linux Conf 2001." The LINUX01 link leads to a copy of *Piekarski 2001* archived by Internet Archive on July 19, 2003, which is presented as **EX1009** in this

declaration. The end of page 3 shows this webpage for "tinmith research papers" was last updated on "17 July, 2002." As discussed earlier, Internet Archive usually does not archive a web file as soon as the file appears on the Internet, meaning there is usually a time lag between the appearance of a web file and the archiving of that file by Internet Archive. The archive date of a web file archived by Internet Archive therefore means that the archived web file is publicly accessible before, and no later than, the archive date. In this case, the webpage for "tinmith research papers" was archived by Internet Archive on August 9, 2002, but the file was last updated on July 17, 2002. It is therefore my opinion that the webpage that contains a link to *Piekarski 2001* became publicly discoverable on the Internet by July 17, 2002. As of that date, interested users could discover the webpage and follow the link to access *Piekarski 2001*.

66. To show what interested users would experience in July 2003 when they followed the "LINUX01" link from page 2, I have included a screen capture as page 4 of **EX1009B**. This page shows a screen capture of a Wayback Machine calendar that shows *Piekarski 2001* was archived 23 times between "19 Jul 2003" and "1 Jun 2023" and this particular copy was archived on "JUL 19 2003" and available at https://web.archive.org/web/20030719115835/http://www.tinmith.net/papers/piekarski-linuxconf-2001.pdf. Although *Piekarski 2001* was not archived until July 19,

2003, it is my opinion that this archive date is not the first public availability date for this paper. Since the webpage for "Tinmith research papers" was last updated on July 17, 2002, it is my opinion that interested users could discover it by that date and follow the LINUX01 link to access *Piekarski 2001*.

C. Usage Records

67. Actual usage of a publication is reflected by other publications that make reference to it. I have reviewed citations to *Piekarski 2001* on Google Scholar to compile a list of citations. **EX1009C** presents four citations from 2002 to 2004. This list shows the earliest citation to *Piekarski 2001* appeared in December 2002, supporting my opinion that *Piekarski 2001* was publicly accessible on the Internet by July 17, 2002. Another citation appeared in January 2003, supporting my opinion that *Piekarski 2001* was publicly accessible definitely no later than July 19, 2003, when the paper was first archived by Internet Archive.

D. Summary of My Opinion on *Piekarski 2001*

68. The copy of *Piekarski 2001* archived by Internet Archive (**EX1009**) is authentic because it contains no signs to raise suspicion about its authenticity. In addition, this copy has the same content as the CiteSeerX (**EX1009A**).

69. A copy of the webpage of "tinmith research papers" archived by Internet Archive on August 9, 2002 (**EX1009B**) includes a link to *Piekarski 2001*, and this webpage was last updated on July 17, 2002. It is therefore my opinion that

Piekarski 2001 was publicly discoverable and accessible by July 17, 2002. Citation history (**EX1009C**) shows the earliest citations appeared in December 2002 and January 2003, supporting my opinion that *Piekarski 2001* was publicly accessible by July 17, 2002, and definitely no later than July 19, 2003, which is the date when Internet Archive first archived this paper.

V. Authenticity and Public Availability of *Milgram* (EX1010)

A. Authentication

70. **EX1010** is a true and correct copy of "A taxonomy of mixed reality visual displays," ("*Milgram*"), by P. Milgram and F. Kishino, *IEICE Transactions on Information and Systems*, Vol. E77-D, No. 12, 1321-1329, that I obtained from the Linda Hall Library. This library copy is presented as **EX1010** in this declaration.

71. Page 1 is the issue cover that shows the journal title, issue number ("VOL. E77-D, No. 12"), issue date ("December 1994"), and a library date stamp of "Linda Hall Library FEB 09 1995." Page 5 is the table of contents that shows this issue has a "1994" copyright date and The Institute of Electronics, Information and Communication Engineers holds the copyright. The table of contents shows this issue is "Special Issue on Networked Reality" and *Milgram* is one of the invited papers and begins on page 1321. Pages 7 to 15 (internal pages 1321 to 1329) are the full text of *Milgram*. **EX1010** shows *Milgram* has a total of nine pages, including five figures and 33 references.

72. To authenticate **EX1010**, I searched Google Scholar for records for this article, and an entry led me to the webpage for *Milgram* at https://globals.ieice.org/en_transactions/information/10.1587/e77-d_12_1321/_p in the IEICE Digital Library. I then followed the PDF link to obtain a copy of *Milgram*. **EX1010A** is a true and correct copy of *Milgram*. I have closely compared **EX1010** with this IEICE copy (**EX1010A**) and found them to have the same content for *Milgram*.

73. **EX1010** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, and there are no visible alterations to the document. Furthermore, the library copy of *Milgram* has the same content as the publisher's copy (**EX1010A)**. Based on my review and analysis, it is my opinion that **EX1010** is authentic.

B. Records of Linda Hall Library

74. To determine the public availability date of *Milgram* at libraries, I obtained records for *IEICE Transactions on Information and Systems* that contains *Milgram* from the online catalog of the Linda Hall Library. **EX1010B** is a true and correct copy of the bibliographic and MARC records for this journal. I personally located, identified, and obtained these records. They are the type of records experts in my field would reasonably rely upon when forming their opinions.

75. Pages 1 to 4 of **EX1010B** are the bibliographic serial record that shows

IEICE Transactions on Information and Systems began publication in 1992 and is available at "Linda Hall Library Closed Stacks – Serial." The record details on page 3 include the journal title, other titles, creator, subject, ISSN (International Standard Serial Number) of this journal ("0916-8532"), publisher, and publication frequency.

76. Page 5 is the MARC serial record. The first six digits of Field 008 show the MARC record was created on "920326" (*i.e.*, March 26, 1992), and the code of "c19929999" following the record creation date indicates this publication is a continuing resource that began publication in 1992 and has no end date of publication yet. Subfields "a" and "c" of Field 040 shows "COD" created the original record and entered it into the OCLC WorldCat database, and subfield "d" shows "LHL" modified the original record later. According to the *Directory of OCLC Members* (https://www.oclc.org/en/contacts/libraries.html), "COD" is the OCLC library symbol for the University of Colorado at Boulder, and "LHL" is the OCLC library symbol for the Linda Hall Library. Data from Fields 008 and 040 of the MARC record (**EX1010B**) inform my opinion that the Linda Hall Library used the original serial record created by the library of the University of Colorado at Boulder to create their copy cataloging record.

77. As discussed earlier, libraries usually catalog a serial by creating one record for the entire serial without creating records for individual journal issues. To document the receipt of individual journal issues, libraries usually place newly

received issues through the serial check-in process. The date stamp of "FEB 09 1995" on **EX1010** shows that the Linda Hall Library received the journal issue containing *Milgram* on February 9, 1995. It is therefore my opinion that the copy cataloging record for *IEICE Transactions on Information and Systems* became discoverable at library's catalog by at least February 9, 1995, if not earlier. A customary library practice is to process a new journal issue promptly for public access after it has completed the serial check-in process, usually within a week. It is therefore my opinion that the journal issue containing *Milgram*, after processing, would become publicly accessible at the Linda Hall Library by February 16, 1995.

78. Field 022 of the MARC record shows the ISSN of this journal, Field 245 shows the journal title, and Fields 246 show three variant titles are included to help users discover this journal. Field 260 shows the publisher and publication date. Field 362 shows the journal began with "Vol. E75-D, no. 1" in January 1992, and Field 310 shows the journal has been published "Bimonthly." Field 710 shows the publisher is included in the record.

79. The subject of this journal is represented in Field 650 by a Library of Congress subject heading, using "Information technology" as the main topic, followed by "Periodicals" as a form subheading encoded in subfield "v" ("|v") to indicate the main topic is treated in a journal. The original serial record created by the library of the University of Colorado at Boulder includes a Library of Congress

Classification number in Field 050, but that number is not used at the Linda Hall Library, because this library organizes its journals by journal title. Nevertheless, Field 650 shows interested users could conduct subject searches to discover this journal.

80. This MARC record (**EX1010B**) shows that the Linda Hall Library created a copy cataloging serial record for *IEICE Transactions on Information and Systems*, and **EX1010** shows the library received the journal issue containing *Milgram* on February 9, 1995, meaning this journal was discoverable at this library by at least that date. As of February 9, 1995, interested users could search for this journal by its ISSN, title, variant titles, and publisher. They would also be able to conduct subject searches to discover this journal. The physical copy of the issue containing *Milgram* would become publicly accessible by February 16, 1995 at this library.

81. As evidence that the Linda Hall Library had an online catalog in operation in 1995 when the library received the journal issue containing *Milgram* on February 9, 1995, I obtained a profile of the library at https://librarytechnology.org/library/2294 from libraries.org, a directory of libraries throughout the world. I personally located, identified, and obtained this profile. This is the type of record experts in my field would reasonably rely upon when forming their opinions. This profile is presented as **EX1010C** in this declaration.

82. The Technology Profile on page 2 of **EX1010C** shows that the Linda

Hall Library began using Horizon as their online catalog in 1994, and changed to Voyager in 2010. These dates mean that in 1995 interested users were able to use the Horizon system to search for the journal that contains *Milgram* and access this article at the Linda Hall Library.

C. Usage Records

83. Actual usage of a publication is reflected by other publications that make reference to it. I have reviewed citations to *Milgram* on Google Scholar to compile a list of early citations. **EX1010D** presents five citations from 1996 to 1998. It shows the earliest citation to *Milgram* is an IEEE article published in May 1996.

D. Summary of My Opinion on *Milgram*

84. The Linda Hall Library copy of *Milgram* (**EX1010**) is authentic because it contains no signs to raise suspicion about its authenticity. In addition, this library copy has the same content for *Milgram* as the publisher copy (**EX1010A**).

85. The date stamp on **EX1010** shows the Linda Hall Library received the journal issue containing *Milgram* on February 9, 1995. It is therefore my opinion that the physical copy of this journal issue, after processing, would become publicly available at this library by February 16, 1995. The MARC record for *IEICE Transactions on Information and System* from the Linda Hall Library (**EX1010B**) shows the library's serial record is a copy cataloging record. The date stamp on **EX1010** means that this journal would be discoverable in the library's online catalog

by at least February 9, 1995, if not earlier. Interested users would be able to discover this journal by its ISSN, title, variant titles, publisher, and subject heading. Citation history (**EX1010D**) shows the earliest citation to *Milgram* was published in May 1996.

86. Based on the records and documents I have reviewed and analyzed, it is my opinion that *IEICE Transactions on Information and Systems* was publicly discoverable at the Linda Hall Library by February 9, 1995, and the physical copy of the journal issue containing *Milgram*, after processing, would become publicly available at this library by February 16, 1995.

VI. Authentication and Public Availability of *Rolland* (EX1013)

A. Authentication

87. **Exhibit 1013** is a true and correct copy of "Comparison of optical and video see-through, head-mounted displays," ("*Rolland*"), by Rolland, Holloway, and Fuchs, in *Telemanipulator and Telepresence Technologies : 31 October-1 November 1994, Boston, Massachusetts*, Proceedings of SPIE vol. 2351, pp. 293-307, that I obtained from the Linda Hall Library. This copy is presented as **EX1013** in this declaration.

88. Page 1 is the cover that shows the conference name, conference chair and editor, and the date and location of the conference. The top of the page indicates this work is the proceedings of "SPIE – The International Society for Optical

Engineering" and the page identifies this work as "Volume 2351." Page 2 shows the same information as the cover, and indicates "SPIE – The International Society for Optical Engineering" sponsored and published this work, and "IEEE NCC – Virtual Reality Technical Committee" is a cooperating organization. Page 3 is the copyright page that shows this work has a "1994" copyright date and SPIE holds the copyright. It also shows the ISBN (International Standard Book Number) of this work is "0-8194-1686-X" and the Library of Congress Catalog Card No. for this work is "94-67548." The top of the page shows a hand-written call number of "TJ210.3 .T442 1994." Pages 4 to 6 (internal pages iii to v) are the table of contents, and the left side of page 4 shows an annotation of "3-14-95" (*i.e.*, March 14, 1995), indicating the Linda Hall Library added this work to their collections on this date. The knowledge of this date annotation practice is based on my personal experience with the library and its collections. This page also shows a library stamp of the Linda Hall Library. Page 6 (internal page v) shows *Rolland* begins on page 293.

89. Pages 7 to 21 are the full text of *Rolland*. Page 7 (internal page 293) shows the title, authors, abstract, and keywords of this article. The bottom of the page shows this article appears in "SPIE Vol. 2315 Telemanipulator and Telepresence Technologies (1994)" whose ISBN is "0-8194-1686-X." **EX1013** shows *Rolland* has a total of 15 pages, including seven figures and 29 references.

90. To authenticate **EX1013**, I obtained a copy of *Rolland* from the

webpage for this article at https://www.spiedigitallibrary.org/conference-proceedings-of-spie/2351/0000/Comparison-of-optical-and-video-see-through-head-mounted-displays/10.1117/12.197322.short from the SPIE Digital Library. This SPIE copy is presented as **EX1013A** in this declaration. **EX1013A** shows this article has a total of 15 pages, including seven figures and 29 references. I have closely compared the library copy (**EX1013**) with the publisher copy (**EX1013A**), and found them to contain the same content for *Rolland*.

91. **EX1013** is in a condition that raises no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, and there are no visible alterations to the document. Furthermore, this library copy has the same content as the publisher copy (**EX1013A**) and is held by a well-known public research library. Based on my review and analysis, it is my opinion that **EX1013** is authentic.

B. Records of Linda Hall Library

92. To determine the public availability date of *Telemanipulator and Telepresence Technologies* (Proceedings of SPIE Vol. 2351) that contains *Rolland* in libraries, I obtained records for this work from the online catalog of the Linda Hall Library. **EX1013B** is a true and correct copy of the bibliographic and MARC records for this work. I personally located, identified, and obtained these records. They are the type of records experts in my field would reasonably rely upon when forming their opinions.

93. Pages 1 to 3 of **EX1013B** are the bibliographic record and Page 4 is a copy of the MARC record. Page 1 shows ”conference proceedings” is the format of this work, and it is cataloged as a book and is available at “Linda Hall Library Books – 2nd Floor (TJ210.3.T442 1994).” The record details includes the title, series title, personal and corporate contributors, subjects, ISBNs, series details, publisher, creation date (“c1994”), physical details, and a general note. The title, editor, associated organizations, publisher, the 10-digit ISBN, and series information match the information presented in **EX1013**, confirming this record represents *Telemanipulator and Telepresence Technologies* that contains *Rolland*.

94. Page 4 is a copy of the MARC record. The first six digits of Field 008 show the record was created on “950214” (*i.e.*, February 14, 1995), and the code of “s1994” following the record creation date shows this work has a single publication date of 1994. Subfields ‘a” and “c” of Field 040 show “RVE” created the original record and entered it into the OCLC WorldCat database, and subfield “d” shows “LHL” modified the original record later. According to the *Directory of OCLC Members* (https://www.oclc.org/en/contacts/libraries.html), “RVE” is the OCLC library symbol for the Rochester Institute of Technology Library, and “LHL” is the OCLC library symbol for Linda Hall Library. Based on the data in Fields 008 and 040, it is my opinion that the Rochester Institute of Technology Library created the original record for the conference proceedings containing *Rolland* on February 14,

1995, and Linda Hall Library used the original record to create their copy cataloging record. The date annotation in **EX1013** shows the library added the conference proceedings to their collections on March 14, 1995. It is therefore my opinion that the copy cataloging record for *Telemanipulator and Telepresence Technologies* that contains *Rolland* became discoverable in their online catalog on March 14, 1995. A customary library practice is to process a newly cataloged monograph promptly for public access, usually within a week after the cataloging work is completed. It is therefore my opinion that, after processing, the physical copy of *Telemanipulator and Telepresence Technologies* that contains *Rolland* became publicly accessible at the Linda Hall Library by March 21, 1995.

95. Field 010 shows the Library of Congress card number, Field 020 shows the 13-digit and 10-digit ISBNs, Field 245 shows the title, subtitle, and statement of responsibility, and Field 260 shows the publisher and copyright date. Field 490 shows the series information presented in the publication and Field 830 shows the authorized form of the series title and numbering. The editor is presented in Fields 700, and two sponsoring organizations are included in Fields 710. These fields show interested users could use these data elements to discover the conference proceedings containing *Rolland*.

96. Interested users could also conduct subject searches to discover this conference proceedings, because the MARC record contains subject representations.

Field 090 shows a Library of Congress Classification number ("TJ210.3") that represents "Congresses" on "Mechanical devices and figures. Automata. Ingenious mechanism. Robots (General)" (source: Library of Congress Classification Schedule T at https://www.loc.gov/aba/publications/FreeLCC/LCC_T2019TEXT.pdf), and Fields 650 show four Library of Congress subject headings, with "Manipulators (Mechanism)," "Robotics," "Remote control," and "Virtual reality" representing the main topics, each followed by "Congresses" as a form subheading encoded in subfield "v" to indicate the main topics are treated at a conference.

97. The date annotation in **EX1013** and the MARC record (**EX1013B**) show that the Linda Hall Library completed their copy cataloging record for *Telemanipulator and Telepresence Technologies* that contains *Rolland* on March 14, 1995, making this work discoverable in their online catalog from that date on. As of that date, interested users could discover this work by title, series, editor, and two sponsoring organizations. They could also conduct subject searches to discover this conference proceedings.

98. As evidence that the Linda Hall Library had an online catalog in operation in 1995 when the library added *Telemanipulator and Telepresence Technologies* that contains *Rolland* on March 14, 1995 to their collections, I obtained a profile of the library at https://librarytechnology.org/library/2294 from libraries.org, a directory of libraries throughout the world. I personally located,

identified, and obtained this profile. This is the type of record experts in my field would reasonably rely upon when forming their opinions. This profile is presented as **EX1013C** in this declaration.

99. The Technology Profile on page 2 of **EX1013C** shows the Linda Hall Library began using Horizon as their online catalog in 1994, and changed to Voyager in 2010. These dates mean that in 1995 interested users were able to use the Horizon system to search for the conference proceedings containing *Rolland* and access this article at the Linda Hall Library.

C. Copyright Registration Record

100. **EX1013D** is a true and correct copy of the copyright registration record for *Telemanipulator and Telepresence Technologies* that contains *Rolland*. I personally located, identified, and obtained this record from the public catalog of the US Copyright Office. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

101. The title, subtitle, editor, imprint, series title, and series numbering match the information presented in **EX1013**, confirming this record represents *Telemanipulator and Telepresence Technologies* that contains *Rolland*. The "Date of Publication" field shows this work was published on "1994-12-30" (*i.e.*, December 30, 1994), and the "Registration Number / Date" field shows this work was registered with the US Copyright Office on "1995-04-05" (*i.e.*, April 5, 1995). These dates align

well with the "3-14-95" date annotation in **EX1013** that shows the Linda hall Library added this work to their collections on that date.

D. Usage Records

102. Actual usage of a publication is reflected by other publications that make reference to it. I have reviewed citations to *Rolland* on Google Scholar to compile a list of early citations. **EX1013E** presents six citations published from 1996 to 2000 to show early usage of *Rolland*. This list shows the earliest citation appeared in 1997.

E. Summary of My Opinion on *Rolland*

103. The copyright registration record for *Telemanipulator and Telepresence Technologies* that contains Rolland (**EX1013D**) shows this work was published on December 30, 1994. The date annotation on **EX1013** shows Linda Hall Library added this work to their collections on March 14, 1995, and the MARC record (**EX1013B**) shows their copy cataloging record was based on a record created by the Rochester Institute of Technology Library. The MARC record has made this work discoverable in the online catalog of the Linda Hall Library since March 14, 1995. The physical copy, after processing, would become publicly accessible by March 21, 1995.

VII. Authenticity and Public Availability of *Stratton* (EX1014)

A. Authentication

104. **EX1014** is a true and correct copy of excerpts of *The Legend of Zelda : A Link to the Past : Prima's Official Strategy Guide,* ("*Stratton*"), by Bryan Stratton and Stephen Stratton, published by Prima Games in 2002, that I obtained from the Library of Congress. This copy of *Zelda* is presented as **EX1014** in this declaration.

105. **EX1014** is a true and correct copy of excerpts of *Stratton*. This copy includes the cover, date stamped page, copyright page, pages 2 to 18 and 28 to 30 of the book. Page 1 is the cover of a bound volume that shows a call number of "GV 1469.35 .L43 S77 2002 Copy 1." Page 2 is the cover that shows "The Legend of Zelda" as the main title, "A link to the past" and "Prima's official strategy guide" as the subtitles. Page 3 is the title page that shows this work is "Prima's Official Strategy Guide" for *The Legend of Zelda : A Link to the Past* written by Bryan Stratton and Stephen Stratton, and published by Prima Games of Roseville, California. This page carries a library date stamp of "Library of Congress DEC 17 2002." It also shows a copyright date of "2002" with Prima Games as the copyright holder, "0-7615-4118-7" as the ISBN (International Standard Book Number), and "2002114735" as the Library of Congress Catalog Card Number for this guide. Page 4 is the table of contents that carries a call number label. Pages 4 to 23 are internal pages 2 to 18 and 28 to 30. Page 24 is the back cover that shows the ISBN, authors, and publisher, and

indicates the price of this work as "U.S. $14.99, Can. $21.95, U.K. £12.99."

106. To authenticate **EX1014**, I located a digitized copy of *Stratton* at https://archive.org/details/legendofzeldal00brya on Internet Archive. I have closely compared **EX1014** with this digitized copy and found the pages in **EX1014** (including the back cover) and their corresponding pages in the digitized copy to. Have the same content. As evidence of my comparison, I have produced **EX1014A** that includes, from the digitized copy, the cover, title page, pages 2 to 4 and 28 to 30, and the Internet Archive record for this copy.

107. The record for the digitized copy shows the title, authors, publication year, publisher, language, and ISBN ("0761541187") that match the information presented in **EX1014**, confirming this digitized copy is a copy of **EX1014**. The record also shows this book was donated by Friends of the San Francisco Public Library and digitized and added to Internet Archive Books on September 27, 2011.

108. **EX1014** is in a condition that creates no suspicion about its authenticity. Specifically, within each page range, this copy is not missing any intermediate pages and there are no visible alterations to the pages. Furthermore, **EX1014** is scanned from a copy held by the Library of Congress. In addition, **EX1014** has the same content as the digitized copy in the Internet Archive Books, as illustrated by **EX1014A**. Based on my review and analysis, it is my opinion that **EX1014** is authentic.

B. Record of Library of Congress

109. To determine the public availability date of *Stratton*, I obtained the bibliographic and MARC records for this work from the online catalog of the Library of Congress. I personally located, identified, and obtained these records. They are the type of records experts in my field would reasonably rely upon when forming their opinions.

110. Pages 1 and 2 of **EX1014B** are the bibliographic record that shows the authors, title, publisher, publication date, physical description, and other details. It also shows the ISBN of *Stratton* is "0761541187" and the LCCN (Library of Congress Catalog Card Number) of this record is "2002114735." The authors, title, publisher, publication date, ISBN and LCCN match the information presented in **EX1014**, confirming this record represents *Stratton*. The "Item Availability" area shows this work has a call number of "HAA 0141 Culpeper" indicating this work is stored at the Packard Campus for Audio Visual Conservation at Culpeper, Virginia. The record shows interested users can request access to this copy at the "Moving Image Research Center by Appointment" and the status of the work is "Not Charged" (meaning available for user request).

111. Pages 3 and 4 are the MARC record for *Stratton*. The first six digits of Field 008 show the MARC record was created on "021022" (*i.e.*, October 22, 2002). Field 955 records local cataloging activities. It shows a pre-publication record was

created on "2002-10-22" (*i.e.*, October 22, 2002), and the cataloging work was completed on "2003-03-17" (*i.e.*, March 17, 2003). Field 040 shows that "DLC" created the original record and entered it into the OCLC WorldCat database. According to the *Directory of OCLC Members* (https://www.oclc.org/en/contacts/libraries.html), "DLC" is the OCLC library symbol for the Library of Congress. Fields 008, 955 and 040 inform my opinion that Library of Congress created the original MARC record for *Stratton* on October 22, 2002, before the book was published, received the published work in early 2003, and completed the cataloging work on March 17, 2003. A customary library practice is to process a newly cataloged monograph promptly for public access, usually within a week after the cataloging work is completed. My personal experience with the collections at the Library of Congress is that it can take one to three months for a newly cataloged monograph to become publicly accessible. It is therefore my opinion that *Stratton* became publicly accessible at the Library of Congress no later than June 17, 2003.

112. Field 010 of the MARC record shows the Library of Congress Catalog Card Number and Field 020 show the ISBN of this book. Field 100 shows the first author, Field 245 shows the title, subtitles and statement of responsibility, and Field 260 shows the publisher and copyright year. Field 700 shows the second author is included to help users discover this work.

113. Subjects of this book are represented in Field 050 by a Library of Congress Classification (LCC) number of "GV1469.35.L43" that represents "Legend of Zelda" (source: Library of Congress Classification, Schedule G, at https://www.loc.gov/aba/publications/FreeLCC/LCC_G2019TEXT.pdf), and in Field 082 by a Dewey Decimal Classification (DDC) number of "793.93/25369" where "793.93" represents "Adventure games, including computer adventure games; computer fantasy, video adventure, video fantasy games" (source: 700 The Arts, at https://www.oclc.org/content/dam/oclc/webdewey/help/700.pdf). The subject is also represented in Field 650 by a Library of Congress subject heading: Legend of Zelda (Game). These subject representations enable users to conduct subject searches to discover *Stratton*.

114. This MARC record (**EX1014B**) shows that a pre-publication record was created for *Stratton* on October 22, 2002, and the cataloging record was completed on March 17, 2003, making this book discoverable in the online catalog of the Library of Congress from that date on. As of March 17, 2003, interested users would be able to conduct subject searches by the LCC number, DDC number and the Library of Congress subject heading in the MARC record to discover this book. They would also be able to search for this book by the authors, title, ISBN, and LCCN.

115. As evidence that Library of Congress had an online catalog in operation in 2003, I obtained a profile of the library at

https://librarytechnology.org/library/2263 from libraries.org, a directory of libraries throughout the world. I personally located, identified, and obtained this profile. It is the type of material experts in my field would reasonably rely upon when forming their opinions. This profile is presented as **EX1014C** in this declaration.

116. The Technology Profile on page 2 of **EX1014C** shows Library of Congress began using Voyager as its online catalog in 1998, and changed to FOLIO-EBSCO Information Services in 2023. These dates mean that in 2003 interested users were able to use the Voyager system of the Library of Congress to search for and access *Stratton*.

C. Internet Archive Record

117. To determine the public availability of *Stratton* on the Internet, I searched Internet archive for records and found the publisher's webpage for *Stratton*. The archived copy of this webpage is presented as **EX1014D** in this declaration. I personally located, identified, and obtained this copy. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

118. **EX1014D** is a true and correct copy of the publisher's webpage for *Stratton*. Page 1 is a screen capture of a Wayback Machine calendar that shows the webpage was archive seven times between "18 Feb 2003" and "8 Mar 2005" and this particular copy was archived on "FEB 18 2003" and available at https://web.archive.org/web/20030218203023/http://www.primagames.com/strateg

y/book/6300/. Pages 2 and 3 are the PDF version of the archived copy that shows this webpage is for "The Legend of Zelda: A link to the Past, Prima's Official Strategy Guide." It shows "0-7615-4118-7" as the ISBN of this guide and the price as "$14.99 U.S. / $21.95 Can. / £12.99 U.K." The title, ISBN, and price information match the information presented in **EX1014** (see the back cover for the price information). The webpage includes an "Order a copy" link for interested users. The link leads to an order page archived by Internet Archive on March 2, 2003 and available at https://web.archive.org/web/20030302133235/http://www.primagames.com/strategy/book/order/6300/. This archive copy is included as pages 3 and 4 of **EX1014D**. The archived webpage shows a posting date of "March 2nd, 2003" and a page title of "Order From Our Vendors." It shows Amazon, Barnes and Noble, Electronics Boutique, and Gamestop as vendors. Based on the archive dates of the publisher's webpage for *Stratton* and the webpage for ordering this guide, it is my opinion that *Stratton* became publicly discoverable and accessible on the Internet by February 18, 2003.

D. Summary of My Opinion on *Stratton*

119. **EX1014** is authentic because it contains no signs to raise suspicion about its authenticity. This copy of excerpts is from a copy of *Stratton* held by the Library of Congress, and **EX1014** has the same content as a digitized copy on Internet Archive Books, as evidenced by **EX1014A**.

120. The MARC record of the Library of Congress (**EX1014B**) shows the library created a pre-publication record for *Stratton* on October 22, 2002, and completed the cataloging work on March 17, 2003, making this work discoverable from their online catalog from that date on. The physical copy, after processing, would become publicly accessible no later than June 17, 2003.

121. Archived copies of the publisher's webpage for *Stratton* and the online order form (**EX1014D**) inform my opinion that *Stratton* was publicly discoverable and accessible on the Internet by February 18, 2003.

122. Based on the documents and records I have analyzed, *Stratton* was publicly accessible on the Internet by February 18, 2003. In addition, it became publicly accessible at the Library of Congress by June 17, 2003.

VIII. Conclusion

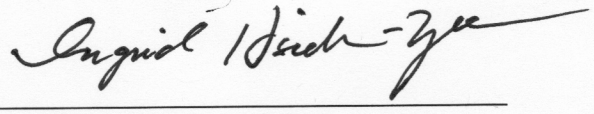
123. In signing this Declaration, I recognize that the Declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in this proceeding. If required, I will appear for cross-examination at the appropriate time.

124. I hereby declare that all statements made herein of my own knowledge are true and that all statements are made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful

false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001.

Dated: March 25, 2025

Respectfully submitted,



Ingrid Hsieh-Yee, Ph.D.
Annapolis, Maryland

Meta Exhibit 1017
Meta v. Mullen - Page 0057

APPENDIX A

Ingrid Hsieh-Yee

Professor Emerita
Dept. of Library and Information Science
Catholic University of America
Washington, D.C. 20064
E-mail: hsiehyee@cua.edu

Education

Ph.D. 1990. Library and Information Studies, University of Wisconsin-Madison
Minors: Sociology and Psychology

M.A. 1984. Library and Information Studies, University of Wisconsin-Madison.

M.A. 1983. Comparative Literature, University of Wisconsin-Madison.

B.A. 1980. Foreign Languages and Literature, National Taiwan University.

Work Experience

Professor, School/Dept. of Library and Information Science, Catholic University of America, 1990-2022 (Assistant Professor, 1990-1996; Associate Professor, 1997-2004; Professor 2004-2022; Professor Emerita 2022)

Co-Chair, Dept. of Library and Information Science, Catholic University of America, June 2015-August 2016.

Acting Dean, School of Library and Information Science, Catholic University of America, January 2010-June 2012.

Cataloger, Dept. of Legislative Reference Library, Annapolis, Maryland, 1989-1990.

Lecturer, School of Library and Information Studies, University of Wisconsin-Madison, 1988.

Teaching Assistant, School of Library and Information Studies, University of Wisconsin-Madison, 1986-1988.

Cataloger, Health Sciences Library, University of Wisconsin-Madison, 1984-1986.

Areas of Teaching and Research Interests

Information Organization and Access; Metadata; Cataloging & Classification; Information Architecture; Information Retrieval; Digital Collections; Social Media; Scholarly

Communication; Information Behavior; Health Informatics; Human Computer Interaction; Usability Studies

Grants & Honors

Cultural Heritage Information Management Project. IMLS grant. Amount: $498,741. Period: Aug. 2012 to July 2015. Co-PI with Dr. Youngok Choi.

D.C. Health Information Technology (HIT4): Building Capacity & Providing Access in Our Nation's Capital. Dept. of Labor H2B Training Grant. Grant amount: $4,175,500. Grant period: Nov. 2011 to Dec. 2015. Partner with the Metropolitan School of Professional Studies of the Catholic University of America, Children's National Medical Center, D.C. Department of Employment Services, Holy Cross Hospital, Howard University, Center for Urban Progress, Providence Hospital, and Sibley Memorial Hospital.

Capital Health Careers Project. Department of Labor Healthcare Sector and Other High Growth and Emerging Industries Grant. Grant amount: $4,953,999. Grant period: March 2010 – February 2013. Awarded to a group of healthcare organizations and educational institutions in Washington, D.C. Providence Health Foundation of Providence Hospital (Lead institution). Part of the grant supported the development of a Master's degree program in Information Technology with a concentration in Health Information Technology offered by the School of Library and Information Science.

The Washington D.C. School Librarians Project. IMLS grant. Grant amount: $412,660. Grant period: Aug. 2007 – June 2011. The School partnered with the District of Columbia Public Schools (DCPS) and the District of Columbia Library Association to educate and mentor school media specialists for the DCPS system. PI, Jan. 2010 to June 2011.

SIG Member of the Year, American Society for Information Science and Technology (2009).

Most Outstanding Paper of *OCLC Systems & Services* (2001).

ALISE Research Grant (2001).

Most Outstanding Paper of *OCLC Systems & Services* (2000).

Research Grant from ERIC (1999-2000).

Best Research Paper Award; Association for Library and Information Science Education (1998).

Research Grants, Catholic University of America. 1991, 1992, 1993, 1996, 1998, 1999, 2004, 2005, 2006, 2007, 2013-14.

Cooperative Faculty Research Grant, Consortium of Universities in the Washington Metropolitan Area (1993-1994).

Cooperative Research Grant, Council on Library Resources (1993-1994).

Journal of the American Society for Information Science Best Paper Award (1993).

ASIS/ISI Information Science Doctoral Dissertation Scholarship (1989).

HEA Title IIB Fellowship (Dept. of Education) (1989)

Chinese-American Librarians Association Scholarship (1987).

Beta Phi Mu (1985).

Vilas Fellowship, University of Wisconsin-Madison. 1984

Publications

Hsieh-Yee, I. (2021). Can We Trust Social Media? *Internet Reference Services Quarterly*, 1-15. Published online: 28 July, 2021. 10.1080/10875301.2021.1947433.

Bailey, T., & Hsieh-Yee, I. (2020). Combating the Sharing of False Information: History, Framework & Literacy Strategies, *Internet Reference Services Quarterly*, 24 (1-2), 9-30.

Choi, Y., and Hsieh-Yee, I. (2010). Finding Images in an OPAC: Analysis of User Queries, Subject Headings, and Description Notes. *Canadian Journal of Information and Library Science,* 34(3): 271 – 295.

Hsieh-Yee, I. (2008). Educating Cataloging Professionals in a Changing Information Environment. *Journal of Education for Library and Information Science,* 46(2): 93-106.

Vellucci, S. L., Hsieh-Yee, I., and Moen, W.E. (2007). The Metadata Education and Research Information Commons (MERIC): A Collaborative Teaching and Research Initiative. *Education for Information,* 25(3&4): 169-178.

NISO Framework for Guidelines for Building Good Digital Collections. 3rd ed. Baltimore, MD: National Information Standards Organization, 2007. Also available online: http://www.niso.org/framework/framework3.pdf (NISO Working Group members: Priscilla Caplan (chair), Grace Agnew, Murtha Baca, Tony Gill, Carl Fleischhauer, Ingrid Hsieh-Yee, Jill Koelling, and Christie Stephenson.)

Choi, Y., Hsieh-Yee, I., and Kules, B. (2007). Retrieval Effectiveness of TOC and LCSH. *Proceedings of the Joint Conference on Digital Libraries*, pp. 233-234.

Vellucci, S., and Hsieh-Yee, I. (2007). They Didn't Teach Me That in Library School! Building

a Digital Teaching Commons to Enhance Metadata Teaching, Learning and Research. *Proceedings of the National Conference of the Association of College and Research Libraries, Baltimore, MD*, pp. 26-31.

Mitchell, Vanessa, and Ingrid Hsieh-Yee. (2007). Converting Ulrich's Subject Headings to FAST Headings: A Feasibility Study. *Cataloging & Classification Quarterly,* 45(1): 59-85.

Hsieh-Yee, I., Tang, R., and Zhang, S. (2007). User Perceptions of a Federated Search System. *IEEE Technical Committee on Digital Libraries Bulletin,* Summer 3(2) (URL = http://www.ieee-tcdl.org).

Tang, R., Hsieh-Yee, I., and Zhang, S. (2007). User Perceptions of MetaLib Combined Search: An Investigation of How Users Make Sense of Federated Searching." *Internet Reference Services Quarterly,* 12(12): 211-236.

Hsieh-Yee, I., Tang, R., and Zhang, S. (2006). User Perceptions of a Federated Search System. *Proceedings of the Joint Conference on Digital Libraries*, *June 11-15, 2006, Chapel Hill*, p. 338.

Hsieh-Yee, I. (2006). *Organizing Audiovisual and Electronic Resources for Access: A Cataloging Guide*. 2nd ed. Westport, Conn.: Libraries Unlimited.

NISO A Framework of Guidance for Building Good Digital Collections. 2nd ed. Bethesda, MD: National Information Standards Organization, 2004. Framework Advisory Group: Grace Agnew, Liz Bishoff, Priscilla Caplan (Chair), Rebecca Gunther and Ingrid Hsieh-Yee.

Hsieh-Yee, I. (2004). Cataloging and Metadata Education in North American LIS Programs. *Library Resources & Technical Services,* 48(1): 59-68.

Hsieh-Yee, I. (2004). Cataloging and Metadata Education. In Gary E. Gorman (Ed.), *International Yearbook of Library and Information Management 2003: Metadata Applications and Management*, (pp.204-234). London: Facet Publishing.

Yee, P. L., Hsieh-Yee, I., Pierce, G.R., Grome, R., and Schantz, L. (2004). Self-Evaluative Intrusive Thoughts Impede Successful Searching on the Internet. *Computers in Human Behavior,* 20(1): 85-101.

Hsieh-Yee, I. (2003). Cataloging and Metadata Education: A Proposal for Preparing Cataloging Professionals of the 21st Century. A report submitted to the ALCTS-Education Task Force in response to Action Item 5.1 of the *Bibliographic control of Web Resources: A Library of Congress Action Plan*. Approved by the Association for Library Collections and Technical Services. Web version available since April 2003 at http://lcweb.loc.gov/catdir/bibcontrol/CatalogingandMetadataEducation.pdf.

Hsieh-Yee, I. (2002). Cataloging and Metadata Education: Asserting a Central Role in Information Organization. *Cataloging & Classification Quarterly* 34(½): 203-222.

Hsieh-Yee, I., and Smith, M. (2001). The CORC Experience: Survey of Founding Libraries, Part I. *OCLC Systems & Services,* 17: 133-140. (Received "The Most Outstanding Paper of OCLC Systems & Services in 2001" award.)

Hsieh-Yee, I., and Smith, M. (2001). The CORC Experience: Survey of Founding Libraries, Part II, Automated Tools and Usage. *OCLC Systems & Services,* 17: 166-177. (Received "The Most Outstanding Paper of OCLC Systems & Services in 2001" award.)

Hsieh-Yee, I. (2001). ERIC User Services: Changes and Evaluation for the Future. *Government Information Quarterly,* 18: 31-42.

Hsieh-Yee, Ingrid. (2001). Research on Web Search Behavior. *Library and Information Science Research,* 23: 167-185.

Logan, E., and Hsieh-Yee, I. (2001). Library and Information Science Education in the Nineties. *Annual Review of Information Science and Technology,* 35: 425-477.

Hsieh-Yee, I. (Ed.) (2001). *Library and Information Science Research*, 23 (2). A special issue in honor of the retirement of Douglas L. Zweizig.

Hsieh-Yee, I. (2000). *ERIC User Services: Evaluation in a Decentralized Environment*. Washington, D.C.: Dept. of Education.

Hsieh-Yee, Ingrid. (2000). *Organizing Audiovisual and Electronic Resources for Access: A Cataloging Guide*. Littleton, CO: Libraries Unlimited.

Hsieh-Yee, I. (2000). Organizing Internet Resources: Teaching Cataloging Standards and Beyond. *OCLC Systems & Services,* 16: 130-143. (Received "The Most Outstanding Paper of OCLC Systems & Services in 2000" award.)

Hsieh-Yee, I. (1998). The Retrieval Power of Selected Search Engines: How Well Do They Address General Reference Questions and Subject Questions? *Reference Librarian,* 60: 27-47.

Hsieh-Yee, I. (1998). Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study. *Reference Librarian,* 60: 61-85. (Received the 1997 Best ALISE Research Paper Award.)

Hsieh-Yee, I. (1997). Access to OCLC and Internet Resources: LIS Educators' Views and Teaching Practices. *RQ,* 36: 569-86.

Hsieh-Yee, I. (1997). Teaching Online and CD-ROM Resources: LIS Educators' Views and Practices. *Journal of Education for Library and Information Science,* 38: 14-34.

Hsieh-Yee, I. (1996). The Cataloging Practices of Special Libraries and Their Relationship with OCLC. *Special Libraries,* 87: 10-20.

Hsieh-Yee, I. (1996). Modifying Cataloging Practice and OCLC Infrastructure for Effective Organization of Internet Resources. In *Proceedings of the OCLC Internet Cataloging Colloquium*. [Online]. Available: http://www.oclc.org/oclc/man/colloq/hsieh.htm

Hsieh-Yee, I. (1996). Student Use of Online Catalogs and Other Information Channels. *College & Research Libraries,* 57: 161-175.

Hsieh-Yee, I. (1995). Ten entries in James S. C. Hu (Ed.), *Encyclopedia of Library & Information Science*, 913, 1028-29, 1036, 1037, 1145-46, 1514, 1575, 1763-64, 2216-27, 2378-79. Taipei, Taiwan: Sino-American Publishing. (Topics include "Advanced Technology/Libraries," "Information Ethics," "Instruction on Cataloging and Classification," "Instruction on Reference Services.")

Hsieh-Yee, I. (1993). Effects of Search Experience and Subject Knowledge on Online Search Behavior: Measuring the Search Tactics of Novice and Experienced Searchers. *Journal of the American Society for Information Science,* 44: 161-174. (Received the 1993 Best JASIS Paper Award.)

Works in Progress

Hsieh-Yee, I. Actionable lessons for debunking false information: A comparative analysis of literacy lessons in communication and library and information science

Hsieh-Yee, I. Representing diverse voices and communities in cataloging and indexing: The evolution of controlled vocabularies

Hsieh-Yee, I. Information Organization and Retrieval in Practice (a monograph scheduled for completion and publication in 2023)

Presentations

Bailey, T. & Hsieh-Yee, I. (February 2020). The Phenomena of Sharing Misinformation and the Need for Information Literacy. Presented at the 2020 Bridging the Spectrum Symposium, Washington, D.C., February 14, 2020.

Hsieh-Yee, I. and Fragan-Fly, J. (May 2018) Trends, Design & Strategies for Digital Scholarship Services. Presented at the 2018 Maryland/Delaware Library Association Conference, Cambridge, MD.

Hsieh-Yee, I. (February, 2018) Research Data Management: What It Takes to Succeed. Presented at the 10th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (February, 2017) *Research Data Management: New Competencies and Opportunities for Information Professionals*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. and Lawton, P. (February, 2017) *Enhancing Catholic Portal Searches with User Terms and LCSH*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (2016, October) *Visualizing Data for Information*. Presented at the 2016 Virginia Library Association Conference, Hot Springs, VA.

Hsieh-Yee, I. (2016, August) *Religious Materials Toolbox for Archivists: Solutions to Problems Facing the Profession*. Presented at Archives * Records 2016, Atlanta, GA.

Hsieh-Yee, I. and Lawton, P. (2016, March) *Enhancing Retrieval of Catholic Materials with LCSH Knowledge Structure*. Presented at the 2016 Catholic Library Association Conference, San Diego, CA.

Fagan-Fry, J. and Hsieh-Yee, I. (2016, February) *Approaches to Digital Scholarship at Top Universities around the World: Scholarly Publishing in the Digital Age.* Presented at the 8th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee and Fagan-Fry, J. (2016, January) *Innovative Services for Digital Scholarship at Top 100 Research Libraries of the World*. Poster presented at the 2016 Annual Conference of the Association for Library and Information Science Education, Boston, Mass.

Hsieh-Yee, I. and Lawton, P. (2015, June). *Crowdsourcing terms for CRRA portal themes.* Poster presented at the third CRRA symposium and annual meeting, Bringing the created toward the Creator: Liturgical art and design since Vatican II. Catholic Theological Union, Chicago, Illinois.

Hsieh-Yee, I. and Lawton, P. (2015, February). *Crowdsourcing terms for thematic exploration in the Catholic Portal.* Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I., James, R., and Fagan-Fry, J. (2015, February). *Support for digital scholarship at top university libraries of the world*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2015, February). *Thus said the end users: Summon experience and support for research workflows*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Yontz, E., Hsieh-Yee, I., & Houston, S. (2015, February). *Healthy Heroes Summer Reading Club: Developing healthy youth at public libraries.* 11th Annual Jean Mills Health Symposium, Greenville, North Carolina.

Yontz, E., Hsieh-Yee, I., and Houston, S. (2015, January). *Healthy youth and libraries: A pilot study.* Association for Library & Information Science Education (ALISE) Annual Conference, Chicago, Illinois.

Hsieh-Yee, I. (2014, May). *Linking CRRA resources to portal themes via authority files*. Presented at the Catholic Research Resources Alliance 2014 Membership Meeting, Marquette, WI.

Hsieh-Yee, I. (2014, April). *Enhancing subject access to CRRA resources*. Presented at the 2014 Catholic Library Association Conference, Pittsburgh, PA.

Hsieh-Yee, I. (2014, January). *Health Information Technology Program: Educational entrepreneurship in action*. Presented at the 2014 annual Conference of the Association for Library and Information Science Education, Philadelphia, PA

Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2014, January). *Discovering information through Summon: An analysis of user search strategies and search success*. Paper presented at the 6th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (2012, December). *National Digital Stewardship Alliance and SLIS at CUA: An Educational Partnership*. Paper presented at Best Practices Exchange: Acquiring, Preserving, and Providing Access to Government Information in the Digital Era, Annapolis, MD

Choi, Y. and Hsieh-Yee, I. (2010, January). *Finding Images in an OPAC: Analysis of User Queries, Subject Headings, and Description Notes*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. and Coogan, J. (2010, January). *Google Scholar vs. Academic Search Premier: What Libraries and Searchers Need to Know*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, November). *Information Science Education: An LIS School's Perspective*. Paper presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada.

Hsieh-Yee, I., Menard, E., Ya-Ning Chen, A., Shu-Jiun Chen, S., Kalfatovic, M. R., Wisser. K. M. (2009, November). *Information Organization in Libraries, Archives and Museums: Converging Practices and Collaboration Opportunities*. Presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada. (Organizer and moderator of this panel.)

Hsieh-Yee, I. and Coogan, J. (2009, July). *Catching up to Google Scholar: The Retrieval Power of Academic Search Premier and Google Scholar*. Poster presented at American Library Association Conference, Chicago, Illinois.

Hsieh-Yee, I., with the CUA Scholarly Communications Project Team. (2009, January). *Digital Scholarship@CUA: Developing an Institutional Repository for CUA*. Poster presented at 1st Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Wise, M., Cylke, K., and Hsieh-Yee, I. **(**2009, January). *Digital Talking Books: Meeting the Needs of the Blind and the Handicapped*. Paper presented at the Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, January). *User Expectations of MERIC*. Presented at the Information Organization Competencies for the 21st Century Discussion Session of the 2009 Conference of the Association for Library and Information Science Education, Denver, Colorado.

Choi, Y., and Hsieh-Yee, I. (2008,November). *Subject Access for Images in an OPAC.* Annual Meeting of the American Society for Information Science and Technology, Columbus, Ohio. (Also co-organized a panel on Retrieving and Using Visual Resources: Challenges and Opportunities for Research and Education.)

Hsieh-Yee, I. (2008, June). *Educating Cataloging Professionals in a Changing Information Environment*. National Taiwan University, Taipei, Taiwan.

Vellucci, S. L., Moen, W.E., Hsieh-Yee, I., Marson, B., and Wisser, K. (2008, January) *Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input*. A panel presented at the 2008 Conference of the Association for Library and Information Science Education, Philadelphia, Pennsylvania.

Hsieh-Yee, I., Choi,Y. and Kules, B. (2007, October). *Searching for Books and Images in OPAC: Effects of LCSH, TOC and Subject Domains.* A poster presented at the American Society for Information Science and Technology Annual Meeting, Milwaukee, Wisconsin.

Hsieh-Yee, I. and Coogan, J. (2007, August) *Google Scholar vs. Academic Search Premier: A Comparative Analysis.* Presented to the Faculty and Staff of the University of the District

of Columbia.

Hsieh-Yee, I. and Coogan, J. (2007, June). *Google Scholar vs. Academic Search Premier: A Comparative Analysis*. Presented to the Washington Research Library Consortium Community, Catholic University of America, Washington, D.C.

Hsieh-Yee, I., Choi, Y., and Kules, B.. (2007, June). *What Users Need for Subject Access: Table of Contents or Subject Headings?* A poster presented at the 2007 American Library Association Annual Conference, Washington, D.C., June 2007.

Choi, Y., Hsieh-Yee, I., and Kules, B. (2007, June). *Retrieval Effectiveness of TOC and LCSH.* A paper presented at the Joint Conference on Digital Libraries 2007, Vancouver, Canada.

Vellucci, S. L., Hsieh-Yee, I., and Moen, W.E. (2007, May). *If We Build It, Will They Come? Building a Community of Practice for Metadata Stakeholders.* A poster presented at the Rutgers University Research Day, Bridgeton, New Jersey.

Hsieh-Yee, I. (2007, May). *Federated Searching: User Experience & Perceptions.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May). *Search Performance of Google Scholar and Academic Search Premier.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May) *MERIC: Building a Digital Commons for Metadata Education & Research.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I., and Coogan, J. (2007, March/April). *A Comparative Analysis of Google Scholar and Academic Search Premier.* Poster presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland.

Vellucci, S. L. and Hsieh-Yee, I. (2007, March/April) *They Didn't Teach Me That in Library School! Building a Digital Teaching Commons to Enhance Metadata Teaching, Learning and Research*. On-site presentation and Webcast by Elluminate. A contributed paper presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland. The acceptance rate for contributed paper was 20%. This paper was one of 10 conference papers chosen for live webcast during the conference.

Moen, W., Hsieh-Yee, I. and Vellucci, S.L. (2007, January) *A DSpace Foundation for a Teaching & Research Commons: The Metadata Education and Research Information Commons.* A poster session presented at the Open Repositories Conference 2007, San Antonio, Texas.

Tang, R., Hsieh-Yee, I., and Zhang, S. (2006, November) *User Perception of MetaLib Combined Search*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas, Nov. 2006.

Hsieh-Yee, I. (2006, November). *Federated Searching: User Perceptions, System Design, and Library Instructions.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter).

Hsieh-Yee, I. (2006, November). *Building a Digital Teaching Commons to Enhance Teaching and Learning: The MERIC Experience and Challenges.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter)

Hsieh-Yee, I. (2006, September). *Search Performance of Google Scholar and Academic Search Premier.* Paper presented at the ERIC Publishers Meeting, Washington, D.C.

Hsieh-Yee, I., Zhang, S., and Rong Tang, R. (2006, June). *User Perceptions of a Federated Search System*. Poster presented at Joint Conference on Digital Libraries, Chapel Hill, North Carolina.

Hsieh-Yee, I. and Zhang, S. (2006, June). *Preparing Users for Federated Search: Implications of a MetaLib User Perceptions Study.* Paper presented at the 2006 Ex Libris User Groups of North America Conference, Knoxville, Tennessee.

Hsieh-Yee, I. (2006, January). *MERIC Organizations and Navigation*. Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2006, January). *Metadata and Cataloging Education: Recommended Competencies.* Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2005, November). *Digital Library Evaluation: Progress & Next Steps.* Presentation at the Annual Meeting of the American Society for Information Science & Technology, Charlotte, North Carolina.

Hsieh-Yee, I. (2005, August). *Providing Access to Digital Content: Issues for DL Managers.* Presentation at MDK12 Digital Library Steering Committee Meeting, Columbia, Maryland.

Hsieh-Yee, I. (2005, April). *Enhancing Teaching and Learning: The Role of School Library Media Specialists.* Presentation at Meeting of the Baltimore County Public School System School Media Specialists, Baltimore, Maryland.

Hsieh-Yee, I. (2005, January). *Subject Access and Users: Insights & Inspirations from Marcia J. Bates.* Paper presented at the Historical Perspectives SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2005, January). *Electronic Resource Management: Practice, Employer Expectations, & CE Interests.* Paper presented at Technical Services Education SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2004, October). *Library Professionals for the Digital Age: Competencies & Preparation.* Paper presented at Bibliographic Access Management Team meeting, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2004, January). *Cataloging and metadata expertise for the digital era.* Presented at Preparing 21st Century Cataloging and Metadata Professionals: A Workshop for Educators and Trainers, San Diego and sponsored by ALCTS, ALISE, LC, and OCLC.

Hsieh-Yee, I. (2004, January). *Educating catalogers for the digital era.* Paper presented at the Technical Services SIG, 2004 Conference of the Association for Library and Information Science Education, San Diego.

Hsieh-Yee, I. (2003, July). *Cataloging Education for the 21st Century.* A presentation at the Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2002, January) *Metadata Education and Research Priorities: A Delphi Study of Metadata Experts.* Presentation at the 2002 Conference of the Association for Library and Information Science Education, New Orleans.

Hsieh-Yee, I. (2001, November). *A Delphi Study of Metadata: Preliminary Findings.* Poster session at the 2001 Annual Meeting of the American Society for Information Science & Technology, Washington, D.C.

Hsieh-Yee, I. (2001, June). *Resources on Asian American Children: Analysis of Retrieval by Search Engines and WorldCat.* Presentation at the National Conference on Asian Pacific American Librarians, San Francisco.

Hsieh-Yee, I. (2001, January). *Delphi Study on Metadata: Project Design.* Presentation at Research Awards Session, Association for Library & Information Science Education, Washington, D.C.

Hsieh-Yee, I. (2000, May). *Web Search Behavior Research: Progress and Implications.* Presentation at the Symposium on Evaluating Library and Information Science Research, University of Wisconsin-Madison, Madison, Wisconsin.

Hsieh-Yee, I. (2000, March). *ERIC User Services: Evaluation in a Decentralized Environment.* Presentation at the National ERIC Joint Directors/Technical Meeting, Arlington, Virginia.

Hsieh-Yee, I. (2000, January). *Enhancing Learning with Web Technology.* Presentation at Faculty Conversations, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2000, January). *From Surrogates to Objects: CUA's Approaches to Organizing Electronic Resources.* Paper presentation at the Annual Conference of the Association for Library and Information Science Education, San Antonio, Texas.

Yee, P., and Hsieh-Yee, I. (1997, November). *Individual Differences in Search Behavior on the WWW.* A poster session presented at the 38th Annual Meeting of the Psychonomic Society, Philadelphia, Pennsylvania.

Hsieh-Yee, I. (1997, April). *Research + Marketing + Preparation = Job!* Presented at the "Workshop on Resume and Interview Techniques," Special Libraries Association, Student Chapter, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Creating CyberCatalogers: Education and Training.* Presentation at ALA's Midwinter Meeting, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study.* Presented at the Conference of the Association for Library and Information Science Education, Washington, D.C.

Hsieh-Yee, Ingrid. "Beginning Your Special Library/Information Center Career." Presented at SLA's "Career Day," Jan. 11, 1997, Catholic University of America.

Hsieh-Yee, I. (1996, September). *The Roles of Library and Information Scientists in Managing Electronic Information.* Presentation at Hamilton College, Clinton, New York.

Hsieh-Yee, I. (1996, May). *The Future of Cataloging as a Profession.* Presented at "The Cataloging Forum, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (1994, October). *The Impact of the Internet on OPACs.* Presented at the Third Workshop on User Interfaces for OPACs, Library of Congress, Washington, D.C.

Reports

Hsieh-Yee, I., with Knowledge Management Competencies and Performance Action Group of the Federal Knowledge Management Initiative. "From Knowledge Management Competencies to Improved Organizational Performance." April 9, 2009.

Hsieh-Yee, I., with Knowledge Practices Action Group of the Federal Knowledge Management Initiative. "KM Practice in Government Agencies: Findings and Recommendations." April 9, 2009.

Hsieh-Yee, I. "Delphi Study on Metadata." 2001. Three quarterly reports submitted to the Association for Library and Information Science Education.

Hsieh-Yee, I. "College Students' Information Channels: Patterns of Use and Possible Factors in Channel Selection." 1995. Submitted to the Catholic University of America.

Hsieh-Yee, I. "The Information-Seeking Patterns of Scholars and Their Use of an Online Information System." 1994. Submitted to the Council on Library Resources.

Book Reviews

Review of *The Measurement and Evaluation of Library Services*, by Sharon L. Baker and F. Wilfrid Lancaster. *Information Processing and Management* 30 (1994): 450-52.

Review of *Subject Access to Films and Videos, by Sheila S. Intner and William E. Studwell; and Cataloging Unpublished Nonprint Materials*, by Verna Urbanski with Bao Chu Chang and Bernard L. Karon. *Information Processing and Management* 30 (1994): 449-50.

Review of *Automated Information Retrieval in Libraries: A Management Handbook*, by Vicki Anders. *Journal of Library and Information Science* 19 (1993): 98-100.

Review of *Full Text Databases*, by Carol Tenopir and Jung Soon Ro. *Information Processing and Management* 28 (1992): 667-68.

Review of *Descriptive Cataloging for the AACR2R And USMARC: A How-to-Do It Workbook*, by Larry Millsap and Terry Ellen Ferl. *Information Processing and Management* 28 (1992): 809-11.

Review of *MARC Manual: Understanding and Using MARC Records*, by Deborah J. Byrne. *Information Processing and Management* 28 (1992): 537-38.

Service

Professional Associations and Societies

- Library of Congress. RDA Training Program for the Profession. Co-authored with Tim Carlton. 2013-2014.
- 2014 Digital Preservation Outreach & Education Survey. Contributed to the design of the survey, 2014.
- National Digital Stewardship Alliance. Outreach Committee. 2011-2014.
- National Digital Stewardship Residency Program. Advisory Group, 2012-2013.
- FEDLINK Health Information Technology Advisory Council, 2011-2015.

- 2012 Joint Conference on Digital Libraries. Program Planning Committee, Pre-Conference Proposals Review Committee, 2012
- Catholic Research Resources Alliance. Five-Year Strategic Plan Task Force, 2011-2012
- Institute of Museum and Library Services. Grant reviewer. 2004, 2005, 2010.

- Association for Library and Information Science Education.
  * ALISE Bodan Wynar Research Paper Award Committee, 2015, 2016, 2017
  * ALISE Eugene Garfield Dissertation Award Competition, Jury, 2013, 2014
  * ALISE Research Grant Competition Committee. Chair, 2012
  * Pratt-Severn Faculty Innovation Award. Chair, 2009, 2010
  * ALISE Doctoral Poster Jury, 2012
  * "Information Organization Competencies for the 21st Century" Discussion session leader. 2009 Conference of the Association for Library and Information Science Education.
  * Assisted Technical Services SIG Convener in organizing a program, ""Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input" for the 2008 ALISE conference.
  * Association for Library Collections and Technical Services/Association for Library and Information Science Education (ALCTS/ALISE) Metadata Education and Research Information Center (MERIC) Advisory Board, Co-Chair (with Sherry Vellucci), 2005-2007. Chair, 2008-2009 (leading the effort to build MERIC, a repository and collaborative space for metadata educators, practitioners, and researchers)
  * Technical Services SIG, Convener, 2004-2005. Organized a program on "Electronic Resources Management: Current Practices, Employer Expectations, and Teaching Strategies" for the 2005 conference in Boston, Massachusetts.
  * Technical Services SIG, Convener, 2003-2004. Organized a program on "Organizing Information with Metadata: Desired Competencies and Teaching Innovations" for the 2004 conference.
  * Technical Services SIG, Convener, 1999-2000. Organized a program on "Teaching the Organization of Electronic Resources" for the 2000 conference.
  * Curriculum SIG, Co-convener (with Sibyl Moses), 1996-97. Organized a program on "Government Information Policy" for the 1997 conference.

- American Society for Information Science & Technology.
  * Reviewer, Conference program panel submissions and poster submissions, 2005, 2006, 2007, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017
  * Nomination Committee, 2009-2011
  * Information Science Education Special Interest Group. American Society for Information Science and Technology. Chair-Elect, 2007-2008. Chair 2008-2009.
  * Committee on Information Science Education. 1999-2006.
  * Committee on Information Science Education. Organizing Committee for an orientation program for students at ASIS annual meetings, 1999-2001
  * Committee on Information Science Education. Sub-committee on Student Welfare (focusing on issues related to master's education), 1998-2001

* SIG ED. Organizing Committee for the "Seminar on Research and Career Development" for junior researchers. 1995-96 (chair), 1997-2001
* ISI Doctoral Dissertation Proposal Scholarship Jury, 1997; 2001, 2002
* Pratt-Severn Best Student Research Paper Award Jury. Chair. 1997
* 1998 Midyear Meeting (referee of contributed papers), 1997
* Organizer and moderator of the ASIS Doctoral Forum and the Doctoral Research Seminar 1994-1995
* SIG Human Computer Interaction. Chair-Elect, Chair, 1993-1995
* Doctoral Forum Award Jury, 1995
* Best Student Paper Award Jury, 1995

- American Library Association.
  * Committee on Accreditation, External Review Panelist, 2009- (site visiting team 2013-2014; site visiting team 2016-2017)
  * Association for Library Collections and Technical Services Task Force on Competencies and Education for a Career in Cataloging, member, 2008-2009
  * Facilitator for "What They Don't Teach in Library School: Competencies, Education and Employer Expectations for a Career in Cataloging," an Association for Library Collections and Technical Services Preconference, June 22, 2007 in Washington, D.C. Also a local liaison for bringing this program to the Catholic University of America.
  * Facilitator for a discussion on "Effect of Electronic Resources on Technical Services" at ALA's Midwinter Meeting held in Feb. 1997 in Washington, D.C.
  * International Relations Committee, Subcommittee Task Force for IFLA and China, 1994-1997

- Virginia Association of School Librarians. Scholarships and Awards Committee. 2010-2012

- Federal Knowledge Management Initiative, Knowledge Management Practices Action Group. Member. 2009 (leading the effort to build a knowledge management repository)
- Federal Knowledge Management Initiative, Knowledge Management Competencies & Learning Action Group. Member. 2009 (developing an action plan for helping government knowledge workers and government agencies to develop knowledge management competencies)
- National Center for Education Statistics. Technical Review Panel. 2008.
- External evaluator for a case of promotion to full professorship. University of Tennessee. 2008.
- National Information Standards Organization (NISO). Advisory Board, Revision of "IMLS Framework of Guidance for Building Good Digital Collections," 2004, 2007.
- Library of Congress, Bibliographic Control of Web Resources: A Library of Congress Action Plan. Principal Investigator of Action Item 5.1, focusing on cataloging and metadata education for students and new librarians, 2002-2003. (worked with the Association for Library Collections and Technical Services, Education Task Force)

- Chinese American Librarians Association
  * Chinese American Librarians Association Outstanding Library Leadership Award in Memory of Dr. Margaret Chang Fung, Award Committee, 2016-2017
  * Achievement Award Jury, 2000-2001
  * CALA Goal 2000 Task Force, 1997
  * Scholarship Committee, 1995, 1996-1997 (chair)
  * Board of Directors, 1994-1997
  * Publication Committee, 1993-1995
  * International Relations Committee, 1993-1996

- Sailor[SM] Assessment Advisory Group (An impact study of Sailor, Maryland's Public Information Network), 1995

- Editorial boards
  Journal of Library & Information Science. Editorial Board, 2012-
  Chinese American Librarians Association, *Occasional Papers Series*. Editorial Board, 2009-2016.
  Library Quarterly. Editorial Board, 2003-2008
  Bulletin of the Medical Library Association, 1994-97
  Newsletter editor for the Chinese American Librarians Association, 1989-92

- Referee for the following journals
  Information Processing and Management
  Journal of Digital Information
  Journal of Education for Library and Information Science
  Journal of Information Science
  Journal of Library & Information Science
  Journal of Library Metadata
  Journal of the American Society for Information Science & Technology
  Library and Information Science Research
  Library Quarterly

- Expert reviewer, "Digital Library" course, Evaluation module, University of North Carolina, Chapel Hill, 2007-2008.
- Expert reviewer, "Information Organization" course, University of Michigan, Ann Arbor. 2007.

Catholic University of America

- Academic Senate Committee on Appointments and Promotions, 2005-2008
- Academic Senate Committee on Committees and Rules, 2009-2012, 2019-2022
- Academic Senate representative (for School of Arts & Sciences), 2017-2020

- Academic Senate representative (for School of Library & Information Science) 2003-2012
- Academic Senate Library Committee, Interim Chair (2007), Member, 2008-2012
- Academic Senate Committee on Computing, 1995-2003

- President's Administrative Council, 2010-2012
- Deans' Council, 2010-2012
- Academic Leadership Group, 2010-2012
- Graduate Board, 2010-2012

- School of Arts & Sciences, Committee on Appointments and Promotions, 2015-2019
- School of Arts & Sciences, Academic Council, 2015-2016.
- School of Arts & Sciences, Ordinary Professor Group, 2013-
- Doctoral Dissertation Defense Committee, Chair, Dept. of Psychology, 2016, 2017, 2018, 2019, 2020, 2021, 2022
- Doctoral Dissertation Defense Committee, Chair, Dept. of Education, 2014, 2015, 2017, 2018, 2019
- Doctoral Dissertation Defense Committee, Chair, National Catholic School of Social Services, 2019, 2020, 2021
- Doctoral Dissertation Defense Committee, Chair, School of Nursing, 2006, 2008
- CUA Scholarly Communication Project Team, Member (2007), Chair, 2008-2009
- Dean Search Committee, 1992-1994, 1998-1999, 2002-2003, 2006-2007
- Fulbright Review Panel, 2006
- CUA Service Learning Advisory Board, 2001-2002
- CUA Faculty Conversations on Enhancing Teaching and Learning through Technology, Planning Group, 1999-2001
- CUA Initiative on Technology and Teaching, 1998-2001

Dept. of Library and Information Science

- Admissions Committee, 2007-2009, Chair 2010-2012, Member 2013-2015, Member 2018-2022
- Appointments and Promotions Committee, 1991-2022
- Student advisement, 1990-2022
- 4+1 Bachelor to Master program, Program Advisor, 2014-2022
- LIS Minor, Advisor, 2017-2022
- Curriculum Committee, 2020-21 (Member), 2021-2022 (Chair)
- Scholarship & Awards Committee, 2016-2018, 2020-21
- Comprehensive examination editor, 2020-21
- Symposium, Colloquium, Lecture Series Committee, May 2018-May 2020 (Chair)
- Symposium and Colloquium Committee, fall 2016-May 2018
- Bridging the Spectrum Symposium session moderator, 2018, 2019, 2020, 2021

- Organization of Information Core Course Outcomes Assessment, 2019, 2020
- The Information Professions in Society Core Course Outcomes Assessment, 2019, 2020
- Community Services Librarianship, Course of Study Review and Revision, 2020
- Organization of Information, Course of Study Review and Revision, 2019
- Organization of Information, Competency and Course Offerings Review, 2018-2019
- Accreditation presentation, Chair, June 2015-August 2016
- Interim Co-Chair, June 2015-August 2016.
- Blended/OWL Learning Committee, spring 2016-2018
- Technology Committee, fall 2016-2017
- Comprehensive examination editor, 2016-2017, reader (every year since 1990)
- LIS Advisory Board, 2015-2016 (chair); fall 2016- May 2018 (member)
- Committee on Planning and Assessment, 2015-2016 (chair)
- Senior Faculty Committee, 2014-2016.
- Accreditation Steering Committee, 2014-2016 (Chair, 2015-2016)
- Accreditation Students Standard Committee, co-chair, 2014-2016
- Accreditation Mission, Goals, and Objectives Standard Committee, co-chair, 2014-2016
- Accreditation Curriculum Standard, member 2014-2-16
- Accreditation Administration and Finance Standard, member 2014-2016
- Cultural Heritage Information Management Project (IMLS-funded), Co-PI, 2012-2015
- Cultural Heritage Information Management Forum (scheduled for June 2015), Co-Organizer, 2013-2015
- Health Information Technology Interim Review Committee, 2015 (chair)
- Health Sciences Librarianship Advisory Group, 2015- (chair)
- Comprehensive examination editors, 2013-2014, 2016-2017
- National Digital Stewardship Alliance liaison, 2011-2014
- Advisory Board, Chair 2010-2012
- Academic Honesty Committee, Chair, 2008-2012
- Blended Learning Committee, 2010-2012
- Colloquium Committee, 2010-2012
- Comprehensive Examination Administration, 2010-2012
- Cultural Heritage Information Management Advisory Committee, 2010-2012 (chair), 2013-
- Curriculum Committee, 1991-2003, 2007-2009, Chair 2010-2012, member 2013-
- Curriculum Subcommittee on Comprehensive Examination, Chair 2009-2012
- Health Information Technology Advisory Board, Chair 2010-2012. Member 2013-
- Health Sciences Advisory Committee, 2009, Chair 2010-2012. Member 2013-
- HIT Expert Forum, Chair 2012. Member 2013-2015
- Health Information Technology Student Group Advisor, 2011-2012
- State Council for Higher Education of Virginia, SLIS Representative, 2010-2012
- Symposium Planning Committee, 2010-2012
- Website Management Team, Chair, 2010-2012
- Urban School Librarianship Project (IMLS-Funded), PI, 2007-2011 (chair, 2010-11)

- Failing Grades Committee, 1995-1997 (chair), 2000-2001 (chair), 2004-2005 (chair), 2007 (chair)-2011
- Faculty Search Committee, 1994-1998, 2002-2004, 2006 (chair), Fall 2007-2009, Chair fall 2009-2012
- Recruitment Committee, Chair 2010-2012
- Strategic Planning Committee, Chair 2010-2012
- Technology Committee, 2010-2012
- Accreditation Advisory Committee, 2007-2009
- Accreditation Coordinating Committee, 2007-2009
- Accreditation Steering Committee, 2007-2009
- SLIS Advisory Group, 2007-2009
- Accreditation Curriculum Standard Committee, Co-chair, 2007-2009
- Accreditation Faculty Standard Committee, Co-chair, 2007-2009
- LSC 551 Information Organization Review Team, Co-chair, 2008-2009, 2015-2016.
- Curriculum Subcommittee on Portfolios, 2009
- LSC 555 Information Systems in Libraries and Information Centers Review Team, contributor, 2008-2009
- Redesign of LSC 730 Use and Users of Libraries and Information. 2009-
- Development of a metadata institute that was taught as LSC 715 Organization of Internet Resources in 2008. The institute is being revised and will be offered in 2010 under a new course title.
- Development of lesson plans, assignments, and evaluation rubrics for LSC 606, Cataloging and Classification, for the School's NCATE accreditation. 2008
- Howard and Mathilde Rovelstad Scholarship Committee, Chair, 2004-2007
- Assistant Dean Search Committee, Chair, Fall 2007
- Liaison to the Association for Library Collections and Technical Services to bring its preconference program, Cataloging Education and Employer Expectations, to CUA during the 2007 American Library Association Annual Meeting in Washington, D.C.
- Organizer of the colloquium presentation and reception for Tamar Sadeh of Ex Libris on PRIMO June 2007
- Practicum review and design (work with potential supervisors, such as the American Indian Museum internship description revision) 2006-
- Comprehensive examinations (edits, proctoring, and grading), 1990-
- SLIS Web site redesign: Comments and suggestions. Fall 2007
- Conducted surveys of current students and alumni in preparation for the 2005 re-accreditation, 2004-2005
- Technology Committee, 1992-1999 (chair, 1996-1998), 2002-2003 (member)
- Colloquia Committee 1997-1999, 2002-2003.
- Advisor of the CUA Student Chapter of the American Society for Information Science and Technology, 2002-2003
- Visiting Professor Search Committee, 1999, 2000, 2001
- Leader, Participation in the CORC experiment, 1999-2000
- Advisor of the Special Libraries Association Student Chapter, 1993-1999; the group was recognized for outstanding leadership by SLA in 1999.

- COA planning Committee, Task Force on Electronic Presentation of SLIS Reports (team leader) 1997-1998
- COA Planning Committee, Subcommittee on Technology 1996-1998
- NLM practicum coordinator, 1997-1998
- Computer Literacy Workshops: Assisted with the development and evaluation of the workshops, 1996-1998
- Leader, Participation in the InterCat project, 1995-1997

APPENDIX B

MARC 21 Reference Materials

Part VII: A Summary of Commonly Used MARC 21 Fields
Part VIII: A List of Other Fields Often Seen in MARC Records
Part IX: The Leader
Part X: Field 008 for Books

Part VII:

A Summary of Commonly Used MARC 21 Fields

This is a summary of the MARC 21 tags used most frequently by libraries in entering their own bibliographic records. For full listings of all MARC 21 tags, indicators, and subfield codes, see *MARC 21 Format for Bibliographic Data*.

In the explanations on these pages:

Tags -- The tags (3-digit numbers) are followed by the names of the fields they represent. In this summary, and in the *MARC 21 Format for Bibliographic Data*, if a tag can appear more than once in one bibliographic record, it is labeled repeatable (R). If it can only be used once, it is labeled non-repeatable (NR). For example, a catalog record can have several subjects, so the tags for subject added entries (6XX) are labeled repeatable (R).

Indicators -- The use of indicators is explained in fields where they are used. Indicators are one-digit numbers. Beginning with the 010 field, in every field -- following the tag -- are two character positions, one for Indicator 1 and one for Indicator 2. The indicators are not actually defined in all fields, however. And it is possible that a 2nd indicator will be used, while the 1st indicator remains undefined (or vice versa). When an indicator is undefined, the character position will be represented by the character # (for blank space).

Subfield codes -- All the data in each field (beginning with the 010 field) is divided into subfields, each of which is preceded by a delimiter-subfield code combination. The most common subfield codes used with each tag are shown. Each subfield code is preceded by the character $, signifying a delimiter. The name of the subfield follows the code.

In general, every field MUST have a subfield 'a' (**$a**). One exception that is often seen is in Field 020 (ISBN), when the ISBN information (subfield **$a**) is unavailable but the price (subfield **$c**) is known. Some subfields are repeatable. In this summary, repeatability is noted for only the more common repeatable subfields.

Examples: Examples follow the explanation for each field. For clarity, one space has been placed between the tag and the first indicator, one space has been placed between the second indicator and the first delimiter- subfield code, and one space has been inserted between the delimiter-subfield code and the subfield data.

010 Library of Congress Control Number -- (LCCN)
(NR, or Not Repeatable
Indicators undefined.
Subfield used most often:
$a -- Library of Congress control number

```
Example:    010 ##  $a ###86000988#
```

020 International Standard Book Number -- (ISBN)
(R, or Repeatable)
Indicators undefined.
Subfields used most often:
$a -- International Standard Book Number
$c -- Terms of availability (often a price)
$z -- Cancelled/invalid ISBN (R)

```
Example:    020 ##  $a 0877547637
```

040 Cataloging source -- (NR)
Indicators undefined.
Subfields used most often:
$a -- Original cataloging agency
$c -- Transcribing agency
$d -- Modifying agency (R)

```
Example:    040 ## $a DLC
                   $c DLC
                   $d gwhs
```

100 Main entry -- Personal name -- (primary author)
(NR; there can be only one main entry)
Indicator 1: Type of personal name entry element
0 -- Forename
1 -- Surname (this is the most common form)
3 -- Family name
Indicator 2 undefined.
Indicator 2 became obsolete in 1990. Older records may display 0 or 1
Subfields used most often:
$a -- Personal name
$b -- Numeration

$c -- Titles and other words associated with a name (R)
$q -- Fuller form of name
$d -- Dates associated with a name (generally, year of birth)

```
Example:    100 1# $a Gregory, Ruth W.
                   $q (Ruth Wilhelme),
                   $d 1910–
```

130 Main entry -- Uniform title -- (NR)

Indicator 1: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Indicator 2 undefined.

Indicator 2 became obsolete in 1990. (See 100 above.)

Subfields used most often:

$a -- Uniform title
$p -- Name of part/section of a work (R)
$l -- Language of a work
$s -- Version
$f -- Date of a work

```
Example:    130 0# $a Bible.
                   $p O.T.
                   $p Psalms.
```

240 Uniform title (NR)

Indicator 1: Uniform title printed or displayed

0 -- Not printed or displayed
1 -- Printed or displayed (most common)

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Subfields used most often:

$a -- Uniform title
$l -- Language of a work
$f -- Date of a work

```
Example:    240 10 $a Ile mystérieuse.
                   $l English.
                   $f 1978
```

245 Title Statement (NR)

Indicator 1: Title added entry

(Should the title be indexed as a title added entry?)

0 -- No title added entry

(indicates a title main entry; i.e. no author is given)

1 -- Title added entry

(the proper indicator when an author given in 1XX; the most common situation)

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present, including spaces; usually set at zero, except when the title begins with an article; e.g., for *The robe*, the second indicator would be set to 4. The letters *T*, *h*, *e*, and the space following them are then ignored in alphabetizing titles. The record will be automatically filed under "*r*" -- for *Robe*.

Subfields used most often:

$a -- Title proper

$h -- Medium (often used for non-book media)

$p -- Name of part/section of a work (R)

$b -- Reminder of title (subtitles, etc.)

$c -- Remainder of title page transcription/Statement of responsibility

```
Example:    245 14 $a The DNA story :
                   $b a documentary history of gene
                      cloning /
                   $c James D. Watson, John Tooze.
```

246 Varying form of title (R)

Indicator 1: Note/title added entry controller

1 -- Note, title added entry

3 -- No note, title added entry

Indicator 2: Type of title

-- No information provided

0 -- Portion of title

1 -- Parallel title

4 -- Cover title

8 -- Spine title

Subfield used most often:

$a -- Title proper

```
Example:    246 3# $a Four corners power review
```

250 Edition statement (NR)

Indicators undefined.
Subfield used most often:
$a -- Edition statement

```
Example:    250 ## $a 6th ed.
```

260 Publication, distribution, etc. (Imprint) (R)
Indicator 1: Sequence of publishing statements
-- No information provided
Indicator 2: Undefined
Subfields used most often:
$a -- Place of publication, distribution, etc. (R)
$b -- Name of publisher, distributor, etc. (R)
$c -- Date of publication, distribution, etc. (R)

```
Example:    260 ## $a New York :
                   $b Chelsea House,
                   $c 1986.
```

300 Physical description (R)
Indicators undefined.
Subfields used most often:
$a -- Extent (number of pages) (R)
$b -- Other physical details (usually illustration information)
$c -- Dimensions (cm.) (R)
$e -- Accompanying material (for example, "teacher's guide" or "manual")

```
Example:    300 ## $a 139 p. :
                   $b ill. ;
                   $c 24 cm.
```

440 Series statement / Added entry--Title
This field was made obsolete in 2008 to simplify the series statement. See 490 and 830.

490 Series statement (No added entry is traced from field) (R)
Indicator 1: Specifies whether series is traced (whether an 8XX tag is also present)
0 -- Series not traced
1 -- Series traced (8XX is in record)
Indicator 2 undefined.
Subfield used most often:

$a -- Series statement (R)
$v -- Volume number (R)

```
Example:    490 1# $a Colonial American craftsmen
```

500 General note (R)

Indicators undefined.
Subfield used most often:

$a -- General note (Used when no specialized note field has been defined for the information. Examples: Notes regarding the index; the source of the title; variations in title; descriptions of the nature, form, or scope of the item.)

```
Example:    500 ##  $a Includes index.
```

504 Bibliography, etc. note (R)

Indicators undefined.
Subfield used most often:

$a -- Bibliography, etc. note

```
Example:    504 ## $a Includes bibliographical
                      references.
```

505 Formatted contents note (R)

Indicator 1: Type of contents note
0 -- Complete contents
1 -- Incomplete contents (used with multivolume set when some volumes are not yet published)
2 -- Partial contents
Indicator 2: Level of content designation
-- Basic
Subfield used most often:

$a -- Formatted contents note

```
Example:    505 0# $a Pride and prejudice -- Emma
                      -- Northanger Abbey.
```

520 Summary, etc. note (R)

Indicator 1: Display constant controller
-- Summary

1 -- Review
2 -- Scope and content
3 -- Abstract

Indicator 2 undefined

Subfields used most often

$a -- Summary, abstract, or annotation
$b -- Expansion of summary note

```
Example:    520 ## $a This basic guide to parliamentary
                     procedure tells how to conduct
                     and participate in a meeting
                     properly.
```

600 Subject added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename
1 -- Surname (this is the most common form)
3 -- Family name

Indicator 2: Subject heading system/thesaurus (identifies the specific list or file which was used)

0 -- Library of Congress Subject Headings
1 -- LC subject headings for children's literature
2 -- Medical Subject Headings
3 -- National Agricultural Library subject authority file
4 -- Source not specified
5 -- Canadian Subject Headings
6 -- Répertoire de vedettes-matière
7 -- Source specified in subfield $2

(Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

Subfields used most often:

$a -- Personal name (surname and forename)
$b -- Numeration
$c -- Titles and other words associated with a name (R)
$q -- Fuller form of name
$d -- Dates associated with a name (generally, year of birth)
$t -- Title of a work
$v -- Form subdivision (R)
$x -- General subdivision (R)
$y -- Chronological subdivision (R)
$z -- Geographic subdivision (R)
$2 -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Comedies
                   $x Stage history.
```

```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Knowledge
                   $z Rome
                   $v Congresses.
```

Notice that subfields $v, $x, and $z in the 600 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

610 Subject added entry -- Corporate name (R)

*Indicator 1:*Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

Indicator 2: Subject heading system/thesaurus.

See indicator 2 under 600

Subfields used most often:

$a -- Corporate name or jurisdiction name as entry element

$b -- Subordinate unit (R)

$v -- Form subdivision (R)

$x -- General subdivision (R)

$y -- Chronological subdivision (R)

$z -- Geographic subdivision (R)

$2 -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    610 10 $a United States.
                   $b Army Air Forces
                   $v Biography.
```

650 Subject added entry -- Topical term (Most subject headings fit here.) (R)

Indicator 1: Level of subject

-- No information provided

Indicator 2: Subject heading system/thesaurus

(identifies the specific list or file which was used)

0 -- Library of Congress Subject Headings

1 -- LC subject headings for children's literature

2 -- Medical Subject Headings
3 -- National Agricultural Library subject authority file
4 -- Source not specified
5 -- Canadian Subject Headings
6 -- Répertoire de vedettes-matière
7 -- Source specified in subfield $2

Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

Subfields used most often:
$a -- Topical term
$v -- Form subdivision (R)
$x -- General subdivision (R)
$y -- Chronological subdivision (R)
$z -- Geographic subdivision (R)
$2 -- Source of heading or term used with 2nd indicator of 7)

```
Example:    650 #0 $a Theater
                   $z United States
                   $v Biography
                   $v Dictionaries.
```

Notice that subfields $v, $x, and $z in the 650 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

651 Subject added entry -- Geographic name (R)
Indicator 1: undefined.
Indicator 2: Subject heading system/thesaurus.
See indicator 2 under 600
Subfields used most often:
$a -- Geographic name
$v -- Form subdivision (R)
$x -- General subdivision (R)
$y -- Chronological subdivision (R)
$z -- Geographic subdivision (R)
$2 -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    651 #0 $a United States
                   $x History
                   $v Chronology.
```

Notice that subfields $v, $x, and $z in the 651 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

700 Added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

1 -- Surname (this is the most common form)

3 -- Family name

Indicator 2: Type of added entry

-- No information provided (most common; co-authors, editors, etc.)

2 -- Analytical entry (The values for Indicator 2 changed in 1994 with Format Integration, and older records may display additional values. An analytical entry involves an author/title of an item contained in a work.)

Subfields used most often:

$a -- Personal name

$b -- Numeration

$c -- Titles and other words associated with a name (R)

$q -- Fuller form of name

$d -- Dates associated with a name (generally, year of birth)

$e -- Relator term (such as ill.) (R)

$4 -- Relator code (R)

```
Example:    700 1# $a Baldridge, Letitia.
```

710 Added entry -- Corporate name (R)

Indicator 1: Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

Indicator 2: Type of added entry.

See Indicator 2 under 700

-- No information provided

2 -- Analytical entry

Subfields used most often:

$a -- Corporate name or jurisdiction name as entry element

$b -- Subordinate unit (R)

```
Example:    710 2# $a Sunburst Communications (Firm)
```

740 Added entry -- Uncontrolled related/analytical title (R)

Indicator 1: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including

spaces)

*Indicator 2:*Type of added entry. See Indicator 2 under 700

-- No information provided

2 -- Analytical entry

(This field was redefined in 1994 with Format Integration. Prior to 1994, the field was also used for variant titles, such as a different wording on a spine title. In records created since Format Integration, those variant tiles appear in a 246 field.)

Subfield used most often:

$a -- Title

```
Example:    740 02 $a Uncle Vanya.
```

800 Series added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

1 -- Surname

3 -- Family name

Indicator 2 undefined.

Subfields used most often:

$a -- Personal name

$b -- Numeration

$c -- Titles and other words associated with a name (R)

$q -- Fuller form of name

$d -- Dates associated with a name (generally, year of birth)

$t -- Title of a work (the series)

$v -- Volume number

```
Example:    800 1# $a Fisher, Leonard Everett.
                   $t Colonial American craftsmen.
```

830 Series added entry -- Uniform title (R)

Indicator 1 undefined.

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Subfield used most often:

$a -- Uniform title

$v -- Volume number

```
Example:    830 #0 $a Railroads of America (Macmillan)
```

[Back to Top of Page]

Part VIII:

A List of Other Fields Often Seen in MARC Records

001	Control number
003	Control number identifier
005	Date and time of latest transaction
006	Fixed-length data elements -- additional material characteristics
007	Physical description fixed field
008	Fixed length data elements (See Part X)
022	International Standard Serial Number (ISSN)
037	Source of acquisition
041	Language code
043	Geographic area code
050	Library of Congress call number
060	National Library of Medicine call number
082	Dewey Decimal classification number (the one recommended by the Library of Congress; locally-assigned call numbers may appear elsewhere)
110	Main entry -- Corporate name (less frequent under AACR2 rules)
256	Computer file characteristics
263	Projected publication date (indicates a CIP -- Cataloging in Publication -- record)
306	Playing time
508	Creation/production credits note
510	Citation/references note (review sources)
511	Participant or performer note
521	Target audience note (first indicator: 0 = reading grade level, 1 = interest age level, 2 = interest grade level, 3 = special audience characteristics, 4 = motivation interest level)
530	Additional physical form available note
538	System details note
586	Awards note
656	Index term -- Occupation
730	Added entry -- Uniform title
852	Location
856	Electronic location and access
9XX	Reserved for local use. (They are used by vendors, systems, or individual libraries to exchange additional data)

[Back to Top of Page]

Part IX:

The Leader

There are 24 positions in the Leader, numbered from 00 to 23. For fuller explanation, see the *MARC 21 Format for Bibliographic Data*.

00-04 Record length (calculated by the computer for each record)

05 Record status
- a = increase in encoding level
- c = corrected or revised
- d = deleted
- n = new
- p = increase in encoding from prepublication (previous CIP)

06 Type of record
- a = language material
- c = printed music
- d = manuscript music
- e = cartographic material
- f = manuscript cartographic material
- g = projected medium
- i = nonmusical sound recording
- j = musical sound recording
- k = 2-dimensional nonprojectable graphic
- m = computer file
- o = kit
- p = mixed materials
- r = 3-dimensional artifact or naturally occurring object
- t = manuscript language material

07 Bibliographic level
- a = monographic component part
- b = serial component part
- c = collection
- d = subunit
- i = integrating resource
- m = monograph/item
- s = serial

08 Type of control
- # = no specified type
- a = archival

09 Character coding scheme
- # = MARC-8
- a = UCS/Unicode

10 Indicator count (always "2")

11 Subfield code count (always "2")

12-16 Base address of data (calculated by the computer for each record)

17 Encoding level
- # = full level

1 = full level, material not examined
2 = less-than-full level, material not examined
3 = abbreviated level
4 = core level
5 = partial (preliminary) level
7 = minimal level
8 = prepublication level (CIP)
u = unknown
z = not applicable

18 Descriptive cataloging form
= non-ISBD
a = AACR2
i = ISBD
u = unknown

19 Multipart resource record level
= Not specified or not applicable
a = Set
b = Part with independent title
c = Part with dependent title

20 Length of the length-of-field portion (always "4")
21 Length of the starting-character-position portion (always "5")
22 Length of the implementation-defined portion (always "0")
23 Undefined (always "0")

[Back to Top of Page]

Part X:

Field 008 for Books

Field 008 is used for Fixed Length Data Elements ("Fixed Field Codes"). There are 40 character positions in field 008, numbered from 00-39. Undefined positions must contain either a blank (#) or a fill character (|). Positions 00-17 and 35-39 are defined the same way for all media.

The information shown here for positions 18-34 applies only to books. For explanation of all the positions below and for positions 18-34 for other media, see the *MARC 21 Format for Bibliographic Data*.

Note that field 008 has no indicators or subfield codes.

00-05 Date entered on file (YYMMDD),
where Y=year, M=month, and D=day

06 Type of date/publication status:
b = no dates given; B.C. date involved
e = detailed date
s = single known date/probable date
m = multiple dates
r = reprint/reissue date (Date 1) and original date (Date 2)

n = dates unknown
q = questionable date
t = publication date and copyright date
| = no attempt to code

07-10 Date 1/beginning date of publication

11-14 Date 2/ending date of publication

Date fields contain the year(s) of publication. The type of date(s) in these elements are specified in fixed field element 06: Type of date/publication status. (For further details, see the field 008 description in the *MARC 21 Format for Bibliographic Data*.)

15-17 Place of publication, production, or execution

For example:
pk# = Pakistan
cau = California (US)

(For a full list of codes used in these positions, see the *MARC Code List for Countries*.)

18-21 Illustrations (up to 4 codes):

= no illustrations
a = illustrations
b = maps
c = portraits
d = charts
e = plans
f = plates
g = music
h = facsimiles
i = coats of arms
j = genealogical tables
k = forms
l = samples
m = phonodisc, phonowire, etc.
o = photographs
p = illuminations
| = no attempt to code

22 Target audience:

= unknown or not specified
a = preschool
b = primary
c = pre-adolescent
d = adolescent
e = adult
f = specialized
g = general
j = juvenile
| = no attempt to code

23 Form of item:

= none of the following
a = microfilm

b = microfiche
c = microopaque
d = large print
f = braille
r = regular print reproduction
s = electronic
| = no attempt to code

24-27 Nature of contents (up to 4):

= no specified nature of contents
a = abstracts/summaries
b = bibliographies (is one or contains one)
c = catalogs
d = dictionaries
e = encyclopedias
f = handbooks
g = legal articles
i = indexes
j = patent document
k = discographies
l = legislation
m = theses
n = surveys of literature
o = reviews
p = programmed texts
q = filmographies
r = directories
s = statistics
t = technical reports
u = standards/specifications
v = legal cases and notes
w = law reports and digests
z = treaties
| = no attempt to code

28 Government publication:

= not a government publication
i = international intergovernmental
f = federal/national
a = autonomous or semi-autonomous component
s = state, provincial, territorial, dependent, etc.
m = multistate
c = multilocal
l = local
z = other type of government publication
o = government publication -- level undetermined
u = unknown if item is government publication
| = no attempt to code

29 Conference publication:

0 = not a conference publication
1 = conference publication

| = no attempt to code

30 Festschrift:
0 = not a festschrift
1 = festschrift
| = no attempt to code

31 Index:
0 = no index
1 = index present
| = no attempt to code

32 Undefined (since 1990) (Earlier records may contain the values 0 or 1)
= Undefined
| = no attempt to code

33 Literary form:
0 = not fiction (not further specified)
1 = fiction (not further specified)
c = comic strips
d = dramas
e = essays
f = novels
h = humor, satires, etc.
i = letters
j = short stories
m = mixed forms
p = poetry
s = speeches
u = unknown
| = no attempt to code

34 Biography:
= no biographical material
a = autobiography
b = individual biography
c = collective biography
d = contains biographical information
| = no attempt to code

35-37 Language:
A three-letter code. For example: eng fre ger spa rus ita

(For a full list of codes used in these positions, see the *MARC Code List for Languages*.)

38 Modified record:
= not modified
x = missing characters (because of characters unavailable in MARC character set)
s = shortened
d = "dashed-on" information omitted
r = completely romanized/printed cards in script
o = completely romanized/printed cards romanized
| = no attempt to code

39 Cataloging source:

= national bibliographic agency
c = cooperative cataloging program
d = other sources
u = unknown
| = no attempt to code

[Back to Top of Page]

[Back to Table of Contents] -- [Continue to Part 11]



Library of Congress
Library of Congress Help Desk (10/27/2009)

Appendix C. Materials Considered

Ex	Description
1004	Piekarski, W., Gunther, B., & Thomas, B. (1999, October). Integrating virtual and augmented realities in an outdoor application, in *Proceedings 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99)*, pp. 45-54 ("*Piekarski 1999*").
1004A	Copy of *Piekarski 1999*, obtained from IEEE.
1004B	Bibliographic and MARC records for *IWAR'99* that contains *Piekarski 1999*, available at https://catalog.lindahall.org/permalink/01LINDAHALL_INST/19lda7s/alma993272023405961 from the online catalog of the Linda Hall Library.
1004C	Profile of the Linda Hall Library, available from http://librarytechnology.org/library/2294.
1004D	MARC record for *IWAR'99* that contains *Piekarski 1999*, available at https://bruknow.library.brown.edu/discovery/sourceRecord?vid=01BU_INST:BROWN&docId=alma991027189429706966&recordOwner=01BU_INST from the online catalog of Brown University.
1004E	Copyright registration record for *IWAR'99* that contains *Piekarski 1999*, available at https://cocatalog.loc.gov/cgi-bin/Pwebrecon.cgi?Search_Arg=IEEE+and+ACM+International+Workshop+on+Augmented+Reality&Search_Code=TALL&PID=9X-t0-gaYyV_RvDUzG5W_SMonAxx7&SEQ=20250226131211&CNT=25&HIST=1 from the public catalog of the US Copyright Office.
1004F	IEEE metadata record for *Piekarski 1999*, available at https://ieeexplore.ieee.org/abstract/document/803805 from IEEE Xplore.
1004G	Website of IEEE Xplore archived by Internet Archive on February 7, 2001, available at https://web.archive.org/web/20010207003457/http://ieeexplore.ieee.org/lpdocs/epic03/
1004H	Webpage of "tinmith research papers" that includes a link to *Piekarski 1999,* last updated on July 17, 2002, archived by Internet Archive on

	August 9, 2002, available at https://web.archive.org/web/20020809170822/http:/www.tinmith.net/research.htm; and a copy of *Piekarski 1999*, archived by Internet Archive on July 18, 2003, available at https://web.archive.org/web/20030718234001/http://www.tinmith.net/papers/piekarski-iwar-1999.pdf.
1004I	Citations to *Piekarski 1999*, obtained from Google Scholar.
1009	Piekarski, W., & Thomas, B. (2001, January). Augmented reality with wearable computers running linux, in *2nd Australian Linux Conference (Sydney)*, 14 unnumbered pages, archived by Internet Archive on July 19, 2003, available at https://web.archive.org/web/20030719115835/http://www.tinmith.net/papers/piekarski-linuxconf-2001.pdf ("*Piekarski 2001*").
1009A	Copy of *Piekarski 2001*, available at https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=17b8a389559401112a3e826b9393c44588534bc7 from CiteSeerX.
1009B	Webpage of "tinmith research papers" that includes a link to *Piekarski 2001,* last updated on July 17, 2002, archived by Internet Archive on August 9, 2002, available at https://web.archive.org/web/20020809170822/http:/www.tinmith.net/research.htm
1009C	Citations to *Piekarski 2001*, obtained from Google Scholar
1010	Milgram, P., & Kishino, F. (1994, December). A taxonomy of mixed reality visual displays, *IEICE Transactions on Information and Systems*, Vol. E77-D, No. 12, 1321-1329 ("*Milgram*")
1010A	Copy of *Milgram*, obtained from IEICE Digital Library at https://globals.ieice.org/en_transactions/information/10.1587/e77-d_12_1321/_p.
1010B	Bibliographic and MARC records for *IEICE Transactions on Information and Systems* that contains *Milgram*, available at

	https://catalog.lindahall.org/permalink/01LINDAHALL_INST/19lda7s/alma992684223405961 from the online catalog of the Linda Hall Library.
1010C	Profile of the Linda Hall Library, available from http://librarytechnology.org/library/2294.
1010D	Citations to *Milgram*, obtained from Google Scholar.
1013	Rolland, J. P., Holloway, R. L., & Fuchs, H. (1995, December). Comparison of optical and video see-through, head-mounted displays, in *Telemanipulator and Telepresence Technologies : 31 October-1 November 1994, Boston, Massachusetts*, Proceedings of SPIE vol. 2351, pp. 293-307 ("*Rolland*").
1013A	Copy of *Rolland*, obtained from the webpage for this article at https://www.spiedigitallibrary.org/conference-proceedings-of-spie/2351/0000/Comparison-of-optical-and-video-see-through-head-mounted-displays/10.1117/12.197322.short at the SPIE Digital Library
1013B	Bibliographic and MARC records for *Telemanipulator and Telepresence Technologies : 31 October-1 November 1994, Boston, Massachusetts*, Proceedings of SPIE vol. 2351, available at https://catalog.lindahall.org/permalink/01LINDAHALL_INST/19lda7s/alma991809043405961 from the online catalog of the Linda Hall Library.
1013C	Profile of the Linda Hall Library, available at http://librarytechnology.org/library/2294.
1013D	Copyright registration record for *Telemanipulator and Telepresence Technologies : 31 October-1 November 1994, Boston, Massachusetts*, Proceedings of SPIE vol. 2351, available at https://cocatalog.loc.gov/cgi-bin/Pwebrecon.cgi?v1=1&ti=1,1&Search%5FArg=Telemanipulator%20and%20Telepresence%20Technologies&Search%5FCode=TALL&CNT=25&PID=kHsYul4cOnaBUPzkg7E-QFTV3qeYt&SEQ=20250323194255&SID=1 from the public catalog of the US Copyright Office.
1013E	Citations to *Rolland*, obtained from Google Scholar.

1014	Excerpts of *The Legend of Zelda : A Link to the Past : Prima's Official Strategy Guide* by Bryan Stratton and Stephen Stratton (2002), obtained from the Library of Congress ("*Stratton*").
1014A	Select pages from a digitized copy of *Stratton* in Internet Archive Books, available at https://archive.org/details/legendofzeldal00brya
1014B	Bibliographic and MARC records for *Stratton*, available at https://lccn.loc.gov/2002114735 from the online catalog of the Library of Congress.
1014C	Profile of the Library of Congress, available at https://librarytechnology.org/library/2263
1014D	Publisher's webpage for *Stratton* archived by Internet Archive on February 18, 2003, available at https://web.archive.org/web/20030218203023/http://www.primagames.com/strategy/book/6300/ and the online order webpage archived by Internet Archive on March 2, 2003, available at https://web.archive.org/web/20030302133235/http://www.primagames.com/strategy/book/order/6300/
App A	Hsieh-Yee CV
App B	Parts VII to X of Understanding MARC Bibliographic, available at https://www.loc.gov/marc/umb/um07to10.html

EXHIBIT 1004A

Integrating Virtual and Augmented Realities in an Outdoor Application

Wayne Piekarski, Bernard Gunther, and Bruce Thomas

Advanced Computing Research Centre
University of South Australia
Mawson Lakes, SA 5095
Australia
{piekarski, gunther, thomas}@cs.unisa.edu.au

Abstract

This paper explores interconnecting outdoor AR systems with a VR system to achieve collaboration in both domains simultaneously. We envisage multiple mobile users of wearable AR systems interacting with a stationary VR facility via a wireless network. An application in simulated combat training is described, where the AR users are soldiers with wearable computers, and the VR system is located at a command and control centre. For soldiers, AR provides enhanced information about the battlefield environment, which may include the positions and attributes of simulated entities for the purpose of training outdoors at low cost. At the same time a complete picture of the battlefield, including real and simulated troops and vehicles, is available via the VR system. As soldiers move about, their GPS and digital compass hardware provide the remote VR user and other AR users with the means to track their position in real-time. We describe a working system based on our modular Tinmith-II wearable computer, which interacts with a combat simulator to create a synthetic battle environment for safe training and monitoring.

1. Introduction

The advent of wearable computers [3,8,15,16] and lightweight head-mounted displays (HMDs) has made augmented reality applications feasible outdoors. Augmented reality (AR) is the process of a user viewing the physical world and virtual information simultaneously, where the virtual information is overlaid and aligned to the physical world view [1]. Many of the existing applications of AR, such as head-up displays in aviation, assistance for surgery, and maintenance work, are characterised by requiring precise tracking in small operating regions.

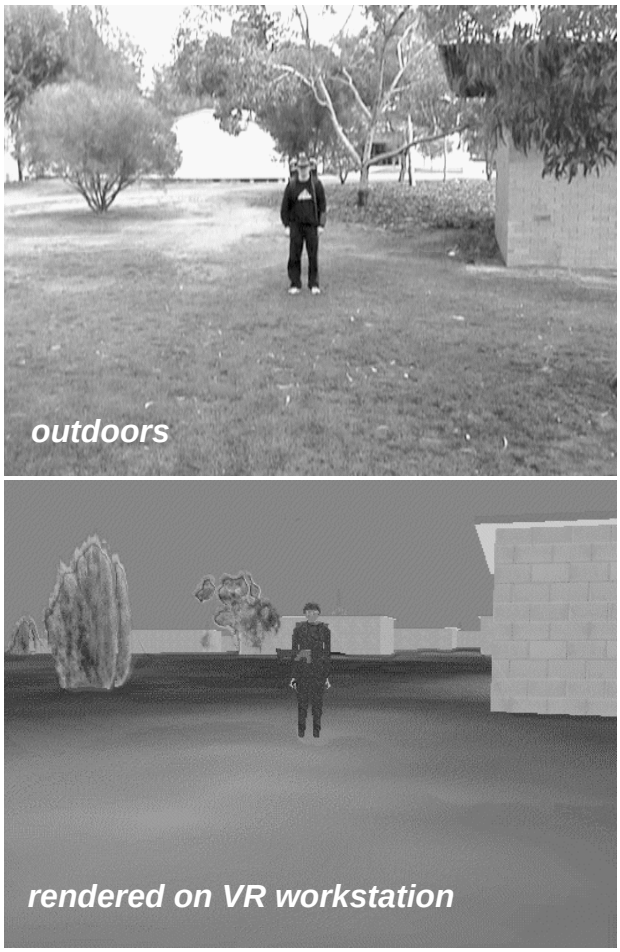


Figure 1. Linking a wearable AR system to a VR system enables mobile entities (the AR user, top) to be shown in relation to fixed entities (the trees and buildings) that exist in the terrain model, bottom.

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However, through coupling global positioning system (GPS) receivers and digital compass with geographic databases, we can create spatially-aware computer systems for mobile users working outdoors. We anticipate outdoor users wishing hands-free operation, and thus related AR applications are especially well supported by wearable computers and non-traditional input devices

The concept of collaboration in virtual reality (VR) has been explored previously [5,7,17], whereas collaboration in AR is somewhat less developed [4,13]. We are intrigued by the possibilities of interconnecting VR and AR systems to achieve collaboration in both domains *simultaneously*. At the simplest level, we can imagine two users—one mobile and one stationary—interacting as suggested in Figure 1. The mobile user dons a wearable AR system and is able to interact with the world outside, while the stationary user (not shown in the figure) wears a HMD or views the screen(s) of a VR workstation situated indoors. Both computer systems are in radio contact with each other. Since the AR user carries no video camera, the VR system must rely on a three-dimensional database of the outdoor environment in order to place the AR user in it. The wearable computer transmits its GPS position so that the VR system can draw an avatar at the appropriate location. Now if the VR user were to insert an object into the virtual world, an iconic representation of that object would appear overlaid on the AR user's outdoor view. We are therefore able to exploit the large computing power of the VR system, without affecting the computing requirements of the wearable AR systems.

Our previous work has demonstrated AR systems functioning as powerful navigation and visualisation tools for individuals [10,12,14]. This paper describes extensions to our work that facilitate collaborative activities in joint AR/VR applications, sited outdoors. We show how the necessary infrastructure for collaborative AR applications readily integrates with a remote VR system. To illustrate the concepts we will focus on an application for military training that incorporates both real and simulated entities, with the latter being used to enrich outdoor training exercises cost-effectively and safely.

In collaboration with the Australian Defence Science and Technology Organisation (DSTO) and the Australian Army we are investigating technology that may improve the effectiveness of the dismounted combat soldier. The initial application that we investigated was the use of a wearable computer to support navigational tasks, since navigation is an essential and time-consuming task for soldiers on foot. The significance of the navigation application lies in its departure from tracking users in small operating regions. In this regard, it relates to recent work in large area augmented reality, such as the *Touring Machine* project by Feiner *et.al* [6], which allows users to walk around the Columbia University campus and access information via a tracked see-through display and a hand-held display.

Beyond knowing his own position, a soldier must also gain awareness of enemy threats and friendly positions alike. The latter case reflects the fact that soldiers normally operate collaboratively. However, collaborators need not be restricted to other dismounted soldiers, but may include vehicles and aircraft, whose presence adds diversity and thus hinders rapid assimilation. We use AR to supply the soldier with easily understood information about his battlefield environment, for example: indications of threats, the location of friendly forces, and the status of aircraft as they approach. Fortunately, the acceptable tracking accuracy required for this application is attainable without special motion compensation in the display system. The open problem of accurate feature registration outdoors is not addressed any further in this paper [2].

Radio data communications between wearable computers underpins an outdoor collaborative AR system. The mobile units are also able to interact with the central command and control centre, which operates a stationary radio base station. This facilitates potentially two-way interaction: communication of situational awareness information to the soldier, and, conversely, detailed information back to the base for populating its 3D model. Thus, in a live training or combat situation the base can track field positions dynamically to provide high-level command and control information; however, in a simulated exercise the base can host a simulated battle accessible through a VR system. This latter scenario is the one we explored in more detail.

In the following sections we define the operational requirements of the larger system, and how it functions. We then describe our wearable AR system, and discuss how this was modified to support collaborative work. We conclude with observations gained from a test evaluation.

2. Augmented Reality Meets Virtual Reality

We set out to develop a system for demonstrating AR techniques for use by an individual using a wearable computer interacting with the Modular Semi-Automated Forces (ModSAF) simulated combat system [18]. The Synthetic Environment Research Facility (SERF) in DSTO's Land Operations Division employs ModSAF to generate synthetic battle environments in simulated exercises. A synthetic battle may, of course, involve fictitious entities (soldiers, vehicles, and aircraft) as well as the real entities actually participating in the exercise. The system is designed so that a helicopter pilot in a training exercise,

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for example, can participate in a virtual battle via a VR system. The pilot sees the output of the VR camera through three angled CRTs, driven by MetaVR running on a high-end PC. The MetaVR software [9] displays photorealistic battlefield terrain and receives dynamic positions of entities via the Distributed Interactive Simulation (DIS) protocol (IEEE Standard 1278), which is the principal protocol used between AR and VR systems in this project. DIS is a high-bandwidth, stateless protocol: entity positions must be continuously retransmitted if the entities are to be displayed, otherwise they are considered to be nonexistent after 5 seconds.

Persistent data about entities known to exist on the battlefield are maintained by the Land Situational Awareness Picture System (LSAP), which provides a Java front-end to an Oracle DBMS. The positions and attributes of entities held in LSAP can be accessed by command and control staff to provide them with situational awareness of the engagement. Units in the field can radio reports back to LSAP to update the battlefield view as entities are detected, eliminated, or known to move.

2.1 Objectives and Overview of the System

The main objective of the system was to demonstrate the possibility of a dismounted soldier interacting with information from remote simulation and situational awareness systems (ModSAF and LSAP) using AR techniques. LSAP and DIS were used to filter appropriate information to users in the field, who see overlaid on their view of the physical battlefield iconic representations of both real and simulated entities that populate the synthetic battle environment. In turn, users of the VR facility have a complete, albeit artificial view of the entire battlefield. We anticipate that the combination of these capabilities can facilitate operational and training developments in information transfer between individual soldiers and higher command systems.

2.2 Interaction with the Wearable Computer

As previously mentioned, we wish to strengthen collaboration by improving communication between mobile and stationary personnel. The interactions we support include:

- the wearable computer overlays on the user's HMD iconic information locating friendly and enemy forces; for example, in a training application the icons may represent the positions of dismounted forces generated by the ModSAF simulator at SERF
- users of wearable computers can update or populate the 3D database maintained centrally; for example, the user may locate a previously unknown enemy and inform the LSAP system as to the *relative* position and nature of the entity
- hardware at SERF presents a virtual view of the battlefield, which includes avatars for 3D viewing, and icons for 2D plan views; as wearable users move, their GPS systems continue to provide real-time positional data to command personnel
- furthermore, with additional real-time data specifying the pitch, roll, and yaw of the soldier's head, the presentation of the virtual world at SERF can be slaved to the soldier's direction of view; in other words, we can provide a virtual camera without video equipment

3. Wearable Computer System

The wearable computer system we used for this work was based on Tinmith-II [10], a complete research system developed at the Wearable Computer Laboratory at the University of South Australia. Figure 2 pictures the current hardware platform.



Figure 2. Photograph of the Tinmith-II wearable computer.

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3.1 Hardware Components

Tinmith-II is built upon a Toshiba 320CDS notebook running the freely available LinuxOS. The laptop is about the size of an A4 book and fits comfortably on a wearer's back. A Sony PLM-100 transparent display, worn on the user's head as shown in Figure 3, allows the video output of the computer to superimpose images over the real world. A Phoenix miniature keyboard attached to the forearm enables the user to interact with the system and enter commands.



Figure 3. Users of the wearable computer see through a Sony PLM-100 transparent head-mounted display, and enter commands on a Phoenix forearm keyboard.

To support the navigation functions of our application, a GPS module (with differential receiver) connects to the laptop, and provides position fixes at most places in the world to within 5 metres accuracy. A TCM2 3-axis digital compass, also attached to the display, allows the computer to determine exactly how the wearer's head is oriented relative to the surface of the Earth. This information is used to render the display so that it remains in correspondence with the user's physical world view.

All of the equipment is attached to a rigid backpack, along with batteries and antennae. The prototype hardware and software system is fully functional in outdoor environments.

3.2 Head-Up Displays and Interfaces

The system is capable of presenting alternative interfaces to the user, namely, two-dimensional and three-dimensional. Since navigation remains an important activity for the soldier, all of the user interfaces feature our original navigational aids.

The 2D interface incorporates a first person perspective, God's-eye view, and traditional non-spatially aware information on one display, as shown in Figure 6. At the top of the display is the compass heading, which is represented as notches and a value every 45 degrees. As the user rotates their head, the compass updates itself and scrolls left or right to indicate the new heading. The various pieces of text in formation placed around the display are used to show position, GPS accuracy, and steering instructions to the nominated waypoint so as to aid navigation by the wearer. Underneath the text is the map and navigation gadget display. At the centre of the display is a cross, indicating the current position of the system and user. Shown in the figure are outlines of objects in the environment, and the circular object in the centre of the screen gives steering instructions to the user indicating in which direction they must turn to reach the target. Every visual cue is rotated in real time as the user moves around. In operation, we were able to maintain approximately 2 to 5 metre accuracy given a good fix on 6 or more GPS satellites.

The alternative interface features a 3D immersive display superimposed on the wearer's field of view. When looking through this display we are able to register the display with the outline of a surveyed object within the accuracy limits of the differential GPS and digital compass. For example, we were able to make a cube lock around an outdoor bench as we walked around it.

3.3 System Architecture

To support a wide range of AR and navigation tasks applications, we developed a highly modular architecture. The software system is broken up into various modules that communicate with each other using a connection-oriented protocol—in this implementation, TCP/IP.

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Modular approach

An example of an application specific module is the *navigation* module, which reads waypoints from a database, along with position and heading information, to produce steering instructions for other modules to present to the user. The *display* module presents data from other modules in a graphical format to the user via the head up display. The modular architecture supports many concepts such as data abstraction and hiding, collaboration with others, and the flexibility to plug new components in without modifications.

Communications

To interconnect modules, we used a client-server style architecture. The server is a data source for other modules, which subscribe to it. Whenever the server updates the value of system data (a GPS position, for example), it will send the new value out to all clients that have registered an interest in the message. A client receiving new data may use it to update the screen, or calculate new navigation parameters for example. Actually, many servers in the system also act as clients for other servers as well. The entire system operates asynchronously, and is data driven; if there is no new data in the system, no action will be taken by any of the software modules.

Suppose a new incoming position was received from the GPS hardware. The new data will be formatted appropriately and then distributed to all client modules. The navigation module will receive this update, and recalculate navigation information. The display module will eventually receive a position update, along with the new steering instructions from the navigation module, and use these to redraw the screen to reflect the user's new location.

3.4 Software design

To implement the modular architecture, an appropriate supporting software library was designed, with goals to be flexible, extensible, and layered. Layering was exploited to provide increasing levels of abstraction for allowing modules to interact with the system at the appropriate level they require, while at the same time minimising code replication across the system, and localising possible errors. The libraries provide functionality for distributive processing, asynchronous I/O, dynamic configuration, and automatic code generation.

Running modules in parallel over TCP/IP

Each of the modules are implemented as separate Unix processes, which communicate via kernel network services. This allows modules to be distributed over multiple processors on one machine, or multiple machines due to the network support. The ability for the system to support this at a fundamental level improves the scalability for larger, resource-intensive applications. For those modules confined to a single machine the networking between them is virtualised by the kernel, and hence the corresponding latency and bandwidth of the communication channels are orders of magnitude better than through a real external network.

Dynamic configuration from a DBMS

Most software tends to use statically compiled controls, or possibly a configuration file. Our system takes configuration to the next level by loading all system parameters such as the 2D maps, 3D object models, location of modules, port numbers, device names, and screen configuration into a collection of relational database tables. When the software initialises, it queries the database and loads the values required. By sending messages throughout the system when changes are made, it is possible for clients to reconfigure themselves by querying the database. The software does not have to be restarted as would be required if the controls were static. The database proved to be very powerful because it can be changed remotely over the wireless network. This feature turned out to be useful when testing outdoors, for example, tuning the various display options such as colours and font sizes. An added feature is the strong type checking by the database engine (in our case PostgreSQL v6.4 [11]) rather than relying on parsing a text file.

4. Integrating a VR Simulation System

Figure 4 pictures the dataflows and interfaces in our concept demonstrator system. A PC running our *modlsapdis* software mediates between the base station and one or more wearables in the field. Internally *modlsapdis* comprises two modules: a protocol converter that translates packet formats between DIS and our internal format; and a communication module that relays packets via a wireless network to any wearables. Lucent WaveLan 2.4GHz wireless network cards at the base station and in each wearable form the basis for a high-speed (faster than 2Mbps) network.

In effect the communication module of *modlsapdis* is really a part of the wearable systems, except that it runs on a stationary computer. As each wearable unit goes on-line it registers with the communication module in order to establish a wireless point-to-point network link with the base station. In the case where several wearables have registered such links the communication module must multicast entity state packets to all registered computers so that every user in the field receives updates to their

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environment. Since communication between Tinmith modules is based on TCP/IP, the base station appears logically to a wearable system as just another software module.

At the base the *modlsapdis* protocol converter listens on the ethernet network for incoming entity state DIS packets from the simulator, while also communicating textual data to LSAP via a Java remote method invocation (RMI) interface. *Modlsapdis* continuously receives information about entities in the battlefield, reformats the information, and passes it to the communication module. To avoid flooding the wireless links, duplicate updates and objects that have not changed are removed from the data stream. Moreover, the AR software is not required to respond to all simulation events.

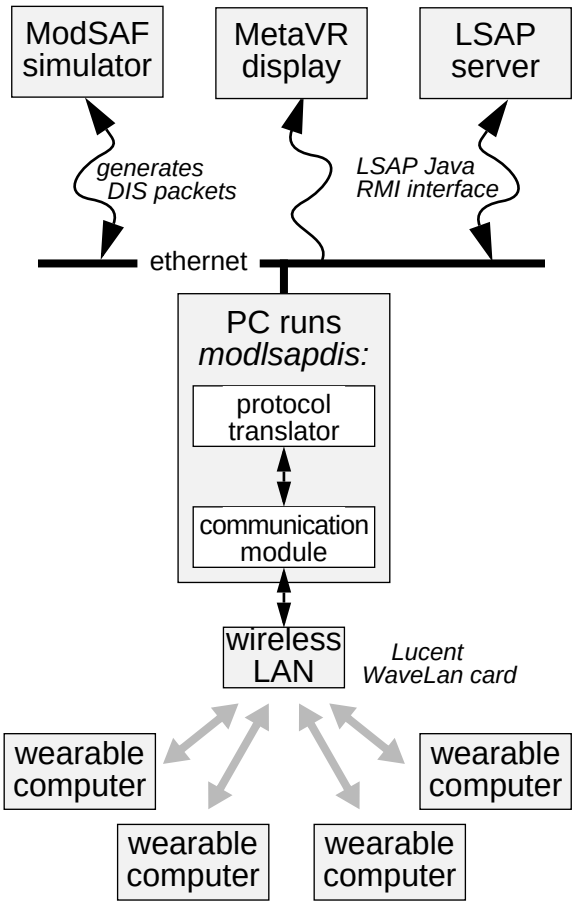


Figure 4. Block diagram of the combined AR/VR system. ModSAF generates a simulated battle environment, which is tracked in the LSAP database. One or more wearable computers in the field interact with the VR host PC via wireless network links. The entire engagement is visible on the MetaVR display.

4.1 Simulation and VR System

ModSAF is a complex, complete military simulation environment with a graphical interface. It can simulate a complete battle, including the movements of tanks, helicopters, and soldiers. Thus, soldiers participate in simulated combat, drive and refuel vehicles, reload ammunition, and fly aircraft, in addition to numerous other activities. During simulation, ModSAF maintains a terrain database, emits DIS packets defining the dynamic positions of entities, and produces a complete map showing a top-down view of all entities moving over the terrain.

The MetaVR visualisation software provides us with battlefield views so that a battle can be observed as it unfolds. MetaVR renders a world with photorealistic terrain, which includes all DIS entities that need to be drawn and animated, such as rotating helicopter rotors, and movable tank turrets.

MetaVR is also used to render displays for an attached helicopter simulator. Three computers running MetaVR provide three views from the simulated cockpit; one machine simulates the motion and dynamics of the helicopter, while another draws views of the helicopter's infrared turret. This is a good example of how DIS caters for distributed processing, even though only one helicopter is being simulated. With wearable computers in the field it is possible for the helicopter pilot to see the location of each wearable unit, while a soldier with a wearable can see simulated helicopters moving around in his field of view.

4.2 Wearable Computer Software

The internal software architecture of the wearable computer is depicted in Figure 5. The *modtracker* module is designed to distribute the data read from the wireless network link to all of the other installed modules. In our system, modules subscribe to other modules. For example, we have the *navigation* and *display* modules both listening for entity information, and it would be wasteful of bandwidth to send two copies over the network each time an update occurs. Moreover, some code might wish to determine the latest location of all battlefield entities, and thus another purpose of *modtracker* is to build and maintain a local copy of the entire environmental state for the remote wearable computer.

In some sense, *modtracker* acts as a proxy; it receives all the external information available to it, stores it, and then redistributes it to other modules on demand. Since *modtracker* is the only module allowed to access the wireless link, we can easily hide the implementation of the communication protocols from the other modules, such as

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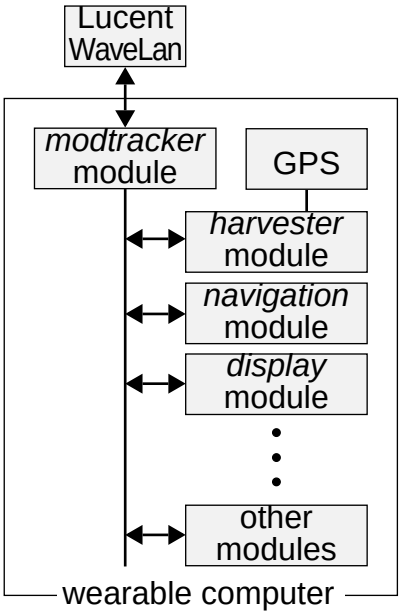


Figure 5. Software architecture of the wearable computer equipped to interact with ModSAF.

the *display* module, for instance. This allows future implementations to include data compression or replacement of TCP/IP without affecting the remainder of the system.

The reverse function of the wearable computer system is to return the position and orientation of each soldier. The *harvester* module sends the GPS location out through *modtracker*, which transmits data packets to the fixed computer at SERF. Ordinarily, these packets identify individuals in the field so that a VR user at SERF can visualise both the simulated and real entities from a bird's eye view. However, it would be equally feasible to slave the VR camera to any individual's head movements so as to gain their *personal view*—albeit with artificial renditions of real objects.

5. Initial Evaluation

The wearable computer system was used in demonstrations of the capability of an individual walking around and interacting simultaneously with the ModSAF and LSAP systems at DSTO.

5.1 Practical Trials

The first exercise involved some 50 entities of all kinds (including tanks, helicopters, and soldiers) generated by ModSAF and populating a synthetic battlefield. We wished to determine whether our system could cope with a large number of dynamic entities, and keep them in the correct position on the AR display. We observed that the display frame rate did not degrade due to the data load, and that the display was being updated with entity positions as they were generated in real-time.

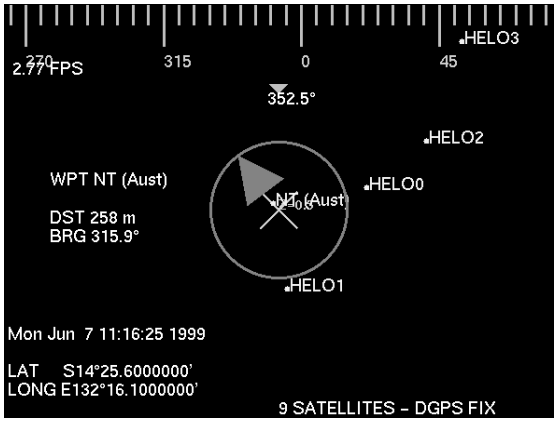


Figure 6. Two-dimensional, plan view of the battlefield, as generated to augment the user's outlook. Central cross marks the user location. Four helicopters, HELO0–HELO3, are shown as labelled dots in relation to the user's position.

In the second experiment, a simulated helicopter was made to "fly" around the wearable computer user standing in MetaVR's synthetic environment. As the helicopter circled overhead, it was easy for the wearable user to track the motion of the helicopter on their display by rotating their head. Of course, the user on the ground could see only an iconic representation of the helicopter, as the simulated craft did not really exist. This experiment proved that moving, simulated entities generated by ModSAF could be observed in real-time through the AR interface. We verified the result by comparing the AR display with a map generated by ModSAF. For example, when the helicopter was located north of the mobile user, they had to face north in order to see the helicopter.

An illustration of the generated 2D AR interface appears in Figure 6, where the dark background would normally be replaced by the user's view of the real environment. In this view, the user occupies the central cross and is navigating with the aid of the compass displayed at the top. The four (in this case, simulated) helicopters flying overhead are indicated on the plan as labelled dots in scale with the user's distance from the waypoint ahead (marked "WPT NT Aust" on the display).

With the press of a button the alternative 3D interface can be invoked, as pictured in Figure 7. Here, the central cross is directed by the user's head orientation, which appears to be just below the horizon in Figure 7. The hashed diamond to the left represents the current waypoint being navigated. Three (simulated) helicopters

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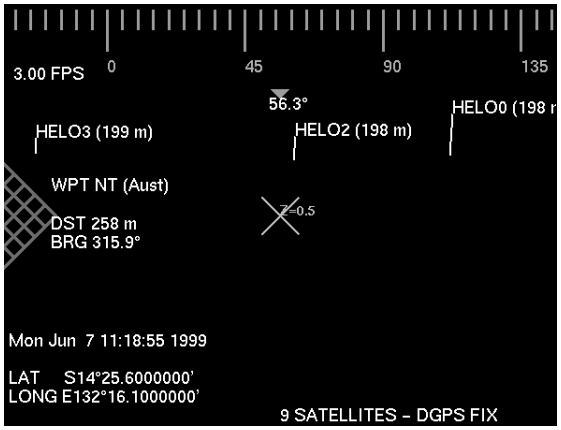


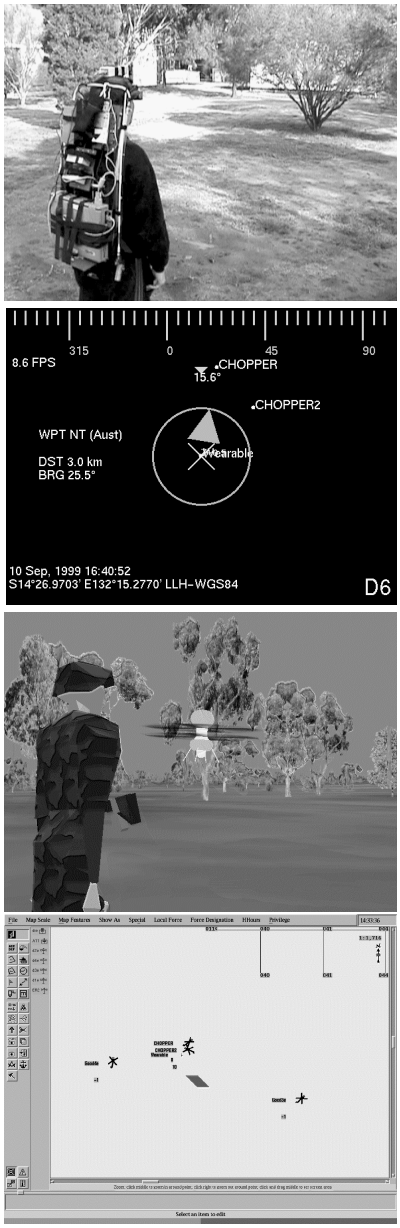
Figure 7. Three-dimensional view of a similar battlefield, as generated to augment user's outlook. Four helicopters, HELO0–HELO3, are shown as labelled altitude bars above the horizon, with HELO0's nearness indicated by the largest bar.

appear as labelled altitude bars emanating from the horizon. All the helicopters are flying at approximately 200 metres, but HELO0 is significantly closer than HELO3 and HELO2, and hence the altitude bar of HELO0 is correspondingly larger to indicate this fact. If an airborne entity is almost directly overhead its altitude bar simply extends to the top of the display.

Thirdly, we ensured that a user of the MetaVR system could visualise wearable AR units in the field. Figure 8 depicts four views of such a trial. Soldiers with AR equipment were rendered as 3D texture-mapped avatars, which correctly appeared and moved in relation to the real and simulated entities. The 3D models responded to movements in the corresponding wearable units, showing walking motion or rotations, for example. And by slaving the VR camera to the head position of a wearable unit, we were able to demonstrate an individual's view of the battlefield to a person sitting at the fixed SERF site.

5.2 Performance Measurement

In the second phase of our evaluation we wished to test the performance of our system to establish responsiveness and capacity to operate with a large number of entities. As part of its event driven nature, Tinmith updates its display in response to any change in user position or entity locations. Since the digital compass sends updates at a rate of 15Hz, the GPS updates at 1Hz, and entities arrive at indeterminate times, the frame rate generally lies between 15 and 20 frames per second, providing a fast updating display for the user.



(a) Mobile user, standing outdoors, observes a virtual helicopter.

(b) God's-eye view, AR screen display superimposed on wearer's view. Note a helicopter (labelled CHOPPER) directly in front of the wearer, whose position is marked by an X.

(c) Scene generated by MetaVR at the base station. It shows representations of both the mobile AR user and the virtual helicopter they are viewing.

(d) Corresponding screen shot from ModSAF, which generated the virtual entities appearing above.

Figure 8. Example application showing the integration between the AR and VR systems, simulator, and the real world in which the AR user stands.

In order to get some quantitative results we added instrumentation code to the Tinmith network libraries, which involved taking a timestamp in microseconds, using POSIX call `gettimeofday()`, embedding this in the message, and then decoding and comparing the result at the receiving end to measure the time taken in creating and transmitting the message.

We created an artificial test situation with the following parameters:

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- ModSAF generating DIS updates at 1 Hz for each of 7 entities sent over the wireless LAN to the wearable
- *modlsapdis* sending DIS packets for all 30 internal markers (waypoints) being tracked at 0.25 Hz. Since these markers are transmitted on the SERF side of the network, the wearable does not concern itself with sending these updates except when changes are made.
- the wearable position and orientation updated at 15 Hz, with this data transmitted over the wireless LAN each time.

During this test we observed that the CPU was reasonably utilised but not working at 100% capacity, and that the measured module to module delay ranged from 2.8 ms to 50 ms, although this increased to 100 ms in the event of the machine being temporarily heavily loaded. The accuracy of these measurements was marginally affected by the limited resolution of the Linux kernel timer and the overheads in calling it.

Module to module delay was measured only for messages being sent to the same machine over the local network. In attempting to measure messaging delays between *modtracker* and *modlsapdis* it was not practical to synchronise the clocks between the machines to microsecond accuracy and hence no proper measurements could be reported.

From the point of view of the MetaVR user, the delay between changes in orientation and the update of the display was definitely noticeable, with a lag of around 500 ms being observed consistently. This lag can be attributed to a small delay in the wearable, data transmission over the wireless LAN, retransmission as a DIS packet to MetaVR, and eventual rendering on the display. Since three separate computers (and their operating systems) and two networks are involved, some delay is to be expected. In practice, update lags to the VR display are not an issue because staff at headquarters are unable to see a real battlefield. Hence, the VR display is still an accurate rendition.

A powerful feature of the *modlsapdis* module is that even if the wireless LAN is disabled temporarily, due to an obstruction, for example, the module still retains state information from the unavailable wearable. *Modlsapdis* will continue to transmit waypoints and the wearable computer's last location, so the VR display and other wearables will still be able to visualise the entity and its markers. Without such a feature, a briefly unavailable wearable would disappear on account of the 5-second DIS protocol timeout.

6. Conclusions

With the emergence of outdoor AR, we expect integration with VR and collaboration to become more widely applicable for two reasons. Firstly, these capabilities give individuals remote from each other the option of an immersive user interface to substitute for physical presence with collaborators. For example, movements of users in the real environment are reflected in the VR. Secondly, multiple AR users can benefit from viewing a superimposed collective information space, which may include simulated entities where appropriate. This concept was exploited in the simulated combat training system to provide the illusion of a rich environment at relatively low cost, yet users of wearable computers are not restricted to training indoors as they might have been with VR equipment.

In regards to the architecture, use of it has shown a few places where changes could be made to improve both the throughput and latency of the system. It was not originally designed to be a system that would run optimally fast for AR registration purposes, but rather as a testbed with which we could test ideas for navigation and interaction across systems, such as those at DSTO's SERF. Future changes being considered are the use of shared memory and/or merging of modules (*display*, *navigation*, and *harvester*) to maximise the performance of local modules. The delays caused by task switching, kernel call overheads, and the like are small, but not negligible when trying to produce real time systems. However, we wish to maintain the network architecture, as it allows us to integrate modules and other software across platforms.

The Lucent WaveLAN cards are particularly suitable for this application due to their size and Mbps+ performance, which exceeds the performance offered by competing technologies such as cellular phones or standard radio modems. This allowed us to perform initial tests indoors using readily available Ethernet to substitute for the WaveLAN cards. Some problems we experienced with the cards include their requirement for line of sight reception, relatively short range (a few hundred metres), and their vulnerability to radio frequency interference.

Although not originally designed to support interaction with ModSAF, our Tinmith-II wearable computer was readily adapted to provide AR support for simulated combat training. The modular, data driven architecture and layered implementation of the software made it possible to incorporate new display sources with relative ease. The navigation module, which previously updated the display as the user moved, now also returned position data to the VR site to enable visualisation remotely. We found the accuracy afforded by differential GPS to be acceptable in a training application, particularly when relying on the

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two-dimensional AR interface. DSTO are interested in continuing development of the concepts described here, and we hope to conduct more detailed evaluations of the system under actual training conditions in future.

Acknowledgements

The authors would like to acknowledge the assistance of Victor Demczuk and Franco Principe of Land Operations Division at DSTO, Salisbury, South Australia. This work was supported in part by a DSTO research contract, No. 486216, “Concept Demonstrator System for Demonstration of Augmented Reality Techniques.”

References

[1] R. Azuma, “Survey of augmented reality,” *Presence: Teleoperators and Virtual Environments*, vol. 6, no. 4, 1997.

[2] R. Azuma, “The challenge of making augmented reality work outdoors,” in *Mixed Reality: Merging Real and Virtual Worlds*, Springer-Verlag, chap. 21, pp. 379–390, 1999.

[3] L. Bass, C. Kasabach, R. Martin, D. Siewiorek, A. Smailagic, J. Stivoric, “The design of a wearable computer,” in *CHI’97 Looking to the Future*, ACM SIGCHI, pp 139–146, 1997.

[4] M. Bauer, T. Heiber, G. Kortuem, and Z. Segall, “A collaborative wearable system with remote sensing,” in *Proceedings 2nd. Int’l Symp. on Wearable Computers*, pp. 10–17, Oct. 1998.

[5] C. Carlsson and O. Hagsand, “Dive—a platform for multi-user virtual environments,” *Computers and Graphics*, pp. 663–669, 1993.

[6] S. Feiner, B. MacIntyre, T. Hollerer, A. Webster, “A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment,” in *Proceedings 1st. Int’l Symp. on Wearable Computers*, pp. 74–81, Oct. 1997.

[7] T.A. Funkhouser, “Ring: A client-server system for multi-user virtual environments,” in *Computer Graphics*, pp. 85–92, April 1995.

[8] S. Mann, “WearCam (The Wearable Camera): Personal imaging systems for long-term use in wearable tetherless computer-mediated reality and personal photo/videographic memory prosthesis,” in *Proceedings 2nd. Int’l Symp. on Wearable Computers*, pp. 124–131, Oct. 1998.

[9] MetaVR, Inc., *MetaVR Virtual Reality Scene Generator*—http://www.metavr.com, 1999.

[10] W. Piekarski, D. Hepworth, V. Demczuk, B. Thomas, B. Gunther, “A mobile augmented reality user interface for terrestrial navigation,” in *Proc. 22nd Australasian Computer Science Conference*, Auckland, NZ, pp 122–133, Jan. 1999.

[11] *PostgreSQL v6.4.2 Database Engine*—http://www.postgresql.org, 1998.

[12] B. Thomas, V. Demczuk, W. Piekarski, D. Hepworth, B. Gunther, “A wearable computer system with augmented reality to support terrestrial navigation,” in *Proceedings 2nd. Int’l Symp. on Wearable Computers*, pp. 168–171, Oct. 1998.

[13] B.H. Thomas and S.P. Tyerman, “Collaboration issues for augmented realities in an outdoor environment,” in *Proceedings INTERACT97 combined Workshop on CSCW in HCI*, Sydney, pp. 29–33, Jan. 1997.

[14] B. Thomas, S. Tyerman, K. Grimmer, “Evaluation of three input mechanisms for wearable computers,” in *Proceedings 1st. Int’l Symp. on Wearable Computers*, pp. 2–9, Oct. 1997.

[15] E.O. Thorp, “The invention of the first wearable computer,” in *Proceedings 2nd. Int’l Symp. on Wearable Computers*, pp. 4–8, Oct. 1998.

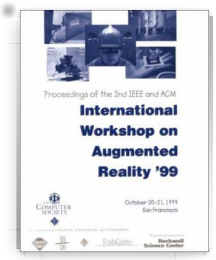
[16] T. Starner, B. Schiele, and A. Pentland, “Visual contextual awareness in wearable computing,” in *Proceedings 2nd. Int’l Symp. on Wearable Computers*, pp. 50–57, Oct. 1998.

[17] B. Thomas, D. Stotts, and L. Kumar, “Warping distributed system configurations,” in *Proceedings 4th. Int’l Conf. on Configurable Distributed Systems*, pp. 136–143,May 1998.

[18] US Army Simulation, Training, and Instrumentation Command (STRICOM), *ModSAF*—http://www-leav.army.mil/nsc/stow/saf/modsaf/index.htm

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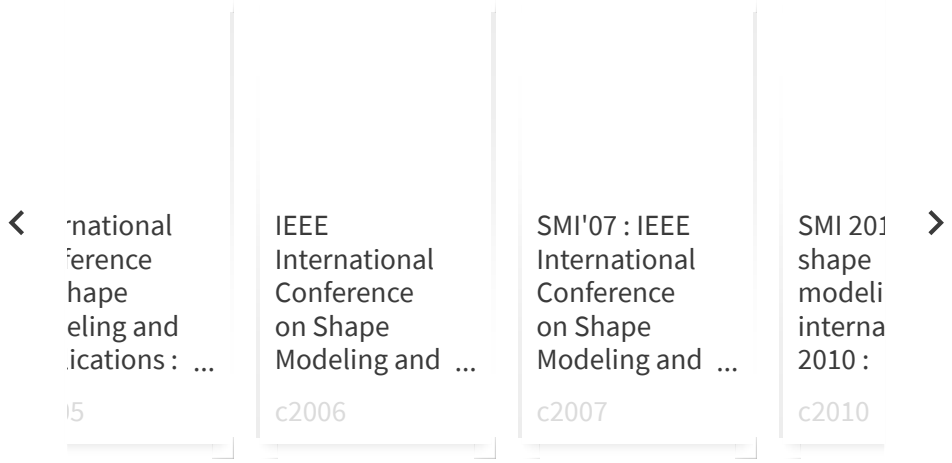
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Abstract:
This paper explores interconnecting outdoor AR systems with a VR system to achieve collaboration in both domains simultaneously. We envisage multiple mobile users of wearable AR systems interacting with a stationary VR facility via a wireless network. An application in simulated combat training is described, where the AR users are soldiers with wearable computers, and the VR system is located at a command and control centre. For soldiers, AR provides enhanced information about the battlefield environment, which may include the positions and attributes of simulated entities for the purpose of training outdoors at low cost. At the same time a complete picture of the battlefield, including real and simulated troops and vehicles, is available via the VR system. As soldiers move about, their GPS and digital compass hardware provide the remote VR user and other AR users with the means to track their position in real-time. We describe a working system based on our modular Tinmith-II wearable computer, which interacts with a combat simulator to create a synthetic battle environment for safe training and monitoring.

Published in: Proceedings 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99)

Date of Conference: 20-21 October 1999
DOI: 10.1109/IWAR.1999.803805
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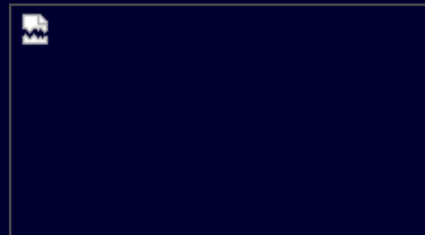
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LINUX01	A very easy to understand paper describing the hardware used when constructing outdoor augmented reality systems, written for Linux Conf 2001.
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IWAR99	Describes our work with making Tinmith communicate using the DIS simulation protocol to collaborate with remote software.

publications

Here is an up to date list of all my publications:

IEEEVR02	Piekarski, W. and Thomas, B. Tinmith-Hand: Unified User Interface Technology for Mobile Outdoor Augmented Reality and Indoor Virtual Reality. In IEEE Virtual Reality, Orlando, FL, Mar 2002.
TR-VR02	Piekarski, W. and Thomas, B. H. Unifying Augmented Reality and Virtual Reality User Interfaces. Technical Report, University of South Australia, Adelaide, SA, Jan 2002.
TR-ARCH01	Piekarski, W. and Thomas, B. Tinmith-evo5 - A Software Architecture for Supporting Research Into Outdoor Augmented Reality Environments. Technical Report, University of South Australia, Adelaide, SA, Dec 2001.
ACM02	Piekarski, W. and Thomas, B. ARQuake: The Outdoor Augmented Reality Gaming System. ACM Communications, Vol. 45, No. 1, pp 36-38, Jan 2002.
AUIC02	Piekarski, W. and Thomas, B. The Tinmith System - Demonstrating New Techniques for Mobile Augmented Reality Modelling. In 3rd Australasian User Interfaces Conference, Melbourne, Vic, Jan 2002. *(Voted best paper at AUIC)*
ISAR01	Piekarski, W. and Thomas, B. Tinmith evolution 5 - A Unified Architecture for Supporting Mobile Augmented Reality User Interfaces. In 2nd Int'l Symposium on Augmented Reality, New York, NY, Oct 2001.

Backpack computer with HMD outdoors

Gloves with 2D/3D cursor overlays and menus



Backpack in A configuration, allowing use like a desk while placed on the ground outdoors

Cube with texture maps captured from camera

ISWC01	Piekarski, W. and Thomas, B. Tinmith-Metro: New Outdoor Techniques for Creating City Models with an Augmented Reality Wearable Computer. In 5th Int'l Symposium on Wearable Computers, Zurich, Switzerland, Oct 2001.
LINUX01	Piekarski, W. and Thomas, B. Tinmith: Outdoor Augmented Reality With Wearable Computers Running Linux. In 2nd Australian Linux Conference, Sydney, NSW, Jan 2001.
ISWC00	Thomas, B., Close, B., Donoghue, J., Squires, J., De Bondi, P., Morris, M., and Piekarski, W. ARQuake: An Outdoor/ Indoor Augmented Reality First Person Application. In 4th Int'l Symposium on Wearable Computers, pp 139-146, Atlanta, Ga, USA, Oct 2000.
DCNET99	Thomas, B., Piekarski, W., and Gunther, B. Using Augmented Reality to Visualise Architecture Designs in an Outdoor Environment. In Design Computing on the Net, pp http:// www.arch.usyd.edu.au/kcdc/conferences/dcnet99, Sydney, NSW, Nov 1999.
IWAR99	Piekarski, W., Gunther, B., and Thomas, B. Integrating Virtual and Augmented Realities in an Outdoor Application. In 2nd Int'l Workshop on Augmented Reality, pp 45-54, San Francisco, Ca, Oct 1999.
KES99	Piekarski, W., Thomas, B., Hepworth, D., Gunther, B., and Demczuk, V. An Architecture for Outdoor Wearable Computers to Support Augmented Reality and Multimedia Applications. In 3rd Int'l Conference on Knowledge-Based Intelligent Information Engineering Systems, pp 70-73, Adelaide, SA, Aug 1999.
ACSC99	Piekarski, W., Hepworth, D., Demczuk, V., Thomas, B., and Gunther, B. A Mobile Augmented Reality User Interface for Terrestrial Navigation. In 22nd Australasian Computer Science Conference, pp 122-133, Auckland, NZ, Jan 1999.
ISWC98	Thomas, B. H., Demczuk, V., Piekarski, W., Hepworth, D., and Gunther, D. A Wearable Computer System With Augmented Reality to Support Terrestrial Navigation. In 2nd Int'l Symposium on Wearable Computers, pp 168-171, Pittsburg, Pa, Oct 1998.



Backpack system in use outdoors, with glove based user interface in use

Wayne Piekarski - University of South Australia, Wearable Computer Lab, Tinmith Project
Contact wayne@cs.unisa.edu.au for more information

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1 of 10 Automatic Zoom

Integrating Virtual and Augmented Realities in an Outdoor Application

Wayne Piekarski, Bernard Gunther, and Bruce Thomas

Advanced Computing Research Centre
University of South Australia
Mawson Lakes, SA 5095
Australia
{piekarski, gunther, thomas}@cs.unisa.edu.au

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Abstract

This paper explores interconnecting outdoor AR systems with a VR system to achieve collaboration in both domains simultaneously. We envisage multiple mobile users of wearable AR systems interacting with a stationary VR facility via a wireless network. An application in simulated combat training is described, where the AR users are soldiers with wearable computers, and the VR system is located at a command and control centre. For soldiers, AR provides enhanced information about the battlefield environment, which may include the positions and attributes of simulated entities for the purpose of training outdoors at low cost. At the same time a complete picture of the battlefield, including real and simulated troops and vehicles, is available via the VR system. As soldiers move about, their GPS and digital compass hardware provide the remote VR user and other AR users with the means to track their position in real-time. We describe a working system based on our modular Tinmith-II wearable computer, which interacts with a combat simulator to create a synthetic battle environment for safe training and monitoring.

1. Introduction

The advent of wearable computers [3,8,15,16] and lightweight head-mounted displays (HMDs) has made augmented reality applications feasible outdoors. Augmented reality (AR) is the process of a user viewing the physical world and virtual information simultaneously, where the virtual information is overlaid and aligned to the physical world view [1]. Many of the existing applications of AR, such as head-up displays in aviation, assistance for surgery, and maintenance work, are characterised by requiring precise tracking in small operating regions.

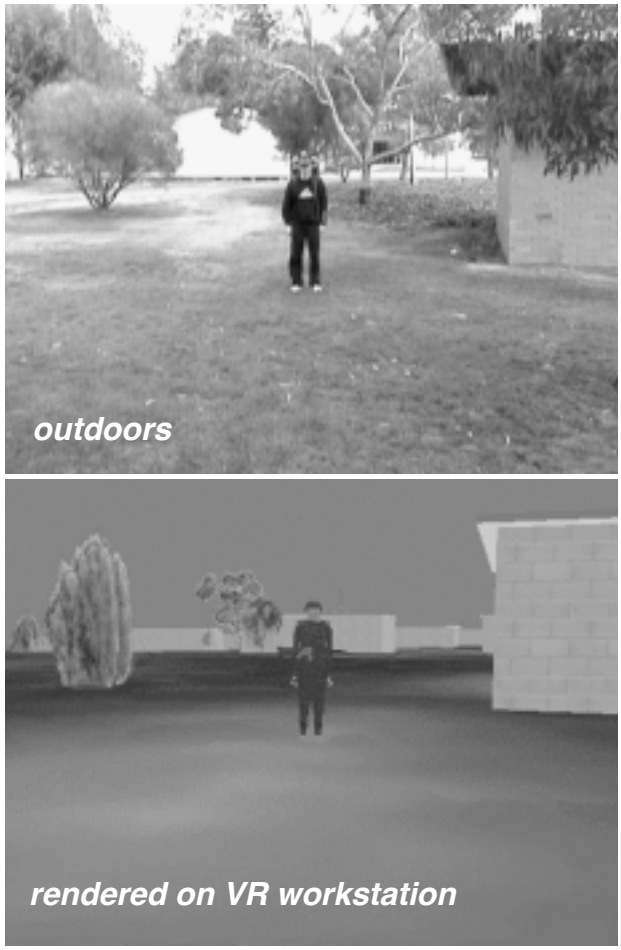


Figure 1. Linking a wearable AR system to a VR system enables mobile entities (the AR user, top) to be shown in relation to fixed entities (the trees and buildings) that exist in the terrain model, bottom.

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However, through coupling global positioning system (GPS) receivers and digital compass with geographic databases, we can create spatially-aware computer systems for mobile users working outdoors. We anticipate outdoor users wishing hands-free operation, and thus related AR applications are especially well supported by wearable computers and non-traditional input devices

The concept of collaboration in virtual reality (VR) has been explored previously [5,7,17], whereas collaboration in AR is somewhat less developed [4,13]. We are intrigued by the possibilities of interconnecting VR and AR systems to achieve collaboration in both domains *simultaneously*. At the simplest level, we can imagine two users—one mobile and one stationary—interacting as suggested in Figure 1. The mobile user dons a wearable AR system and is able to interact with the world outside, while the stationary user (not shown in the figure) wears a HMD or views the screen(s) of a VR workstation situated indoors. Both computer systems are in radio contact with each other. Since the AR user carries no video camera, the VR system must rely on a three-dimensional database of the outdoor environment in order to place the AR user in it. The wearable computer transmits its GPS position so that the VR system can draw an avatar at the appropriate location. Now if the VR user were to insert an object into the virtual world, an iconic representation of that object would appear overlaid on the AR user's outdoor view. We are therefore able to exploit the large computing power of the VR system, without affecting the computing requirements of the wearable AR systems.

Our previous work has demonstrated AR systems functioning as powerful navigation and visualisation tools for individuals [10,12,14]. This paper describes extensions to our work that facilitate collaborative activities in joint AR/VR applications, sited outdoors. We show how the necessary infrastructure for collaborative AR applications readily integrates with a remote VR system. To illustrate the concepts we will focus on an application for military training that incorporates both real and simulated entities, with the latter being used to enrich outdoor training exercises cost-effectively and safely.

In collaboration with the Australian Defence Science and Technology Organisation (DSTO) and the Australian Army we are investigating technology that may improve the effectiveness of the dismounted combat soldier. The initial application that we investigated was the use of a wearable computer to support navigational tasks, since navigation is an essential and time-consuming task for soldiers on foot. The significance of the navigation application lies in its departure from tracking users in small operating regions. In this regard, it relates to recent work in large area augmented reality, such as the *Touring Machine* project by Feiner *et.al* [6], which allows users to walk around the Columbia University campus and access information via a tracked see-through display and a hand-held display.

Beyond knowing his own position, a soldier must also gain awareness of enemy threats and friendly positions alike. The latter case reflects the fact that soldiers normally operate collaboratively. However, collaborators need not be restricted to other dismounted soldiers, but may include vehicles and aircraft, whose presence adds diversity and thus hinders rapid assimilation. We use AR to supply the soldier with easily understood information about his battlefield environment, for example: indications of threats, the location of friendly forces, and the status of aircraft as they approach. Fortunately, the acceptable tracking accuracy required for this application is attainable without special motion compensation in the display system. The open problem of accurate feature registration outdoors is not addressed any further in this paper [2].

Radio data communications between wearable computers underpins an outdoor collaborative AR system. The mobile units are also able to interact with the central command and control centre, which operates a stationary radio base station. This facilitates potentially two-way interaction: communication of situational awareness information to the soldier, and, conversely, detailed information back to the base for populating its 3D model. Thus, in a live training or combat situation the base can track field positions dynamically to provide high-level command and control information; however, in a simulated exercise the base can host a simulated battle accessible through a VR system. This latter scenario is the one we explored in more detail.

In the following sections we define the operational requirements of the larger system, and how it functions. We then describe our wearable AR system, and discuss how this was modified to support collaborative work. We conclude with observations gained from a test evaluation.

2. Augmented Reality Meets Virtual Reality

We set out to develop a system for demonstrating AR techniques for use by an individual using a wearable computer interacting with the Modular Semi-Automated Forces (ModSAF) simulated combat system [18]. The Synthetic Environment Research Facility (SERF) in DSTO's Land Operations Division employs ModSAF to generate synthetic battle environments in simulated exercises. A synthetic battle may, of course, involve fictitious entities (soldiers, vehicles, and aircraft) as well as the real entities actually participating in the exercise. The system is designed so that a helicopter pilot in a training exercise,

for example, can participate in a virtual battle via a VR system. The pilot sees the output of the VR camera through three angled CRTs, driven by MetaVR running on a high-end PC. The MetaVR software [9] displays photorealistic battlefield terrain and receives dynamic positions of entities via the Distributed Interactive Simulation (DIS) protocol (IEEE Standard 1278), which is the principal protocol used between AR and VR systems in this project. DIS is a high-bandwidth, stateless protocol: entity positions must be continuously retransmitted if the entities are to be displayed, otherwise they are considered to be nonexistent after 5 seconds.

Persistent data about entities known to exist on the battlefield are maintained by the Land Situational Awareness Picture System (LSAP), which provides a Java front-end to an Oracle DBMS. The positions and attributes of entities held in LSAP can be accessed by command and control staff to provide them with situational awareness of the engagement. Units in the field can radio reports back to LSAP to update the battlefield view as entities are detected, eliminated, or known to move.

2.1 Objectives and Overview of the System

The main objective of the system was to demonstrate the possibility of a dismounted soldier interacting with information from remote simulation and situational awareness systems (ModSAF and LSAP) using AR techniques. LSAP and DIS were used to filter appropriate information to users in the field, who see overlaid on their view of the physical battlefield iconic representations of both real and simulated entities that populate the synthetic battle environment. In turn, users of the VR facility have a complete, albeit artificial view of the entire battlefield. We anticipate that the combination of these capabilities can facilitate operational and training developments in information transfer between individual soldiers and higher command systems.

2.2 Interaction with the Wearable Computer

As previously mentioned, we wish to strengthen collaboration by improving communication between mobile and stationary personnel. The interactions we support include:

- the wearable computer overlays on the user's HMD iconic information locating friendly and enemy forces; for example, in a training application the icons may represent the positions of dismounted forces generated by the ModSAF simulator at SERF
- users of wearable computers can update or populate the 3D database maintained centrally; for example, the user may locate a previously unknown enemy and inform the LSAP system as to the *relative* position and nature of the entity
- hardware at SERF presents a virtual view of the battlefield, which includes avatars for 3D viewing, and icons for 2D plan views; as wearable users move, their GPS systems continue to provide real-time positional data to command personnel
- furthermore, with additional real-time data specifying the pitch, roll, and yaw of the soldier's head, the presentation of the virtual world at SERF can be slaved to the soldier's direction of view; in other words, we can provide a virtual camera without video equipment

3. Wearable Computer System

The wearable computer system we used for this work was based on Tinmith-II [10], a complete research system developed at the Wearable Computer Laboratory at the University of South Australia. Figure 2 pictures the current hardware platform.



Figure 2. Photograph of the Tinmith-II wearable computer.

3.1 Hardware Components

Tinmith-II is built upon a Toshiba 320CDS notebook running the freely available LinuxOS. The laptop is about the size of an A4 book and fits comfortably on a wearer's back. A Sony PLM-100 transparent display, worn on the user's head as shown in Figure 3, allows the video output of the computer to superimpose images over the real world. A Phoenix miniature keyboard attached to the forearm enables the user to interact with the system and enter commands.



Figure 3. Users of the wearable computer see through a Sony PLM-100 transparent head-mounted display, and enter commands on a Phoenix forearm keyboard.

To support the navigation functions of our application, a GPS module (with differential receiver) connects to the laptop, and provides position fixes at most places in the world to within 5 metres accuracy. A TCM2 3-axis digital compass, also attached to the display, allows the computer to determine exactly how the wearer's head is oriented relative to the surface of the Earth. This information is used to render the display so that it remains in correspondence with the user's physical world view.

All of the equipment is attached to a rigid backpack, along with batteries and antennae. The prototype hardware and software system is fully functional in outdoor environments.

3.2 Head-Up Displays and Interfaces

The system is capable of presenting alternative interfaces to the user, namely, two-dimensional and three-dimensional. Since navigation remains an important activity for the soldier, all of the user interfaces feature our original navigational aids.

The 2D interface incorporates a first person perspective, God's-eye view, and traditional non-spatially aware information on one display, as shown in Figure 6. At the top of the display is the compass heading, which is represented as notches and a value every 45 degrees. As the user rotates their head, the compass updates itself and scrolls left or right to indicate the new heading. The various pieces of text in formation placed around the display are used to show position, GPS accuracy, and steering instructions to the nominated waypoint so as to aid navigation by the wearer. Underneath the text is the map and navigation gadget display. At the centre of the display is a cross, indicating the current position of the system and user. Shown in the figure are outlines of objects in the environment, and the circular object in the centre of the screen gives steering instructions to the user indicating in which direction they must turn to reach the target. Every visual cue is rotated in real time as the user moves around. In operation, we were able to maintain approximately 2 to 5 metre accuracy given a good fix on 6 or more GPS satellites.

The alternative interface features a 3D immersive display superimposed on the wearer's field of view. When looking through this display we are able to register the display with the outline of a surveyed object within the accuracy limits of the differential GPS and digital compass. For example, we were able to make a cube lock around an outdoor bench as we walked around it.

3.3 System Architecture

To support a wide range of AR and navigation tasks applications, we developed a highly modular architecture. The software system is broken up into various modules that communicate with each other using a connection-oriented protocol—in this implementation, TCP/IP.

Modular approach

An example of an application specific module is the *navigation* module, which reads waypoints from a database, along with position and heading information, to produce steering instructions for other modules to present to the user. The *display* module presents data from other modules in a graphical format to the user via the head up display. The modular architecture supports many concepts such as data abstraction and hiding, collaboration with others, and the flexibility to plug new components in without modifications.

Communications

To interconnect modules, we used a client-server style architecture. The server is a data source for other modules, which subscribe to it. Whenever the server updates the value of system data (a GPS position, for example), it will send the new value out to all clients that have registered an interest in the message. A client receiving new data may use it to update the screen, or calculate new navigation parameters for example. Actually, many servers in the system also act as clients for other servers as well. The entire system operates asynchronously, and is data driven; if there is no new data in the system, no action will be taken by any of the software modules.

Suppose a new incoming position was received from the GPS hardware. The new data will be formatted appropriately and then distributed to all client modules. The navigation module will receive this update, and recalculate navigation information. The display module will eventually receive a position update, along with the new steering instructions from the navigation module, and use these to redraw the screen to reflect the user's new location.

3.4 Software design

To implement the modular architecture, an appropriate supporting software library was designed, with goals to be flexible, extensible, and layered. Layering was exploited to provide increasing levels of abstraction for allowing modules to interact with the system at the appropriate level they require, while at the same time minimising code replication across the system, and localising possible errors. The libraries provide functionality for distributive processing, asynchronous I/O, dynamic configuration, and automatic code generation.

Running modules in parallel over TCP/IP

Each of the modules are implemented as separate Unix processes, which communicate via kernel network services. This allows modules to be distributed over multiple processors on one machine, or multiple machines due to the network support. The ability for the system to support this at a fundamental level improves the scalability for larger, resource-intensive applications. For those modules confined to a single machine the networking between them is virtualised by the kernel, and hence the corresponding latency and bandwidth of the communication channels are orders of magnitude better than through a real external network.

Dynamic configuration from a DBMS

Most software tends to use statically compiled controls, or possibly a configuration file. Our system takes configuration to the next level by loading all system parameters such as the 2D maps, 3D object models, location of modules, port numbers, device names, and screen configuration into a collection of relational database tables. When the software initialises, it queries the database and loads the values required. By sending messages throughout the system when changes are made, it is possible for clients to reconfigure themselves by querying the database. The software does not have to be restarted as would be required if the controls were static. The database proved to be very powerful because it can be changed remotely over the wireless network. This feature turned out to be useful when testing outdoors, for example, tuning the various display options such as colours and font sizes. An added feature is the strong type checking by the database engine (in our case PostgreSQL v6.4 [11]) rather than relying on parsing a text file.

4. Integrating a VR Simulation System

Figure 4 pictures the dataflows and interfaces in our concept demonstrator system. A PC running our *modlsapdis* software mediates between the base station and one or more wearables in the field. Internally *modlsapdis* comprises two modules: a protocol converter that translates packet formats between DIS and our internal format; and a communication module that relays packets via a wireless network to any wearables. Lucent WaveLan 2.4GHz wireless network cards at the base station and in each wearable form the basis for a high-speed (faster than 2Mbps) network.

In effect the communication module of *modlsapdis* is really a part of the wearable systems, except that it runs on a stationary computer. As each wearable unit goes on-line it registers with the communication module in order to establish a wireless point-to-point network link with the base station. In the case where several wearables have registered such links the communication module must multicast entity state packets to all registered computers so that every user in the field receives updates to their

environment. Since communication between Tinmith modules is based on TCP/IP, the base station appears logically to a wearable system as just another software module.

At the base the *modlsapdis* protocol converter listens on the ethernet network for incoming entity state DIS packets from the simulator, while also communicating textual data to LSAP via a Java remote method invocation (RMI) interface. *Modlsapdis* continuously receives information about entities in the battlefield, reformats the information, and passes it to the communication module. To avoid flooding the wireless links, duplicate updates and objects that have not changed are removed from the data stream. Moreover, the AR software is not required to respond to all simulation events.

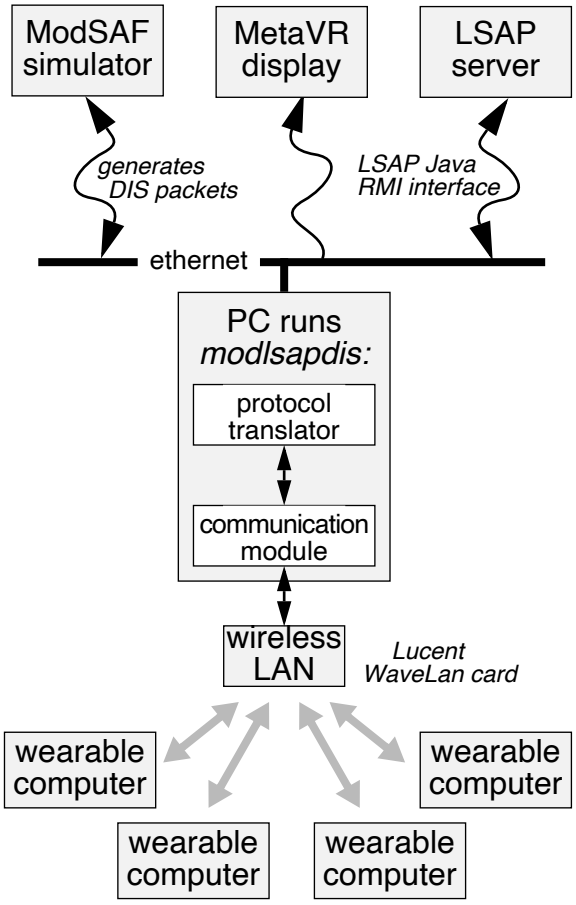


Figure 4. Block diagram of the combined AR/VR system. ModSAF generates a simulated battle environment, which is tracked in the LSAP database. One or more wearable computers in the field interact with the VR host PC via wireless network links. The entire engagement is visible on the MetaVR display.

4.1 Simulation and VR System

ModSAF is a complex, complete military simulation environment with a graphical interface. It can simulate a complete battle, including the movements of tanks, helicopters, and soldiers. Thus, soldiers participate in simulated combat, drive and refuel vehicles, reload ammunition, and fly aircraft, in addition to numerous other activities. During simulation, ModSAF maintains a terrain database, emits DIS packets defining the dynamic positions of entities, and produces a complete map showing a top-down view of all entities moving over the terrain.

The MetaVR visualisation software provides us with battlefield views so that a battle can be observed as it unfolds. MetaVR renders a world with photorealistic terrain, which includes all DIS entities that need to be drawn and animated, such as rotating helicopter rotors, and movable tank turrets.

MetaVR is also used to render displays for an attached helicopter simulator. Three computers running MetaVR provide three views from the simulated cockpit; one machine simulates the motion and dynamics of the helicopter, while another draws views of the helicopter's infrared turret. This is a good example of how DIS caters for distributed processing, even though only one helicopter is being simulated. With wearable computers in the field it is possible for the helicopter pilot to see the location of each wearable unit, while a soldier with a wearable can see simulated helicopters moving around in his field of view.

4.2 Wearable Computer Software

The internal software architecture of the wearable computer is depicted in Figure 5. The *modtracker* module is designed to distribute the data read from the wireless network link to all of the other installed modules. In our system, modules subscribe to other modules. For example, we have the *navigation* and *display* modules both listening for entity information, and it would be wasteful of bandwidth to send two copies over the network each time an update occurs. Moreover, some code might wish to determine the latest location of all battlefield entities, and thus another purpose of *modtracker* is to build and maintain a local copy of the entire environmental state for the remote wearable computer.

In some sense, *modtracker* acts as a proxy; it receives all the external information available to it, stores it, and then redistributes it to other modules on demand. Since *modtracker* is the only module allowed to access the wireless link, we can easily hide the implementation of the communication protocols from the other modules, such as

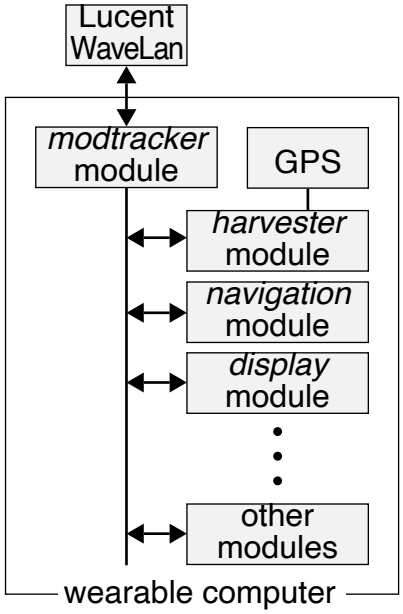


Figure 5. Software architecture of the wearable computer equipped to interact with ModSAF.

the *display* module, for instance. This allows future implementations to include data compression or replacement of TCP/IP without affecting the remainder of the system.

The reverse function of the wearable computer system is to return the position and orientation of each soldier. The *harvester* module sends the GPS location out through *modtracker*, which transmits data packets to the fixed computer at SERF. Ordinarily, these packets identify individuals in the field so that a VR user at SERF can visualise both the simulated and real entities from a bird's eye view. However, it would be equally feasible to slave the VR camera to any individual's head movements so as to gain their *personal view*—albeit with artificial renditions of real objects.

5. Initial Evaluation

The wearable computer system was used in demonstrations of the capability of an individual walking around and interacting simultaneously with the ModSAF and LSAP systems at DSTO.

5.1 Practical Trials

The first exercise involved some 50 entities of all kinds (including tanks, helicopters, and soldiers) generated by ModSAF and populating a synthetic battlefield. We wished to determine whether our system could cope with a large number of dynamic entities, and keep them in the correct position on the AR display. We observed that the display frame rate did not degrade due to the data load, and that the display was being updated with entity positions as they were generated in real-time.

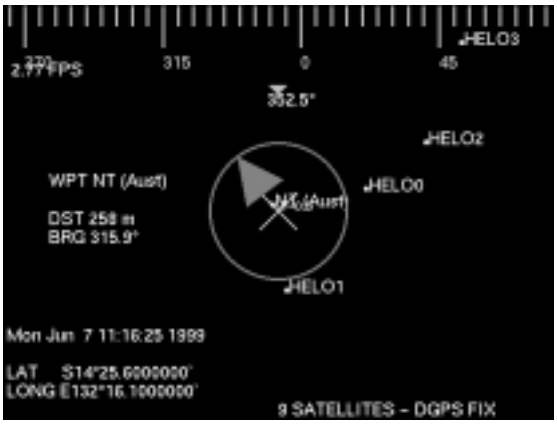


Figure 6. Two-dimensional, plan view of the battlefield, as generated to augment the user's outlook. Central cross marks the user location. Four helicopters, HELO0–HELO3, are shown as labelled dots in relation to the user's position.

In the second experiment, a simulated helicopter was made to "fly" around the wearable computer user standing in MetaVR's synthetic environment. As the helicopter circled overhead, it was easy for the wearable user to track the motion of the helicopter on their display by rotating their head. Of course, the user on the ground could see only an iconic representation of the helicopter, as the simulated craft did not really exist. This experiment proved that moving, simulated entities generated by ModSAF could be observed in real-time through the AR interface. We verified the result by comparing the AR display with a map generated by ModSAF. For example, when the helicopter was located north of the mobile user, they had to face north in order to see the helicopter.

An illustration of the generated 2D AR interface appears in Figure 6, where the dark background would normally be replaced by the user's view of the real environment. In this view, the user occupies the central cross and is navigating with the aid of the compass displayed at the top. The four (in this case, simulated) helicopters flying overhead are indicated on the plan as labelled dots in scale with the user's distance from the waypoint ahead (marked "WPT NT Aust" on the display).

With the press of a button the alternative 3D interface can be invoked, as pictured in Figure 7. Here, the central cross is directed by the user's head orientation, which appears to be just below the horizon in Figure 7. The hashed diamond to the left represents the current waypoint being navigated. Three (simulated) helicopters

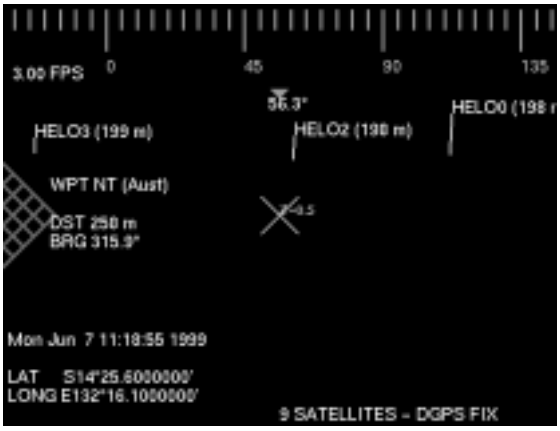


Figure 7. Three-dimensional view of a similar battlefield, as generated to augment user's outlook. Four helicopters, HELO0–HELO3, are shown as labelled altitude bars above the horizon, with HELO0's nearness indicated by the largest bar.

appear as labelled altitude bars emanating from the horizon. All the helicopters are flying at approximately 200 metres, but HELO0 is significantly closer than HELO3 and HELO2, and hence the altitude bar of HELO0 is correspondingly larger to indicate this fact. If an airborne entity is almost directly overhead its altitude bar simply extends to the top of the display.

Thirdly, we ensured that a user of the MetaVR system could visualise wearable AR units in the field. Figure 8 depicts four views of such a trial. Soldiers with AR equipment were rendered as 3D texture-mapped avatars, which correctly appeared and moved in relation to the real and simulated entities. The 3D models responded to movements in the corresponding wearable units, showing walking motion or rotations, for example. And by slaving the VR camera to the head position of a wearable unit, we were able to demonstrate an individual's view of the battlefield to a person sitting at the fixed SERF site.

5.2 Performance Measurement

In the second phase of our evaluation we wished to test the performance of our system to establish responsiveness and capacity to operate with a large number of entities. As part of its event driven nature, Tinmith updates its display in response to any change in user position or entity locations. Since the digital compass sends updates at a rate of 15Hz, the GPS updates at 1Hz, and entities arrive at indeterminate times, the frame rate generally lies between 15 and 20 frames per second, providing a fast updating display for the user.



(a) Mobile user, standing outdoors, observes a virtual helicopter.

(b) God's-eye view, AR screen display superimposed on wearer's view. Note a helicopter (labelled CHOPPER) directly in front of the wearer, whose position is marked by an X.

(c) Scene generated by MetaVR at the base station. It shows representations of both the mobile AR user and the virtual helicopter they are viewing.

(d) Corresponding screen shot from ModSAF, which generated the virtual entities appearing above.

Figure 8. Example application showing the integration between the AR and VR systems, simulator, and the real world in which the AR user stands.

In order to get some quantitative results we added instrumentation code to the Tinmith network libraries, which involved taking a timestamp in microseconds, using POSIX call `gettimeofday()`, embedding this in the message, and then decoding and comparing the result at the receiving end to measure the time taken in creating and transmitting the message.

We created an artificial test situation with the following parameters:

- ModSAF generating DIS updates at 1 Hz for each of 7 entities sent over the wireless LAN to the wearable
- *modlsapdis* sending DIS packets for all 30 internal markers (waypoints) being tracked at 0.25 Hz. Since these markers are transmitted on the SERF side of the network, the wearable does not concern itself with sending these updates except when changes are made.
- the wearable position and orientation updated at 15 Hz, with this data transmitted over the wireless LAN each time.

During this test we observed that the CPU was reasonably utilised but not working at 100% capacity, and that the measured module to module delay ranged from 2.8 ms to 50 ms, although this increased to 100 ms in the event of the machine being temporarily heavily loaded. The accuracy of these measurements was marginally affected by the limited resolution of the Linux kernel timer and the overheads in calling it.

Module to module delay was measured only for messages being sent to the same machine over the local network. In attempting to measure messaging delays between *modtracker* and *modlsapdis* it was not practical to synchronise the clocks between the machines to microsecond accuracy and hence no proper measurements could be reported.

From the point of view of the MetaVR user, the delay between changes in orientation and the update of the display was definitely noticeable, with a lag of around 500 ms being observed consistently. This lag can be attributed to a small delay in the wearable, data transmission over the wireless LAN, retransmission as a DIS packet to MetaVR, and eventual rendering on the display. Since three separate computers (and their operating systems) and two networks are involved, some delay is to be expected. In practice, update lags to the VR display are not an issue because staff at headquarters are unable to see a real battlefield. Hence, the VR display is still an accurate rendition.

A powerful feature of the *modlsapdis* module is that even if the wireless LAN is disabled temporarily, due to an obstruction, for example, the module still retains state information from the unavailable wearable. *Modlsapdis* will continue to transmit waypoints and the wearable computer's last location, so the VR display and other wearables will still be able to visualise the entity and its markers. Without such a feature, a briefly unavailable wearable would disappear on account of the 5-second DIS protocol timeout.

6. Conclusions

With the emergence of outdoor AR, we expect integration with VR and collaboration to become more widely applicable for two reasons. Firstly, these capabilities give individuals remote from each other the option of an immersive user interface to substitute for physical presence with collaborators. For example, movements of users in the real environment are reflected in the VR. Secondly, multiple AR users can benefit from viewing a superimposed collective information space, which may include simulated entities where appropriate. This concept was exploited in the simulated combat training system to provide the illusion of a rich environment at relatively low cost, yet users of wearable computers are not restricted to training indoors as they might have been with VR equipment.

In regards to the architecture, use of it has shown a few places where changes could be made to improve both the throughput and latency of the system. It was not originally designed to be a system that would run optimally fast for AR registration purposes, but rather as a testbed with which we could test ideas for navigation and interaction across systems, such as those at DSTO's SERF. Future changes being considered are the use of shared memory and/or merging of modules (*display*, *navigation*, and *harvester*) to maximise the performance of local modules. The delays caused by task switching, kernel call overheads, and the like are small, but not negligible when trying to produce real time systems. However, we wish to maintain the network architecture, as it allows us to integrate modules and other software across platforms.

The Lucent WaveLAN cards are particularly suitable for this application due to their size and Mbps+ performance, which exceeds the performance offered by competing technologies such as cellular phones or standard radio modems. This allowed us to perform initial tests indoors using readily available Ethernet to substitute for the WaveLAN cards. Some problems we experienced with the cards include their requirement for line of sight reception, relatively short range (a few hundred metres), and their vulnerability to radio frequency interference.

Although not originally designed to support interaction with ModSAF, our Tinmith-II wearable computer was readily adapted to provide AR support for simulated combat training. The modular, data driven architecture and layered implementation of the software made it possible to incorporate new display sources with relative ease. The navigation module, which previously updated the display as the user moved, now also returned position data to the VR site to enable visualisation remotely. We found the accuracy afforded by differential GPS to be acceptable in a training application, particularly when relying on the

two-dimensional AR interface. DSTO are interested in continuing development of the concepts described here, and we hope to conduct more detailed evaluations of the system under actual training conditions in future.

Acknowledgements

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References

[1] R. Azuma, "Survey of augmented reality," *Presence: Teleoperators and Virtual Environments*, vol. 6, no. 4, 1997.

[2] R. Azuma, "The challenge of making augmented reality work outdoors," in *Mixed Reality: Merging Real and Virtual Worlds*, Springer-Verlag, chap. 21, pp. 379–390, 1999.

[3] L. Bass, C. Kasabach, R. Martin, D. Siewiorek, A. Smailagic, J. Stivoric, "The design of a wearable computer," in *CHI'97 Looking to the Future*, ACM SIGCHI, pp 139–146, 1997.

[4] M. Bauer, T. Heiber, G. Kortuem, and Z. Segall, "A collaborative wearable system with remote sensing," in *Proceedings 2nd. Int'l Symp. on Wearable Computers*, pp. 10–17, Oct. 1998.

[5] C. Carlsson and O. Hagsand, "Dive—a platform for multi-user virtual environments," *Computers and Graphics*, pp. 663–669, 1993.

[6] S. Feiner, B. MacIntyre, T. Hollerer, A. Webster, "A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment," in *Proceedings 1st. Int'l Symp. on Wearable Computers*, pp. 74–81, Oct. 1997.

[7] T.A. Funkhouser, "Ring: A client-server system for multi-user virtual environments," in *Computer Graphics*, pp. 85–92, April 1995.

[8] S. Mann, "WearCam (The Wearable Camera): Personal imaging systems for long-term use in wearable tetherless computer-mediated reality and personal photo/videographic memory prosthesis," in *Proceedings 2nd. Int'l Symp. on Wearable Computers*, pp. 124–131, Oct. 1998.

[9] MetaVR, Inc., *MetaVR Virtual Reality Scene Generator*—http://www.metavr.com, 1999.

[10] W. Piekarski, D. Hepworth, V. Demczuk, B. Thomas, B. Gunther, "A mobile augmented reality user interface for terrestrial navigation," in *Proc. 22nd Australasian Computer Science Conference*, Auckland, NZ, pp 122–133, Jan. 1999.

[11] *PostgreSQL v6.4.2 Database Engine*—http://www.postgresql.org, 1998.

[12] B. Thomas, V. Demczuk, W. Piekarski, D. Hepworth, B. Gunther, "A wearable computer system with augmented reality to support terrestrial navigation," in *Proceedings 2nd. Int'l Symp. on Wearable Computers*, pp. 168–171, Oct. 1998.

[13] B.H. Thomas and S.P. Tyerman, "Collaboration issues for augmented realities in an outdoor environment," in *Proceedings INTERACT97 combined Workshop on CSCW in HCI*, Sydney, pp. 29–33, Jan. 1997.

[14] B. Thomas, S. Tyerman, K. Grimmer, "Evaluation of three input mechanisms for wearable computers," in *Proceedings 1st. Int'l Symp. on Wearable Computers*, pp. 2–9, Oct. 1997.

[15] E.O. Thorp, "The invention of the first wearable computer," in *Proceedings 2nd. Int'l Symp. on Wearable Computers*, pp. 4–8, Oct. 1998.

[16] T. Starner, B. Schiele, and A. Pentland, "Visual contextual awareness in wearable computing," in *Proceedings 2nd. Int'l Symp. on Wearable Computers*, pp. 50–57, Oct. 1998.

[17] B. Thomas, D. Stotts, and L. Kumar, "Warping distributed system configurations," in *Proceedings 4th. Int'l Conf. on Configurable Distributed Systems*, pp. 136–143,May 1998.

[18] US Army Simulation, Training, and Instrumentation Command (STRICOM), *ModSAF*—http://www-leav.army.mil/nsc/stow/saf/modsaf/index.htm

EXHIBIT 1004I

EX1004I
Citations to Piekarski 1999

Source Document:

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Citations: 2000 (in chronological order)

Jalkanen, J. (2000, March). Building a spatially immersive display-HUTCAVE. *Licenciate Thesis, Helsinki University of Technology, Espoo, Finland*.

Behringer, R., Tam, C., McGee, J., Sundareswaran, S., & Vassiliou, M. (2000, October). A wearable augmented reality testbed for navigation and control, built solely with commercial-off-the-shelf (COTS) hardware. In *Proceedings IEEE and ACM International Symposium on Augmented Reality (ISAR 2000)* (pp. 12-19). IEEE.

Behringer, R., Tam, C., McGee, J., Sundareswaran, S., & Vassiliou, M. (2000, October). Two wearable testbeds for augmented reality: itWARNS and WIMMIS. In *Digest of Papers. Fourth International Symposium on Wearable Computers* (pp. 189-190). IEEE.

Hoff, B., & Azuma, R. (2000, October). Autocalibration of an electronic compass in an outdoor augmented reality system. In *Proceedings IEEE and ACM International Symposium on Augmented Reality (ISAR 2000)* (pp. 159-164). IEEE.

Baillot, Y., Gagas, E., Höllerer, T., Julier, S., & Feiner, S. (2000). *Wearable 3D graphics for augmented reality: a case study of two experimental backpack computers*. NRL Technical Report.

EXHIBIT 1009A

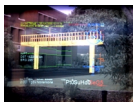
Tinmith evolution 5

Augmented Reality With Wearable Computers Running Linux

Wayne Piekarski, Bruce Thomas
School of Computer and Information Science
University of South Australia, Mawson Lakes, SA, Australia






Abstract

This paper describes the concept of augmented reality, the process of drawing virtual images over the real world using a head mounted display. Using wearable computers, it is possible to take augmented reality software outdoors and visualise data that only exists in a computer. The paper discusses all concepts in detail, and the hardware used to build the system, explaining the various components and costs. Examples of AR applications developed by the authors are explored, showing some ideas as to what the technology could be used for.

The Tinmith system is a complete software architecture designed to develop AR and other software that deals with trackers, input devices, and graphics. The design of the code is explained, including how it was developed. Tinmith is based on a completely free software system comprising the Linux kernel, GNU tools and libraries, the GNU C/C++ compiler, XFree86 graphics server, GGI graphics interface, OpenGL 3D renderer, PostgreSQL database, and Freetype font renderer.

1 Introduction

In recent times, numerous advances have been made in many areas of electronics and computing, allowing us to explore many previously unknown areas and open up new opportunities for research.

Technology such as powerful portable computers, head-mounted displays (HMD), global positioning systems (GPS), and software have made it possible to develop an augmented reality (AR) system which can be operated in a non-computer friendly, outdoor environment.

Imagine a user wearing a head-mounted display, allowing them to watch TV or their computer on a virtual screen projected into their eyes, similar to virtual reality (VR) technology you may have seen before. However, using an optical combiner inside the HMD, it is possible to see both the real world, and overlaid computer imagery at the same time. This ability to view physical and virtual worlds at the same time is called augmented reality, and is the focus of this paper. AR is an exciting new field and the authors feel that it has enormous potential for both commercial and recreational use.

Since this is a field with new technology that many people have not been previously exposed to, this paper will provide an introduction explaining the technology and components in some detail. Some of the AR applications developed by the authors are then discussed, showing how the technology can be used in the real world. Most of all, since this is a conference about Linux and software, the rest of the paper then discusses how the system works from a software point of view. We discuss the free tools we used (such as Linux, GNU, and X) to build the system, and the overall architecture of the software.

The software developed for this system is called Tinmith, which was started in 1998 as an undergraduate engineering project, and is now being used further as part of the author's PhD thesis. The system is always under continuous development as it is a test bed for many new research ideas. The main goal was to provide a complete architecture to develop AR and other applications that deal with trackers, input devices, and graphics, something that is currently not very well developed.

Most of all, the paper has been written to give information about constructing your own hardware. Hacking isn't just about software, its about using a soldering iron to modify your hardware, and making mistakes. The components and their costs are discussed, however, it is not a cheap field to be in as some of the hardware tends to be expensive and hard to find. So read on to find out more.

2 Hardware

The most important aspect of this work is the hardware, as it is what enables us to do our work. Some of the hardware is what would be termed 'exotic', in that most people do not know they even exist, let alone own them and dream of attaching

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Meta Exhibit 1017
Meta v. Mullen - Page 00150

them to a PC. Without these components, this research would not even be possible, so it is important to explain what each of them do. [AZUM97a]

The first thing to realise is that hardware enables software to do things, you can have the best software in the world but if you don't have a computer to run it on then it is useless. So in order to do AR while walking around outdoors, we need certain parts before the software can be executed.

So, to perform our research, we have built up a wearable computer [MANN96, BASS97] based around a standard PC laptop, mounted on a backpack. When walking around outdoors, traditional components such as big displays and keyboards are all useless, and so these have been replaced with more exotic components such as a GPS receiver, 3-axis magnetic compass, head mounted displays, and custom built input devices.

2.1 Integration

Everything needs to be carried around by the user, making them completely independent and able to move autonomously. In order to connect everything together and make it portable for outdoor use, each of the components are firmly attached to a hiking frame, with the cables tied up and secured. The figure below shows each of the devices mentioned in this section, plus the batteries, straps, and cables used to hold everything together.



Figure 1 – Tinmith Backpack Outdoors

The first thing that most people observe when seeing the backpack is that it is heavy and bulky, and we agree with them. But it does work however, and the main objective of the project is to perform research into augmented reality – the wearable computer aspect is not so important. As a result, flexibility with hardware and ease of use are the most important driving factors. Given sufficient manufacturing and financial resources it would be straightforward to produce a smaller footprint device containing all the components fully integrated, but this is not the area of interest. Some companies are starting to produce hardware for this application and so it is only really a matter of time.

2.2 Portable Computer

The core of the system that brings everything together is the laptop computer, which is used to process the information from the sensors, and then provide feedback to the user looking through the HMD. For our system, we initially used a Toshiba 320CDS (P-200), although now we use a Gateway Solo (PII-450) which is considerably more powerful. Laptops are very useful for a wearable because they are already portable, highly integrated, are power efficient, and you don't have to solder anything. It is also possible to buy small, embedded OEM biscuit PC boards, which usually have more I/O capabilities, but require you to build the case and connectors yourself.

Any kind of laptop can be used for a wearable, depending on your personal taste, needs, and financial resources. Some important factors are CPU, memory, video, I/O, and Linux compatibility - and most Pentium-based laptops work quite nicely. The most critical ability is to have a laptop with serial, USB, and PCMCIA connectors to allow the connection of various kinds of devices.

2.3 Head Mounted Displays

The most obvious part of the system is the head mounted display. We use two kinds of Sony Glasstron devices: the PLM-S700E, which runs at 800x600, and the PLM-100 display, which runs at NTSC resolution with a VGA converter.

A HMD is a relatively simple device, (although the most expensive) containing an LCD display similar to that used inside a small TV, and uses mirrors and lenses to steer the light into the user's eyes. When wearing a HMD, the wearer is given the impression of looking at a large screen floating several metres away.



Figure 2 – Sony Glasstron HMDs

A traditional HMD for virtual reality is opaque, in that the user wears it as part of a helmet, and the rest of the world is completely blacked out so you are immersed into the VR environment. When the power goes, out everything is dark and you must take the display off to see anything. The key difference with the HMDs we are using is that they are partially transparent.

Meta Exhibit 1017
Meta v. Mullen - Page 00151

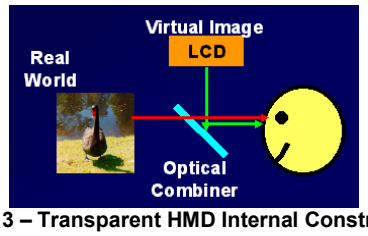


Figure 3 – Transparent HMD Internal Construction

Instead of using standard optics like in opaque HMDs, these use a half-silvered, optical combiner mirror. The image from the LCD display is still shown to the user as before, except now the mirror also allows light from the real world. The end result is a ghosted image where you can see the physical world but also computer generated imagery, as shown in the figure below.

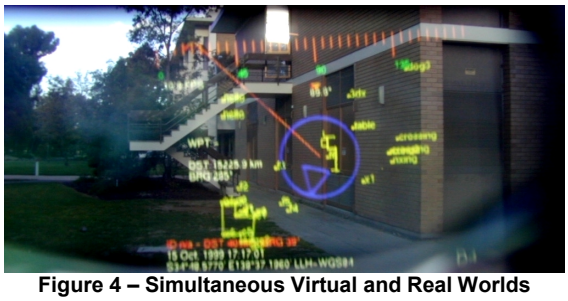


Figure 4 – Simultaneous Virtual and Real Worlds

There are many kinds of HMDs on the market, although most of them tend to be expensive (thousands of dollars) as there is not a large market for these yet. Also, HMDs vary in image quality and field of view depending on the price. Some displays have very dull looking images, do not work well in sunlight, and have very low resolution. The term field of view (FOV) is defined as how much of the user's vision the display can draw over, the larger the view then the more complex the internal optics are.

Recently, a new generation of laser displays has emerged, which paint an image on to the retina in the back of the eye directly. These displays have a much higher quality image, and will soon be small and cheap enough to be actually used. These are still being developed but are something to look out for.

2.4 Position Tracking

In order to allow the computer to draw images that match the real world, it needs to know where you are. When trying to overlay three dimensional models over the real world, having an accurate position is very important, otherwise the images will not overlay correctly and the user will have trouble understanding the image.

Since we are operating outdoors, we use US Global Positioning System (GPS) satellites, along with a Garmin 12XL receiver unit. The GPS receiver calculates its position once per second by working out its distance from a constellation of GPS satellites in space. Due to atmospheric noise and intentional signal degradation by the US Department of Defence, (selective availability) the accuracy of GPS can vary to around 30 metres, which is not acceptable. By using a differential GPS receiver, it is possible to receive correction signals from base stations that allow us to get position updates that are at around 5 metres accuracy, although this can vary.

Position trackers rely on some kind of infrastructure being in place before they can be used. Systems exist that use magnetic and ultrasonic trackers, although these have limited range and require fixed transmitters. Other systems use video cameras to capture images to work out location, but image recognition is immature and requires prior knowledge of the surroundings. The advantage of GPS receivers is that their reference points are in orbit, meaning they are visible almost all the time, and work anywhere in the world. The only catch with GPS is that it does not work indoors.



Figure 5 – Garmin 12XL GPS

Most GPS manufacturers support the NMEA-0183 standard, which allows us to transmit the GPS position information over an RS-232 serial cable to a PC for processing. This format is very easy to process and contains the current world location in latitude/longitude/height (LLH) values.

Since the GPS receiver is only being used as a way of calculating position, having a unit with an inbuilt display or map is a waste of money and not useful, as it is mounted onto the backpack. When purchasing a GPS unit, a good quality receiver is the criticial part, as some units cut corners here. A 5 metre (using differential) GPS unit can be bought for about $500, while more accurate units (from 1 to 50 cm) range from $8,500 to $50,000.

2.5 Orientation Tracking

Just knowing where the user is located in the real world is still not enough for the computer to know everything about where you are and what you are looking at. The heading, pitch, and roll of the user's head is also important, as people very rarely look exactly north. As a result, we use another sensor, a TCM2-80 from Precision Navigation.

This unit uses a 3-axis magnetometer to calculate heading relative to north, and pitch and roll. A fluid filled sensor is used to provide extra calibration information to the onboard microcontroller for processing, and the data is then sent to a PC via an easy to process serial protocol, at a rate of 16 Hz.

Meta Exhibit 1017
Meta v. Mullen - Page 00152

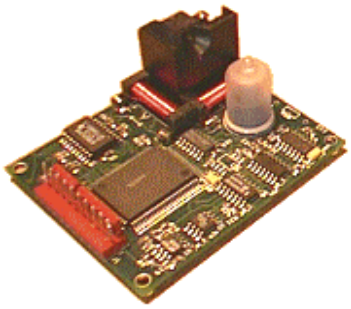


Figure 6 – TCM2 Magnetic Orientation Sensor

The device is mounted onto the HMD, (which is worn by the user) so that it can sense the movements of the user. As they rotate their head, the display updates itself to match.

There are not many devices of this calibre on the market (due to a small demand) and vary in price depending on accuracy and range. The price for the TCM2 range of trackers is around the $1000 mark, which is cheap in comparison to other units. The problem with the TCM2 compass is that it tends to jitter and suffers from magnetic distortion. Large metal objects such as cars and street signs tend to cause the compass to output incorrect information. Other techniques like using gyroscopes and accelerometers are immune to interference, but tend to have problems with drift and alignment. One solution is to use hybrid techniques, [AZUM99] that combine magnetic sensors and gyroscopes together to take advantage of their individual strengths. The Intersense-300 (for $8,500) uses this technique to produce output that is much more stable and accurate, and is something we would like to acquire in the future.

2.6 Miscellaneous Hardware

To provide networking, a Lucent WaveLAN card is used. These operate at 11 Mbit/s and have reasonable range around the building. They tend to suffer from interference from large machinery and thick buildings however, so we are experimenting with antennae placement in the building.

One problem with current PCs is the lack of serial ports – each of the tracker devices sends its data via RS-232 cables, and most laptops only come with one port. As a result, we have had to use PCMCIA based adaptor cards to provide extra ports. These come at a cost however, a four port Quatech card costs about $800, and the connector contains a lot of very fine pins that can break easily when being used outdoors.

We are patiently waiting for USB technology to mature, then we can use RS-232 to USB converters and a hub to connect up as many serial devices as we like – this solution is a lot more expandable and cost effective than using PCMCIA cards. Currently, the converters are not properly supported under Linux, and also are not integrated enough to allow us to have ten of them without requiring lots of USB hubs and power supplies to match.

2.7 Input Devices

A portable backpack computer is useless if the user cannot interact with it. The HMD allows the user to receive information from the computer, but not to input information. Traditional desktop devices like keyboards and mice are not practical outdoors as they are too bulky and require a fixed surface. Instead, devices such as small forearm keyboards, touch pad mice, and track balls are required as an initial starting point at least.



Figure 7 – Phoenix Forearm Keyboard and Usage

One thing that should be stressed is that we are in a different environment from a desktop, with much more freedom of movement, so why should we be restricted to primitive two-dimensional input devices from 20 or more years ago? Rather than try and fit a 3D immersive environment around 2D devices, why not use devices that are designed for the environment? As a result, other more exotic input means like speech recognition and 3D input devices are also currently being looked into.

At this point in time, we are experimenting with using USB cameras to capture video, then perform image recognition of special marker patterns to allow the computer to work out the position and orientation of the user's hands. Hand tracking is traditionally performed indoors using expensive magnetic trackers, but these are too bulky and unworkable outside. By using hand gesturing, voice recognition, and home made data gloves, we hope to develop a useable user interface for AR. This user interface will allow users to manipulate and create new objects in a 3D outdoor AR environment, as shown in the mock up figure below.

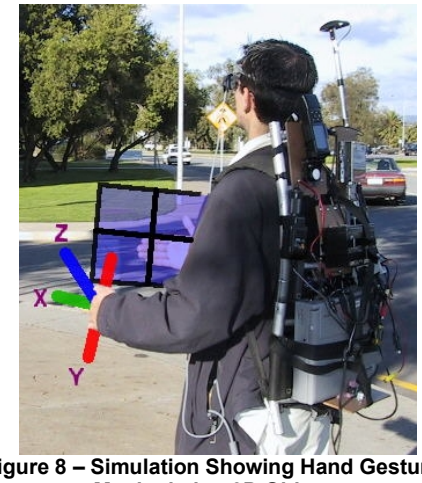


Figure 8 – Simulation Showing Hand Gestures Manipulating 3D Objects

Meta Exhibit 1017
Meta v. Mullen - Page 00153

3 Outdoor Augmented Reality

Given the previously integrated hardware components, plus a suitable software system, it is possible to take the equipment outdoors to use. [AZUM97b, FEIN97] We have implemented a number of AR applications using the Tinmith system, and these will be explained in the following sections.

3.1 Outdoor Problems

As with most research, it usually takes place indoors under nicely controlled conditions. Factors such as lighting, metal, power, and portability can be easily controlled, as everything is static.

Moving outdoors is a real challenge because everything must be portable, power must be carried, each unit uses a different supply voltage, and fragile connectors easily break. Things that work indoors, like the latest and greatest processors, hard disks, and 3D cards, cannot be made portable. Many tracking techniques stop working in large areas. As a result, sacrifices must be made in order to work outside.

Probably the biggest challenge with working outdoors is the cabling and integration – most PC equipment is very fragile and not designed to be moved and put under stress, and as a result, things tend to break a lot. Wiring needs to be tied to the backpack, but at the same time needs to be able to be removed once indoors when things are changed. If the HMD does not work, you cannot use the laptop screen because it is fixed down to the backpack. The tracker devices fail to send serial data due to fragile PCMCIA connectors. Sometimes things don't work, and then a faulty connector will begin to work again for no real reason.

As a result, working with this equipment can be frustrating at times, and going outside usually involves quite a bit of preparation, including going down three flights of stairs in the CS building from our lab. In most cases, things are tested indoors as much as possible before venturing into the hostile outdoor environment.

3.2 Wire Frame Augmented Reality

Once the hardware issues are resolved, the real research is in augmented reality however. The main output of the Tinmith software system is 3D rendered output. This renderer is similar to that used for games such as Quake, except the renderer is a lot simpler and has been optimised for AR, and runs in a variety of different modes. The different versions of Tinmith each have renderers of different capabilities, and so the release number will be mentioned for each one.

In this example, we are using the wire-frame based renderer in Tinmith-III. A model of some UniSA campus buildings was carefully designed in AutoCAD over a period of about two weeks, (most designers use this program so there is no choice in this matter) using information from the GPS to align it with the real world. The figure below shows roughly what the model looks like from an aerial perspective, and the images presented here are based on this.

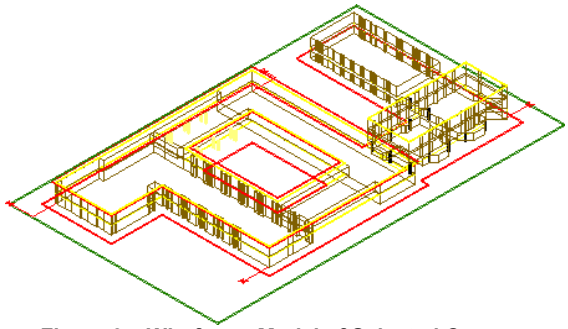


Figure 9 – Wireframe Model of Selected Campus Buildings

For the renderer, instead of the user controlling the position of the camera, the GPS and compass are used instead. So as you walk around the real world, the computer renders a scene to the display that attempts to match the real world.

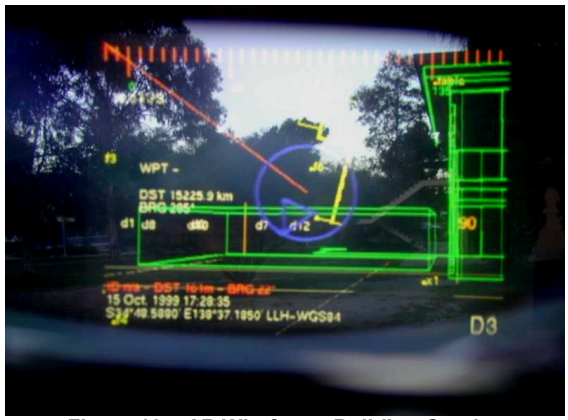


Figure 10 – AR Wireframe Building Overlay

The figure above shows one such example, showing the edge of the building on the right, and the computer has overlaid the wireframe in green over the top. In the centre of the display is a green box, which was used to visualise an extension to a lecture theatre at UniSA. The wireframe is useful for overlaying on real objects, but not very useful for visualising non-existent objects. As a result, a solid renderer is used to produce better displays and was introduced in Tinmith evo4. The rest of the screen components will be explained in a later subsection.

The wireframe model does not line up with the building due to tracker errors – the GPS and compass are not perfect and as a result the image tends to drift and jitter across the screen instead of being perfectly stable. [AZUM99] This can be partly fixed with more expensive equipment, but there is no such thing as perfect tracking, and there are still problems with the computer not rendering frames to the display fast enough. As the user moves their head, the tracker returns a value of the current position, which is sent to the computer with a small delay. The computer then redraws the display, then waits for the retrace in the HMD to redraw the screen. This all takes time (40

Meta Exhibit 1017
Meta v. Mullen - Page 00154

ms and up) and even delays near 1 ms can be noticed by the user.

3.3 Architectural Visualisation

The new solid renderer in Tinmith evo4 allowed more powerful visualisation – rather than just looking at enhancements of existing objects, it allowed us to see what things would look like before they are built. This is useful for people like architects and town planners, they can use the computer to see in real-time what changes to a city landscape would look like without having to use a bulldozer. To do this, the AutoCAD wire-frame model was extended to contain an air bridge connecting two of the campus buildings, drawn using solid polygons.

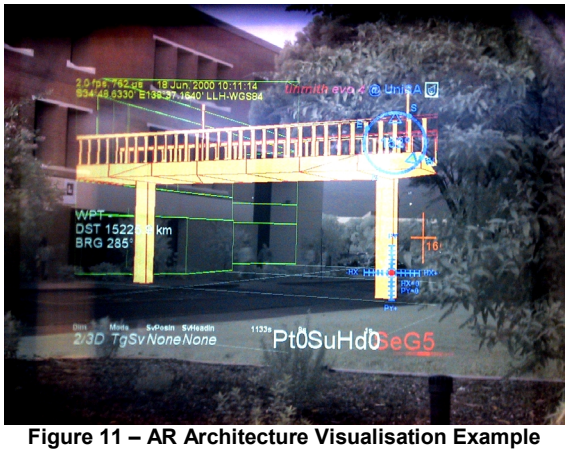


Figure 11 – AR Architecture Visualisation Example

The figure above shows the scene outdoors through the HMD. Notice the green wireframe outline does not line up to the building once again. Also note the limited area that the display can actually draw on, the field of view of most HMDs is quite small.

3.4 Outdoor Navigation System

The original Tinmith-II system was designed to be used as a navigation system by DSTO. To navigate outdoors in unfamiliar terrain, a map and compass must be used to avoid getting lost. This tends to rely on using local landmarks, plus counting paces and using a compass. This fails to work during the night when there is no light, or in featureless terrain. Also, if an obstacle like a forest or river is encountered while dead reckoning, you must plow through it rather than walk around it, otherwise you will lose your position. However, using a suitable navigation system mapped to a HMD, it is possible to see exactly where you are in the world, what objects are around, dangerous places to avoid, and steering instructions to get where you are going. The goal was to improve situational awareness, make someone's job easier, and give them time to think about more important problems.

The main interface for this navigation system is a 2D top down gods-eye view of the world, with fixed information overlaid on top, shown in the figure below.



Figure 12 – Outdoor Navigation System Example

At the top of the display is the compass heading, which is represented as notches and a value every 45 degrees. As the user rotates their head, the compass updates itself and scrolls left or right to indicate the new heading. The various pieces of text information placed around the display are used to show position, GPS accuracy, and steering instructions to the nominated waypoint.

At the centre of the display is a blue circle indicating current position at the centre, with a blue triangle indicating the direction of where the user wants to go. Shown in yellow is the outline of the buildings in the area, which could be used to walk around the buildings. A red line with crosshair is controlled with a touch pad mouse to designate new waypoints on the map. The entire display is presented as a top down view, where the direction the wearer is facing is up. Every visual cue is rotated in real time as the user moves around.

3.5 Integration With DSTO DIS Simulations

As part of our collaboration with DSTO, we modified the system (to produce Tinmith-III) so it would be able to interact with other systems. At DSTO, they run a lot of simulation software, such as ModSAF [ARMY99] and MetaVR [META99] (very expensive commercial programs). The ModSAF program is used to generate entities for virtual battles, containing code to generate realistic intelligence for tanks, helicopters, and soldiers. These entities generate DIS packets which are broadcast onto a network for other software to use. The Distributed Information Standard (IEEE standard 1278) is an open standard using UDP, designed to allow simulation software to share information. The MetaVR program takes in these DIS entities and renders them on realistic 3D terrain.

DSTO uses these programs for training simulations, and have tank and helicopter cockpits that people can sit in (using real helicopter controls and seats, and three projectors for an immersive feel) and interact with the virtual entities. As part of a joint research project, [PIEK99c] it was thought it could be useful if the DIS systems could share information with Tinmith. Using a Lucent WaveLAN card in the laptop, the DIS packets were passed from the DSTO network to the wearable by a Linux based desktop machine. This interface allows the DIS simulations to see the wearable moving outdoors, and also allows the wearable to see all the DIS entities. The wearable computer can then participate in the exercise just like

Meta Exhibit 1017
Meta v. Mullen - Page 00155

anything else.

The screen shots above show the displays seen by the users indoors. The top four are MetaVR output, and the lower one is the ModSAF entity generator. Each of them are projected onto the walls of the development room at DSTO, giving a command centre like feel. As the wearable person walks around outdoors, people indoors can keep track of their location and current surroundings from the 3D rendered displays. The flying vehicles are generated by the helicopter simulator, which is being flown by a human pilot indoors. The wearable user can see all the simulated entities on their HMD. The goal achieved was to improve the situational awareness of all the users of the system.

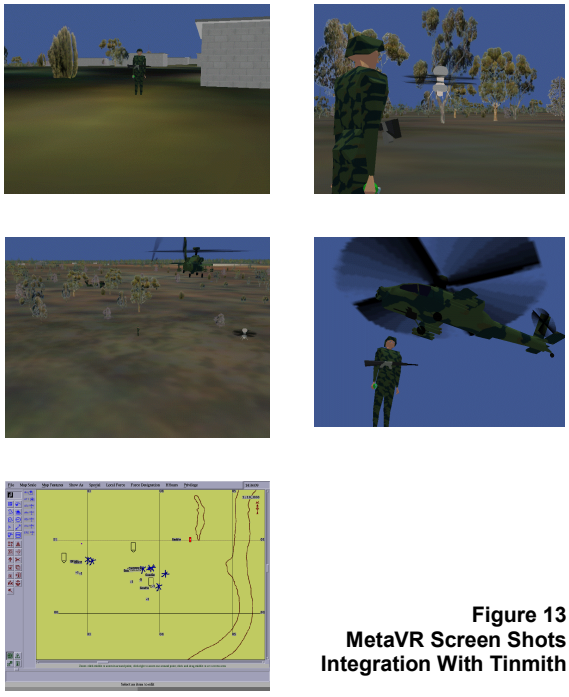


Figure 13
MetaVR Screen Shots
Integration With Tinmith

3.6 AR-Quake

A project just completed this year was performed by a group of computer science honours students. The display module used in Tinmith was turned off, and instead, the open source version of Quake was used to draw the displays. The program was modified to read UDP packets generated from Tinmith's sensor processing code, and the renderer was slaved to the GPS and compass positions.

By supplying the game with models of the UniSA campus, the user can run around outside and play a game of Quake, except it is now a physical game rather than just sitting down. If you want to move in the game, you must move in real life. By having multiple wearables and wireless networking, it is possible to play against other people in real life.



Figure 14 – ARquake Game On Campus

The figure above shows some example shots of a person playing the game. Some of the Quake monsters were modified to improve their visibility, and the controls for moving the player are non-existent, but apart from that, the game plays exactly the same as normal.

3.7 Summary

The previous subsections have covered some of the examples we have developed using the Tinmith system. These are designed to show what AR is capable of, but this is by no means the limit. AR and VR systems have traditionally lacked anything in the way of a user interface, and so the systems tend to be very much read only – you can't interact with them, and this limits what you can do. By making them more interactive, this should allow lots of new applications.

4 Software Support

When the Tinmith system was initially being designed, there were a number of requirements that had to be met for the development environment. This includes kernels, libraries, and development tools. Since a large investment of time was going to be made into something that could be reused in the future, making the right decision the first time was important.

4.1 Operating System

Some of the operating system requirements were:

- True pre-emptive multitasking
- 32-bit memory management and protection
- Interprocess communication
- TCP/IP network support
- Fast graphics rendering support
- Interface to diverse types of legacy hardware
- Low resource requirements
- High reliability

DOS is a good system if you want to talk low level with hardware, as it is only a program launcher and then gets out of the way, but there is no support for this any more, and does not support many of the requirements above.

Win32 has good support for new hardware being released, with all manufacturers writing drivers, and has a good working support base of APIs to do everything from multimedia to 3D. However, it does not allow tinkering with internals, no remote administration, wastes resources, has questionable

Meta Exhibit 1017
Meta v. Mullen - Page 00156

reliability and protection, and just generally lacks the flexibility and control required to build a system like this.

The Linux and FreeBSD kernels, with GNU tools, and the X window system, tend to be very stable, and problems can be always be fixed. Resources are kept track of carefully, and used minimally, and it is almost impossible to crash the systems due to their design. The support for most hardware (both new and legacy) is excellent, with well-written drivers. The only catch is that driver support tends to lag by a few months for new hardware, and some rare hardware takes longer. Also, the APIs for things like USB, sound, multimedia, and 3D are also lagging behind Win32, although just recently this is starting to change. Many of these problems are caused by hardware manufacturers, (the developers of these drivers do a fantastic job) but at the end of the day, if you are building something to be used in the real world, you have to use what works. Our machines previously used Slackware, but now use RedHat 6 distributions. The system has been tested under FreeBSD as well, and will port to any Unix-like system that has all the libraries we use.

4.2 Free Software

The technical superiority of the system chosen was the main factor in selection - things like licensing, cost, or favouritism were not part of the process. If there were tools that could have done the job better, but with some kind of cost and no source code, we would have selected them instead. Having a kernel with open source is handy, but during the life of the Tinmith system, we have not yet made any changes to it. In reality, most people are not able to write their own video or network card driver, or fix a bug in the kernel, without a lot of experience and dedication. Since we are not making any changes to other's code, there are not too many differences between GPL, BSD, and other open source licenses.

4.3 Development Tools

The GNU tools form a major core for the development environment, using programs such as Emacs, and the GNU C/C++ compiler and debugger. These programs have proven to be of excellent quality, although there are some rare bugs that occur in the g++ compiler. The PostgreSQL database is used to store configuration information for the system instead of traditional text files. Other programs such as CVS and KDE are used to complete the code development environment, along with the rest of the standard programs included with most Linux distributions.

4.4 Graphics Support Libraries

Implementing everything from scratch can be quite difficult, and so where possible, other libraries were used to provide functionality. The most important area was graphics rendering, and so the main focus is on this.

The original prototype Tinmith-I system onwards used X protocol drawing calls, and double-buffering in pixmaps for smooth refreshes. The displays were quite primitive with only 2D objects, and so it was possible to render frames at a reasonable speed using this method. However, when rendering thousands of primitives per frame at very high refresh rates, X protocol breaks down. The amount of task switching and IPC between the X server and display module causes the system to waste most of its CPU time in the kernel instead of getting real work done. The one major flaw we can see with the X model for high performance graphics is that it requires IPC to do anything, although this is changing, with support for new architectures like DGA and GLX.

As a result of this, a more direct approach was needed. It would have been possible to use the shared memory extensions to send client rendered frames to the X server, but this would require writing a complete graphics library for handling lines, triangles, and so forth. This could take a lot of time to implement properly, and has been done before many times already. Unix users have tended to focus on the X window system as the only way to do graphics, but some times direct to hardware is the only way to go.

Libraries like SVGAlib allow the programmer to write to the display directly, but this library is very old and has limited support for newer video hardware. It does not seem to be maintained by anyone any more, and my impression is that it is basically dead. OpenGL hardware acceleration was not supported under Linux at the time (Only Mesa with slow software rendering, more on this later). The only available alternative was the Generic Graphics Interface (GGI) project. [GGIP00] The purpose of this library is to provide an abstraction layer for all graphics and input device hardware, and it works on the console, in X windows using both Xlib and shared memory, the new frame buffer drivers in the kernel, plus other special XFree86 extensions like DGA. We used the X shared memory target, as it was faster than the DGA (direct graphics aperture) interface, and it did not lock up the console. The GGI's ability to abstract away input devices on a variety of targets was a big plus, as handling this can be quite tricky in some cases.

So Tinmith-evo4 was created to use the GGI libraries, and with the speed restrictions removed, it was possible to add support for a full 3D polygon-based renderer. The performance increase was phenomenal, the number of system calls dropped to the point where strace() only showed IPC calls at the end of each frame being rendered. The GGI project is definitely a work in progress, the SVGAlib target does not support double buffering, and many of the other drivers are not yet complete. There were a few bugs present in the code for 16-bit mode which we had to hack out to make things work properly. Also, there is no decent font support built in, so a wrapper was written to the Freetype font renderer, allowing us to draw cached anti-aliased True Type fonts to the

Meta Exhibit 1017
Meta v. Mullen - Page 00157

display at very high speeds. Speed is everything, and so we use large amounts of memory (which is cheap and abundant) to store things that we will use more than once, rather than create them repeatedly.

4.5 OpenGL Support

The GGI library was selected as it was the only available solution at the time that worked properly. Speed is everything, and so having proper 3D hardware handle the rendering is always preferable. Most of the processing in Tinmith happens quite quickly except for the rendering stage, which is the most complex when dealing with large models.

OpenGL was, and always will be, the real goal, but unfortunately, the Mesa software-only renderer was useless as it was too slow. Windows has always had drivers for OpenGL hardware, but these were not available to use with Linux. At the start of 2000, proper hardware accelerated 3D under XFree86 was almost non-existent, but recently a number of new drivers have been written to support this. When these drivers become stable, available with standard distributions, and are able to operate with laptop 3D chipsets like ATI Mobile Rage, then Tinmith will be modified to use this, as having hardware do 3D rendering is always preferable.

When the system was ported to GGI, a custom 3D renderer was written to handle the drawing of the models. However, the internal structure of this was optimised for OpenGL rather than the custom renderer, and the code was written so it would be easy to add the necessary OpenGL calls when it became feasible.

Due to the design of the GGI library, it should be possible to make GGI work with OpenGL, rather than having to throw all the previous code away. GGI supports dynamic loading and extensions, and some work is currently being done on writing a generic 3D API which fits into OpenGL – the progress of this project is unknown however.

4.6 Summary

Using free software tools and libraries has provided the ability to be very flexible and create some powerful software. The operating system is very efficient and can be stripped down to the minimum required software so that majority of the CPU time is dedicated to processing incoming data to render the HMD output. However, Linux currently lacks API support for things like writing games (which Tinmith is very similar to in requirements) and as a result, a number of wrapper libraries and hacks were made to make everything fit together. Having proper 2D and 3D with hardware support would make the development of the system a lot easier. Fortunately, a dedicated team of developers is making new progress in this area all the time, however, these things all take time and resources.

5 Software Architecture

5.1 Introduction

Kernels tend to provide only very limited services to hardware – open(), read(), write(), and some simple controls via ioctl(). However, only limited functionality is supplied and so the rest of it is implemented in user-land using libraries like GNU libC. Other systems like X provide interfaces to devices like mice and displays, to remove the complexity of having to deal with so many different kinds of hardware. However, just having low level libraries that can read desktop input devices and draw 2D pictures is not sufficient for AR/VR technology.

AR/VR is a very new area and is also immature, with lots of different kinds of trackers, input devices, and graphics hardware available. Each of them supports a different standard, and there are no standard APIs to interface to them.

In order to implement test AR applications for our research, a set of libraries needed to be developed to provide a set of basic functions that could be reused. The Tinmith system is an architecture that developers can use to develop AR (and other) applications that deal with trackers, input devices, networks, and graphics. Many of the interfaces to the kernel in libC are very primitive and so higher level interfaces are provided to hide away many of the details, making life easier for the developer. It also provides support at very high levels to process the protocols from various different tracking devices into a common format, for other code to read. This makes coding the rest of the system easier as the developer only has to worry about high level problems and not trivial ones like parsing tracker outputs.

5.2 Overall Modular Structure

The HMD snap shots shown as examples in this paper are really only the tip of the iceberg. The Tinmith system is not just a single process running on a machine, but in fact a collection of separate software processes that communicate with each other using TCP/IP. Each process tends to perform a separate function and can be plugged in together as certain needs arise. Proper Unix processes were originally used because threads were not fully stable at the time of initial design. Modules that have bugs can be kept separate so any memory problems can be isolated from the rest of the system and debugged individually. The architecture allows us to manage complexity by keeping things separate from each other, where possible. Some of the modules in the system are outlined in the following subsections.

5.2.1 Harvester Module

The most important module is the harvester, which gathers data in the system. This module polls all the serial ports available, and parses the incoming data from the variety of different hardware trackers plugged in. Tinmith defines special structures for storing position and orientation information, and the

Meta Exhibit 1017
Meta v. Mullen - Page 00158

values are parsed and stored into these standard containers. These values are then made available on a networked object bus for other modules to receive.

5.2.2 Navigation Module

This module takes in position information, and uses it to make steering calculations for the user. The module contains a list of all waypoints in the system, as well as the currently selected one, and as each new position update is received from the harvester module, the bearing and distance are recalculated. These values are then made available for other modules to use.

5.2.3 Display Module

This module is the other core module, it takes in values from the harvester and navigation modules, and uses these to produce the display seen by the user. Any key presses received on the keyboard are made available to other modules that need to use this information for controls.

5.2.4 Sound and Watchdog Modules

This process continuously monitors the various variables in the system, and will sound audible (beeps or wave sound files) and/or spoken (synthesized voice) alarms when it is detected that these values have exceeded some parameter. For example, you could setup the watchdog module to sound an alarm or speak an announcement when you arrive within 100 metres of the destination waypoint.

5.2.5 Web Module

This process interfaces to CGI programs run by the Apache web server, allowing users to find out information about the wearable computer from a web browser. The module provides information about the wearable location and orientation, and refreshes continuously on the screen. This is a good example of how the system can be interfaced to systems that are of different design.

5.2.6 DIS and LSAP Module

The wearable computer contains an in-built object tracking module, which allows it to know the location of objects in the world, and follow their movements. This interface has been written to allow this tracker to share information (both ways) with the DIS (Distributed Interactive Simulation) and LSAP (Land Situational Awareness Picture System) based software used at DSTO. This ability once again demonstrates that the network architecture of Tinmith allows it to be extended and modified to fit the need relatively easily. Given something like a radar tracking device, it should be possible to modify the system to process targets and track moving real world objects. If the hardware is capable of it, the system should be able to handle it.

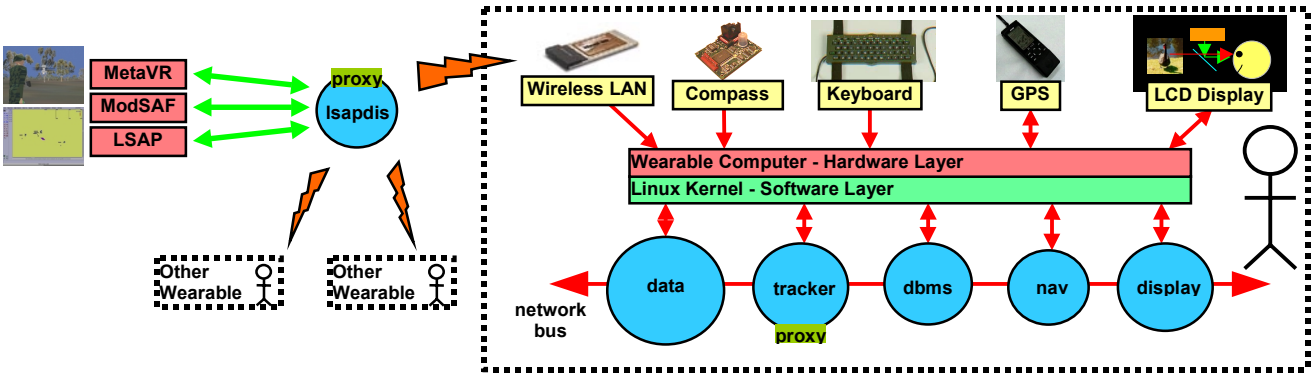
5.3 Module Communications

To interconnect modules, we used a client-server style architecture. The server is a data source for other modules, and it listens on a TCP/IP socket waiting for incoming requests from clients. A client that wishes to receive data will contact the server, and send a listen message to subscribe to it. Whenever the server updates the value of this data, it will send the new value out to all clients that have registered an interest in the message. A client receiving new data may use it to update the screen, or calculate new navigation parameters, for example. Note that many servers in the system are actually clients for other servers as well.

The entire system operates asynchronously, and is data driven; if there is no new data in the system, no action will be taken by any of the software modules. To illustrate this, consider the case of a new incoming position from the GPS. The harvester will process the new data, and then distribute it to all clients. The navigation module will receive this update, and recalculate navigation information. The display module will eventually receive an update from the harvester, and the new steering instructions from the navigation module, and use these to redraw the screen to reflect the user's new location.

5.4 Software Library

To implement the modular architecture, a software library to support this was designed, with goals being to be flexible, extendible, and layered. Layering was employed to provide increasing levels of abstraction for allowing modules to interact with the system at the appropriate level they require, while at the same time minimising code replication across the system, and localising possible errors. Rather than modules focusing on communicating with each other, the code



Meta Exhibit 1017
Meta v. Mullen - Page 00159

only does the tasks it needs to do, and then makes calls to library functions that actually make connections, subscribe, and process new incoming data. As a result, writing software modules to fit into the system is simple, and with many of the low level and repetitive details hidden away, also quite small.

The libraries provide functionality for distributed processing, asynchronous I/O, dynamic software configuration, and automatic code generation (among others):

5.4.1 Running modules in parallel over TCP/IP

Each of the modules are implemented as separate Unix processes. This allows modules to be distributed over multiple processors on one machine, or multiple machines due to the network support. The ability for the system to support this at a fundamental level improves the scalability for larger, resource intensive applications. For example, the outdoor navigation system was distributed over both the laptop and a second 486 wearable, which was included to increase the limited I/O capabilities of the laptop.

5.4.2 Asynchronous I/O event handling

The core of the library revolves around an event handler which monitors open file descriptors and waits for them to become available for reading or writing. When data arrives on the socket, the data is read, processed, and then handed to the calling code. As the complexities of doing I/O are abstracted away from the calling code, (to the point where even the type of transport is not specified) it is straightforward for the TCP implementation to be replaced by UDP by simply rewriting the library code. Slow serial links requiring writes to be buffered, and support for handling devices such as X servers, tty devices, and serial ports are integrated in.

One interesting feature of the I/O library is the ability to plug in simulated devices. During testing indoors, it was possible to plug in software simulations instead of real GPS and compass hardware, enabling us to test the modules easily. Running GDB through a HMD outdoors, with a keyboard on the ground, is not easy and very tiring on the eyes.

5.4.3 Dynamic configuration from the DBMS

Most software tends to use statically compiled controls, or possibly a configuration text file. Our system takes configuration to the next level by loading all system parameters such as the location of modules, port numbers, device names, and screen colours into a series of relational database tables. When the software initialises, it queries the database and loads the values required. By sending messages throughout the system when changes are made, it is possible for clients to reconfigure themselves by querying the database again. The software does not have to be restarted as would be required if the controls were static. The database proved to be very powerful because someone inside can change it remotely via the network if needed. A second feature is the strong type checking by the database engine (in our case PostgreSQL v6.5) rather than relying on parsing a text file, which could contain errors. This feature proved useful when performing testing outdoors, for example, tuning the various display options such as colours and font sizes.

5.4.4 Automatic message code generation

Each of the data values in the system (represented by messages) needs to be able to be sent in a portable fashion across the network. Since Tinmith is designed to be compiled on both big and little endian machines (Sun and SGI machines use different byte ordering than Intel), it is not good enough just to send the message in binary format. Also, as versions of the software change, it would be a good feature if older versions of the software could handle messages that have new fields added, but the old ones still remain the same. A custom program called STC is used to compile special message definition files into code and headers that is responsible for serialising and deserialising them for the network. The precompiler saves a lot of effort needed to write the code by hand.

5.5 Summary

The Tinmith software architecture was designed from the start to be flexible, and able to be extended in the future. The modular design enables new components to be plugged in easily, and many of the prototypes created with this system were not designed until after the architecture was complete. The architecture is data driven, and can benefit from distributing components as separate processes across multiple computers. A layered implementation eases application development, increases the overall reliability of the software, and gives a degree of device independence.

6 Problems and Notes

During the development of the work presented here, a number of issues and problems became apparent. Linux and its support environment is not perfect, and there are lots of places with room for improvement. However, improvement is always something the free software community has excelled at, a good example being the KDE and Gnome projects, and so given time these issues will surely be addressed.

6.1 USB Support

Proper USB support for devices like video cameras is currently only available in development kernels, and the code has been buggy at the best of times. Since the USB code is only very new, we had to put in a lot of effort to try and make Linux talk to the cameras. At times the machine would lock up, or refuse to communicate with the camera until reboot.

Also, support for many kinds of other cameras and serial port interfaces is non-existent, as the manufacturers have not released specifications or no one has written a driver yet. We had to shop carefully

Meta Exhibit 1017
Meta v. Mullen - Page 00160

for USB devices to ensure they would work at all. This is something that will improve with time, but as of now the support is limited.

6.2 Graphics

Hardware accelerated 3D under XFree86 is just coming of age now. New extensions to XFree86 v3 and v4 have been made to support certain cards, and some manufacturers have supplied drivers for their hardware. However, many chipsets are not supported, or only with partial functionality. Also, tinkering with all these new drivers and patches takes a lot of precious time, having this supported as a standard feature in some type of future Linux distribution would be a lot easier to handle. For now, we are still using custom written renders, but using OpenGL will mean we can make the code simpler and faster at the same time, freeing up CPU resources for other uses.

6.3 Higher Level APIs

Linux and FreeBSD operating systems have wonderfully designed kernels, and good low level support in libC. However, there is not much higher level functionality beyond that. Authors who wish to write games for Linux must currently roll their own libraries for sound, video, input devices, and graphics, or they have to hunt around for development libraries which may or may not do the job properly. This can take a considerable amount of time and is probably a reason why some have not ported their games to Linux. There is currently an effort in the community to fix this, but these are far from complete and some projects may not be completed or have been abandoned.

7 Current Work

7.1 Tinmith Evolution 5

The Tinmith system (up to version four) worked quite well for a number of years, however there are also a number of limitations and problems with the design. While the design had some features that seemed like a good idea, some of them turned out to be not used but a performance penalty was still imposed in the design. Also, there were limitations in the design which were making it hard to implement new user interface techniques that we wanted to try out.

As a result, a new Tinmith design, evolution 5, written in C++, was put on to the drawing board in May, and work is currently progressing on that. The first major difference is the use of C++, version four used only standard C but portions of the code were dedicated to providing object oriented features. In reality, if you are using OO, you should use a proper OO language. The code contained a lot of void* pointers internally and this was starting to cause confusion and problems. Also, extra features like the STL provide functionality that does not have to be implemented yourself, and generally more efficient at the same time.

The other major problem was the software modules – being implemented as separate Unix processes required them to use IPC to communicate with each other. As a result, processing large amounts of data also required large numbers of system calls to move all the data around. Waiting for the kernel to task switch around four or more processes takes time, and this was causing lag in the renderer output, and as mentioned before, any lag that is preventable should be eliminated to improve the quality of the system. Serialisation, rather than parallelisation, is the key to efficiency here. Due to the way the libraries were written, it was not possible to combine all the modules together into one without making changes everywhere, and the effort was not worth it.

So as a result, the code was converted into C++, each part of the system was either modified or rewritten to fit the new design. The low level parts were rewritten into C++ code, and the high level code (which took the most time to write) like the renderer, parsers, navigation calculations, 3D modeller, and graphical displays – were all ported over relatively easily. The original code has now been completely converted and works as before, but now as a single process with no threads. Spreading the system over a network is still supported, but not a requirement like before. The streamlined design makes the system run faster and more efficiently, and the code is easier to understand overall.

The lesson learned from this is that C++ (used correctly of course) can write programs that are much easier to understand, especially when they become very complicated. Trying to solve an object oriented problem using traditional functions and structures is really a hack and produces code which can cause problems in the long run. The effort required to convert from C to C++ has already paid off, with new changes being easier to implement.

7.2 Software Availability

The Tinmith system is currently not available to the public at this time. This system is the vehicle I use to perform the research for my PhD thesis, and is currently undergoing major changes to support new user interface techniques I am developing. The architecture is usually having changes made, and is not complete to the point where someone else could write their own applications easily – there is minimal documentation except for my own designs and notes.

During the completion of my research, the Tinmith-evo5 architecture will be finalised, and used to develop a number of custom testing applications for user evaluation trials. At this time, the code should be useable by others and the university may allow the release the code to the general public. Also, I do not have enough time at this point to prepare the code for distribution, accept patches or code contributions from other authors, and at the same time complete my PhD thesis on schedule.

Keep an eye on the web page references included at

Meta Exhibit 1017
Meta v. Mullen - Page 00161

the back, or contact the authors for more information if you would like to work with Tinmith.

8 Conclusion

The purpose of this paper was to give the user an idea as to what augmented reality is, and some of the things it can do. Tinmith is one of only a handful of augmented reality systems in the world today, and with the new changes for evo5 being made, will also be one of the most advanced.

Currently, most AR and VR systems tend to be read only, the user participates by looking at things. With Tinmith, the authors intend to allow users to interact with the environment using custom built 3D input devices to manipulate 3D widgets and objects. The goal at the end is to produce for 3D environments what people have been using on 2D desktops. There are a number of research problems that need to be solved before this is possible however, just using 2D techniques from the desktop is not good enough.

Augmented reality is an exciting field to be participating in, it is relatively new, and there are lots of ideas to be explored. Rather than just reimplementing the wheel, we are researching and designing the original wheel itself.

9 References

[ARMY99] US Army Simulation, Training, and Instrumentation Command (STRICOM), ModSAF – http://www-leav.army.mil/nsc/stow/saf/modsaf/index.htm

[AZUM97a] R. Azuma, Survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4). 1997.

[AZUM97b] R. Azuma, The challenge of making augmented reality work outdoors. In *Mixed Reality: Merging Real and Virtual Worlds*. Y. Ohta, H. Tamura (ed), Springer-Verlag, 1999. Chp 21 pp. 379-390.

[AZUM99] R. Azuma, B. Hoff, H. Neely, R. Sarfaty. A Motion-Stabilized Outdoor Augmented Reality System. In *Proc. of IEEE Virtual Reality '99*, Houston, TX, Mar 1999. pp 252-259.

[BASS97] L. Bass, C. Kasabach, R. Martin, D. Siewiorek, A. Smailagic, J. Stivoric. The design of a wearable computer. In *CHI 97 Looking to the Future,* pp 139-146. ACM SIGCHI, ACM. 1997.

[FEIN97] S. Feiner, B. MacIntyre, T. Hollerer, A. Webster. A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. In *1st Intl. Symposium on Wearable Computers*, Cambridge, Ma, Oct, 1997. pp 74-81.

[GGIP00] Generic Graphics Interface Project, http://www.ggi-project.org, 2000.

[JACO97] M. Jacobs, M. Livingston, A. State, Managing Latency in Complex Augmented Reality Systems. In *Proc. 1997 Symposium on Interactive 3D Graphics*, Providence, RI, Apr 1997. pp 49-54.

[MANN96] S. Mann, Smart Clothing: The Shift to Wearable Computing. In *Communications of the ACM*, Vol 39, No. 8, pp 23-24, Aug 1996.

[META99] MetaVR, Inc., *MetaVR Virtual Reality Scene Generator* – http://www.metavr.com, 1999.

[PIEK98a] W. Piekarski, D. Hepworth, Outdoor Augmented Reality Navigation System – Project Documentation. University of South Australia, 1998.

[PIEK99a] W. Piekarski, D. Hepworth, V. Demczuk, B. Thomas, B. Gunther. A Mobile Augmented Reality User Interface for Terrestrial Navigation. In *Proc. of the 22nd Australasian Computer Science Conference*, Auckland, NZ, Jan 1999. pp 122-133

[PIEK99b] W. Piekarski, B. Thomas, D. Hepworth, B. Gunther, V. Demczuk. An Architecture for Outdoor Wearable Computers to Support Augmented Reality and Multimedia Applications. In *Proc. of the 3rd International Conference on Knowledge-Based Intelligent Information Engineering Systems*, Adelaide, South Australia, Aug 2000. pp 70-73.

[PIEK99c] W. Piekarski, B. Gunther, B. Thomas. Integrating Virtual and Augmented Realities in an Outdoor Application. In *Proc. of the 2nd International Workshop on Augmented Reality,* San Francisco, Ca, Oct 1999. pp 45-54.

[THOM97] B. Thomas, S. Tyerman, K. Grimmer, Evaluation of Three Input Mechanisms for Wearable Computers. In *1st Intl. Symposium on Wearable Computers*, Cambridge, Ma, Oct, 1997. pp 2-9.

[THOM98] B. Thomas, V. Demczuk, W. Piekarski, D. Hepworth, B. Gunther, A Wearable Computer System With Augmented Reality to Support Terrestrial Navigation. In *2nd Intl. Symposium on Wearable Computers*, Pittsburg, Pa, Oct 1998. pp 168-171.

10 Further Information

10.1 Reading Sources

There is a lot of information about the topics discussed here on the Internet, use a search engine to look for it. A number of conferences proceedings from IEEE and ACM contain interesting material, such as:

- ACM CHI (Computer Human Interaction)
- ACM I3D (Interactive 3D Graphics)
- ACM SIGGRAPH (Graphics)
- ACM UIST (User Interface Software and Technology)
- IEEE ISAR (International Symposium on Augmented Reality)
- IEEE ISWC (International Symposium on Wearable Computers)

Meta Exhibit 1017
Meta v. Mullen - Page 00162

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- QuakeVR Project - Ben Close, John Donoghue, John Squires, Philip De Bondi, Mick Morris
- DSTO - Victor Demczuk and Franco Principe
- Campus Models – Arron Piekarski

10.3 About The Wearable Computer Lab

The Wearable Computer Lab is part of the School of Computer and Information Science, Advanced Computing Research Centre, at the University of South Australia. Research areas in the lab include outdoor wearable computing, augmented reality, 3D user interfaces, computer graphics, and virtual reality.

Apart from just hacking code, we have also been known to use soldering irons and sticky tape on computer hardware occasionally. The original backpack in 1998 had the laptop attached to the backpack using packing tape, and when wearing the computer, an assistant was always present to apply more tape as needed.

10.3.1 The Authors

Wayne Piekarski is currently doing a PhD at UniSA, the thesis being titled, *Human Machine Interfacing In Augmented Reality Worlds.* He is the person behind the Tinmith system, designing and coding it to support his research. He is an avid Linux fan, starting off in 1994 with Slackware 2.0 and kernel 1.1.59, although has been known to use Windows and FreeBSD boxes as well.

Dr. Bruce Thomas is a researcher and lecturer at UniSA, performing work in a number of areas including AR, VR, wearable computers, and user interfaces. He is the supervisor for Wayne's PhD research.

10.3.2 More Information

For more information about our work, please visit the following URLs or email us. We always like to hear about what people think about our research. If you feel that there is something you would like to contribute, then please contact us.

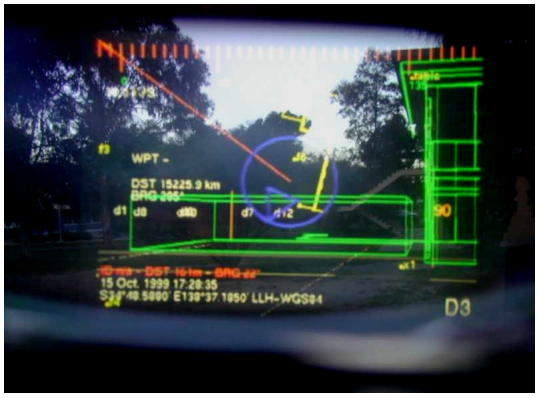
Information about the wearable lab
http://wearables.unisa.edu.au

Information on the Tinmith project
http://tinmith.unisa.edu.au

The author's home page and email address
http://www.cs.unisa.edu.au/~ciswp
wayne@cs.unisa.edu.au
thomas@cs.unisa.edu.au

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Meta Exhibit 1017
Meta v. Mullen - Page 00163

EXHIBIT 1009B

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About this capture

This page contains all the research papers which have been written as a part of the Tinmith project

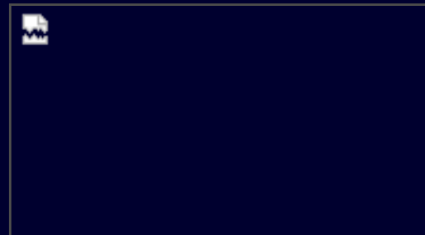
useful readings

Read the papers in this section (also referenced below) to find out about the work being done in this area.

TR-ARCH01	Complete description of the Tinmith-evo5 software architecture, explaining the internals of our current applications.
ISAR01	Poster version of above tech report presented at ISAR 2001.
ISWC01	Our first paper on using Tinmith to model outdoor structures, using our novel infinite planes technique and user interfaces.
LINUX01	A very easy to understand paper describing the hardware used when constructing outdoor augmented reality systems, written for Linux Conf 2001.
IWAR99	Describes our work with making Tinmith communicate using the DIS simulation protocol to collaborate with remote software.



Backpack computer with HMD outdoo



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tinmithresearchpapers

tinmith project research papers

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IWAR99	Describes our work with making Tinmith communicate using the DIS simulation protocol to collaborate with remote software.

publications

Here is an up to date list of all my publications:

IEEEVR02	Piekarski, W. and Thomas, B. Tinmith-Hand: Unified User Interface Technology for Mobile Outdoor Augmented Reality and Indoor Virtual Reality. In IEEE Virtual Reality, Orlando, FL, Mar 2002.
TR-VR02	Piekarski, W. and Thomas, B. H. Unifying Augmented Reality and Virtual Reality User Interfaces. Technical Report, University of South Australia, Adelaide, SA, Jan 2002.
TR-ARCH01	Piekarski, W. and Thomas, B. Tinmith-evo5 - A Software Architecture for Supporting Research Into Outdoor Augmented Reality Environments. Technical Report, University of South Australia, Adelaide, SA, Dec 2001.
ACM02	Piekarski, W. and Thomas, B. ARQuake: The Outdoor Augmented Reality Gaming System. ACM Communications, Vol. 45, No. 1, pp 36-38, Jan 2002.
AUIC02	Piekarski, W. and Thomas, B. The Tinmith System - Demonstrating New Techniques for Mobile Augmented Reality Modelling. In 3rd Australasian User Interfaces Conference, Melbourne, Vic, Jan 2002. *(Voted best paper at AUIC)*
ISAR01	Piekarski, W. and Thomas, B. Tinmith evolution 5 - A Unified Architecture for Supporting Mobile Augmented Reality User Interfaces. In 2nd Int'l Symposium on Augmented Reality, New York, NY, Oct 2001.

Backpack computer with HMD outdoors

Gloves with 2D/3D cursor overlays and menus



Backpack in A configuration, allowing use like a desk while placed on the ground outdoors

Cube with texture maps captured from camera

ISWC01	Piekarski, W. and Thomas, B. Tinmith-Metro: New Outdoor Techniques for Creating City Models with an Augmented Reality Wearable Computer. In 5th Int'l Symposium on Wearable Computers, Zurich, Switzerland, Oct 2001.
LINUX01	Piekarski, W. and Thomas, B. Tinmith: Outdoor Augmented Reality With Wearable Computers Running Linux. In 2nd Australian Linux Conference, Sydney, NSW, Jan 2001.
ISWC00	Thomas, B., Close, B., Donoghue, J., Squires, J., De Bondi, P., Morris, M., and Piekarski, W. ARQuake: An Outdoor/ Indoor Augmented Reality First Person Application. In 4th Int'l Symposium on Wearable Computers, pp 139-146, Atlanta, Ga, USA, Oct 2000.
DCNET99	Thomas, B., Piekarski, W., and Gunther, B. Using Augmented Reality to Visualise Architecture Designs in an Outdoor Environment. In Design Computing on the Net, pp http:// www.arch.usyd.edu.au/kcdc/conferences/dcnet99, Sydney, NSW, Nov 1999.
IWAR99	Piekarski, W., Gunther, B., and Thomas, B. Integrating Virtual and Augmented Realities in an Outdoor Application. In 2nd Int'l Workshop on Augmented Reality, pp 45-54, San Francisco, Ca, Oct 1999.
KES99	Piekarski, W., Thomas, B., Hepworth, D., Gunther, B., and Demczuk, V. An Architecture for Outdoor Wearable Computers to Support Augmented Reality and Multimedia Applications. In 3rd Int'l Conference on Knowledge-Based Intelligent Information Engineering Systems, pp 70-73, Adelaide, SA, Aug 1999.
ACSC99	Piekarski, W., Hepworth, D., Demczuk, V., Thomas, B., and Gunther, B. A Mobile Augmented Reality User Interface for Terrestrial Navigation. In 22nd Australasian Computer Science Conference, pp 122-133, Auckland, NZ, Jan 1999.
ISWC98	Thomas, B. H., Demczuk, V., Piekarski, W., Hepworth, D., and Gunther, D. A Wearable Computer System With Augmented Reality to Support Terrestrial Navigation. In 2nd Int'l Symposium on Wearable Computers, pp 168-171, Pittsburg, Pa, Oct 1998.



Backpack system in use outdoors, with glove based user interface in use

Wayne Piekarski - University of South Australia, Wearable Computer Lab, Tinmith Project
Contact wayne@cs.unisa.edu.au for more information

Last Updated 17 July, 2002

Meta Exhibit 1017
Meta v. Mullen - Page 00167

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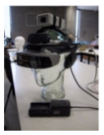
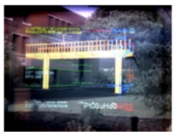
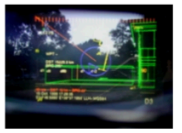
Tinmith
evolution 5

Augmented Reality With Wearable Computers Running Linux

Wayne Piekarski, Bruce Thomas
School of Computer and Information Science
University of South Australia, Mawson Lakes, SA, Australia





Meta Exhibit 1017
Meta v. Mullen - Page 00168

EXHIBIT 1009C

EX1009C
Citations to Piekarski 2001

Source Document:

Piekarski, W., & Thomas, B. (2001, January). Augmented reality with wearable computers running linux. In *2nd Australian Linux Conference (Sydney)* (pp. 1-14), **EX1009** ("*Piekarski 2001*")

Citations: 2002 – 2004 (in chronological order)

Ribo, M., Lang, P., Ganster, H., Brandner, M., Stock, C., & Pinz, A. (2002, December). Hybrid tracking for outdoor augmented reality applications. *IEEE Computer Graphics and Applications*, *22*(6), 54-63.

Gutiérrez, M. D., Márquez, A. M., & Trefftz, H. (2003, January). Achieving object persistence in an augmented reality indoor environment. In *Proceedings of the IASTED International Conference on Computer Science and Technology* (pp. 259-263).

Siegl, H., Ganster, H., & Pinz, A. (2003). Mobile AR Setups. Published in *Proceedings of the 27th Workshop of the ÖAGM/AAPR, Laxenburg, 2003*, pages 245-252.

Siegl, H., Schweighofer, G., & Pinz, A. (2004, May). An AR human computer interface for object localization in a cognitive vision framework. In *International Workshop on Computer Vision in Human-Computer Interaction* (pp. 176-186). Berlin, Heidelberg: Springer Berlin Heidelberg.

EXHIBIT 1010A

INVITED PAPER *Special Issue on Networked Reality*

A Taxonomy of Mixed Reality Visual Displays

Paul MILGRAM†, *Nonmember and* **Fumio KISHINO**††, *Member*

SUMMARY This paper focuses on Mixed Reality (MR) visual displays, a particular subset of Virtual Reality (VR) related technologies that involve the merging of real and virtual worlds somewhere along the "virtuality continuum" which connects completely real environments to completely virtual ones. Probably the best known of these is Augmented Reality (AR), which refers to all cases in which the display of an otherwise real environment is augmented by means of virtual (computer graphic) objects. The converse case on the virtuality continuum is therefore Augmented Virtuality (AV). Six classes of hybrid MR display environments are identified. However, an attempt to distinguish these classes on the basis of whether they are primarily video or computer graphics based, whether the real world is viewed directly or via some electronic display medium, whether the viewer is intended to feel part of the world or on the outside looking in, and whether or not the scale of the display is intended to map orthoscopically onto the real world leads to quite different groupings among the six identified classes, thereby demonstrating the need for an efficient taxonomy, or classification framework, according to which essential differences can be identified. The 'obvious' distinction between the terms "real" and "virtual" is shown to have a number of different aspects, depending on whether one is dealing with real or virtual objects, real or virtual images, and direct or non-direct viewing of these. An (approximately) three dimensional taxonomy is proposed, comprising the following dimensions: Extent of World Knowledge ("how much do we know about the world being displayed?"), Reproduction Fidelity ("how 'realistically' are we able to display it?"), and Extent of Presence Metaphor ("what is the extent of the illusion that the observer is present within that world?").

key words: *virtual reality (VR), augmented reality (AR), mixed reality (MR)*

1. Introduction—Mixed Reality

The next generation telecommunication environment is envisaged to be one which will provide an "ideal virtual space with [sufficient] reality essential for communication."* Our objective in this paper is to examine this concept, of having both "virtual space" on the one hand and "reality" on the other available within the same visual display environment.

The conventionally held view of a *Virtual Reality* (VR) environment is one in which the participant-observer is totally immersed in, and able to interact with, a completely synthetic world. Such a world may mimic the properties of some real-world environments, either existing or fictional; however, it can also exceed the bounds of physical reality by creating a world in which the physical laws ordinarily governing space, time, mechanics, material properties, etc. no longer hold. What may be overlooked in this view, however, is that the VR label is also frequently used in association with a variety of other environments, to which total immersion and complete synthesis do not necessarily pertain, but which fall somewhere along a *virtuality continuum*. In this paper we focus on a particular subclass of VR related technologies that involve the merging of real and virtual worlds, which we refer to generically as *Mixed Reality (MR)*. Our objective is to formulate a taxonomy of the various ways in which the "virtual" and "real" aspects of MR environments can be realised. The perceived need to do this arises out of our own experiences with this class of environments, with respect to which parallel problems of inexact terminologies and unclear conceptual boundaries appear to exist among researchers in the field.

The concept of a "virtuality continuum" relates to the mixture of classes of objects presented in any particular display situation, as illustrated in Fig. 1, where *real environments*, are shown at one end of the continuum, and *virtual environments*, at the opposite extremum. The former case, at the left, defines environments consisting solely of real objects (defined below), and includes for example what is observed via a conventional video display of a real-world scene. An additional example includes direct viewing of the same real scene, but not via any particular electronic display system. The latter case, at the right, defines environments consisting solely of virtual objects (defined below), an example of which would be a conventional

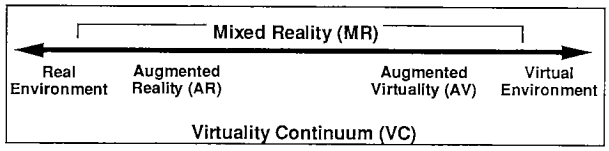


Fig. 1 Simplified representation of a "virtuality continuum."

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† The author is with the Department of Industrial Engineering, University of Toronto, Toronto, Ontario, Canada M5S 1A4.
†† The author is with ATR Communication Systems Research Laboratories, Kyoto-fu, 619-02 Japan.

* Quoted from Call for Papers for this IEICE Transactions on Information Systems special issue on Network Reality.

Meta Exhibit 1017
Meta v. Mullen - Page 00172

computer graphic simulation. As indicated in the figure, the most straightforward way to view a Mixed Reality environment, therefore, is one in which real world and virtual world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum.

Although the term "Mixed Reality" is not (yet) well known, several classes of existing hybrid display environments can be found, which could reasonably be considered to constitute MR interfaces according to our definition:

1. Monitor based (non-immersive) video displays—i.e. "window-on-the-world" (WoW) displays—upon which computer generated images are electronically or digitally overlaid [1]-[4]. Although the technology for accomplishing such combinations has been around for some time, most notably by means of chroma-keying, practical considerations compel us to be interested particularly in systems in which this is done *stereoscopically* [5], [6].
2. Video displays as in Class 1, but using immersive head-mounted displays (HMD's), rather than WoW monitors.
3. HMD's equipped with a see-through capability, with which computer generated graphics can be optically superimposed, using half-silvered mirrors, onto directly viewed real-world scenes [7]-[12].
4. Same as 3, but using video, rather than optical, viewing of the "outside" world. The difference between Classes 2 and 4 is that with 4 the displayed world should correspond orthoscopically with the immediate outside real world, thereby creating a "video see-through" system [13], [14], analogous with the optical see-through of option 3.
5. Completely graphic display environments, either completely immersive, partially immersive or otherwise, to which video "reality" is added [1].
6. Completely graphic but partially immersive environments (e.g. large screen displays) in which real physical objects in the user's environment play a role in (or interfere with) the computer generated scene, such as in reaching in and "grabbing" something with one's own hand [15], [16].

In addition, other more inclusive computer augmented environments have been developed in which real data are sensed and used to modify users' interactions with computer mediated worlds beyond conventional dedicated visual displays [17]-[20].

As far as terminology goes, even though the term "Mixed Reality" is not in common use, the related term "Augmented Reality" (AR) has in fact started to appear in the literature with increasing regularity. As an operational definition of Augmented Reality, we take the term to refer to any case in which an otherwise real environment is "augmented" by means of virtual (computer graphic) objects, as illustrated in Fig. 1. The most prominent use of the term AR in the literature appears to be limited, however, to the Class 3 types of displays outlined above [8], [10]-[12]. In the authors' own laboratories, on the other hand, we have adopted this same term in reference to Class 1 displays as well [5], [21], not for lack of a better name, but simply out of conviction that the term Augmented Reality is quite appropriate for describing the essence of computer graphic enhancement of video images of real scenes. This same logic extends to Classes 2 and 4 displays also, of course.

Class 5 displays pose a small terminology problem, since that which is being augmented is not some direct representation of a real scene, but rather a *virtual* world, one that is generated primarily by computer. In keeping with the logic used above in support of the term Augmented Reality, we therefore proffer the straightforward suggestion that such displays be termed "*Augmented Virtuality*" (AV), as depicted in Fig. 1†. Of course, as technology progresses, it may eventually become less straightforward to perceive whether the primary world being experienced is in fact predominantly "real" or predominantly "virtual," which may ultimately weaken the case for use of both *AR* and *AV* terms, but should not affect the validity of the more general *MR* term to cover the "grey area" in the centre of the virtuality continuum.

We note in addition that Class 6 displays go beyond Classes 1, 2, 4 and 5, in including directly viewed real-world objects also. As discussed below, the experience of viewing one's own *real* hand directly in front of one's self, for example, is quite distinct from viewing an image of the same real hand on a monitor, and the associated perceptual issues (not discussed in this paper) are also rather different. Finally, an interesting alternative solution to the terminology problem posed by Class 6 as well as composite Class 5 AR/AV displays might be the term "*Hybrid Reality*" (HR)††, as a way of encompassing the concept of blending many types of distinct display media.

2. The Need for a Taxonomy

The preceding discussion was intended to introduce the concept of Mixed Reality and some of its various manifestations. All of the classes of displays listed

† Cohen (1993) has considered the same issue and proposed the term "Augmented Virtual Reality." As a means of maintaining a distinction between this class of displays and Augmented Reality, however, we find Cohen's terminology inadequate

†† One potential piece of derivative jargon which immediately springs to mind as on extension of the proposed term "Hybrid Reality" is the possibility that (using a liberal dose of poetic license) we might refer to such displays as "Hyberspace"!

Meta Exhibit 1017
Meta v. Mullen - Page 00173

above clearly share the common feature of juxtaposing "real" entities together with "virtual" ones; however, a quick review of the sample classes cited above reveals, among other things, the following important distinctions:

- Some systems {1, 2, 4} are primarily video based and enhanced by computer graphics whereas others {5, 6} are primarily computer graphic based and enhanced by video.
- In some systems {3, 6} the real world is viewed directly (through air or glass), whereas in others {1, 2, 4, 5} real-world objects are scanned and then resynthesized on a display device (e.g. analogue or digital video).
- From the standpoint of the viewer relative to the world being viewed, some of the displays {1} are exocentric (WoW monitor based), whereas others {2, 3, 4, 6} are egocentric (immersive).
- In some systems {3, 4, 6} it is imperative to maintain an accurate 1 : 1 orthoscopic mapping between the size and proportions of displayed images and the surrounding real-world environment, whereas for others {1, 2} scaling is less critical, or not important at all.

Our point therefore is that, although the six classes of MR displays listed appear at first glance to be reasonably mutually delineated, the distinctions quickly become clouded when concepts such as real, virtual, direct view, egocentric, exocentric, orthoscopic, etc. are considered, especially in relation to implementation and perceptual issues. The result is that the different classes of displays can be grouped differently depending on the particular issue of interest. Our purpose in this paper is to present a taxonomy of those principal aspects of MR displays which subtend these practical issues.

The purpose of a taxonomy is to present an ordered classification, according to which theoretical discussions can be focused, developments evaluated, research conducted, and data meaningfully compared. Four noteworthy taxonomies in the literature which are relevant to the one presented here are summarised in the following.

- Sheridan [22] proposed an operational measure of *presence* for remotely performed tasks, based on three determinants: extent of sensory information, control of relation of sensors to the environment, and ability to modify the physical environment. He further proposed that such tasks be assessed according to task difficulty and degree of automation.
- Zeltzer [23] proposed a three dimensional taxonomy of *graphic simulation systems*, based on the components autonomy, interaction and presence. His "AIP cube" is frequently cited as a framework for categorising virtual environments.
- Naimark [24], [25] proposed a taxonomy for categorising different approaches to recording and reproducing visual experience, leading to *real-space imaging*. These include: monoscopic imaging, stereoscopic imaging, multiscopic imaging, panoramics, surrogate travel and real-time imaging.
- Robinett [26] proposed an extensive taxonomy for classifying different types of technologically mediated interactions, or *synthetic experience*, associated exclusively with HMD based systems. His taxonomy is essentially nine dimensional, encompassing causality, model source, time, space, superposition, display type, sensor type, action measurement type and actuator type. In his paper a variety of well known VR-related systems are classified relative to the proposed taxonomy.

Although the present paper makes extensive use of ideas from Naimark and the others cited, it is in many ways a response to Robinett's suggestion (Ref. [26], p. 230) that his taxonomy serve as "a starting point for discussion." It is important to point out the differences, however. Whereas technologically mediated experience is indeed an important component of our taxonomy, we are not focussing on the same question of how to classify different varieties of such interactions, as does Robinett's classification scheme. Our taxonomy is motivated instead, perhaps more narrowly, by the need to distinguish among the various technological requirements necessary for realising, and researching, mixed reality displays, with no restrictions on whether the environment is supposedly immersive (HMD based) or not.

It is important to point out that, although we focus in this paper exclusively on mixed reality *visual* displays, many of the concepts proposed here pertain as well to analogous issues associated with other display modalities. For example, for auditory displays, rather than isolating the participant from all sounds in the immediate environment, by means of a helmet and/or headset, computer generated signals can instead be mixed with natural sounds from the immediate real environment. However, in order to "calibrate" an *auditory augmented reality* display accurately, it is necessary carefully to align binaural auditory signals with synthetically spatialised sound sources. Such a capability is being developed by Cohen and his colleagues, for example (Ref. [27]), by convolving monaural signals with left/right pairs of directional transfer functions. Haptic displays (that is, information pertaining to sensations such as touch, pressure, etc.) are typically presented by means of some type of hand held master manipulator (e.g. Ref. [28]) or more distributed glove type devices [29]. Since synthetically produced haptic information must in any case necessarily be superimposed on any existing haptic sensations otherwise produced by an actual physical manipulator or glove, *haptic AR* can almost be considered the

Meta Exhibit 1017
Meta v. Mullen - Page 00174

natural mode of operation in this sense. *Vestibular AR* can similarly be considered a natural mode of operation, since any attempt to synthesize information about acceleration of the participant's body in an otherwise virtual environment, as is commonly performed in commercial and military flight simulators for example, must necessarily have to contend with existing ambient gravitational forces.

3. Distinguishing Virtual from Real: Definitions

Based on the examples cited above, it is obvious that as a first step in our taxonomy it is necessary to make a useful distinction between the concept of *real* and the concept of *virtual*. Our need to take this as a starting point derives from the simple fact that these two terms comprise the foundation of the now ubiquitous term "Virtual Reality." Intuitively this might lead us simply to define the two concepts as being orthogonal, since at first glance, as implied by Fig. 1, the question of whether an object or a scene is real or virtual would not seem to be difficult to answer. Indeed, according to the conventional sense of VR (i.e. for completely virtual immersive environments), subtle differences in interpreting the two terms is not as critical, since the basic intention there is that a "virtual" world be synthesized, by computer, to give the participant the impression that that world is not actually artificial but is "real," and that the participant is "really" present within that world.

In many MR environments, on the other hand, such simple clarifications are not always sufficient. It has been our experience that discussions of Mixed Reality among researchers working on different classes of problems very often require dealing with questions such as whether particular objects or scenes being displayed are real or virtual, whether images of scanned data should be considered real or virtual, whether a real object must look 'realistic' whereas a virtual one need not, etc. For example, with Class 1 AR systems there is little difficulty in labelling the remotely viewed video scene as "real" and the computer generated images as "virtual." If we compare this instance, furthermore, to a Class 6 MR system in which one must reach into a computer generated scene with one's own hand and "grab" an object, there is also no doubt, in this case, that the object being grabbed is "virtual" and the hand is "real." Nevertheless, in comparing these two examples, it is clear that the reality of one's own hand and the reality of a video image are quite different, suggesting that a decision must be made about whether using the identical term "real" for both cases is indeed appropriate.

Our distinction between real and virtual is in fact treated here according to *three* different aspects, all illustrated in Fig. 2. The first distinction is between *real objects* and *virtual objects*, both shown at the left

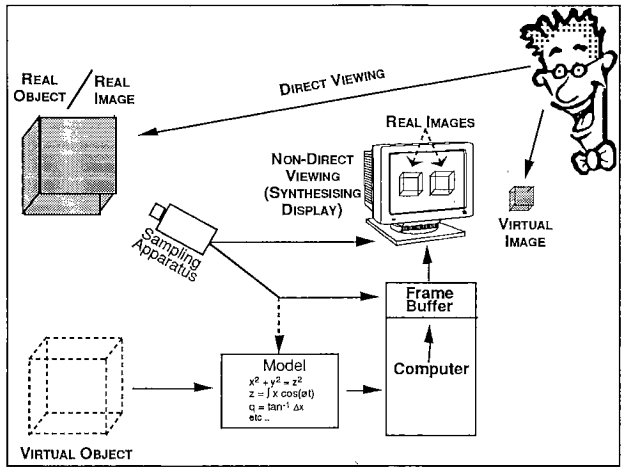


Fig. 2 Different aspects of distinguishing *reality* from *virtuality*: i) Real vs Virtual Object; ii) Direct vs Non-direct viewing; iii) Real vs Virtual Image.

of the figure. The operational definitions† that we adopt here are:

- Real objects are any objects that have an actual objective existence.
- Virtual objects are objects that exist in essence or effect, but not formally or actually.

In order for a real object to be viewed, it can either be observed directly or it can be sampled and then resynthesized via some display device. In order for a virtual object to be viewed, it must be *simulated*, since in essence it does not exist. This entails use of some sort of a description, or *model*††, of the object, as shown in Fig. 2.

The second distinction concerns the issue of *image quality* as an aspect of reflecting reality. Large amounts of money and effort are being invested in developing technologies which will enable the production of images which look "real," where the standard of comparison for realism is taken as *direct viewing* (through air or glass) of a real object, or "*unmediated reality*" [24]. *Non-direct viewing* of a real object relies on the use of some imaging system first to sample data about the object, for example using a video camera, laser or ultrasound scanner, etc., and then to resynthesize or reconstruct these data via some display medium, such as a (analogue) video or (digital) computer monitor. Virtual objects, on the other hand,

† All definitions are consistent with the Oxford English Dictionary [30].

†† Note that virtual objects can be designed around models of either non-existent objects or existing real objects, as indicated by the dashed arrow to the model block in Fig. 2. A model of a virtual object can also be a real object itself of course, which is the case for sculptures, paintings, mockups, etc., however, we limit ourselves here to computer generated syntheses only.

Meta Exhibit 1017
Meta v. Mullen - Page 00175

by definition can not be sampled directly and thus can only be synthesized. Non-direct viewing of either real or virtual objects is depicted in Fig. 2 as presentation via a Synthesizing Display. (Examples of non-synthesizing displays would be include binoculars, optical telescopes, etc., as well as ordinary glass windows.) In distinguishing here between direct and non-direct viewing, therefore, we are not in fact distinguishing real objects from virtual ones at all, since even synthesized images of formally non-existent virtual (i.e. non-real) objects can now be made to look extremely realistic. Our point is that just because an image "looks real" does not mean that the object being represented *is* real, and therefore the terminology we employ must be able carefully to reflect this difference.

Finally, in order to clarify our terms further, the third distinction we make is between real and virtual images. For this purpose we turn to the field of optics, and operationally define a *real image* as any image which has some luminosity at the location at which it appears to be located. This definition therefore includes direct viewing of a real object, as well as the image on the display screen of a non-directly viewed object. A *virtual image* can therefore be defined conversely as an image which has no luminosity at the location at which it appears, and includes such examples as holograms and mirror images. It also includes the interesting case of a stereoscopic display, as illustrated in Fig. 2, for which each of the left and right eye images on the display screen is a real image, but the consequent fused percept in 3D space is virtual. With respect to MR environments, therefore, we consider any virtual image of an object as one which appears *transparent*, that is, which does not occlude other objects located behind it.

4. A Taxonomy for Merging Real and Virtual Worlds

In Sect. 2 we presented a set of distinctions which were evident from the different Classes of MR displays listed earlier. The distinctions made there were based on whether the primary world comprises real or virtual objects, whether real objects are viewed directly or non-directly, whether the viewing is exocentric or egocentric, and whether or not there is an orthoscopic mapping between the real and virtual worlds. In the present section we extend those ideas further by transforming them into a more formalised taxonomy, which attempts to address the following questions:

- How much do we know about the world being displayed?
- How realistically are we able to display it?
- What is the extent of the illusion that the observer is present within that world?

As discussed in the following, the dimensions proposed for addressing these questions include respectively *Extent of World Knowledge, Reproduction Fidelity*, and *Extent of Presence Metaphor*.

4.1 Extent of World Knowledge

To understand the importance of the Extent of World Knowledge (EWK) dimension, we contrast this to the discussion of the Virtuality Continuum presented in Sect. 1, where various *implementations* of Mixed Reality were described, each one comprising a different proportion of real objects and virtual objects within the composite picture. The point that we wish to make in the present section is that simply counting the relative number of objects, or proportion of pixels in a display image, is not a sufficiently insightful means for making design decisions about different MR display technologies. In other words, it is important to be able to distinguish between design options by highlighting the differences between underlying basic prerequisites, one of which relates to how much we know about the world being displayed.

To illustrate this point, in Ref. [2] a variety of capabilities are described about the authors' display system for superimposing computer generated stereographic images onto stereovideo images (subsequently dubbed ARGOS™, for Augmented Reality through Graphic Overlays on Stereovideo [5], [21]. Two of the capabilities described there are:

- a virtual stereographic pointer, plus tape measure, for interactively indicating the locations of real objects and making quantitative measurements of distances between points within a remotely viewed stereovideo scene;
- a means of superimposing a wireframe outline onto a remotely viewed real object, for enhancing the edges of that object, encoding task information onto the object, and so forth.

Superficially, in terms of simple classification along a Virtuality Continuum, there is no difference between these two cases; both comprise virtual graphic objects superimposed onto an otherwise completely video (real) background. Further reflection reveals an important fundamental difference, however. In that particular implementation of the virtual pointer / tape measure, the "loop" is closed by the human operator, whose job is to determine where the virtual object (the pointer) must be placed in the image, while the computer which draws the pointer has no *knowledge* at all about what is being pointed at. In the case of the wireframe object outline, on the other hand, two possible approaches to achieving this can be contemplated. By one method, the operator would interactively manipulate the wireframe (with 6 degrees of freedom) until it coincides with the location and attitude of the object, as she perceives it—which is fundamentally no different from the pointer example. By the other method, however, the computer would

Meta Exhibit 1017
Meta v. Mullen - Page 00176

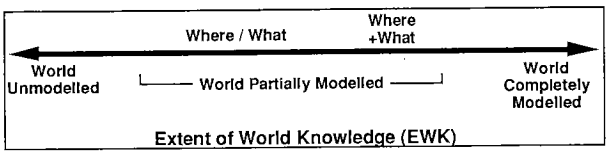


Fig. 3 Extent of World Knowledge (EWK) dimension.

already *know* the geometry, location and attitude of the object relative to the remote cameras, and would place the wireframe onto the object.

The important fundamental difference between these sample cases, therefore, is the amount of knowledge held by the display computer about object shapes and locations within the two global worlds being presented. It is this factor, Extent of World Knowledge (EWK), rather than just accounting of the classes of objects in the MR mixture, that determines many of the operational capabilities of the display system. This dimension is illustrated in Fig. 3, where it has been broken down into three main divisions.

At one extreme, on the left, is the case in which nothing is known about the (remote) world being displayed. This end of the continuum is reserved for images of objects that have been 'blindly' scanned and synthesized for non-direct viewing, as well as for directly viewed real objects. In the former instance, even though such an image might be displayed by means of a computer, no information is present within the knowledge base about the *contents* of that image. The other end of the EWK dimension defines the conditions necessary for displaying a completely virtual world, in the 'conventional' sense of VR, which can be created only when the computer has complete knowledge about each object in that world, its location within that world, the location and viewpoint of the observer within that world and, when relevant, the viewer's attempts to change that world by manipulating objects within it.

The most interesting section of the EWK continuum of course is the portion which covers all cases between the two extrema, and the extent to which real and virtual objects can be merged into the same display will be shown to depend highly on the EWK dimension. In Fig. 3, three types of subcases have been shown. The first, "*Where*," refers to cases in which some quantitative data about locations in the remote world are available. For example, suppose the operator of a telerobot views a closed circuit video monitor and moves a simple cross-hair (a form of augmented reality) to a particular location on the screen. This action explicitly communicates to the computer that there is 'something of interest' at point $\{x, y\}$ on that video image (or at point $\{x, y, z\}$ if the cursor can be calibrated and manipulated in three dimensions), but it does not provide any enlightenment at all about *what* is at that location. Another illustration involves the processing of raw scanned data, obtained by means of video, laser, sonar, ultrasound scanners, etc., which on their own do not add any information at all about what or where objects in the scanned world are located. If, however, such data were to be passed through some kind of digital edge detection filters, for example, then the system could now be considered to have been taught some quantitative "where" type information, but nothing which would allow identification of what objects the various edges belong to.

The "*What*" label in Fig. 3 refers to cases in which the control software does have some knowledge about objects in the image, but has no idea where they are. Reflecting a common case for many AR systems, suppose for example that, as part of a registration procedure, an accurate geometrical model of a calibration object is available. An image of that object can then be drawn graphically and superimposed upon an associated video image; however, unless the computer knows exactly where the real object is located and what its orientation is, in order to determine the correct scale factor and viewpoint, the two will not coincide, and the graphic object will appear simply to be floating arbitrarily within the rest of the remote scene.

Medical imaging is an important instance of an environment in which many of these factors are relevant. Many medical imaging systems are highly specialised and have as their objective the creation of a completely modelled world. For example, a system developed especially for cardiac imaging might perform model based fitting of raw scanned data, to generate a properly scaled image of the patient's cardiac system . If the scanned and reconstructed medical data were then to be superimposed upon a (video) image of the patient whence the data were taken, as in Ref. [14], the computer would have to have a model of not only how the reconstructed sampled data relate to each other, but also where corresponding points are located with respect to the real world, if accurate unmediated superimposition is to be possible.

4.2 Reproduction Fidelity

The remaining two dimensions both attempt to deal with the issue of *realism* in MR displays, but in different ways: in terms of *image quality* and in terms of immersion, or presence, within the display. It is interesting to note that this approach is somewhat different from those taken by others. Both Sheridan's [22] and Robinett's [26] taxonomies, for example, focus on the feeling of presence as the ultimate goal. This is consistent as well with the progression in "realspace imaging" technology outlined in Naimark's [24], [25] taxonomy, towards more and more realistic displays which eventually make one feel that one is participating in "unmediated reality." In our taxonomy we purposely separate these two dimensions,

Meta Exhibit 1017
Meta v. Mullen - Page 00177

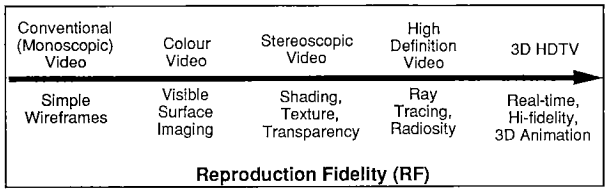


Fig. 4 Reproduction Fidelity (RF) dimension.

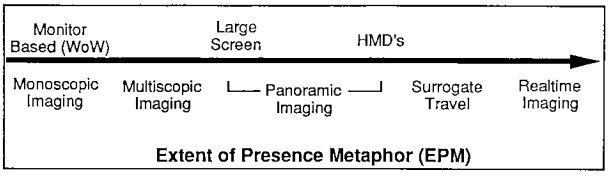


Fig. 5 Extent of Presence Metaphor (EPM) dimension.

however, in recognition of the practical usefulness of some high quality visual displays which nevertheless do not attempt to make one feel *within* the remote environment (e.g. Class 1), as well as some display situations in which the viewer in fact is already physically immersed within the displayed environment but may be provided with only relatively low quality graphical aids (e.g. Classes 3 and 4).

The elements of the Reproduction Fidelity (RF) dimension are illustrated in Fig. 4, where we follow the approach introduced in Fig. 2 for classifying non-direct viewing, of either real objects or virtual objects. The term "Reproduction Fidelity" therefore refers to the quality with which the synthesizing display is able to reproduce the actual or intended images of the objects being displayed. It is important to point out that this figure is actually a gross simplification of a complex topic, and in fact lumps together several different factors, such as display hardware, signal processing, graphic rendering techniques, etc., each of which could in turn be broken down into its own taxonomic elements.

In terms of our earlier discussion, it is important to realise that this dimension pertains to reproduction fidelity of *both* real and virtual objects. The reason for this is not only because many of the hardware issues are related. Even though the simplest wireframe display of a virtual object and the lowest quality video image of a real object are quite distinct, the converse is not true for the upper extrema. In Fig. 4 the progression above the axis is meant to show a rough progression, mainly in hardware, of video reproduction technology. Below the axis the progression is towards more and more sophisticated computer graphic modelling and rendering techniques. At the right hand side of the figure, the "ultimate" video display, denoted here as "3D HDTV" might be just as close in quality to photorealism, or even direct viewing, as the 'ultimate' graphic rendering, denoted here as "real-time, hi-fidelity 3D animation." If this claim is accepted, one can then easily appreciate the problem if real and virtual display quality were to be treated as separate orthogonal dimensions, since if the maxima of each were ever reached, there would be no qualitative way for a human observer to distinguish between whether the image of the object or scene being displayed has been generated by means of data sampling or whether it arises synthetically from a model.

4. 3 Extent of Presence Metaphor

The third dimension in our taxonomy, outlined in Fig. 5, is the Extent of Presence Metaphor (EPM) axis, that is, the extent to which the observer is intended to feel "present" within the displayed scene. In including this dimension we recognise the fact that Mixed Reality displays include not only highly immersive environments, with a strong presence metaphor, such as Classes 2, 3, 4 and 6 displays, but also important exocentric Class 1 type AR displays.

Just as the subdimensions of RF for virtual and real objects in Sect. 4. 2 were shown to be not quite orthogonal, so too is the EPM axis in some sense not entirely orthogonal to the RF axis, since each dimension independently tends towards an extremum which ideally is indistinguishable from viewing reality directly. In the case of EPM the axis spans a range of cases extending from the metaphor by which the observer peers from outside into the world from a single fixed monoscopic viewpoint, up to the metaphor of "realtime imaging," by which the observer's sensations are ideally no different from those of unmediated reality. (Much of the terminology used in this section coincides with that used by Naimark in his proposed taxonomy of realspace imaging [24], [25].) Along the top of the axis in Fig. 5 is shown the progression of display media corresponding to the EPM cases below.

Adjacent to the monitor based class of WoW displays at the left hand side of the EPM axis are "Multiscopic Imaging" displays. These go beyond the class of stereoscopic displays indicated on the RF axis of Fig. 4, to include displays which allow multiple points of view, that is, lateral movements of the observer's head while the body remains more or less still [24], [25]. The resulting sensation of local motion parallax should result in a much more convincing metaphor of presence than a simple static stereoscopic display. In order to accomplish multiscopic viewpoint dependent imaging, the observer's head position must normally be tracked. For simple scanned images (left hand side of the EWK axis in Fig. 3) it is necessary to have either a sufficiently rapid and accurate remote head-slaved camera system or to be able to access or interpolate images within a rapid access video storage medium (Ref. [31], [32]). Since the viewing of virtual world images (right hand side of the EWK axis in Fig.

Meta Exhibit 1017
Meta v. Mullen - Page 00178

3), on the other hand, is less dependent on critical hardware components beyond reliable head-tracking, realisation of multiscopic imaging is somewhat more straightforward. Ware et al. [33] refer to such a display capability as "fish tank virtual reality."

Panoramic imaging is an extension of multiscopic imaging which allows the observer also to look around a scene, but based on the progressively more immersive metaphor of being on the inside, rather than on the outside looking in [24], [25]. Panoramic imaging can be realised partially by means of large screen displays, but the resulting metaphor is valid only for execution of tasks which are constrained to a suitably restricted working volume. A more inclusive instantiation of this class of displays can be realised by means of head-mounted displays (HMD's), which are inherently compatible with the metaphor of being on the inside of the world being viewed. Some of the technical issues associated with realising such displays are similar to those outlined above for multiscopic imaging.

Surrogate travel refers to the ability to move about within the world being viewed, while realtime imaging refers to the solution of temporally related issues, such as sufficiently rapid update rates, simulation of dynamics, etc. [24], [25]. The ultimate goal of "unmediated reality," not shown in Fig. 5, should be indistinguishable from direct-viewing conditions at the actual site, either real or virtual.

5. Conclusion

In this paper we have defined the term "Mixed Reality," primarily through non-exhaustive examples of existing display systems in which real objects and virtual objects are displayed together. Rather than relying on obvious distinctions between the terms "real" and "virtual," we have attempted to probe deeper and examine some of the essential factors which distinguish different Mixed Reality display systems from each other: Extent of World Knowledge (EWK), Reproduction Fidelity (RF) and Extent of Presence Metaphor (EPM). One of our main objectives in presenting our taxonomy has been to clarify a number of terminology issues, in order that apparently unrelated developments being carried out by, among others, VR developers, computer scientists and (tele) robotics engineers can now be placed within a single framework, which will allow comparison of the essential similarities and differences between various research endeavours.

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References

[1] Metzger, P. J., "Adding reality to the virtual," *Proc. IEEE Virtual Reality International Symposium (VRAIS'93)*, Seattle, WA, pp. 7-13, 1993.

[2] Milgram, P., Drascic, D. and Grodski, J. J., "Enhancement of 3-D video displays by means of superimposed stereographics," *Proceedings of Human Factors Society 35th Annual Meeting*, pp. 1457-1461, 1991.

[3] Rosenberg, L. B., "Virtual fixtures: Perceptual tools for telerobotic manipulation," *Proc. IEEE Virtual Reality International Symposium (VRAIS'93)*, pp. 76-82, 1993.

[4] Tani, M., Yamaashi, K., Tanikoshi, K., Futakawa, M. and Tanifuji, S., "Object-oriented video: Interaction with real-world objects through live video," *Proc. CHI '92 Conf on Human Factors in Computing Systems*, pp. 593-598, 1992.

[5] Drascic, D., Grodski. J. J., Milgram, P., Ruffo, K., Wong, P. and Zhai S., "ARGOS: A Display System for Augmenting Reality," *ACM SIGGRAPH Tech Video Review, Vol 88 : InterCHI '93 Conf on Human Factors in Computing Systems*, (Abstract in *Proceedings of InterCHI'93*, p. 521), Amsterdam, 1993.

[6] Lion, D., Rosenberg, C. and Barfield, W., "Overlaying three-dimensional computer graphics with stereoscopic live motion video: Applications for virtual environments," *SID Conference Proceedings*, 1993.

[7] Bajura, M., Fuchs, H. and Ohbuchi, R., "Merging virtual objects with the real world : Seeing ultrasound imagery within the patient," *Computer Graphics*, vol. 26, no. 2, 1992.

[8] Caudell, T. P. and Mizell, D. W., "Augmented reality an application of heads-up display technology to manual manufacturing processes," *Proc. IEEE Hawaii International Conference on Systems Sciences*, 1992.

[9] Ellis, S. R. and Bucher, U. J., "Depth perception of stereoscopically presented virtual objects interacting with real background patterns," *Psychonomic Society Conference*, St. Louis, 1992.

[10] Feiner, S., MacIntyre, B. and Seligmann, D., "Knowledge-based augmented reality," *Communications of the ACM*, vol. 36, no. 7, pp. 52-62, 1993.

[11] Feiner, S., MacIntyre, B., Haupt, M. and Solomon, E., "Windows on the world: 2D windows for 3D augmented reality," *Proc. ACM Symposium on User Interface Software and Technology (UIST'93)*, Atlanta, GA, 1993.

[12] Janin, A. L., Mizell, D. W. and Caudell, T. P., "Calibration of head-mounted displays for augmented reality," *Proc. IEEE Virtual Reality International Symposium (VRAIS'93)*, pp. 246-255, 1993.

[13] Edwards, E. K., Rolland, J. P. and Keller, K. P., "Video see-through design for merging of real and virtual environments," *Proc. IEEE Virtual Reality International Symposium (VRAIS'93)*, Seattle, WA, pp. 223-233, 1993.

[14] Fuchs, H., Bajura, M. and Ohbuchi, R., "Merging virtual objects with the real world: Seeing ultrasound imagery within the patient," *Video Proceedings of IEEE Virtual Reality International Symposium (VRAIS'93)*, Seattle, WA, 1993.

[15] Kaneko, M., Kishino, F., Shimamura, K. and Harashima,

Meta Exhibit 1017
Meta v. Mullen - Page 00179

H., "Toward the new era of visual communication," *IEICE Trans. Commun.*, vol. E76-B, pp. 577-591, 1993.

[16] Takemura, H. and Kishino, F., "Cooperative work environment using virtual workspace," *Proc. Computer Supported Cooperative Work (CSCW'92)*, pp. 226-232, 1992.

[17] Ishii, H., Kobayashi, M. and Grudin, J., "Integration of interpersonal space and shared workspace: Clearboard design and experiments," *ACM Transactions on Information Systems (TOIS) (Special issue on CSCW'92)*, vol. 11, no. 7, 1993.

[18] Krüger, M., "Environmental technology: Making the real world virtual," *Communications of the ACM*, vol. 36, no. 7, pp. 36-51, 1993.

[19] Wellner, P., "Interacting with paper on the digital desk," *Communications of the ACM*, vol. 36, no. 7, pp. 86-96, 1993.

[20] Mackay, W., Velay, G., Carter, K., Ma, C. and Pagani, D., "Augmenting reality: Adding computational dimensions to paper," *Communications of the ACM*, vol. 36, no. 7, pp. 96-97, 1993.

[21] Milgram, P., Zhai, S., Drascic, D. and Grodski, J. J., "Applications of augmented reality for human-robot communication," *Proceedings of IROS'93: International Conference on Intelligent Robots and Systems.*, Yokohama, pp. 1467-1472, 1993.

[22] Sheridan, T. B., "Musings on telepresence and virtual reality," *Presence*, vol. 1, no. 1, pp. 120-126, 1992.

[23] Zeltzer, D., "Autonomy, interaction and presence," *Presence*, vol. 1, no. 1, pp. 127-132, 1992.

[24] Naimark, M., "Elements of realspace imaging," *Apple Multimedia Lab Technical Report*, 1991.

[25] Naimark, M., "Elements of realspace imaging: A proposed taxonomy," *Proc. SPIE*, vol. 1457, *Stereoscopic Displays and Applications II*, 1991.

[26] Robinett, W., "Synthetic experience: A proposed taxonomy," *Presence*, vol. 1, no. 2, pp. 229-247, 1992.

[27] Cohen, M., Aoki, S. and Koizumi, N., "Augmented audio reality: Telepresence/VR hybrid acoustic environments," *Proc. IEEE International workshop on robot and human communication (RO-MAN'93)*, Tokyo, pp. 361-364, 1993.

[28] Brooks, F. P., Jr, Ming, O.-Y., Batter, J. J. and Kilpatrick, P.J., "Project GROPE—Haptic displays for scientific visualization," *Computer Graphics*, vol. 24, no. 4, pp. 177-185, 1990.

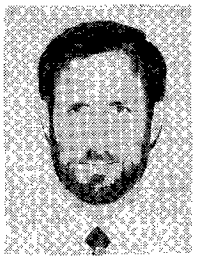
[29] Shimoga, K., "A Survey of Perceptual Feedback Issues in Dexterous Telemanipulation: Part 1. Finger Force Feedback," *Proc. IEEE Virtual Reality Annual International Symposium (VRAIS '93)*, pp. 263-270, 1993.

[30] Little, W., Fowler, H. W. and Coulson, J.,/ with revision by CT Onions. *Oxford English Dictionary, Third Edition*. Clarendon Press: Oxford, 1988.

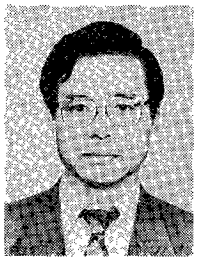
[31] Hirose, M., Takahashi, K., Koshizuka, T. and Watanabe, Y., "A study on image editing technology for synthetic sensation," *Proceedings of ICAT '94*, Tokyo, 1994.

[32] Liu, J. and Skerjanc, R., "Construction of intermediate pictures for a multiview 3D system," *Proc. SPIE*, vol. 1669, *Stereoscopic Displays and Applications III*, 1992.

[33] Ware, C., Arthur, K. and Booth, K. S., "Fish tank virtual reality," *InterCHI '93 Conference on Human Factors in Computing Systems*, Amsterdam, pp. 37-42, 1993.



Paul Milgram received the B.A.Sc. degree from the University of Toronto in 1970, the M.S.E.E. degree from the Technion (Israel) in 1973 and the Ph.D. degree from the University of Toronto in 1980. From 1980 to 1982 he was a ZWO Visiting Scientist and a NATO Postdoctoral Fellow at the TNO Institute for Perception in the Netherlands, researching automobile driving behaviour. From 1982 to 1984 he was a Senior Research Engineer in Human Engineering at the National Aerospace Laboratory (NLR) in Amsterdam, where his work involved the modelling of aircraft flight crew activity, advanced display concepts and control loops with human operators in space teleoperation. Since 1986 he has worked at the Industrial Engineering Department of the University of Toronto, where he is currently an Associate Professor and Coordinator of the Human Factors Engineering group. He is also cross appointed to the Department of Psychology. In 1993-94 he was an invited researcher at the ATR Communication Systems Research Laboratories, in Kyoto, Japan. His research interests include display and control issues in telerobotics and virtual environments, stereoscopic video and computer graphics, cognitive engineering, and human factors issues in medicine. He is also President of Translucent Technologies, a company which produces "Plato" liquid crystal visual occlusion spectacles (of which he is the inventor), for visual and psychomotor research.



Fumio Kishino is a head of Artificial Intelligence Department, ATR Communication Systems Research Laboratories. He received the B.E. and M.E. degrees from Nagoya Institute of Technology, Nagoya, Japan, in 1969 and 1971, respectively. In 1971, he joined the Electrical Communication Laboratories, Nippon Telegraph and Telephone Corporation, where he was involved in work on research and development of image processing and visual communication systems. In mid-1989, he joined ATR Communication Systems Research Laboratories. His research interests include 3D visual communication and image processing. He is a member of IEEE and ITEJ.

Meta Exhibit 1017
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Linda Hall Library



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Meta Exhibit 1017
Meta v. Mullen - Page 00188

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Meta Exhibit 1017
Meta v. Mullen - Page 00189

EXHIBIT 1010D

EX1010D
Citations to Milgram

Source Document:

Milgram, P., & Kishino, F. (1994, December). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems*, *77*(12), 1321-1329.

Citations: 1996 – 1998 (in chronological order)

Ohzu, H., & Habara, K. (1996, May). Behind the scenes of virtual reality: vision and motion. *Proceedings of the IEEE*, *84*(5), 782-798.

Anumba, C. J., Baron, G., & Duke, A. (1997, July). Information and communications technologies to facilitate concurrent engineering in construction. *BT Technology Journal*, *15*(3), 199-207.

Traill, D. M., Bowshill, J. D., & Lawrence, P. J. (1997, October). Interactive collaborative media environments. *BT Technology Journal*, *15*(4), 130-140.

Wilson, J. R. (1997). Virtual environments and ergonomics: needs and opportunities. *Ergonomics*, *40*(10), 1057-1077.

Hoffman, H. G. (1998, March). Physically touching virtual objects using tactile augmentation enhances the realism of virtual environments. In *Proceedings. IEEE 1998 Virtual Reality Annual International Symposium (Cat. No. 98CB36180)* (pp. 59-63). IEEE.

EXHIBIT 1013A

A comparison of optical and video see-through head-mounted displays

J. P. Rolland, R. L. Holloway, and H. Fuchs

Department of Computer Science
University of North Carolina
Chapel Hill, NC 27599-3175
{rolland,holloway,fuchs}@cs.unc.edu

Abstract

One of the most promising and challenging future uses of head-mounted displays (HMDs) is in applications where virtual environments enhance rather than replace real environments. To obtain an enhanced view of the real environment, the user wears a see-through HMD to see 3D computer-generated objects superimposed on his/her real-world view. This see-through capability can be accomplished using either an optical or a video see-through HMD. We discuss the tradeoffs between optical and video see-through HMDs with respect to technological, perceptual, and human factors issues, and discuss our experience designing, building, using, and testing these HMDs.

Keywords: augmented reality, see-through head-mounted displays, superimposition, optics, video cameras

Introduction

One of the most promising and challenging future uses of head-mounted displays (HMDs) is in applications where virtual environments enhance rather than replace real environments. This is often referred to as *augmented reality*. To obtain an enhanced view of the real environment, the user wears a see-through HMD that allows her to see 3D computer-generated objects superimposed on her real-world view. This see-through capability can be accomplished using either an optical or a video see-through HMD, as shown in Figures 1 and 2, respectively.

With optical-see-through HMDs, the real world is seen through semi-transparent mirrors placed in front of the user's eyes, as shown in Figure 1. These mirrors are also used to reflect the computer-generated images into the user's eyes, thereby combining the real- and virtual-world views. With a video see-through HMD, the real-world view is captured with two miniature video cameras mounted on the head gear, as shown in Figure 2, and the computer-generated images are electronically combined with the video representation of the real world.

In the same way that x-ray technology has provided us with a means to see aspects of the inner world of objects and living beings that were unseen before, see-through virtual reality technology provides us with a novel way of visualizing those aspects: the dynamic superimposition of inner worlds registered on their outer parts.

See-through HMDs have been around since the 1960s with Ivan Sutherland's first HMD which was a see-through stereo system with miniature CRTs as the display devices, a mechanical tracker to provide head position and orientation in real time, and a hand-tracking device (Sutherland, 1965).

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Meta Exhibit 1017
Meta v. Mullen - Page 00193

Most see-through systems that have been designed and/or built are of the optical see-through type.

Examples are the VCASS system (Furness 1986), (Buchroeder et al., 1981), the Tilted Cat HMD (Droessler and Rotier, 1990), and the CAE Fiber-Optic HMD (Barrette, 1992). Several systems have been developed by Kaiser Electronics and McDonnell Douglas, all of them optical see-through systems (Kandebo, 1988).

See-through HMDs at the University of North Carolina at Chapel Hill (UNC-CH) have been developed since the 1980s. Applications with both video and optical see-through HMDs have been developed. The driving application for video see-through has been real-time 3D visualization of a human fetus during ultrasound echography (Bajura et al., 1992).[1] An augmented reality system displaying live ultrasound data in real time and properly registered in 3D space within a scanned subject would be a powerful and intuitive tool; it could be used for needle-guided biopsies, obstetrics, cardiology, etc. With the current system, the ultrasound images captured in real time appear to be pasted in front of the patient's body, as shown in Figure 3, rather than fixed within it. Figure 4 shows a recent near-real-time implementation where the fetus is rendered more convincingly within the body (State et al., 1994).

Another medical application of see-through HMD technology at UNC is a system developed for cranio-facial surgery planning. The eventual goal of this system is to superimpose CT skull data onto the head of the real patient, thereby giving the surgeon "x-ray vision", or the ability to "see" the patient's bone through the soft tissue. The promise of this system is that viewing the data *in situ* will allow surgeons to make better surgical plans because they will be able to see the complex relationships between the bone and soft tissue more clearly. Because of the precision required for this task, however, most of the work in this project has focused on identifying and quantifying the sources of registration error between the real and virtual objects (Holloway, 1994).



Figure 1. Optical see-through head-mounted display (Photo courtesy of Kaiser Electro-Optics).

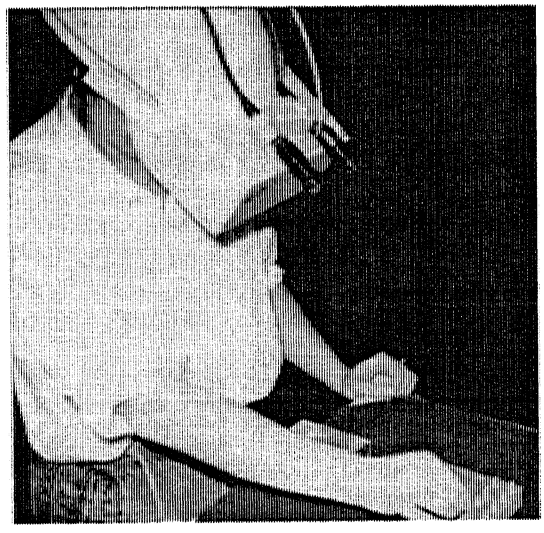


Figure 2. A video see-through head-mounted display.

[1] To our knowledge, the first video see-through system with walk-around capability in addition to merging of real and synthetic information was developed at UNC-CH. The authors would be grateful for any information on other video STHMD systems.

Meta Exhibit 1017
Meta v. Mullen - Page 00194

An example in the non-medical arena is the work of Caudell and Mizell at Boeing, which uses optical see-through HMD technology to assist workers in the manufacturing assembly of airplanes (Caudell and Mizell, 1992). Combined with head-position sensing and a real-world registration system, the see-through technology in this case allows computer-generated diagrams to be superimposed and stabilized on specific locations of a real-world foamboard. The main difficulty with a complex manufacturing assembly task is the need to have sufficient registration of real and virtual information so that workers may perform their jobs without any risk of errors due to limitations in the apparatus. The successful use of the technology will enable cost reductions and efficiency improvements in several of the manual operations in aircraft manufacturing.

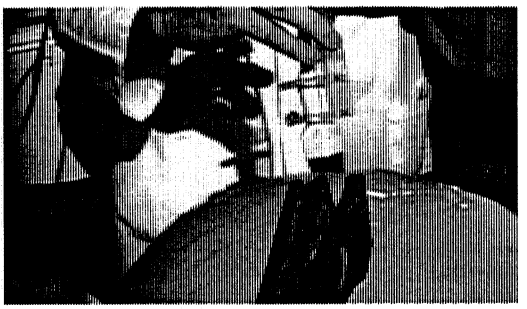


Figure 3. Real-time acquisition and superimposition of ultrasound slice images on a pregnant woman.

Another example is that of providing assistance with complex maintenance tasks (Feiner et al., 1993). The system developed at Columbia University uses a knowledge-based graphics component in order to aid the user in an end-user laser printer maintenance task. They use graphics superimposed on the laser writer to provide information on various tasks, and use tracker sensors on the printer's moving parts to reflect movements of the real-world objects in the virtual scene.



Figure 4. More convincing rendering of fetus inside abdomen.

A more recent application being developed at UNC-CH is the visualization of dynamic 3D anatomy using an optical see-through HMD. This work aims at developing a novel teaching tool to impart better understanding of bone dynamics during radiographic positioning for the radiological science student (Kancherla et al., 1994). In our first prototype, we concentrate on the positioning of the arm about the elbow joint. We use an optical see-through HMD coupled with tracking devices positioned along the arm of the patient to visualize the 3D anatomy directly superimposed on the patient as illustrated in Figure 5. We want to simulate "x-ray vision" as much possible. Therefore, we want the patient's arm to be seen as one would with unaided eyes, but enhanced with computer-simulated bones. This implies that the real scene must be very realistic, the field of view (FOV) should be sufficient to capture the whole arm, and the tracking devices and image-generation system must be fast enough to track motion in real time. The biggest challenge is dynamic registration of the real arm with the virtual bones.

As alluded to with the description of these example applications, the main goal of augmented reality systems is to merge virtual objects into the view of the real scene so that the user's visual system is fooled into perceiving those objects as part of the real environment. Current systems are far from perfect, and system designers typically end up making a number of application-dependent tradeoffs. The goal of this paper is to list and discuss these tradeoffs in order to illustrate under which conditions one might choose one type of see-through system over the other.

Meta Exhibit 1017
Meta v. Mullen - Page 00195

In both systems there are two image sources: the real world and the computer-generated world; these two image sources are to be merged. Optical see-through HMDs take what might be called a "minimally invasive" approach; that is, they leave the view of the real world nearly intact and attempt to augment it by merging a reflected image of the computer-generated scene into the view of the real world. Video see-through HMDs are more invasive in the sense that they block out the real-world view in exchange for the ability to merge the two views more convincingly. The fundamental tradeoff, then, is whether the additional features afforded by the more invasive approach justify the loss of the unobstructed real-world view.

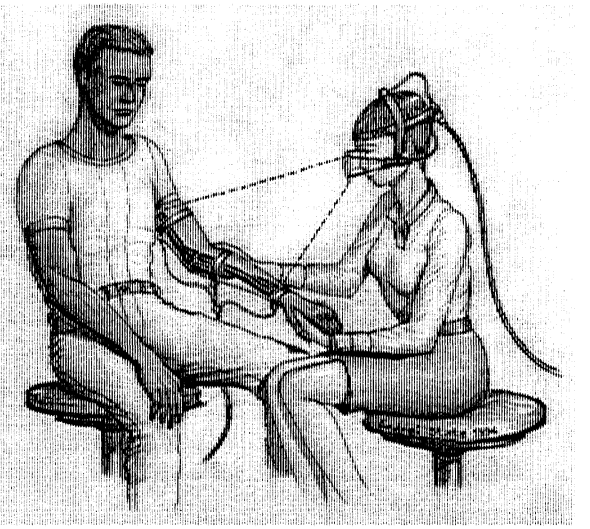


Figure 5. Teaching tool for dynamically superimposing virtual bones onto real arm (drawing by Andrei State).

We discuss the tradeoffs between optical and video see-through HMDs with respect to technological, perceptual, and human factors issues from our experience designing, building, using, and testing these HMDs. Those tradeoffs are also discussed with respect to systems built today, those buildable with today's technology, and those perhaps buildable 5 to 10 years from now. An outline of the issues discussed in the paper is illustrated in Figure 6.

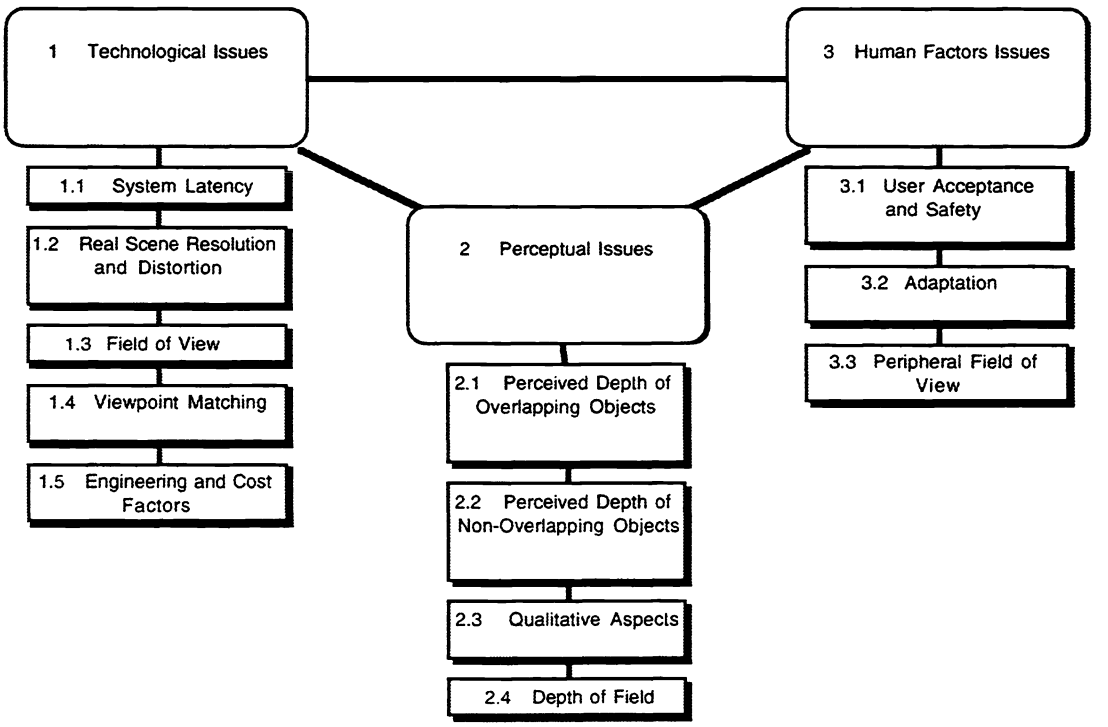


Figure 6. Paper Outline

Meta Exhibit 1017
Meta v. Mullen - Page 00196

1. Technological Issues

The technological issues discussed in this section include latency of the system, resolution and distortion of the real scene, FOV of the see-through device, and engineering and cost factors.

1.1. System Latency

An essential component of see-through HMDs is the capacity to properly register the user's surroundings and the synthetic space. Assuming geometric calibration between tracking and the HMD optics, the major impediment to achieving this registration is the gap in time, referred to as *lag*, between the moment when the HMD position is measured and the moment when the synthetic image for that position is fully completed and presented to the user. Lag is the largest source of registration error in most current HMD systems (Holloway, 1994).

This lag in typical systems is between 60 and 180 ms. The user's head can move significantly during such a period of time, and the discrepancy destroys the illusion of the synthetic objects being fixed in the environment. The synthetic objects "swim" around so much, in fact, that they don't even seem to be part of the environment. Azuma and Bishop demonstrated this swimming effect and show how one can minimize it using predicted HMD positions instead of measured ones (Azuma and Bishop, 1994). They use an optical tracking system augmented with accelerometers and rate gyros and have found that their system can predict well 60 ms ahead, but not well 120 ms ahead.

One of the major advantages of video see-through HMDs is the capability of enforcing registration of the real and synthetic images. In other words, because the system has access to both the real and synthetic images, it can manipulate them in space or in time in order to register them.

The spatial approach to forcing registration in video see-through systems is to correct registration errors by tracking landmark points in the real-world images and registering virtual objects with respect to those. This technique was successfully demonstrated by (Bajura & Neumann, 94) who tracked a pair of red light-emitting diodes (LEDs) placed on two real objects and then registered two virtual objects with respect to them. By tracking more landmarks, better registration of real and virtual objects can be achieved. The problem with this approach is that it is an attempt to register three-dimensional scenes using two-dimensional constraints. If the user rotates his head rapidly or if a real-world object moves, there may be no "correct" transformation for the virtual scene image: one must either allow misregistration of some of the landmarks or perform a non-linear warping of the virtual scene in order to align all of the landmarks (which may induce undesirable distortions of virtual objects). The non-trivial solution to this problem is to increase the speed of the system until scene changes between frames are small and can be approximated with simple 2D transformations.

Enforcing registration in the time domain can be done by introducing delay to the video real-scene images to match the delay of the computer-generated images. This may be done in conjunction with the spatial methods just mentioned. If the delay is too large, however, it may cause sensory conflicts between vision and proprioception, since video images no longer correspond to the real-world scene. Any manual interactions with real objects could suffer as a result. In a similar vein, it is also important to note that the video view of the real scene will normally have some lag due to the time it takes to acquire and display the video images. Thus, video see-through HMDs will normally be slightly delayed with respect to the real world even without adding delay to match the synthetic images. This delay may become even worse if an image-processing step for enforcing registration or performing occlusion is added. The key issue, of course, is whether the delay in the system is too great for the user to adapt to it. This subject has been treated at length in the teleoperation literature; (Held and Durlach, 1987) discuss this problem and give an extensive list of references on the subject.

Systems using optical see-through HMDs have no way to introduce artificial delays to the real scene, so the system needs to be optimized for low latency; that is, less than 60 ms according to (Azuma

Meta Exhibit 1017
Meta v. Mullen - Page 00197

and Bishop, 1994). For any remaining lag, the user can restrain himself to using slow head motions or predictive tracking can be used as described earlier. The advantage, however, of not introducing artificial delays is that real objects will always be where they are perceived to be, and this may be crucial for certain applications.

1.2. Real-Scene Resolution and Distortion

The best real-scene resolution a see-through-device can provide is that reached with the naked eye. This assumes that the see-through device has no image-processing capability. A resolution extremely close to that obtained with the naked eye is easily achieved with an optical see-through HMD because the optical interface to the real world is simply a thin parallel plate positioned between the eyes and the real scene. Such an interface typically introduces only very small amounts of optical aberrations to the real scene. For example, for a real-point object seen through a 2 mm planar parallel plate placed in front of a 4 mm diameter eye pupil, the diffusion spot due to spherical aberration would subtend a $2\ 10^{-7}$ arc-minute visual angle for a point object located 500 mm away. Such an aberration is negligible compared to the ability the human eye to resolve a visual angle of 1 minute of arc. Similarly, planar plates introduce very little distortion of the real scene, typically below 1%. There is no distortion for those chief rays that pass the plate parallel to the plate's normal.[2]

In the case of video see-through HMDs, real-scene images are digitized by miniature cameras and converted to an analog signal which is fed to the HMD displays. These images are then magnified by the HMD viewing optics which typically use eyepiece design. The perceived resolution of the real scene can thus be limited by the resolution of either of the three components of the system: the video cameras, the HMD displays, or the HMD viewing optics.

Currently available miniature video cameras typically have a resolution of 720x480, which is also near the resolution limit of the miniature displays currently used in HMDs[3]. Both the miniature displays and the video cameras currently limit the resolution of most systems.

In addition, eyepiece designs have also been recognized for many decades to be extremely limited in optical quality due to their fairly large FOVs and their need for an exit pupil size large enough to accommodate the size of the pupils of the person's eyes. Thus, even with higher resolution cameras and displays, video see-through HMDs may remain limited in their ability to provide a real-scene view of high resolution if conventional eyepiece designs continue to be used.

A new technology, referred to as *tiling*, may overcome the current limitations of conventional eyepiece design (Kaiser, 94). The idea is to use multiple narrow-FOV eyepieces coupled with miniature displays to completely cover (or *tile*) the user's FOV. Because the individual eyepieces now have a fairly narrow FOV, high image quality can be achieved. The challenge is in the assembly process and in rendering seamless views from multiple displays.

Theoretically, distortion is not a problem in video see-through systems since the cameras can be designed to compensate for the distortion of the optical viewer, as demonstrated by Edwards et al. (1993). However, if the goal is to merge real and virtual information, as in ultrasound echography, having a warped real scene increases the complexity of the synthetic image generation significantly (State et al., 1994). An alternative is to use ultra-low distortion cameras, merge unprocessed real scenes with virtual scenes, and warp the merged images to compensate for the distortion of the HMD viewing optics as a last step.

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[2] The chief ray is defined as a ray that passes through a point in the FOV and through the center of the pupils of the sytem. The exit pupil in an HMD is the entrance pupil of the human eye.

[3] The number of physical elements is typically 720 x 240, and one uses signal processing to interpolate between lines to get 720 x 480.

Meta Exhibit 1017
Meta v. Mullen - Page 00198

The need for high real-scene resolution is highly task-dependent. Demanding tasks such as surgery or engineering training, for example, may not be able to tolerate any loss in real-scene resolution. Current video see-through systems are seriously limited in terms of resolution, but with new tiling technologies and the growing availability of high-resolution flat-panel displays, video see-through HMDs may match the resolution of the human visual system five years from now.

1.3. Field of View

Another challenging issue is that of providing the user with a large FOV. What we refer to here is the monocular FOV at a given time, head position and orientation, unless otherwise specified. The binocular FOV is a function of the monocular FOV's overlap and can be calculated for each system based on its geometry. For 100% overlap, the binocular FOV is equal to the monocular FOV, while for no overlap, it is twice the monocular FOV. A decrease in binocular overlap, however, results in a decrease of the binocular fusion zone where stereo vision is possible. For most applications, having a larger binocular FOV means that fewer head movements are required to perceive an equivalently large scene. However, in many cases, one would prefer to have a large binocular FOV without trading off the amount of binocular overlap that is necessary for stereo vision. In those cases, the monocular FOV itself must be optimized. We believe that a large FOV is especially important for tasks that require grabbing and moving objects and that it provides increased situation awareness when compared to narrow FOV devices. We will use the term *overlay FOV* to describe the merged virtual and real FOV.

Optical see-through HMDs typically provide from 20° to 60° overlay FOV via the semi-transparent mirror placed in front of the eyes, a value which may appear somewhat limited. Larger FOVs have been obtained, up to 82.5 x 67 degrees (Welch and Shenker, 1984), at the expense of reduced brightness, increased complexity, and massive, expensive technology. Optical see-through HMDs, however, have been designed open enough that the user can use his/her peripheral vision around the device, thus increasing the total real-world FOV to numbers that match closely one's natural FOV. An annulus of obstruction usually results from the mounts of the thin see-through mirror similar to the way that our vision may be partially occluded by a frame when wearing eye- or sun-glasses.

Video see-through HMDs, on the other hand, can provide as large a see-through FOV as can be displayed with the viewing optics. Typical values range from 20° to 90°. However, because current HMDs used in video see-through are of the opaque type where the peripheral FOV of the user is occluded, the effective real-world FOV is often smaller than in optical see-through systems. We found in a recent human-factors study using a video see-through system that users needed to perform larger head movements to scan an active field of vision required for a task than when they used the unaided eye (Rolland at al., 1994). We predict that the need to make larger head movements would not arise as much with see-through HMDs with large peripheral FOVs.

An increase in peripheral FOV in video see-through systems can be accomplished in two ways: 1) in a folded optical design as used for optical see-through HMDs but with an opaque mirror instead of a semi-transparent mirror; 2) in a non-folded design but with non-enclosed mounts, which calls for innovative opto-mechanical design since heavier optics have to be supported than in either optical or folded video see-through. Folded systems only require a thin mirror in front of the eyes, and the heavier optical components are placed around the head. The tradeoff with folded systems, however, is a significant reduction in the overlay FOV (as experienced with optical see-through HMDs).

Most current high-resolution HMDs achieve their higher resolution at the expense of a reduced FOV. That is, they use smaller, high-resolution CRTs and optics with less magnification in order to achieve higher angular resolution, but the resulting FOV may be too narrow for many applications. A solution to this problem is again, perhaps, to move towards tiling techniques to improve resolution without trading FOV.

Meta Exhibit 1017
Meta v. Mullen - Page 00199

These techniques also bring new practical and computational challenges that need to be confronted. In particular, for a tiled video see-through system, one either needs multiple, correlated cameras for each eye, or an ultra-wide-FOV camera for each eye whose image can then be segmented somehow. Thus, while tiling is a promising approach for wide-FOV, high-resolution HMDs, it also introduces some challenging technical problems for use in video see-through HMD systems.

1.4 Viewpoint Matching

The viewpoint of a camera or eye is equivalent to the center of projection used in the computer graphics model and is taken here to be the center of the entrance pupil of the eye or camera. A problem with video see-through HMDs is that the straightforward method of mounting the cameras introduces an error in the viewpoints for the real-world images.

The straightforward method of mounting the cameras on a video see-through HMD is to separate them by the appropriate interpupillary distance (IPD) and mount them on the front or top of the HMD, or to mount them on the side of the HMD, in which case they will be separated by more than the IPD. The problem with this approach is that the viewpoint of the camera does not correspond to the viewpoint of the eye, which introduces a shift in the perceived scene for each eye, which may lead to perceptual anomalies (see the Human Factors section for more on this).

Since the camera cannot be physically placed at the actual eyepoint, one alternative is to use mirrors to fold the optical path (much like a periscope) in order to make the camera viewpoint correspond to the real eyepoint. The following figure illustrates this idea.

While this approach solves the viewpoint-shift problem, it increases the optical path length which reduces the field of view (for the same reason that optical see-through HMDs tend to have smaller fields of view). Thus, video see-through HMDs must either trade their large FOV for correct real-world viewpoints or require the user to adapt to the shifted viewpoints (more on this later).

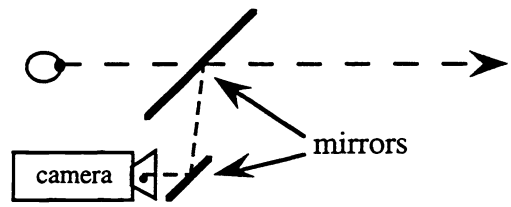


Figure 7. Folded path to make viewpoints for real and virtual scenes optically identical

1.5. Engineering and Cost Factors

Simple HMD designs suffer from low resolution, limited FOV, poor ergonomic design, and heavy weight. To overcome any of these limitations, one must face new challenges and further tradeoffs. A good ergonomic design implies that either the HMD is light enough that it does not weigh much more than a pair of eyeglasses or the HMD folds around the user's head so that the center of gravity of the device falls more or less near the center of rotation of the head (Rolland, 1994). This assures maximum comfort and usability. Reasonably light HMD designs currently suffer very narrow FOVs, on the order of 20 degrees. As far as we know, there are currently no large FOV see-through HMDs of any type that are comparable in weight to a pair of eyeglasses.

With optical see-through, the folding can be accomplished with either an on-axis or an off-axis design. Off-axis designs are not only more elegant but also by far more attractive since they free the user from seeing ghost images that plague current on-axis designs. The reason we cannot buy off-axis designs is that very few prototypes have been built and those that have been built have been classified. Moreover, off-axis systems are difficult to design and have turned out to be hard to build (Shenker, 1994). Moreover, they are usually more expensive to design and build due to the cost of off-axis and/or non spherical optical elements that come with such systems. A non-classified off-axis design was designed by Rolland (1994) at UNC-CH. Multiple factors, including cost, have so far

Meta Exhibit 1017
Meta v. Mullen - Page 00200

prohibited us from building the first prototype.

Video see-through systems usually do not use a folded design and therefore suffer from a lack of peripheral FOV, since they use rigid helmets to hold the optics and displays in front of the user's eyes. With tiling techniques, no folding is required since the large FOV that drove the need for complex optics, and thus that of folding it, is now created by multiple narrow FOV devices that are a lot simpler optically. It is an open question whether such devices can be successfully built. Moreover, the cost of such a device may be significantly higher due to the need for multiple miniature high-resolution displays, precision alignment of the displays, and image-generation hardware to drive them.

Since their beginning, high resolution HMDs have been CRT-based. Early systems were even monochrome but color CRTs using color wheels or frame sequential color have been fabricated and incorporated into HMDs (Allen, 1993). In the next five to ten years, we predict that high-resolution color flat-panel displays will be the first choice for HMDs. It has been predicted for years that CRTs would become obsolete, yet they are still used today. The reason for renewed optimism is the support given to the development of flat panel technologies by government agencies such as ARPA and the existence of a market for high-resolution miniature displays in video camcorders.

2. Perceptual Issues

The ultimate system is one that provides quantitative and qualitative visual representation of scenes that conforms to that given by the real world. This includes 1. accuracy and precision of depth, 2. accuracy and precision of size, of real and virtual objects in a scene, and 3. an unobstructed peripheral FOV which is important for many tasks from situation awareness to simple manipulation of objects and accessories. In this section, perceived depth and size, qualitative aspects of the real scene, and depth of field issues will be discussed. Peripheral FOV issues will be discussed in the human factors section.

Perceived depth and size of objects are important because they determine the 3D space they occupy. Perceived depth will be accurate and precise if objects appear on average at the location predicted by the computational model used to position virtual objects. Perceived depth will be precise if objects appear within a small spatial zone around that average location. A strong component of rendering depth accurately is occlusion of overlapping objects. Because the ability to perform occlusion is an important issue of comparison between optical and video see-through HMDs, we discuss it first.

2.1. Perceived Depth of Overlapping Objects

One of the most important differences between these two technologies is how they handle the depth cue known as *occlusion* (or interposition). In real life, an opaque object can block the view of another object so that part or all of it is not visible. While there is no problem in making computer-generated objects occlude each other in either system, it is considerably more difficult to make real objects occlude virtual objects and vice versa. Moreover, occlusion is a strong monocular cue to depth perception and may be required in certain applications.

In both systems, any attempt to do occlusion between the real and virtual scenes requires a depth map of both scenes. A depth map of the virtual scene is usually available (for z-buffered image generators), but a depth map of the real scene is a much more difficult problem. While progress in this area is being made (Tomasi & Kanade 1991),(Laveau & Faugeras 1994), the problem is far from solved. Thus, occlusion cues for either type of display will be limited by the state of the art in this area. We can now move on to a discussion of the tradeoffs with respect to occlusion for each type of see-through HMD.

Assuming the system has a depth map of the real environment, video see-through HMDs are

Meta Exhibit 1017
Meta v. Mullen - Page 00201

perfectly positioned to take advantage of this information. They can, on a pixel-by-pixel basis, selectively block out the view of either scene or even blend them to minimize edge artifacts. One of the chief advantages of video see-through HMDs is that they handle this problem so well.

The situation for optical see-through HMDs is more complex. Existing optical see-through HMDs blend the two images with beam splitters, which blend the real and virtual images uniformly throughout the FOV. Normally, the only control the designer has is the amount of reflectance versus transmittance of the beam splitter, which can be chosen to match the brightness of the displays with the expected light levels in the real-world environment. If the system has a model of the real environment, it is possible to cause real objects to occlude virtual ones simply by not drawing the occluded parts of the virtual objects. The only light will then be from the real objects, giving the illusion that they are occluding the virtual ones.

This technique is currently used by CAE Electronics in their flight simulator: When the pilot looks out the window, s/he sees computer-generated objects. If s/he looks inside the cockpit, however, the appropriate pixels of the computer-generated image are masked so s/he can see the real instruments. They keep the room fairly dark so that this technique will work (Barrette, 1992). Tom Caudell and David Mizell from Boeing Seattle are also using this technique; they refer to it as "fused reality" (Mizell, 1994).

While optical see-through HMDs can allow real objects to occlude virtual objects, the reverse is not easy to do since normal beam splitters have no way of selectively blocking out the real environment. There are at least two possible solutions to this problem, neither of them perfect. The first solution is to control the light levels in the real environment and to use displays that are bright enough so that the virtual objects mask the real ones by reason of contrast. This approach is used in the flight simulator just mentioned for creating the virtual instruments. This may be a solution for certain applications, but probably not for all. A possible second solution would be to locally attenuate the real-world view by using an addressable filter device placed on the see-through mirror. The problem with this approach is that the user does not focus on the beam splitter, but rather on the virtual image it creates. Thus, any blocking done at the beam splitter will be out of focus, which might lead to odd visual effects.

A final possibility is that some applications may work acceptably without properly rendered occlusion cues. That is, in some cases, the user may be able to use other depth cues, such as head-motion parallax, to resolve the ambiguity caused by the lack of occlusion cues.

2.2. Perceived Depth of Non-Overlapping Objects

In the case of non-overlapping objects, one may resort to depth cues other than occlusion. These include familiar sizes, stereopsis, perspective, texture, and motion parallax. A psychophysical investigation of perceived depth using stereopsis and perspective as the visual cues to depth in a virtual environment is given in (Rolland et al., 1994). The apparatus consisted of an optical see-through bench prototype HMD. Some of the main results were that a systematic, but relatively small shift, in perceived depth from predicted values was found, but that the precision of the measures varied significantly across subjects. Data were only reported for three subjects, and further data need to be acquired to confirm those findings. Some measures of perceived size were conducted by Roscoe and colleagues in see-through HMDs and a main result was that objects seemed to be perceived smaller than they actually were (Roscoe, 1984, 1991). It is an experimental question whether current computational models correctly predict perceived depth and sizes in virtual environments.

For video see-through HMDs, the problems with viewpoint and FOV matching between the displays and the cameras can introduce additional errors in perceived depth. Although it is possible in theory to eliminate such mismatches, real systems are often limited by the available technology and therefore leave it to the user to adapt to the discrepancy. The effect of viewpoint mismatches will be

Meta Exhibit 1017
Meta v. Mullen - Page 00202

discussed in the section on human factors.

2.3. Qualitative Aspects

The representation of virtual objects, and in some cases of real objects, is altered by see-through devices. Aspects of perceptual representation include the shape of objects, their color, brightness, contrast, shading, texture, and level of detail. In the case of optical see-through HMDs, the real objects are seen basically unaltered since they are only perceived through an ultra-thin plate of glass, as mentioned earlier.

Other aspects of objects' representation besides brightness attenuation and distortion may be altered in video see-through HMDs. Our experience with at least one system is that real objects' color and brightness are altered along with the loss in texture and levels of detail due to the limited resolution (this includes spatial, luminance, and color resolution) of the miniature video cameras and wide angle optical viewer present in the system (Rolland et al., 1994). This is perhaps resolvable with improved technology but currently limits the ability of the HMD user to perceive real objects as they would appear with unaided eyes. We do not foresee a breakthrough in the next five years, but perhaps in the next ten years.

For optical see-through systems, folding the optical path by using a semi-transparent mirror is necessary because it is the only configuration that leaves the real scene almost unaltered. A thin folding mirror will introduce a small shift in depth of real objects equal to $e(n-1)/n$ where e is the thickness of the plate and n is its index of refraction. This is in addition to a small amount of distortion of the scene at the edges of the FOV, as discussed earlier.

2.4. Depth of Field

One important property of the human visual system not yet addressed is *depth of field.* Depth of field refers to the range of distances from the eye in which an object appears to be in focus without the need for a change in eye accommodation. If an object is accurately focused monocularly, other objects somewhat nearer and further away are also seen clearly without any change in accommodation. Still nearer or further away objects are blurred. Depth of field reduces the necessity for precise accommodation, but is markedly influenced by the diameter of the pupil. The larger the pupil, the smaller the depth of field. For a 2 mm and 4 mm pupil, the depth of field is +/- 0.06 and +/- 0.03 diopters, respectively. For a 4 mm pupil, for example, such a depth of field translates as a clear focus from 0.94 to 1.06 meter for an object 1 meter away, and to 11 meters to 33 meters for an object 17 meters away (Campbell, 1957; Moses, 1970). The important point to note is that accommodation may play an important role only at close working distance where depth of field is narrow.

With video see-through systems, the miniature cameras used for acquiring the real scene images must provide a depth of field equivalent to the required working distance for a task. For a large range of working distances, the camera may need to be focused at the middle working distance. For closer distances, the small depth of field may require an autofocus instead of a fixed-focus camera.

With optical see-through systems, the available depth of field for the real scene is essentially that of the human visual system, but for a larger pupil than would be accessible with unaided eyes. This can be explained by the brightness attenuation of the real scene by the semi-transparent mirror. As a result, the pupils are dilated (we assume here that the real and virtual scenes are matched in brightness). Therefore, the effective depth of field will be slightly less than with unaided eyes. This is only a problem if the user is working with nearby objects and the virtual images are focused outside of the depth of field required for nearby objects. With current displays, the virtual images suffer so much from blur due to the poor resolution of the displays themselves that the need to accommodate at different planes, for real and virtual objects to be seen clearly, may not even come into play.

Meta Exhibit 1017
Meta v. Mullen - Page 00203

Since retinal images are never truly sharp, the visual system is constantly processing somewhat blurred images and tends to tolerate blur up to the point at which essential detail is obscured. This tolerance for blur extends the apparent depth of field considerably, so that the eye may be as much as +/-0.25 diopters out of focus without stimulating accommodative change (Moses, 1970). From this observation, convergence and accommodation in a HMD may not be as decoupled as one theoretically would predict. This would occur at the expense of more blurry images that may be properly handled by the visual system. Whether these factors affect depth perception is worth further investigation.

3. Human Factors Issues

Some of the issues discussed in this section currently have few quantitative proofs because too few human factors studies have been conducted with VR technology in general, and even less with see-through VR technology. We shall therefore offer our opinions based on our experience.

3.1. User Acceptance and Safety

A fair question for either type of technology is "will anyone actually wear one of these devices for extended periods?" The answer will doubtless be application- and technology-specific, but will probably boil down to the issue of whether the advanced capabilities afforded by the technology offset the problems induced by the encumbrance and sensory conflicts associated with it. In particular, video see-through HMDs may meet with resistance in the workplace since they take away the direct real-world view in order to augment it; there is an issue of trust that may be difficult to overcome for some users. Moreover, current problems with low resolution and camera/eye viewpoint mismatches will tend to push the acceptance threshold further into the future for video see-through systems.

The problem is exacerbated in safety-critical applications. A key difference in such applications may turn out to be the failure mode of each technology. A failing in technology in the case of optical see-through may leave the subject without any computer-generated images but still with the real world view. In the case of video see-through, a failing in technology may leave the user with complete suppression of the real-world view, as well as the computer-generated view. Such a loss may be unacceptable in many applications for reasons of safety and liability.

3.2. Adaptation

When a system does not offer what the user ultimately wants, two paths may be taken: 1) improving on the current technology, or 2) studying the ability of the human system to adapt to an imperfect technological unit and developing adaptation training when appropriate. This is possible because of the astonishing ability of the human visual and proprioceptive systems to adapt to new environments, as has been shown in multiple studies on adaptation (Rock, 1966).

We recently conducted a study of adaptation to visual displacement in see-through HMDs (Rolland & Biocca et al., 1994). Users see the real world through two cameras which are located 62 mm higher, and 165 mm forward from their natural eyepoints. Subjects showed evidence of perceptual adaptation to sensory disarrangement during the course of the study. This revealed itself as improvement in performance over time while wearing the see-through HMD and as negative aftereffects once they removed it. More precisely, the negative aftereffect manifested itself clearly as a large overshoot in a depth pointing task, as well as an upward translation in a lateral pointing task after wearing the HMD.

The presence of negative after-effects has some potentially disturbing practical implications for the diffusion of see-through HMDs. Some of the intended earlier users of these HMDs are surgeons and

Meta Exhibit 1017
Meta v. Mullen - Page 00204

other individuals in the medical profession. Hand-eye sensory recalibration for highly skilled users like surgeons could have potentially disturbing consequences if the surgeon were to enter surgery within some period after use of a HMD. It is an empirical question how long the negative aftereffects might persist, and whether a program of gradual adaptation (Welch, 1994) or dual adaptation (Welch, 1993) might minimize the effect altogether. In any case, any shift in the camera eyepoints need to be minimized as much as possible to facilitate any adaptation process that is taking place.

3.3. Peripheral FOV

Given that peripheral vision can be provided for both optical and video see-through systems, the next question is whether it is used as effectively for both systems. In optical see-through, there is almost no transition or discrepancy between the real scene captured by the see-through device and the peripheral vision seen on the side of the device.

For video see-through, the peripheral FOV can be also captured by video cameras or may be provided by letting the user see around the device, as with optical see-through. Especially in the latter case, it remains to be seen whether the difference in presentation of the superimposed real scene and the peripheral real scene will cause discomfort or provide conflicting cues to the user.

Conclusion

We have presented a comparison of optical and video see-through head-mounted displays. In our opinion, the most important issues are system latency, occlusion, and the fidelity of the real-world view. Optical see-through systems offer an essentially unhindered view of the real environment; they also provide an instantaneous real-world view which assures that visual and proprioception information is synchronized. Video systems give up the unhindered view in return for improved ability to render occlusion cues; the issue of how to really perform occlusion is far from solved, however, and remains an active area of research. Video see-through systems can also guarantee registration of the real and virtual scenes at the expense of a mismatch between vision and proprioception, which may or may not be perceived as a penalty if the human observer is able to adapt to such a mismatch. Clearly, there is no "right" system for all applications: each of the tradeoffs discussed in this paper must be examined with respect to the planned application and available technology to determine which type of system is most appropriate.

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References

Allen, D. (1993)., "A 1" high resolution field sequential display for head-mounted applications. " Proc IEEE Virtual reality annual international symposium (VRAIS).

Azuma, R., and G. Bishop (1994), "Improving static and dynamic registration in an optical see-through HMD." *Computer Graphics: Proceedings of SIGGRAPH '94.* (Orlando, July 24-29, pp. 197-204).

Meta Exhibit 1017
Meta v. Mullen - Page 00205

Bajura, M., H. Fuchs, and R. Ohbuchi (1992) "Merging Virtual Objects with the Real World," Computer Graphics, number 26, pp. 203 -10.

Barrette, R.E. (1992), "Wide Field of View, Full-Color, High-Resolution, Helmet-Mounted Display," SID '92 Symposium, pp. 69-72.

Buchroeder, R.A., Seeley, G.W., and Vukobradatovich, D. (1981), "Design of a Catadioptric VCASS Helmet-Mounted Display," Optical Sciences Center, University of Arizona, under contract to U.S. Air Force Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio, AFAMRL-TR-81-133.

Campbell, F.W. (1957), "The depth of field of the human eye," Optica Acta, 4, 157-164.

Caudell, T.P., and Mizell, D.W. (1992), "Augmented Reality: An application of heads-up display technology to manual manufacturing processes," Proc. of the 1992 IEEE Hawaii International Conference on Systems Sciences, pp. 659-669.

Droessler, J.G., and Rotier, D.J. (1990), "Tilted cat helmet-mounted display," Optical Engineering, 29 (8).

Edwards, E.K., J.P. Rolland, and K.P. Keller (1993), "Video see-through design for merging of real and virtual environments," Proc. of IEEE VRAIS'93, pp 223-233.

Feiner, S., B. Macintyre, D. Seligmann (1993), "Knowledge-based augmented reality," Communications of the ACM, 36 (7), 53-62.

Furness, T A . (1986), "The super cockpit and its human factors challenges". Proceedings of the Human Factors Society. 30, 48-52.

Held, R, and N. Durlach. (1987), "Telepresence, time delay and adaptation". NASA Conference publication 10032.

Holloway, Richard. (1994), "An Analysis of Registration Errors in a See-Through Head-Mounted Display System for Craniofacial Surgery Planning", Ph.D. dissertation, University of North Carolina at Chapel Hill. In preparation.

Kaiser Electro-Optics (1994), Personal communication from Frank Hepburn of KEO, Carlsbad, CA. General description of Kaiser's VIM system ("Full immersion head-mounted display system") is available via ARPA's ESTO World-Wide Web home page: http://esto.sysplan.com/ESTO/.

Kancherla, A., J.P. Rolland, D.L. Wright, and G. Burdea (1995), "A novel virtual reality tool for teaching dynamic 3D anatomy". In press.

Kandebo, S.W. (1988), "Navy to evaluate Agile Eye helmet-mounted display system," Aviation week & space technology, August 15, 94-99.

Laveau, S., and O. Faugeras. (1994), "3-D scene representations as a collection of images and fundamental matrices," Institut National de Recherche en Informatique et en Automatique (INREA) Report 2205. February.

Mine, Mark. (1993), "Characterization of end-to-end delays in head-mounted display systems", Technical Report TR93-001, University of North Carolina at Chapel Hill.

Rolland, J.P. (1994), "Head-mounted displays for virtual environments: the optical interface," presented at the International Optical Design Conference 94, Proc. OSA 22 (in press).

Rolland, J.P., F. Biocca, T. Barlow, and A. Kancherla (1994), " Quantification of Perceptual Adaptation to Visual Displacement in See-Through Head-Mounted Displays," forthcoming.

Rock, I (1966), *The nature of perceptual adaptation*, New York: Basic Books.

Roscoe S.N. (1984), "Judgments of size and distance with imaging displays," Human Factors, 26 (6), 617-629.

Roscoe S.N. (1991), "The eyes prefer real images," in Pictorial Communication in Virtual and Real Environments," ed. Stephen R. Ellis, Taylor and Francis.

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Meta v. Mullen - Page 00206

State, A, D Chen, C Tector, A Brandt, H Chen, R Ohbuchi, M Bajura, and H Fuchs. (1994). "Case study: Observing a volume rendered fetus within a pregnant patient," Proceedings of Visualization '94. Washington, DC. pp. 364-373.

Sutherland, I. (1965), "The ultimate display," *Information Processing 1965 : Proc. of IFIP Congress 65.* 506-508.

Tomasi, C., and T. Kanade. (1991), "Shape and motion from image streams: a factorization method–Part 3: Detection and tracking of point features," Carnegie Mellon technical report CMU-CS-91-132.

Welch, B., and M. Shenker. (1984), "The fiber-optic Helmet-Mounted Display," Image III, 345-361.

Welsh, R.B. (1993), "Alternating prism exposure causes dual adaptation and generalization to a novel displacement," Perception and Psychophysics, 54 (2), 195-204.

Welsh, R. B. (1994), "Adapting to virtual environments and teleoperators," Unpublished manuscript, NASA-Ames Research Center, Moffett Field, CA.

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Kim, H., Jang, B., Kim, J., Kim, J., & Kim, D. (1997). An outdoor augmented reality system for understanding remote geographical information. In *International Conference on Artificial Reality Telexistence* (Vol. 7, pp. 154-158).

Schumann, H., Burtescu, S., & Siering, F. (1998, June). Applying augmented reality techniques in the field of interactive collaborative design. In *European Workshop on 3D Structure from Multiple Images of Large-Scale Environments* (pp. 290-303). Berlin, Heidelberg: Springer Berlin Heidelberg.

Livingston, M. A. (1998). *Vision-based tracking with dynamic structured light for video see-through augmented reality*. The University of North Carolina at Chapel Hill.

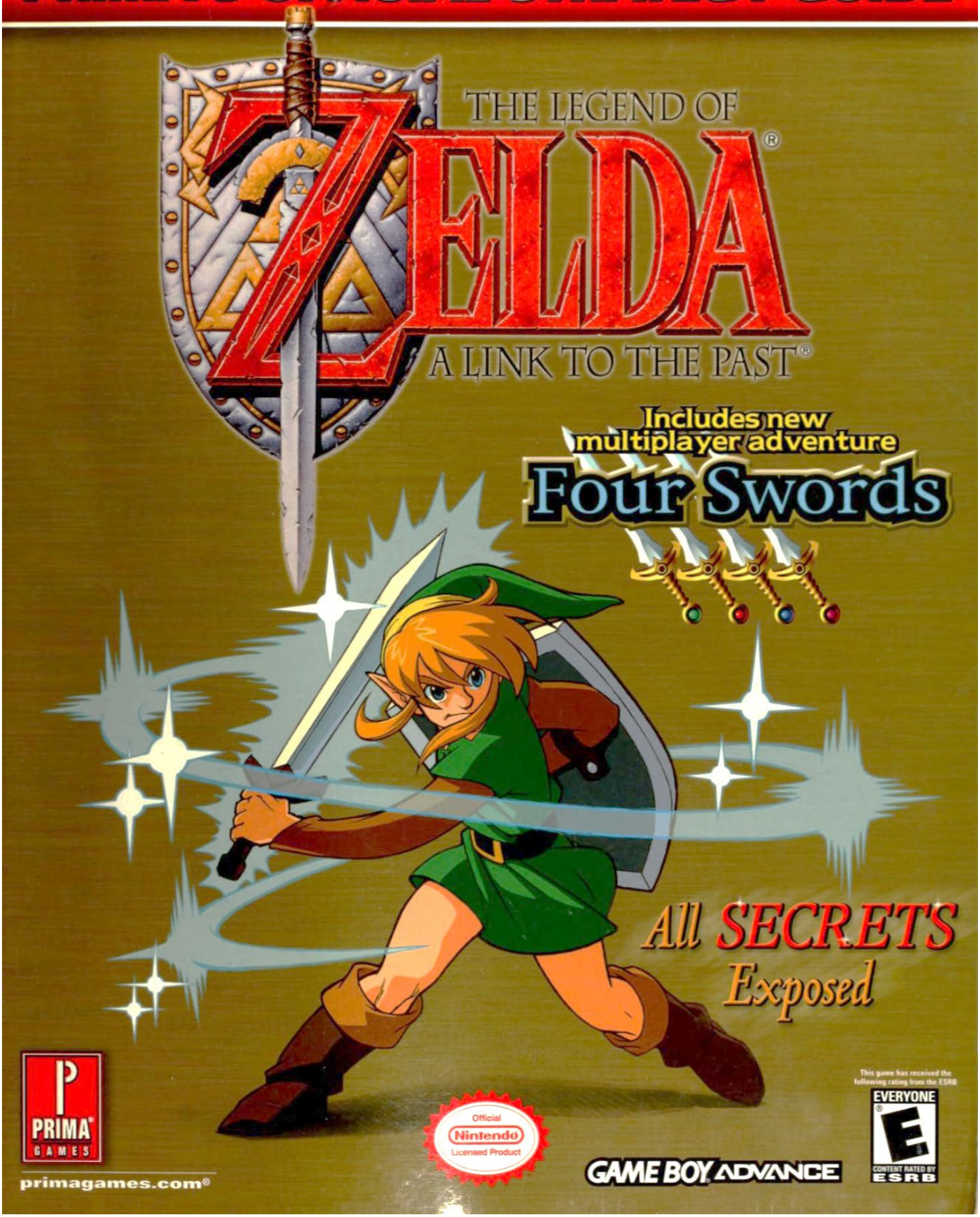
Vallino, J. R. (1998). *Interactive augmented reality*. University of Rochester.

Robinson, I. N. (2000). *U.S. Patent No. 6,037,914*. Washington, DC: U.S. Patent and Trademark Office.

Wheeler, A. (2000). *Virtual primitives for the representation of features and objects in a remote telepresence environment*. University of Surrey (United Kingdom).

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A LINK TO THE PAST®

Includes new multiplayer adventure
Four Swords





Prima's Official Strategy Guide

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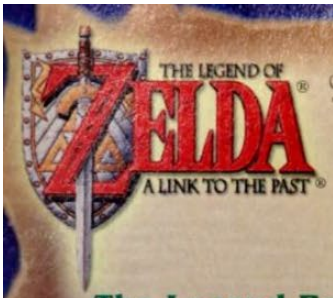
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Prima's Official Strategy Guide

Contents

The Legend Begins 3
- How to Use This Book 3
- File Management 3
- An Introduction to *A Link to the Past* 4
- Items 8
- Common Items 8
- Dungeon Items 8
- Magic Items 9
- Weapons 9
- Defensive Items 10
- Other Items 10

Characters and Enemies 13
- Major Characters 13
- Overworld Enemies 14
- Dungeon Enemies 15
- Bosses 18

Light Overworld Map 20

Dark Overworld Map 21

The Legend of Zelda: A Link to the Past Walkthrough 22
- Hyrule Castle 22
- Kakariko Village 33
  - Missing Links 34
- East Palace 40
  - Missing Links 48
- Desert Palace 52
  - Missing Links 58
- Death Mountain and the Tower of Hera 61
- Return to Hyrule Castle 70
  - Missing Links 76
- Palace of Darkness 78
  - Missing Links 89
- Skull Dungeon 100
- Thieves' Town 108
  - Missing Links 116
- Ice Palace 120
- Misery Mire 130
  - Missing Links 140
- Turtle Rock 141
- Ganon's Tower 152
  - Missing Links 164

The Legendary Checklist 169
- Heart Containers 169
- Pieces of Heart 169
- Fairy Ponds 171
- Shops 172
- Zora Whirlpools 172

Introduction to *Four Swords* 173
- Legend of the Four Sword 173
- Setting up *Four Swords* 173
- Playing *Four Swords* 174
- Items 175
- Enemies 176

***Four Swords* Walkthroughs** 177
- Chambers of Insight 177
- To Vaati's Palace 183
- Vaati's Palace 183
- The Palace of the Four Sword 184
- Scavenger Hunt 189

Meta Exhibit 1017
Meta v. Mullen - Page 00224

The Legend Begins

How to Use this Book

Thank you for purchasing Prima's Official Strategy Guide to *The Legend of Zelda: A Link to the Past/Four Swords*. This guide has all the tips, tricks, strategies, and information you need to conquer the forces of darkness that threaten Hyrule.

The first part of this guide deals with the single-player *A Link to the Past*. Refer to the end of this guide for information and strategies for the multiplayer *Four Swords* game. Here's a quick overview of the following pages:

The Legend Begins

The introduction section that you're reading now gives you all the basic information you need to begin playing *A Link to the Past*, including a quick rundown on controls, game mechanics, and environmental features.

Items



You can find more than 50 different items in *A Link to the Past*, and we give detailed descriptions of each, including tips for using them to their fullest potential.

Characters and Enemies



A Link to the Past has about 100 characters and enemies, and the Characters and Enemies section of this guide is the least painful way to learn their strengths and weaknesses.

A Link to the Past Walkthrough



The bulk of this guide is devoted to giving you the most comprehensive walkthrough to *A Link to the Past* possible. It includes fully labeled dungeon maps created from actual game screens, tips on finding every item, Piece of Heart, and treasure, and the best strategies for defeating every dungeon boss. If it's not in here, you don't need it!

The Legendary Checklist



Having trouble finding a Piece of Heart? Need to know which shop has the best deal on Medicine of Life? Curious as to where those Zora whirlpools lead? Turn to the Legendary Checklist section for all your quick-reference needs.

Introduction to *Four Swords*



When you're ready to link up to a friend's Game Boy® Advance and play the first ever multiplayer Legend of Zelda game, consult Introduction to *Four Swords* for all of the tips you need to come out on top.

Four Swords Walkthrough



Our *Four Swords* walkthrough has answers to every dungeon puzzle, including the final battle with the sorcerer Vaati. Amaze your friends with your knowledge and take their Rupees!

File Management



Read the following information before playing either *A Link to the Past* or *Four Swords*, because the information applies to both games.

Game Files

When you start playing *A Link to the Past/Four Swords*, you need to create a file in which to save your game information. This game file is used to save progress in both *A Link to the Past* and *Four Swords*. In fact, your progress in one game affects your progress in the other!

Creating a File

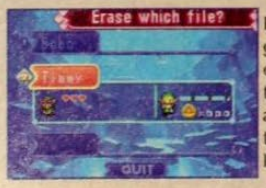
At the File menu, press Ⓐ to create a new file. If you want to create another file later on, select one of the blank files and press Ⓐ. You can have up to three files on your Game Pak.

Choosing a Name



Choose a name for your character. We entered the character's official name, Link, but you can enter whatever you like, as long as it isn't more than six characters long.

Game Options



Press → on the + Control Pad while a game file is highlighted to change the options for that game file. You can set the Message Speed so that the text appears slow, normal, or fast. Use Adjust the Brightness to make the screen lighting dark, normal, or bright.

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Choosing Your Game



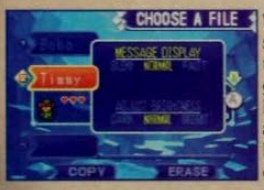
Finally, use ↑ and ↓ on the + Control Pad on the Choose a Game screen to select *A Link to the Past* or *Four Swords*, and press Ⓐ to start the game.

Saving Game Progress



At nearly any point in the game, you can press START to bring up the in-game menu. Choose Save to record your progress. Don't turn the power off while your game is being saved! Once the game is saved, you have two options: Continue Game or Quit.

Loading a File



When you've created a file and saved some game data to it, you can turn off the Game Boy Advance and resume your game later by loading the file. Simply highlight your game file on the File menu and press Ⓐ. You can resume from the last location at which you saved or from one of several other locations in Hyrule.

Note

If you save your progress in a dungeon, you must resume your game from the entrance to that dungeon. You can't resume from the room in which you saved the game.

Copying a File



If you want to copy a game file to an empty file slot, highlight Copy at the bottom of the File menu, select the file you want to copy, and choose the empty file slot to which you want to copy the game. Don't turn the power off while it's copying!

Erasing a File



To erase a saved game file, choose Erase at the bottom of the File menu, and then choose the file you want to erase. You will be asked to confirm that you want to erase the game. If you do, the game file is erased permanently. Don't turn the power off while it's erasing!

Note

Erased games can never, ever, ever be brought back. If you're worried about your little brother or sister accidentally erasing your game, hide the Game Pak where they won't find it!

An Introduction to *A Link to the Past*



A Link to the Past is an amazingly faithful recreation of the original Super Nintendo single-player game of the same name. You take on the role of Link, a young boy who was born to be a hero and save the land of Hyrule from disaster.

The Legend of Hyrule

"Aeons ago, the Deities of Power, Courage, and Wisdom descended to the World of Chaos. They created the world that we know and left behind a symbol of their strength, the golden emblem known as the Triforce, which they hid in the Golden Land.

"After many years, an opening was found that led from our fair Hyrule to the Golden Land, where the mystical Triforce was still hidden. Many sought treasure in this place, but none returned—only beings of great evil emerged from the Golden Land.

"The King of Hyrule gathered the seven sages to find a way to seal the entrance to the Golden Land so that his kingdom would be safe from the evil there. The sages succeeded and brought peace again to Hyrule.

"However, strange things have been happening in Hyrule since the appearance of Agahnim, a mysterious sorcerer who gained fame for extinguishing a devastating blaze of unknown origin some years ago.

"And now...

"One night, a girl's voice wakes you from sleep. 'Help me...my name is Zelda...I am in the castle dungeon.' Not knowing if the voice was a dream or reality, you step into the rain and forbidding darkness...and the Legend of Zelda begins."

Controls

Now that you have your game file created, it's time to play. Before you can save Hyrule, you need to know how to control Link. The controls are simple to learn and easy to master.

Controls for *A Link to the Past*

Command	Button
WHILE PLAYING THE GAME	
Use your equipped item	Ⓐ
Open a chest	Ⓐ or R while standing in front of the chest
Speak to a character	Ⓐ or R while standing in front of the character
Read signs	Ⓐ or R while standing in front of the sign
Swing your sword	Ⓑ

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Meta v. Mullen - Page 00226

Escape From Hyrule Castle



Backtrack along the route you took to reach the third basement floor until you reach 1F Room 4. You must travel from B3F through B2F, B1F Room 5, B1F Room 3, B1F Room 2, B1F Room 1, and take the stairs up to 1F Room 4.

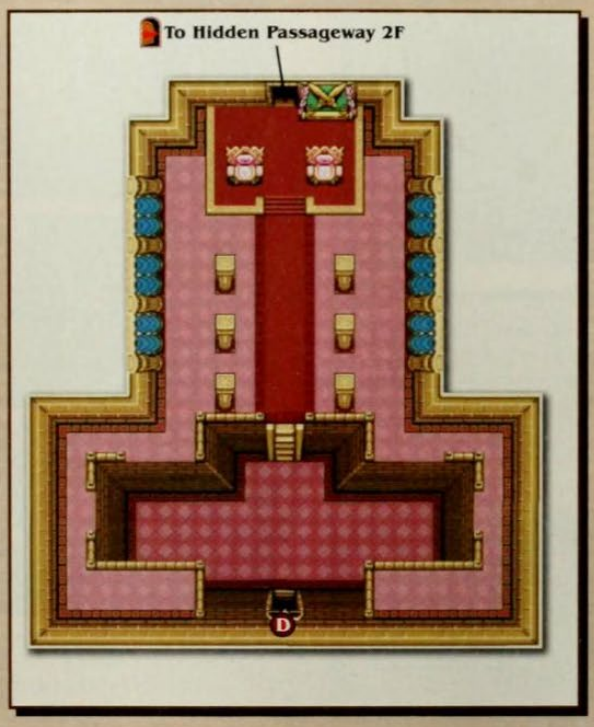
Tip

Use the elevated narrow pathway in B1F Room 2 to avoid having to fight all the Blue Knights.



From 1F Room 4, head through the west door and travel through the castle rooms in a counterclockwise direction until you reach 1F Room 1. Alternatively, go through the east door in 1F Room 4 and move clockwise until you reach 1F Room 1. That route has a few more enemies, however, making it a little more difficult.

Hyrule Castle, Second Floor (2F)





As you approach the thrones, Zelda says that an ornamental shelf along the north wall can be pushed from the left to reveal a hidden passageway. She also cautions you to make sure you have a lamp, because the passageway is pitch-black. Fortunately, you grabbed the lamp from Link's house.



Push the shelf to the side to reveal the hidden passageway, and enter.



When you reach 1F Room 1, Zelda tells Link of a secret passage in the throne room that leads to the Sanctuary. Zelda is sure an old man who resides there will help them.



Defeat the Green Knights in 1F Room 1 and head up the stairs in the north wall of the room to reach the second floor of Hyrule Castle and the throne room.



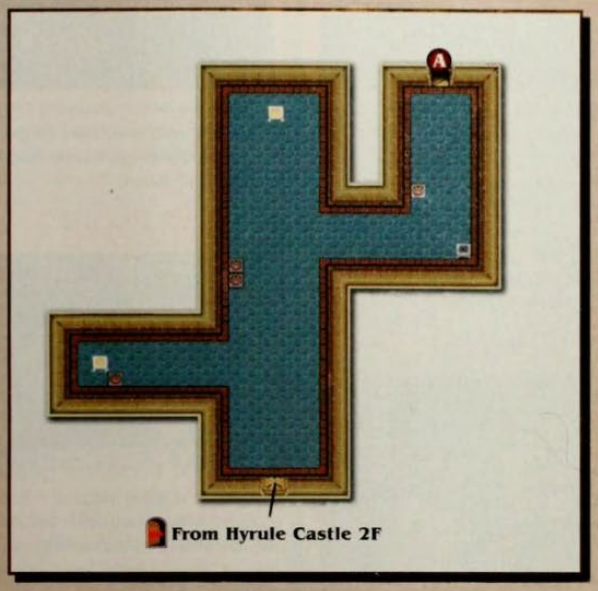
Two Blue Knights wait by the south entrance of the throne room, where you appear. Use your Boomerang to stun them, take them out quickly, and then head north to the thrones.



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Hidden Passageway

Passageway, Second Floor (2F)





Zelda wasn't kidding—it's really dark in here. Link's lamp produces a small area of light, but not enough to prevent an ambush by Mice. To make matters worse, the door slams shut behind you and does not reopen under any circumstances.



You can light two other torches in the room, one in the center of the north wall and one in the east part of the room. Lighting more than one at a time makes the room only slightly brighter, however, and it depletes your Magic Meter. Light only one at a time, especially once all the Mice are gone.



Head west until you find a torch. Press Ⓐ to light it. This illuminates the room dimly, but not for long. Take advantage of the light to defeat the four Mice in the room.

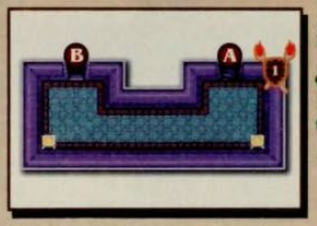


A Magic Vial is in the pot next to the first torch at the west end of the room. Between the west and north torches are two more pots; one contains a Rupee and the other conceals another Magic Vial. A fourth pot near the east torch has a Heart.



Grab all the valuable items, then head to the northeast corner of the room. A set of stairs leads down to the first floor of the hidden passageway.

Passageway, First Floor (1F)



1F Room 1



1F Room 1 is a small room filled with Cobras. First, light the torch in the southeast corner of the room so you can see to defeat the Cobras.

Tip

Take out several Cobras at once with Link's spin attack (hold down Ⓑ to charge your sword, then release).

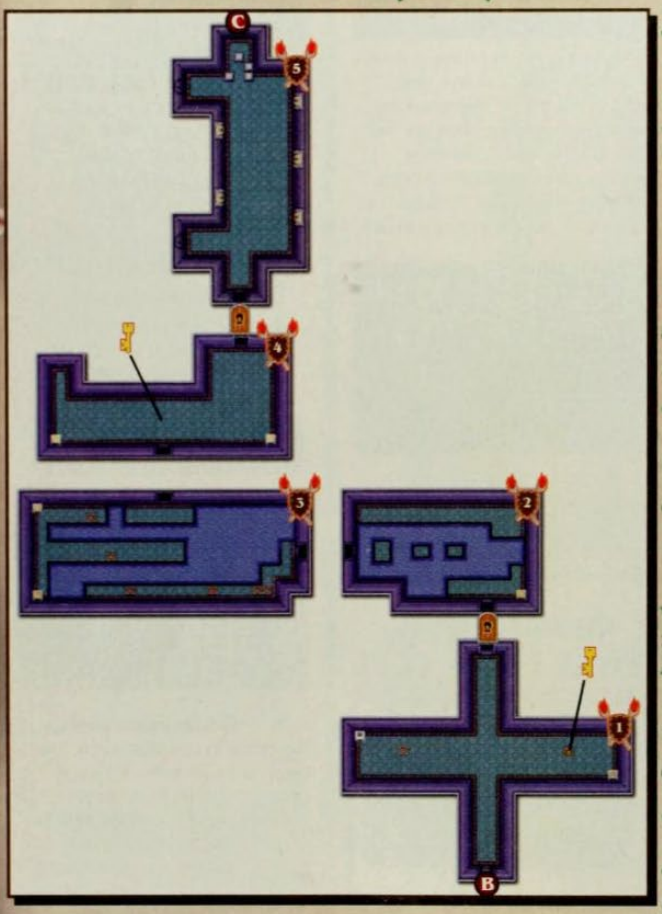


In the southwest corner of the room is another torch, but there is no reason to light it once the Cobras are gone. Head down the northwest stairs to reach the first basement floor of the hidden passageway.



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Passageway Basement, First Floor (B1F)



B1F Room 1



B1F Room 1 is a cross-shaped room. Enter through the south doorway from the first floor of the passageway. Proceed north carefully, fighting off Cobras and Bats.



When you reach the center of the room, head west to find a torch and light it. Quickly clear the room of enemies. The east end of the room has two more torches if you need them.



Near the west torch is a pot with a Magic Vial. Near the two east torches is a chest with a Key. Pick up both items and head to the north end of the room, where you find a locked door that the Key opens nicely. Head through the door and into B1F Room 2.

B1F Room 2



As they enter the sewers of B1F Room 2, Zelda reassures Link that they are getting very close to the Sanctuary. Like the rest of the hidden passageway, B1F Room 2 is pitch-black except for the light of Link's lamp.



As you enter through the southeast door, a torch is just to the east. Light it and head due north across the sewer water to attack the Mice in the northeast corner of the room. Light the torch there, because the one in the southeast corner goes out soon.

Tip

Mice can't enter water, so stand at the water's edge and eliminate them with your spinning sword attack.



Dispose of a remaining Mouse or two and head through the west doorway, which takes you to B1F Room 3.

B1F Room 3



B1F Room 3 is similar to B1F Room 2: a fairly large rectangular room with islands of dry stone in a river of sewer water. From your entry point at the east end of the room, head west through the water. Remember: Mice can't enter water.



Light one of the torches in the northwest and southwest corners of the room. Take out all the Mice and Bats, relighting the torches if necessary.



One of the pots along the south wall contains a Magic Vial, and another near it contains a Heart. You can also get another Magic Vial from a pot in the center of the room.

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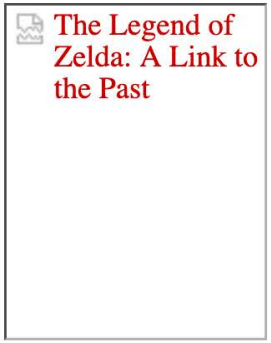
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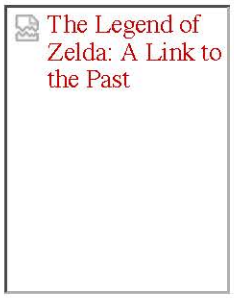
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