UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

META PLATFORMS, INC.

Petitioner

U.S. Patent No. 9,674,628

DECLARATION OF INGRID HSIEH-YEE, PH.D, UNDER 37 C.F.R. § 1.68 IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW

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I. Introduction

I, Ingrid Hsieh-Yee, Ph.D., do hereby declare as follows:

1. I have been retained as an independent expert witness on behalf of META Platforms, Inc. ("META") for proceedings before the United States Patent and Trademark Office ("PTO") regarding the authenticity and public availability of certain prior art references in relation to US Patent No. 9,674,628.

2. I am being compensated for my work in this matter at my customary hourly 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

3. 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.

4. In 2022 I was conferred the title of Professor Emerita after 32 years as a professor in the Department of Library and Information Science of the Catholic University of America. I have experience working in an academic library, a medical library, and a legislative library. I hold a Ph.D. in Library and Information Studies from the University of Wisconsin-Madison and a Masters in Library and Information Studies from the University of Wisconsin-Madison.

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5. 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.

6. 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. I am also personally familiar with the Online Computer Library Center (OCLC), which is the largest bibliographic

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network of the world, with more than 554 million records and thousands of member institutions (many of which are libraries of some type) in more than 100 countries. I am also personally familiar with WorldCat, which is a free web portal for users to explore more than 10,000 libraries worldwide. I provide a brief overview of MARC records, OCLC, and WorldCat below at Section D.

7. I am also 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)
- IEEE Xplore Digital Library (https://ieeexplore.ieee.org/Xplore/home.jsp)
- 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)
- Online catalog of the University of Michigan Library (https://search.lib.umich.edu/catalog)
- Public catalog of the US Copyright Office (https://cocatalog.loc.gov/)
- WorldCat (https://www.worldcat.org)

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B. Scope of This Declaration

8. I have been asked to offer expert opinions on the authenticity and public availability date of the following documents:

> Billinghurst, M., Bowskill, J., Jessop, M., & Morphett, J., (1998, October), "A wearable spatial conferencing space, in the *Second International Symposium on Wearable Computers : Digest of Papers*," (Cat. No. 98EX215), pp. 76-83, published by IEEE, **Ex. 1010** ("*Billinghurst*");
>
> Zhou, Z., Cheok, A. D., Yang, X., & Qiu, Y., (2004, October), "An experimental study on the role of software synthesized 3D sound in augmented reality environments, *Interacting with Computers*, vol. 16, issue 5, pp. 989-1016, **Ex. 1018** ("*Zhou*").

C. Evidence Considered in Forming My Opinions

9. In the preparation of this Declaration, I have reviewed the documents referenced below and any other documents I reference herein, and each of these is a type of material that experts in my field would reasonably rely upon when forming their opinions:

(1) The document referenced above in Section I.B;

(2) IEEE metadata record for *Billinghurst*, available at https://ieeexplore.ieee.org/abstract/document/729532 from the IEEE Xplore Digital Library, accessed and obtained on December

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5, 2022, **Appendix 1010A**;

(3) Linda Hall Library copy of *Billinghurst*, obtained on December 7, 2022, **Appendix 1010B**;

(4) Bibliographic and MARC records for the *Second International Symposium on Wearable Computers : Digest of Papers* that contains *Billinghurst*, accessed and obtained on December 6, 2022, **Appendix 1010C**;

(5) Copyright registration record for the *Second International Symposium on Wearable Computers : Digest of Papers* that contains *Billinghurst*, available at https://cocatalog.loc.gov/cgi-bin/Pwebrecon.cgi?Search_Arg=Second+International+Symposium+on+Wearable+Computers&Search_Code=TALL&PID=bRSe5ddGYeHW1g0o4boUEfvOWDYpX&SEQ=20221229170100&CNT=25&HIST=1 from the public catalog of the U.S. Copyright Office, accessed and obtained on December 6, 2022, **Appendix 1010D**;

(6) Library of Congress copy of *Billinghurst*, obtained on December 7, 2022, **Appendix 1010E**;

(7) Bibliographic and MARC records for the *Second International Symposium on Wearable Computers : Digest of Papers* that contains *Billinghurst*, available at https://lccn.loc.gov/98087390 from the online catalog of the Library of Congress, accessed and obtained on December 6, 2022, **Appendix 1010F**;

(8) Early citations to *Billinghurst*, obtained from Google Scholar, **Appendix 1010G**;

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(9) IEEE metadata record for *Zhou*, available at https://ieeexplore.ieee.org/document/8160489 from the IEEE Xplore Digital Library, accessed and obtained on January 13, 2023, **Appendix 1018A**;

(10) Library of Congress copy of *Zhou*, obtained on January 13, 2023, **Appendix 1018B**;

(11) Bibliographic and MARC records for *Interacting with Computers* that contains *Zhou*, available at https://lccn.loc.gov/89658522/ from the online catalog of the Library of Congress, accessed and obtained on January 13, 2023, **Appendix 1018C**;

(12) University of Michigan Library copy of *Zhou*, obtained on January 17, 2023, **Appendix 1018D**;

(13) Bibliographic and MARC records for *Interacting with Computers* that contains *Zhou*, available at https://search.lib.umich.edu/catalog/record/990024764370106381 from the online catalog of the University of Michigan Library, accessed and obtained on January 13, 2023, **Appendix 1018E**;

(14) Citations to *Zhou*, obtained from Google Scholar, **Appendix 1018F**.

D. Overview of MARC Records, OCLC, and WorldCat

10. 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. A MARC record consists of

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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" (http://www.loc.gov/marc/umb/um07to10.html) from the Library of Congress 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 characteristics of a publication are recorded in Field 300, and topical subjects are recorded in Fields 650.

11. OCLC was founded in 1967 to promote and support library cooperation. According to the "Third Article, 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).

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12. 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 in Field 008, 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).

13. After a MARC record is created in Connexion, it also becomes searchable and viewable on WorldCat, which is a free web portal for users to explore more than 10,000 libraries worldwide. Records in WorldCat, 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.

14. 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

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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 now 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.

15. Libraries create MARC records for works they acquire, including books, serials, motion pictures, and publications in other formats. MARC records are representations of materials held by libraries and are critical for the discovery and access to those materials. 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 OCLC 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 OCLC WorldCat. If it is a copy cataloging record, the library's holding symbol

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is attached to the existing original record in OCLC WorldCat to facilitate searching and interlibrary loan.

16. 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." (MARC Discussion Paper No. 2020-DP16 at https://www.loc.gov/marc/mac/2020/2020-dp16.html). 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 place a date stamp on 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.

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17. 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.

II. Authenticity and Public Availability of *Billinghurst* (Ex. 1010)

A. Authentication

72. **Ex. 1010** is a true and correct copy of "A wearable spatial conferencing space," ("*Billinghurst*"), by Billinghurst et al. in the *Second International Symposium on Wearable Computers : Digest of Papers* (Cat. No. 98EX215), pp. 76-83, that I obtained from the publisher IEEE. I began my research on this work on Google Scholar and found a record that led me to an IEEE metadata record for this article at https://ieeexplore.ieee.org/document/729532 in the IEEE Xplore Digital Library. I followed the PDF link to purchase this article from the publisher. The IEEE copy is presented as **Ex. 1010** in this Declaration.

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19. **Ex. 1010** is a true and correct copy of *Billinghurst* that I obtained from the IEEE Xplore Digital Library, the digital library created and maintained by the Institute of Electrical and Electronics Engineers. **Ex. 1010** is not numbered, and the first page shows the title, authors, and abstract of the *Billinghurst* article. This publisher copy shows *Billinghurst* has a total of eight pages, including eight sections, six figures (some in color), and a reference section with 32 references.

B. IEEE Metadata Record

20. **Appendix 1010A** is a true and correct copy of the metadata record for *Billinghurst* that I obtained from the IEEE Xplore Digital Library. I personally located, identified, and obtained this record, and used screen captures to produce **Appendix 1010A**. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

21. Page 1 of **Appendix 1010A** shows the title, authors and abstract of *Billinghurst*. It also shows IEEE as the publisher, and indicates the full text of this article is available in PDF. The record shows *Billinghurst* has 40 paper citations, 17 patent citations, and 276 full text views. Page 2 shows the article was published in "Digest of Papers. Second International Symposium on Wearable Computers" that has the IEEE Catalog Number of "98EX215." The metadata record also shows the conference took place from "19-20 October 1998" at Pittsburgh, PA, USA, the "Digest of Papers" has an ISBN (International Standard Book Number) of "0-8186-

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9074-7," the DOI (digital object identifier) of *Billinghurst* is "10.1109/ISWC.1998.729532" and the IEEE metadata record for this article was added to IEEE Xplore on "06 August 2002."

22. The "Published in" field of the IEEE metadata record for *Billinghurst* provides a live link to the conference proceedings in IEEE Xplore. Page 3 of **Appendix 1010A** is a screen capture of the top of the conference information in IEEE Xplore, showing the URL of this proceedings, the name of the symposium, and a link (https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=729522) that provides free access to front matter of this conference proceedings. Pages 4 to 8 are the first 19 articles included in the conference proceedings, and page 6 shows *Billinghurst* appears from pages 76 to 83. Pages 9 to 14 are the front matter of the conference proceedings, including the half title page, a blank page, the title page, copyright page, table of contents and "Message from the General Chair." Page 11 is the title page that shows the same title and conference dates as the IEEE metadata record, indicates the symposium was sponsored by "The IEEE Computer Society, Task Force on Wearable Information Systems in cooperation with ACM SIGMobile," and shows the IEEE Computer Society of Los Alamitos, California, is the publisher. Page 12 is the copyright page that shows this conference proceedings has a "1998" copyright date and the Institute of Electrical and Electronics Engineers, Inc. is the copyright holder. This page also shows the IEEE Computer Society Order

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Number for this publication is "PR09074," the ISBN of this work is "0-8186-9074-7," the ISBN for the microfiche version is "0-8186-9077-1," the Library of Congress Number for this work is "98-87390" and the IEEE Order Plan Catalog Number for this work is "98EX215."

C. Linda Hall Library Copy

23. To determine the availability of the print copy of *Billinghurst* in libraries, I searched WorldCat by "second international symposium on wearable computers" and found a record at https://worldcat.org/title/40240426 that shows the Linda Hall Library and the Library of Congress are two of the holding libraries. I searched the online catalog of the Linda Hall Library, one of the largest public research libraries for scholarly publications in science, engineering and technology, for holdings information, and the search results confirmed the library held the conference proceedings containing *Billinghurst*. I then asked the Document Delivery Service of the Linda Hall Library to provide a scanned copy of this article and received a copy on December 7, 2022. The Linda Hall Library copy is presented as **Appendix 1010B** in this Declaration.

24. **Appendix 1010B** is a true and correct copy of *Billinghurst* obtained from the Linda Hall Library. This copy includes the front matter of the conference proceedings containing *Billinghurst* and the full text of the *Billinghurst* article.

25. Page 1 of **Appendix 1010B** is a color cover that identifies this work as

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"Digest of Papers" of "The Second International Symposium on Wearable Computers, October 19-20, 1998, Pittsburgh, Pennsylvania" published by the IEEE Computer Society. The cover also shows "Wearable Computers 02." Page 2 is the title page and page 3 is the copyright page, which are the same as the front matter included in **Appendix 1010A**. The only difference is the copyright page shows a hand-written local call number of "QA76.5 .I68 1998." Pages 4 to 6 are the table of contents and page 4 is identical to the corresponding page in **Appendix 1010A**. The upper left area of page 4 shows a hand-written notation of "11-4-98" that indicates the date when this conference proceedings was added to the collections of the Linda Hall Library. My knowledge of this practice is based on my experience using the Linda Hall Library and their collections. The library MARC record discussed below will show that the Linda Hall Library cataloged this publication very soon after it was added to their collections. Page 5 of **Appendix 1010B** shows *Billinghurst* is placed in "Session 3: Augmented Reality/Spatial Context" and appears from pages 76 to 83.

26. Pages 7 to 14 of **Appendix 1010B** are the full text of *Billinghurst*. I have closely compared this copy with the IEEE copy (**Ex. 1010**) and concluded that these two copies have the same content. The only differences are that the Linda Hall Library copy carries a "1998" copyright date and shows the IEEE as the copyright holder, the article pages are numbered from pages 76 to 83, and the figures are black

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and white.

27. The Linda Hall Library copy of *Billinghurst* (**Appendix 1010B**) is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. Furthermore, I have compared this Linda Hall Library copy with the IEEE copy of *Billinghurst* (**Ex. 1010**) and found them to have the same content. **Appendix 1010B** was found in the custody of a public research library, a place where, if authentic, it would likely be found. Accordingly, I see no reason to question the authenticity of this library copy of *Billinghurst* (**Appendix 1010B**).

D. Linda Hall Library Records

28. **Appendix 1010C** contains a true and correct copy of the bibliographic and MARC records for *the Second International Symposium on Wearable Computers* that contains *Billinghurst*. I personally located, identified, and obtained these records from the online catalog of the Linda Hall Library. Because the records could not be downloaded cleanly, I used screen captures of these records to produce **Appendix 1010C**. These are the type of records experts in my field would reasonably rely upon when forming their opinions.

29. Page 1 of **Appendix 1010C** identifies this publication as "Conference Proceeding" and indicates it is available at "Linda Hall Library Books – 2nd Floor

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(QA76.5.I68 1998).” It also shows the link to this record. The “Location Items” area on page 2 shows this work is in place and “loanable.” Page 2 also shows details of the bibliographic record, including the title, creator and contributors, subjects, identifiers, publisher, creation date, physical format, and general notes. Page 3 shows a “Display Source Record” link that leads to the MARC record.

30. Page 4 of **Appendix 1010C** is the MARC record and the first six digits of Field 008 show this MARC record was created on “981105” (*i.e.*, November 5, 1998), and the “s1998” code following the record creation date shows this publication is a monograph with a single publication date of 1998. Field 005 records the date and time the MARC record was last revised, and data in this field are machine generated. Field 005 shows the Linda Hall Library last modified this record on November 5, 1998. Subfields “a” and “c” of Field 040 show that “LHL” created this MARC record. 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, 005 and 040, it is my opinion that the Linda Hall Library created this MARC record on November 5, 1998, which was also the date of last record modification by this library. The Linda Hall Library copy of *Billinghurst* (**Appendix 1010B**) shows the conference proceedings was added to the library collections on November 4, 1998, and the MARC record shows this work was cataloged on November 5, 1998, making it

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discoverable at this library from that date on. A common library practice is to make newly cataloged monographs available to the public soon after the cataloging work is completed, usually within a week. It is therefore my opinion that the copy of this conference proceedings containing *Billinghurst* would have become publicly accessible at the Linda Hall Library no later than November 12, 1998.

31. As evidence of the availability of an online catalog at the Linda Hall Library in 1998, I searched "Libraries.org: A directory of libraries throughout the world" for the library profile of the Linda Hall Library. The profile located at https://librarytechnology.org/library/2294 shows that Linda Hall Library contracted with Horizon in 1994 for their automation system and changed to Voyager in 2010, meaning the Horizon system would likely be the online catalog at that library in 1998 for users to explore the library's collections.

32. Field 010 shows the Library of Congress control number for the conference proceedings containing *Billinghurst*, Fields 020 show the ISBNs for the print and microfiche versions, Field 111 shows the authorized form of the conference name is used as the author of this work, Field 245 shows the title of the conference proceedings and conference sponsors, Field 260 shows the publisher information, Field 300 shows physical details of this work, Fields 500 show two IEEE order numbers, and Fields 710 show the Task Force on Wearable Information Systems of the IEEE Computer Society and ACM SIGMOBILE are included in the MARC

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record to help users discover this work. The Library of Congress control number, 10-digit ISBNs, IEEE order numbers, conference name, title, publisher, and the sponsor information match the information presented in the Linda Hall Library copy of *Billinghurst* (**Appendix 1010B**) and confirm this MARC record represents the conference proceedings that contains *Billinghurst*.

33. Subjects of this conference proceedings are represented in Field 090 by a locally assigned Library of Congress Classification (LCC) number of "QA76.5" that represents general works on digital computers (source: Library of Congress Classification – Schedule Q at https://www.loc.gov/aba/publications/FreeLCC/LCC_Q2020TEXT.pdf), and in Fields 650 by two Library of Congress subject headings, with "Portable computers" and "Mobile computing" as the main topics, each followed by "Congresses" as a form subdivision encoded in subfield "v" ($v) to indicate the topics are treated at a conference.

34. The MARC record (**Appendix 1010C**) and the Linda Hall Library copy (**Appendix 1010B**) inform my opinion that the Linda Hall Library cataloged the conference proceedings containing *Billinghurst* as a book on November 5, 1998, making this work discoverable in their online catalog from that date on, and the copy of the conference proceedings would have become publicly accessible no later than November 12, 1998. Interested users would have been able to conduct subject

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searches by the LCC number and the Library of Congress subject headings to discover this work. They would also have been able to discover this work by the Library of Congress control number, ISBNs, IEEE order numbers, conference name, title, and sponsors.

E. Copyright Registration Record

35. **Appendix 1010D** is a true and correct copy of the copyright registration record for the "Second international symposium on wearable computers : October 19-20, 1998." I obtained this record from the public catalog of the United States Copyright Office in the Library of Congress by first accessing the http://www.copyright.gov/ website, selecting the "Learn More" link under "Search Copyright Records," and selecting the link for "Official Public Catalog (1978-present)" to perform a search by "Second International Symposium on Wearable Computers" to retrieve the record. I personally located, identified and obtained this record. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

36. The "Type of Work" field identifies this publication as "Text." The title, imprint, and copyright claimant match the information presented in the conference front matter in the Linda Hall Library copy (**Appendix 1010B**). The "Date of Publication" field shows this work was published on "1998-10-19" (*i.e.*, October 19, 1998) and the "Registration Number / Date" field shows it was

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registered with the US Copyright Office on "1998-10-30" (*i.e.*, October 30, 1998) with a registration number of "TX0004875683."

F. Library of Congress Copy

37. My research on WorldCat located a record at https://worldcat.org/title/40240426 for the *Second International Symposium on Wearable Computers* that identified the Library of Congress as one of the holding libraries. I searched their online catalog for records, and the search results (https://lccn.loc.gov/98087390) confirmed the holdings information. I then obtained a scanned copy of *Billinghurst* from the Library of Congress through Wisconsin TechSearch (WTS), a document delivery service based at the University of Wisconsin-Madison. The Library of Congress copy is presented as **Appendix 1010E** in this Declaration.

38. **Appendix 1010E** is a true and correct copy of *Billinghurst* obtained from the Library of Congress. The spine on page 1 identifies this work as "International Symposium on Wearable Computers," the front cover shows a label of "QA 76.5 .I613 1998 Copy 2, Ft Meade GenColl" and the back cover shows a Library of Congress barcode. Page 2 is a color cover identifying the work as "The Second International Symposium on Wearable Computers, October 19-20, 1998, Pittsburgh, Pennsylvania, Digest of Papers," page 3 is the back cover that shows "ISWC" and an ISBN of "0-8186-9074-7." Page 4 is the half title, page 5 is the title

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page, page 6 is the copyright page that shows a date stamp of "Library of Congress OCT 30 1998 Copyright Office" and a hand-written call number of "QA76.5 .I613 1998 Copy 2." Pages 7 to 9 are the table of contents, and page 8 (internal page vi) shows *Billinghurst* is included in "Session 3: Augmented Reality/Spatial Context" and begins on page 76. Pages 10 to 17 (internal pages 76 to 83) are the full text of *Billinghurst*. I have compared the front matter in the Library of Congress copy with the corresponding pages in the Linda Hall Library copy (**Appendix 1010B**) and found them to be identical. I have also compared the *Billinghurst* article in the IEEE copy (**Ex. 1010**), the Linda Hall Library copy (**Appendix 1010B**), and the Library of Congress copy (**Appendix 1010E**) and concluded that these three copies show the same *Billinghurst* article. The differences are that the pages in the IEEE copy are not numbered, some figures are in color and the copy does not show a copyright date or a copyright holder, while the two library copies are black and white copies that show the same content and includes a "1998" copyright date with the IEEE as the copyright holder.

39. The Library of Congress copy of *Billinghurst* (**Appendix 1010E**) has the same content as the publisher's copy (**Ex. 1010**). It is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. Moreover,

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Billinghurst (**Appendix 1010E**) was found in the custody of a national library, a place where, if authentic, it would likely be found. Accordingly, I see no reason to question the authenticity of the Library of Congress copy of *Billinghurst*.

G. Library of Congress Records

40. **Appendix 1010F** is a true and correct copy of the bibliographic and MARC records for the conference proceedings that contains *Billinghurst*. I personally located, identified, and obtained these records from the online catalog of the Library of Congress. These are the type of records experts in my field would reasonably rely upon when forming their opinions.

41. Pages 1 and 2 of **Appendix 1010F** are the bibliographic record for the *Second International Symposium on Wearable Computers : digest of papers* that contains *Billinghurst*. The record indicates this conference proceedings is a "Book" about an international symposium and was published by the IEEE Computer Society Press of Los Alamitos, California in 1998. The record also shows the main title, the Library of Congress control number, physical description, ISBNs, and other details of this publication. The "Item Availability" area on page 2 shows the Library of Congress has two copies that are stored offsite and users can request access at the Jefferson or Adams Building Reading Rooms. The "Status" of the two copies is "Not Charged," meaning they are available.

42. Pages 3 and 4 are the MARC record for the conference proceedings that

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contains *Billinghurst*. The first six digits of Field 008 show the record was created on "980805" (*i.e.*, August 5, 1998), and the "s1998" code following the record creation date indicates this work has a single publication date of 1998. Field 955 is a field for recording local cataloging activities and it shows a copy of the conference proceedings was sent to the cataloging unit on "12-18-98" (*i.e.*, December 18, 1998) and then sent to ddc (the Dewey Decimal Classification unit) on "01-20-99" (*i.e.*, January 20, 1999). Field 005 is a machine-generated field that records the last date when the library modified this MARC record, and it shows "19990127" (*i.e.*, January 27, 1999) as the last record modification date. Subfields "a" and "c" of Field 040 show "MoKL" created the original MARC record, and subfield "d" shows "DLC" modified the original record to create a copy cataloging record. Field 042 shows this Library of Congress record is an "lccopycat" (meaning a Library of Congress copy cataloging record). According to the *MARC Code List for Organizations* (https://www.loc.gov/marc/organizations/org-search.php), "MoKL" is the MARC organization code for the Linda Hall Library and "DLC" is the MARC organization code for the Library of Congress. Data in Fields 008, 955, 005, 040 and 042 inform my opinion that the Linda Hall Library cataloged the conference proceedings as a book and created the original MARC record, which was later used by the Library of Congress to create their copy cataloging record, and the Library of Congress MARC record was completed no later than January 27, 1999. As discussed above, a

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customary library practice is to make newly cataloged monographs available soon after the cataloging work is completed, usually within a week. Based on my experience with the Library of Congress collections, the processing time at the Library of Congress can take one to three months because of the amount of works they process. It is therefore my opinion that the copy of this conference proceedings containing *Billinghurst* would have become publicly accessible as early as February 1999 and no later than April 1999 at the Library of Congress.

43. Because the Library of Congress MARC record (**Appendix 1010F**) is based on the record created by the Linda Hall Library (**Appendix 1010C**), the two MARC records have the same data in many fields, including Field 010 for the Library of Congress control number, Fields 020 for the 10-digit ISBNs, Field 111 for the conference name as the author, Field 245 for the title, Field 260 for publisher information, Field 300 for physical description, Field 500 for the order number of the IEEE Computer Society, Field 504 for the bibliographical note and index, Fields 710 for the conference sponsors, and Fields 650 for two Library of Congress subject headings. The differences are that the Library of Congress MARC record includes a variant title in Field 246 and a Dewey Decimal Classification number in Field 082, encodes the Library of Congress classification number in Field 050, and does not include the IEEE Order Plan Catalog Number 98EX215.

44. The MARC record (**Appendix 1010F**) shows that the Library of

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Congress cataloged the conference proceedings containing *Billinghurst* as a book, used the MARC record created by the Linda Hall Library as the basis for their copy cataloging record, and completed their record no later than January 27, 1999, making this conference proceedings discoverable in their online catalog from that date on. Interested users would have been able to conduct subject searches to discover this work. They would also have been able to discover it by the conference name, the title of the conference proceedings, variant title, Library of Congress control number, ISBNs, the order number of the IEEE Computer Society, and the two sponsors of the conference. The copy of this conference proceedings (and *Billinghurst* included therein) would have become publicly accessible as early as February 1999 and no later than April 1999 at the Library of Congress.

H. Usage Record

45. Actual usage of a publication is reflected by the papers that make reference to it. The citation history on Google Scholar shows *Billinghurst* has been cited 179 times, and 14 citations appeared in 1998 and 1999. **Appendix 1010G** is a list of six citations published in 1998 and 1999 that I compiled from Google Scholar to demonstrate early usage. In addition, page 2 of **Appendix 1010G** is a screen capture of Google Scholar showing *Billinghurst* has 179 citations and page 3 is a screen capture showing 14 citations that appeared in 1998 and 1999. *Billinghurst* was published in October 1998, and the earliest citation appeared in December 1998.

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Five more citations to *Billinghurst* appeared in 1999.

I. Summary of My Opinion on *Billinghurst*

46. The IEEE copy of *Billinghurst* (**Ex. 1010**) shows this article was published in October 1998, and the IEEE metadata record (**Appendix 1010A**) was added to the IEEE Xplore Digital Library on August 6, 2002. The Linda Hall Library copy of *Billinghurst* (**Appendix 1010B**) and the library's bibliographic and MARC records (**Appendix 1010C**) show the library cataloged the conference proceedings containing *Billinghurst* as a monograph on November 5, 1998, making it discoverable in their online catalog from that date on. The copyright registration record (**Appendix 1010D**) shows the conference proceedings containing *Billinghurst* was published on October 19, 1998. The Library of Congress copy of *Billinghurst* (**Appendix 1010E**) and the library's bibliographic and MARC records (**Appendix 1010F**) show the Library of Congress completed their MARC record in January 1999, making the copy publicly accessible as early as February 1999 and no later than April 1999 at that library. The records and documents that I have reviewed inform my opinion that *Billinghurst* was publicly accessible as early as November 1998 and no later than April 1999. Citation records from Google Scholar show the earliest citation appeared in December 1998, and at least five more citations appeared in 1999.

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III. Authenticity and Public Availability of *Zhou* (Ex. 1018)

A. Authentication

47. **Ex. 1018** is a true and correct copy of "An experimental study on the role of software synthesized 3D sound in augmented reality environments," ("*Zhou*"), by Zhou et al., *Interacting with Computers*, vol. 16, issue 5, pp. 989-1016 that I obtained from the IEEE Xplore Digital Library (IEEE Xplore) of the Institute of Electrical and Electronics Engineers (IEEE). When I began my researching this article I searched Google Scholar for records for *Zhou* and found a record that led me to the metadata record for this article at https://ieeexplore.ieee.org/document/8160489 on IEEE Xplore. I followed the "PDF" link in the metadata record to obtain a copy of *Zhou*. This copy is presented as **Ex. 1018** in this Declaration.

48. Page 1 of **Ex. 1018** shows the title, authors, and abstract of *Zhou*. The top of the page shows this article was published in "Interacting with Computers 16 (2004) 989-1016" and is available online at www.sciencedirect.com, and the journal's website is at www.elsevier.com/locate/intcom. This page also shows the manuscript of *Zhou* was received on "19 January 2004; revised 17 April 2004; accepted 17 June 2004," and the article was "[a]vailable online 5 August 2004." The bottom of page 1 shows the ISSN (International Standard Serial Number) of the

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journal containing *Zhou* is "0953-5438" and the doi (digital object identifier) of *Zhou* is "10.1016/j.intcom.2004.06.014."

49. Page 2 of **Ex. 1018** shows the article has a "2004" copyright date, and was published by Elsevier B.V. This page also shows seven author keywords for *Zhou*, including "3D sound; Augmented reality; Depth perception; Localization of sound; Task performance; Collaboration; User studies." **Ex. 1018** shows *Zhou* has five sections, 13 figures (some color) and 40 references.

50. The IEEE copy of *Zhou* (**Ex. 1018**) is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. Moreover, **Ex. 1018** was found in the custody of a digital library owned and managed by the publisher, a place where, if authentic, it would likely be found. I therefore see no reason to question the authenticity of the IEEE copy of *Zhou* (**Ex. 1018**).

B. IEEE Metadata Record

51. **Appendix 1018A** is a true and correct copy of the IEEE metadata record for *Zhou* that I obtained from IEEE Xplore. I personally located, identified and obtained this metadata record. This is the type of record experts in my field would reasonably rely upon when forming their opinion. I used screenshots of the record to produce **Appendix 1018A**.

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52. Page 1 of **Appendix 1018A** shows the metadata record for *Zhou* is available at https://ieeexplore.ieee.org/document/8160489. The metadata record shows the title, authors, and abstract of this article. Page 2 shows the article DOI (digital object identifier) is "10.1016/j.intcom.2004.06.014" and the article appeared in volume 16, Issue 5 (October 2004), pages 989 to 1016 of *Interacting with Computers* published by OUP. The record also shows the print ISSN of this journal is 0953-5438 and the electronic ISSN is 1873-7951. It also shows seven author keywords for this article. The title, authors, abstract, journal information and author keywords match the information presented in **Ex. 1018**, confirming this record represents *Zhou*.

C. Library of Congress Copy

53. To determine the availability of *Zhou* in libraries, I searched WorldCat by "Interacting with computers" for records, and a WorldCat record at https://worldcat.org/title/20745502 shows the Library of Congress and the University of Michigan Library are two of the holding libraries. I searched the online catalog of the Library of Congress for records for this journal, and the search result confirmed the holdings information. I then obtained a scanned copy of *Zhou* from the Library of Congress through Wisconsin TechSearch, a document delivery service based at the University of Wisconsin-Madison. This scanned copy is presented as **Appendix 1018B** in this Declaration.

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54. **Appendix 1018B** is a true and correct copy of *Zhou* obtained from the Library of Congress. Page 1 shows the covers and spine of a bound volume marked as "Interacting with Computers 16 2004 QA 76.9 .H85 I59 Set 1." Page 2 is the issue cover that shows the journal title and identifies this issue as "Volume 16, Issue 5, October 2004" and the journal's ISSN as "0953-5438." The cover also shows this issue is a special issue on "Physiological Computing" and was published by Elsevier. Page 3 is the issue title page. Page 4 is the copyright page that shows this issue has a "2004" copyright date and Elsevier B.V. holds the copyright. Page 5 is the table of contents of volume 16, Issue 5 (October 2004) of *Interacting with Computers* that carries a date stamp of "Library of Congress DEC 7 2004 Copyright Office" and shows seven articles are included in this issue and *Zhou* begins on page 989. The table of contents also shows that "*Interacting with Computers* is the journal of the British HCI Group, a Specialist Group of the British Computer Society." Pages 6 to 33 (internal pages 989 to 1016) are the full text of *Zhou*. I have closely compared the Library of Congress copy of *Zhou* (**Appendix 1018B**) with the publisher's copy obtained from IEEE (**Ex. 1018**) and found them to be identical. The only difference is that figures in **Appendix 1018B** are black and white, while some figures in **Ex. 1018** are in color.

55. **Appendix 1018B** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text

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on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. Furthermore, this copy of *Zhou* was found in the custody of a national library, a place where, if authentic, it would likely be found. I therefore see no reason to question the authenticity of this copy of *Zhou*.

D. Library of Congress Records

56. **Appendix 1018C** is a true and correct copy of the bibliographic record and MARC record for *Interacting with Computers* whose vol. 16, issue 5 (October 2004) contains *Zhou*. I personally located, identified, and obtained these records from the online catalog of the Library of Congress. They are the type of records experts in my field would reasonably rely upon when forming their opinion.

57. Pages 1 to 3 of **Appendix 1018C** show the bibliographic record and holdings information of *Interacting with Computers* that contains *Zhou*. The record shows the main title of this journal, and Butterworths of Guildford, Surrey as the publisher since 1989. Notes on page 2 show Elsevier has been the publisher since 1999 and the journal is issued by the British Computer Society, Human Computer Interaction Specialist Group. The "Item Availability" area on page 3 shows the journal's call number is "QA76.9.H85 I59" and older issues held by the library include "v.14:issue5-v.29:issue6 (2002:Oct.-2017:Nov.)," meaning vol. 16, issue 5 that contains *Zhou* is held at the Library of Congress.

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58. Pages 4 to 7 of **Appendix 1018C** are the MARC record and holdings information. The first six digits of Field 008 show the MARC record was created on "891207" (*i.e.*, December 7, 1989), and the code of "c19899999" after the record creation date indicates this publication is a continuing resource that began publication in 1989 and has no end date of publication yet. Subfield |a of Field 040 shows the record was originally created by "DLC." According to the *Directory of OCLC Members* (https://www.oclc.org/en/contacts/libraries.html), "DLC" is the OCLC symbol for the Library of Congress. Subfield |a of Field 042 shows that this record is verified and authenticated by "pcc" (Program for Cooperative Cataloging of the Library of Congress) and "nsdp" (National Serials Data Program). Field 022 shows the ISSN of this journal is "0953-5438," which is the same as the ISSN on the issue cover of **Appendix 1018B**. Field 245 shows the journal title, Field 260 shows Butterworths was the publisher from 1989 on, Field 362 shows the journal began publication with vol. 1, no. 1 in April 1989, and Field 310 shows the publication frequency since 1999 has been "[s]ix no. a year." Field 530 shows the journal is also issued as an online journal. Field 710 shows the British Computer Society, Human Computer Interaction Specialist Group is included in the MARC record to help users discover this journal.

59. Subjects of this journal are represented in Field 050 by a Library of Congress Classification (LCC) number of "QA76.9.H85," which represents

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"Human-computer interaction" in computer science, and in Field 082 by a Dewey Decimal Classification (DDC) number of "004.019," which represents "Psychological principles" in computer science. Subject is also represented by a Library of Congress subject heading in Field 650, with "Human-computer interaction" as the main heading, followed by "Periodicals" as a form subdivision encoded in subfield "v" ("|v") to indicate the topic is treated in a journal. These subject representations in the MARC record enable users to conduct subject searches to discover this journal.

60. This MARC record shows that *Interacting with Computers* is a long-running journal, and the MARC record has made the journal discoverable at the online catalog of the Library of Congress since December 1989. Users would have been able to conduct subject searches by the LCC and DDC numbers and by the Library of Congress subject heading to discover this journal. They would also have been able to search for the journal by title, ISSN and the British Computer Society, Human Computer Interaction Specialist Group.

61. The Library of Congress copy of *Zhou* (**Appendix 1018B**) shows a date stamp of "DEC 7 2004," meaning this issue was received by the Library of Congress in December 2004. The date stamp has the appearance and distinctive characteristics of a typical check-in date stamp utilized by the library. As discussed earlier, libraries usually create one record for an entire journal, instead of creating records for

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individual issues of a journal, and they rely on a serial check-in system to monitor the receipt of new issues and update holdings information for users. Because journals publish latest research, the customary practice of libraries is to make a newly received issue available soon after serial check-in, usually within a week. At the Library of Congress, this would mean the newly checked-in issue would be placed in the Newspaper and Current Periodical Reading Room for easy user access soon after the serial check-in process is completed. It is therefore my opinion that the issue containing *Zhou* would have been publicly accessible by December 14, 2004, at the Library of Congress.

E. University of Michigan Library Copy

62. As evidence that *Zhou* was publicly accessible in more than one library, I searched WorldCat by the journal title for records and identified the University of Michigan Library as another holding library. I searched their online catalog for records for the journal, and the search result confirmed the holdings information. I then obtained a copy of *Zhou* from the University of Michigan Library via Wisconsin TechSearch, a document delivery service based at the University of Wisconsin-Madison. This copy is presented as **Appendix 1018D** in this Declaration.

63. **Appendix 1018D** is a true and correct copy of *Zhou*. Page 1 is the cover that shows the issue is volume 16, issue 5 (October 2004) of *Interacting with Computers* published by Elsevier, and the issue carries a date stamp of "University

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of Michigan DEC 02 2004 Michigan AAE Library." Page 2 is the issue title page and it carries the same date stamp. Page 3 is the copyright page, page 4 is the table of contents, and pages 5 to 32 (internal pages [989] to 1016) are the full text of *Zhou*. I have closely compared the University of Michigan Library copy of *Zhou* (**Appendix 1018D**) with the publisher's copy obtained from IEEE (**Ex. 1018**) and the Library of Congress copy (**Appendix 1018B**), and concluded that these three copies have the same full text of *Zhou*, and that the front matter in the University of Michigan Library copy is the same as the front matter in the Library of Congress copy. The only difference is the Library of Congress copy includes the covers of the bound volume, a color cover and a table of contents from the back of the issue.

64. **Appendix 1018D** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. Furthermore, this copy of *Zhou* was found in the custody of an academic library, a place where, if authentic, it would likely be found. I therefore see no reason to question the authenticity of this copy of *Zhou*.

F. University of Michigan Library Records

65. **Appendix 1018E** is a true and correct copy of the bibliographic record and MARC record for *Interacting with Computers* whose vol. 16, issue 5 (October 2004) contains *Zhou*. I personally searched for records for this journal by its ISSN

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and located, identified, and obtained these records from the online catalog of the University of Michigan Library. They are the type of records experts in my field would reasonably rely upon when forming their opinion.

66. Pages 1 to 3 of **Appendix 1018E** are the bibliographic record that shows *Interacting with Computers* is a journal published by Butterworths since 1989, and its ISSN is "0953-5438." The "Available at" area shows this journal is available as an online resource and at the HathiTrust Digital Library. In addition, the University of Michigan Library has 17 items in their "offsite shelving" and page 5 shows "v.16 2004" is "On shelf" and its call number is QA 76.9 .H85 I591.

67. Pages 4 to 7 are the MARC record for this journal. The first six digits of Field 008 of the MARC record (**Appendix 1018E**) show the record was created on "911021" (*i.e.*, October 21, 1991) at the University of Michigan Library, and the "c19899999" code following the record creation date indicates this journal is a continuing resource that began publication in 1989 and has no publication end date yet. Subfield "a" of Field 040 shows "DLC" (*i.e.*, Library of Congress) created the original MARC record. Data from Field 008 and Field 040 inform my opinion that the University of Michigan Library used the MARC record created by the Library of Congress to create their copy cataloging record on October 21, 1991, making this journal discoverable in their online catalog from that date on.

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68. Because the University of Michigan MARC record is based on the Library of Congress record, except for fields with data specific to each library, the two records contain the same data in essential fields, including the Library of Congress control number in Field 010, the ISSN in Field 022, the original MARC record creator in Field 040, the Library of Congress Classification number in Field 050, the abbreviated key title for the journal in Field 210, key title in Field 222, main title in Field 245, publisher information in Field 260, physical description in Field 300, beginning numeric and chronological designations in Field 362, the title source note in Field 500, issuing body note in Field 550, Library of Congress subject heading in Field 650 and issuing body in Field 710.

69. This MARC record shows that *Interacting with Computer* is a long-running journal, and the MARC record has made the journal discoverable at the online catalog of the University of Michigan Library since 1991. Users would have been able to conduct subject searches to discover this journal. They would also have been able to search for the journal by title, ISSN, and the issuing body.

70. The University of Michigan copy of *Zhou* (**Appendix 1018D**) shows a date stamp of "DEC 02 2004." The stamp has the appearance and distinctive characteristics of a typical check-in date stamp utilized by the library. As discussed earlier, libraries usually create one record for an entire journal, instead of creating records for individual issues of a journal, and they rely on a serial check-in system

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to monitor the receipt of new issues and update holdings information for users. Because journals publish latest research, the customary practice of academic libraries is to make a newly received issue available soon after serial check-in, usually within a week. It is therefore my opinion that the University of Michigan Library copy of the journal issue containing *Zhou* would have been publicly accessible by December 9, 2004.

G. Usage Record

71. Actual usage of an article is reflected by other publications that make reference to it. The citation history of Google Scholar shows *Zhou* was cited 26 times. **Appendix 1018F** presents four 2006 citations and two 2010 citations to demonstrate early usage. Page 2 of this appendix is a screenshot of Google Scholar showing the top of the 26 citation list, and pages 3 and 4 are screenshots of the citations from 2006 to 2010. The earliest citation appeared in October 2006.

H. Summary of My Opinion on *Zhou*

72. The publisher's copy of *Zhou* obtained from IEEE (**Ex. 1018**) shows the manuscript was accepted for publication on June 17, 2004, the article became available online on August 5, 2004, and the print copy appeared in vol. 16, issue 5 of *Interacting with Computers* that has "October 2004" as its issue date. The date stamps on the Library of Congress copy of *Zhou* (**Appendix 1018B**) and the University of Michigan copy of *Zhou* (**Appendix 1018D**) show copies of the journal

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issue containing *Zhou* were received by the Library of Congress on December 7, 2004, and by the University of Michigan Library on December 2, 2004. It is therefore my opinion that these two copies would have become publicly accessible by December 14, 2004, at the Library of Congress, and by December 9, 2004, at the University of Michigan Library. MARC records of these two libraries show the journal containing *Zhou* has been discoverable in the library catalogs of these two libraries since 1989 and 1991, respectively. Citation history shows that at least four citations to *Zhou* appeared in 2006 and the earliest citation appeared in October 2006.

IV. Conclusion

73. I hereby declare that all statements made herein on my own knowledge are true and that all statements 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 made under penalty of perjury.

Date: 5-15-2023 Executed: Ingrid Hsieh-Yee

Ingrid Hsieh-Yee, Ph.D.

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Exhibit 1010

A Wearable Spatial Conferencing Space

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Abstract

Wearable computers provide constant access to computing and communications resources. In this paper we describe how the computing power of wearables can be used to provide spatialized 3D graphics and audio cues to aid communication. The result is a wearable augmented reality communication space with audio enabled avatars of the remote collaborators surrounding the user. The user can use natural head motions to attend to the remote collaborators, can communicate freely while being aware of other side conversations and can move through the communication space. In this way the conferencing space can support dozens of simultaneous users. Informal user studies suggest that wearable communication spaces may offer several advantages, both through the increase in the amount of information it is possible to access and the naturalness of the interface.

1: Introduction

One of the broad trends emerging in human-computer interaction is the increasing portability of computing and communication facilities. However it remains an open question as to how computing can best be used to aid mobile communication.

Wearable computers are the most recent generation of portable machines. Worn on the body, they provide constant access to computing and communications resources. In general, a wearable computer may be defined as a computer that is subsumed into the personal space of the user, controlled by the wearer and has both operational and interactional constancy, i.e. is always on and always accessible [1]. Wearables are typically composed of a belt or back pack PC, see-though or see-around head mounted display (HMD), wireless communications hardware and an input device such as touchpad or chording keyboard. This configuration has been demonstrated in a number of real world applications including aircraft maintenance [2], navigational assistance [3] and vehicle mechanics [4]. In such applications wearables have dramatically improved user performance, halving task time in the case of vehicle inspection [4].

Many of the target application areas are those where the user could benefit from expert assistance. Network enabled wearable computers can be used as a communications device to enable remote experts to collaborate with the wearable user. In such situations the presence of remote experts have been found to significantly improve task performance [5], [6]. For example, Kuzuoka finds that a head mounted camera and display increases interaction efficiency in a remote collaborative object manipulation task [7]. However, most current collaborative wearable applications have only involved connections between one local and one remote user. The problem we are interested in is how a wearable computer can be used to support collaboration between multiple remote people. In particular we want to explore the following issues:

- What visual and audio enhancements can be used to aid communication?
- How can a collaborative communications space be created between users?
- How can remote users be represented in a wearable computing environment?

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These issues are becoming increasingly important as telephones incorporate more computing power and portable computers become more like telephones. A key issue is whether we need computer-mediated communication at all when a conference phone call may be just as effective. Prior work in the fields of teleconferencing and computer supported collaborative work addresses this question.

2: Background

Research on the roles of audio and visual cues in teleconferencing has produced mixed results. There have been many experiments conducted comparing face-to-face, audio and video, and audio only communication conditions. Sellen summarizes these by reporting that the main effect on collaborative performance is due to whether the collaboration was technologically mediated or not, not on the type of technology mediation used [8]. While people generally do not prefer the audio only condition, they are often able to perform tasks as effectively as in the audio and video condition, although in both cases they perform worse than face-to-face collaboration. Naturally this varies somewhat according to task. While face-to-face interaction is no better than speech-only for cognitive problem solving tasks [9], visual cues can be important in tasks requiring negotiation [10]. In general, the usefulness of video for transmitting non-verbal cues may be overestimated and video may be better used to show the communication availability of others or views of shared workspaces [11]. Even when users attempt non-verbal communication in a video conferencing environment their gestures must be exaggerated to be recognized as the equivalent face-to-face gestures [12].

Based on these results, and the fact that speech is the critical medium in teleconferencing experiments [13], it may be thought that audio alone should be suitable for a creating a shared communication space. An example of this, Thunderwire [14], was a purely audio system which allowed high quality audio conferencing between multiple participants at the flip of a switch. In a 3 month trial Hindus et. al. found that audio can be sufficient for a usable communication space. However several major problems were observed:

- Users were not able to easily tell who else was within the space.
- Users were not able to use visual cues to determine other's willingness to interact.

With more users it becomes increasingly difficult to discriminate between speakers and there is a higher incidence of speaker overlap and interruptions. These problems are typical of audio only spaces and suggest that while audio may be useful for small group interactions, it becomes less usable the more people present.

These shortcomings can be overcome through the use of visual and spatial cues. In face-to-face conversation, speech, gesture, body language and other non-verbal cues combine to show attention and interest. Simple versions of these cues can be replicated in desktop video conferencing. For example, the Passepartout [15] enhanced desktop conferencing tool includes visual representation of a conference table alongside shared documents and a text chat facility. The conference table includes icons of those people within the conference and simple cues, such as microphone on/off, which allow a participant's activity or interest to be inferred. However the absence of spatial cues in most video conferencing systems means that users often find it difficult to know when people are paying attention to them, to hold side conversations, and to establish eye contact [16].

Several video conferencing systems have attempted to provide spatial cues. The Hydra system uses multiple small monitors, one for each participant, positioned about the local user [17]. The user can easily attend to individual participants by turning to face the appropriate monitor and side conversations can be supported. The MAJIC system uses several wall projectors and a one way transmissive screen to create the illusion of several remote life-sized participants seated around the same real table [18]. Users can make eye contact and conduct parallel conversations. The MPEC prototype also supports spatial video conferencing and multi-party eye contact [19]. However a common disadvantage of these systems is that the users cannot control remote camera position and so their viewpoint and spatial relationships to the other participants is fixed, unlike in face-to-face collaboration. There are also many technical problems to be overcome before such systems scale to support large groups of participants.

Virtual reality can provide an alternative medium that allows groups of people to share the same communications space. British Telecom has demonstrated virtual conferencing in which many users can be represented as life like virtual avatars of themselves within virtual rooms [20]. Users can freely move through the space setting their own viewpoints and spatial relationships. In collaborative virtual environments (CVEs) spatial visual and audio cues can combine in natural ways to aid communication [21]. The well known "cocktail-party" effect shows that people can easily

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monitor several spatialized audio streams at once, selectively focusing on those of interest [22], [23]. Even a simple virtual avatar representation and spatial audio model enables users to discriminate between multiple speakers [24]. Spatialized interactions are particularly valuable for governing interactions between large groups of people; enabling crowds of people to inhabit the same virtual environment and interact in a way impossible in traditional video or audio conferencing [25].

3: A Wearable Communication Space

The results in the previous section suggest that an ideal wearable communications space should have three elements:

- High quality audio communication
- Visual representations of the collaborators
- An underlying spatial metaphor

One of the most important aspects of creating a collaborative communication interface is the visual and audio presentation of information. Most current wearable computers use see-through or see-around monoscopic head mounted displays with stereo headphones. With these displays information can be presented in a combination of three ways:

Head-stabilized - information is fixed to the users viewpoint and doesn't change as the user changes viewpoint orientation or position.

Body-stabilized - information is fixed relative to the users body position and varies as the user changes viewpoint orientation, but not as they change position. This requires the users viewpoint orientation to be tracked.

World-stabilized - information is fixed to real world locations and varies as the user changes viewpoint orientation and position. This requires the users viewpoint position and orientation to be tracked.

Body and World stabilized information display is attractive for a number of reasons. As Reichlen [26] demonstrates, a body-stabilized information space can overcome the resolution limitations of head mounted displays. In his work a user wears a head mounted display while seated on a rotating chair. By tracking head orientation the user experiences a hemispherical information surround - in effect a "hundred million pixel display". World-stabilized information presentation enables annotation of the real world with context dependent visual and audio data, creating information enriched environments [27]. This increases the intuitiveness of real world tasks. Despite these advantages, most current wearables only use head-stabilized information display.

In our work we have chosen to begin with the simplest form of body-stabilized display; one which uses one degree of orientation to give the user the impression they are surrounded by a virtual cylinder of visual and auditory information. Figures 1.0a and 1.0b contrast this with the traditional head stabilized wearable interface.

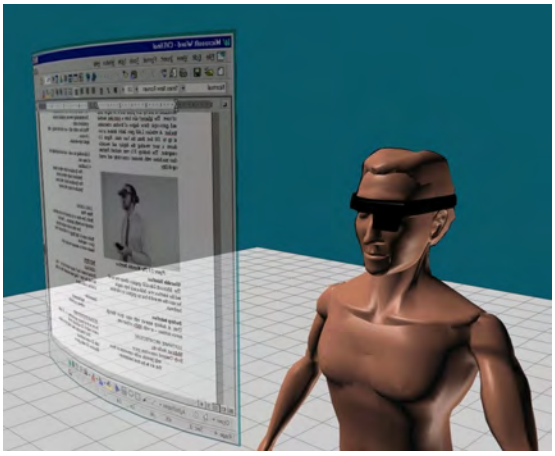


Figure 1.0a Head Stabilized Information Display



Figure 1.0b One Degree of Freedom Body-Stabilized Display

When using a head mounted display to navigate a cylindrical body-stabilized space, only the portion of the information space in its field of view can be seen. There are two ways the rest of the space can be viewed; by rotating the information space about the user's head, or tracking the user's head orientation as they look around the space. The first requires no additional hardware and

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can be done by mapping mouse, switch or voice input to direction and angle of rotation, while the second requires only a simple one degree of freedom tracker. The minimal hardware requirements make cylindrical spatial information displays particularly attractive. The cylindrical display is also very natural to use since most head and body motion is about the vertical axis, making it very difficult for the user to become disoriented.

In a previous paper we have found that users can locate information more rapidly with this type of information display than the more traditional head-stabilized wearable information space [28]. Sawhney and Schmandt also demonstrate how body-stabilized spatial audio can improve access to audio information on a wearable platform, allowing a user to browse up to three simultaneous audio streams [29].

With this display configuration a wearable conferencing space could be created that allows remote collaborators appear as virtual avatars distributed about the user (figure 2.0). The avatars could be live video streams and as they speak their audio streams spatialized in real time so that they appear to emit from the corresponding avatar.

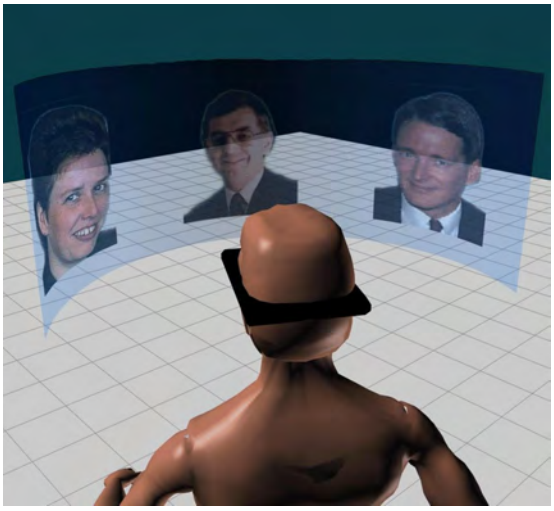


Figure 2.0 A Spatial Conferencing Space.

Just as in face-to-face collaboration, users could turn to face the collaborators they wanted to talk to while still being aware of the other conversations taking place. The user could also move about the space enabling them to choose their own viewpoint and the spatial relationships between the collaborators. In this way the space could support dozens of simultaneous users, similar to current collaborative virtual environments. Since the displays are see-through or see-around the user could also see the real world at the same time, enabling the remote collaborators to help them with real world tasks. These remote users may also be using wearable computers and head mounted displays or could be interacting through a desktop workstation. The wearable conferencing space would also allow the faces of remote users to appear life-size, a crucial factor for establishing equal relationships in remote collaboration [30].

The technical requirements for such a conferencing space place it several years in the future, however in the remainder of this paper we describe a prototype we have developed which has many of the same features.

4: Implementation

Our research is initially focused on collaboration between a single wearable computer user and several desktop PC users. This situation might be encountered when a wearable user in the field is requesting help from remote deskbound experts. The aim is to develop a wearable interface to support medium sized meetings (5-6 people) in a manner that is natural and intuitive to use.

4.1: Hardware

The wearable computer we use is a custom built 586 PC 104 based computer with 20mb of RAM running Windows 95. Figure 3.0 shows a user wearing the display and computer.



Figure 3.0 The Wearable Hardware.

A hand held Logitech wireless radio trackball with three buttons is used as the primary input device. The display is a pair of Virtual i-O iglasses! converted into a monoscopic display by the removal of the left eyepiece.

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The Virtual i-O head mounted display can either be used in see-through or occluded mode, has a resolution of 262 by 230 pixels and a 26-degree field of view. The iglasses! also have a sourceless two-axis inclinometer and a magnetometer used as a three degree of freedom orientation tracker. A BreezeCom wireless LAN is used to give 2mb/s Internet access up to 500 feet from a base station. The wearable also has a soundBlaster compatible sound board with headmounted microphone. The desktop PCs are standard Pentium class machines with Internet connectivity and sound capability.

4.2: The Wearable Interface

Our wearable computer has no graphics acceleration hardware and limited wireless bandwidth so the interface is deliberately kept simple. The conferencing space runs as a full screen application that is initially blank until remote users connect. When users join the conferencing space they are represented by blocks with 128x128 pixel texture mapped static pictures of themselves on them. Each user determines the position and orientation of their own avatar in space, which changes as they move or look about environment. Although the resolution of the images is crude it is sufficient to identify who the speakers are and more importantly their spatial relationship to the wearable user. It is hoped that in the near future wearable computer CPU power and wireless bandwidth will be sufficient to support real time video texture mapping.

The wearable user has their head tracked so they can simply turn to face the speakers they are interested in. Users can also navigate through the space; by rolling the trackball forwards or backwards their viewpoint is moved forwards or backwards along the direction they are looking. Since the virtual images are superimposed on the real world, when the user rolls the trackball it appears to them as though they are moving the virtual space around them, rather than navigating through the space. Users are constrained to change viewpoint on the horizontal plane, just as in face-to-face conversations. The two different navigation methods (trackball motion, head tracking), match the different types of motion used in face to face communication; walking to join a join a group for conversation, and body orientation changes within a conversational group.

A radar display shows the location of the other users in the conferencing space, enabling users to find each other easily. Figure 4.0 shows the wearable interface from the wearable user's perspective. The interface was developed using Microsoft's Direct3D, DirectDraw and DirectInput libraries from the DirectX suite.

The wearable interface also supports 3D spatialized Internet telephony. When users connect to the conferencing space their audio is broadcast to all the other users in the space. This is spatialized according to the distance and direction between speaker and listener. As users face or move closer to different speakers the speaker volume changes due to the sound spatialisation. Since the speakers are constrained to remain in the same plane as the listener the audio spatialisation is considerably simplified. Audio culling is also used so that only the audio streams from the speakers closest to the listener are broadcast and spatialized. This significantly reduces the CPU load. The conferencing space uses custom developed telephony libraries that incorporate the Microsoft Direct Sound libraries.

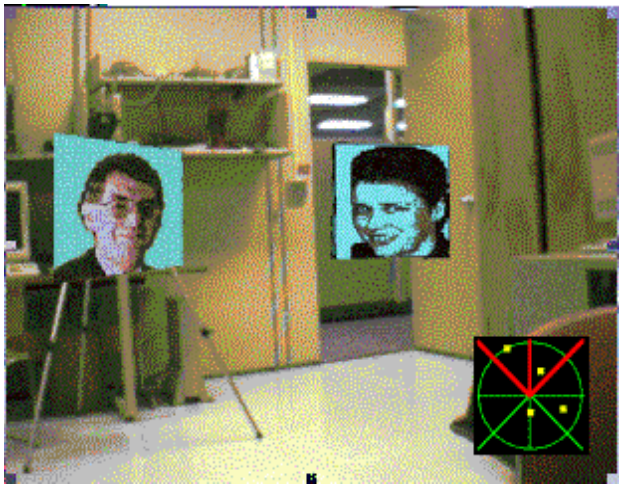


Figure 4.0 The User's View of the Wearable Conferencing Space

4.3: The Desktop interface

Users at a desktop workstation interact with the conferencing space through a similar interface as the wearable user, although in this case the application runs as a Windows application on the desktop. Users navigate through the space using the mouse. Mouse movements rotate head position when the left mouse button is held down, otherwise they translate the user backwards and forwards in space. Mapping avatar orientation to mouse movement means that the desktop interface is not quite as intuitive as the wearable interface. Users at the desktop machine wear headmounted microphones to talk into the conferencing space and listen through stereo headphones. Just as with the wearable interface, desktop users are aware of the spatial relationships between participants. When a participant turns and talks to someone else, the desktop user sees their avatar turn and face the person they're talking to.

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5: Distributed Software Architecture

The wearable and desktop interfaces are based around custom libraries for collaborative virtual environments being developed at British Telecom. When the wearable and desktop client applications are run TCP/IP multicast groups are created that enable the clients to communicate with each other through multicast sockets. The multicast protocol is an efficient mechanism for broadcasting data to multiple network nodes [31] and has been shown to scale well in large CVEs [32].

Communications within the conferencing space are routed through one of two multicast groups, as shown in figure 5.0. One is for transformational data representing an avatar's position and orientation plus any messaging data and the second for audio data. When users connect to the communication space they are assigned a unique identification tag, (ID). As a user moves through the space, their avatar's ID tag, positional and orientation information is broadcast onto the transformation multicast group. This transformational data flows at a rate of 10.0Kb/s per user. When received by each client in the group it is used to update the relevant avatar's position and orientation. The transformational information is also used in spatialising the user's audio stream relevant to the receiving user's position.

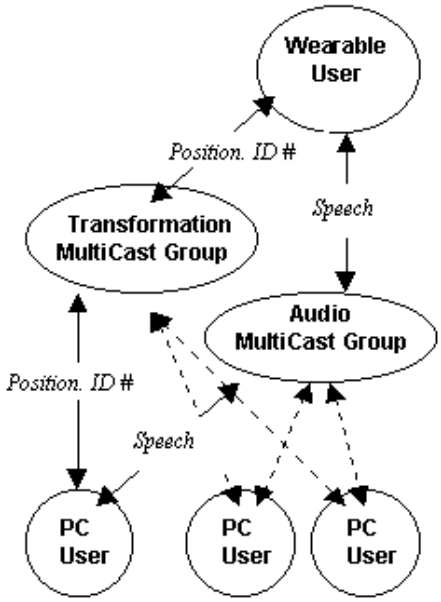


Figure 5.0 Distributed Software Architecture

Similarly when a user speaks, their speech is digitized and broadcast to the audio multicast group. When received by the other clients the senders IP address identifies the avatar that the audio belongs to and its position and orientation. The audio is then spatialized in real time. The audio is implemented utilizing Microsoft's Direct Sound technology. This allows for the capture of audio to a buffer, which can then be broadcast over the audio multicast group. Once received at a client computer the buffer can be played back through Direct Sound. In order for the audio to operate in full duplex mode it has to be captured at a rate of 8 bit 22KHz, resulting in a data rate 172Kb/s. All connections to the multicast groups are bi-directional and users can connect and disconnect at will without affecting other users in the conferencing space.

6: Initial User Experiences

In developing a wearable conferencing space we set out to explore the usefulness of spatial visual and audio cues compared to traditional portable communications devices, namely audio only collaboration with a mobile phone. We are in the process of conducting user trials to evaluate how the use of spatialized audio and visual representations affects communication between collaborators. Preliminary informal trials have found the following results:

Users are able to easily discriminate between three simultaneous speakers when their audio streams are spatialized, but not when non-spatialized audio is used. It is expected that this effect will become even more noticeable as the number of simultaneous participants is increased.

Participants preferred seeing a visual representation of their collaborators as opposed to just hearing their speech. Even though it was relatively poor quality the visual representation enabled them to see who is connected and the spatial relationship of the speakers. This allowed them to use some of the non-verbal cues commonly used in face-to-face communication such as gaze modulation and body motion. The radar display was useful for finding collaborators that were far away and barely visible.

Users found that they could continue doing real world tasks while talking to collaborators in the conferencing space and it was possible to move the conferencing space with the trackball so that collaborators weren't blocking critical portions of the users field of view.

The interface is easy and intuitive to use, although using the head tracking on the wearable was easier than the mouse only desktop interface.

However, as more users connect to the conferencing space the need to spatialize multiple audio streams puts a

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severe load on the CPU, slowing down the graphics and head tracking. This makes it difficult for the wearable user to conference with more than two or three people simultaneously. This problem will be reduced as faster CPUs and hardware support for 3D graphics become available for wearable computers. More severe spatial culling of the audio streams could also be used to overcome this limitation, through the coagulation of selected streams into a single spatial location, or removing the audio altogether.

7: Conclusions

We have presented a prototype wearable communication space that uses spatial visual and audio cues to enhance communication between remote groups of people. Our interface shows what is possible when computing and communications facilities are coupled together on a wearable platform. Preliminary results have found that users prefer using both the audio and visual cues together and that spatialized audio makes it easy for users to discriminate between speakers. This suggests that for some applications wearable computers may provide a useful alternative to traditional audio-only communication devices. We are currently conducting formal user studies to confirm these results and evaluate the effect of spatial cues on communication patterns. In the future we plan to investigate how the presence of spatialized video can further enhance communication. We will incorporate live video texture mapping into our interface, enabling users to see their remote collaborators as they speak. This will also allow users to send views of their workspace, improving collaboration on real-world tasks.

We believe that a wearable communications space can be used to support numerous collaborative applications in which some participants are either not sitting at desks or need mobility. A shared virtual environment facilitates audiovisual communications for groups of people with the added potential for embedded graphical, textual or audio information. A specific trait that we believe to be particularly important is that in an augmented communications space it is possible for the user to form effective cognitive maps by associating the annotated information with physical objects within their surroundings. We have demonstrated a body-stabilized system in which the communications space is located relative to the user themselves. With the ability to explicitly position object in the communications space relative to the user's real world location an exciting range of applications become possible. A user could, for example, choose to view avatars of conference participants overlaid and attached to a physical notice board. This represents a powerful vision of conferencing for all platforms; with remote video conferencing participants not in separate windows on a screen but spread around the user's environment, positioned in space where the user prefers.

8: Acknowledgements

We would like to thank our colleagues at British Telecom and the HIT Lab for many insightful and productive conversations, Nick Dyer for producing the renderings used in some of the figures and the anonymous reviewers for their useful comments.

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An experimental study on the role of software synthesized 3D sound in augmented reality environments

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Abstract

Investigation of augmented reality (AR) environments has become a popular research topic for engineers, computer and cognitive scientists. Although application oriented studies focused on audio AR environments have been published, little work has been done to vigorously study and evaluate the important research questions of the effectiveness of 3D sound in the AR context, and to what extent the addition of 3D sound would contribute to the AR experience.

Thus, we have developed two AR environments and performed vigorous experiments with human subjects to study the effects of 3D sound in the AR context. The study concerns two scenarios. In the first scenario, one participant must use vision only and vision with 3D sound to judge the relative depth of augmented virtual objects. In the second scenario, two participants must co-operate to perform a joint task in a game-based AR environment.

Hence, the goals of this study are (1) to access the impact of 3D sound on depth perception in a single-camera AR environment, (2) to study the impact of 3D sound on task performance and the feeling of 'human presence and collaboration', (3) to better understand the role of 3D sound in human-computer and human–human interactions, (4) to investigate if gender can affect the impact of 3D sound in AR environments. The outcomes of this research can have a useful impact on the development of audio AR systems which provide more immersive, realistic and entertaining experiences by introducing 3D sound. Our results suggest that 3D sound in AR environment significantly improves the accuracy of depth judgment and improves task performance. Our results

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also suggest that 3D sound contributes significantly to the feeling of 'human presence and collaboration' and helps the subjects to 'identify spatial objects'.
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Keywords: 3D sound; Augmented reality; Depth perception; Localization of sound; Task performance; Collaboration; User studies

1. Introduction

Audio feedback, especially 3D sound, has proven itself to be an effective addition to human–computer interfaces in many studies. Sounds can be used to present information that would otherwise be difficult to convey through other means (Gaver et al. 1991). Moreover, 3D sound can convey location information for specific alerts or warnings. Also, 3D sound was reported to increase the immersive experience in virtual reality (VR) environments and hence provide a more realistic virtual environment (Begault 1994). Furthermore, the addition of 3D sound has been shown to increase the performance in active tasks (Wenzel, 1996; Avionique). In previous works, Mereu (1995) suggested that sound could improve depth perception in 3D interfaces. Makino et al. (1996) also indicated that spatialized sound from virtual acoustic display helps fast and accurate navigation. Additionally, simulations by Gaver et al. (1991) suggested that auditory icons can play a significant role in multiprocessing and collaborative system. Unlike VR in which extensive research has been carried on 3D sound, augmented reality (AR) aided by 3D sound is still a relative new research area.

AR, as placed on the reality–virtuality continuum (Milgram et al., 1994), refers to the incorporation of virtual computer graphics objects into a real world scene, or alternatively the inclusion of real world elements into a virtual environment. The former case is generally referred to as AR, and the latter as augmented virtuality. Azuma (1997) has defined three characteristics that are integral to an AR interface. First, it combines the real and the virtual. Second, it is interactive in real time. Third, it is registered in three dimensions. Although AR is often associated with visualization (starting with the first head-mounted display by Sutherland (1968)), augmentation is also possible in the aural domain (Cohen et al., 1993; Mynatt et al., 1997). If we extend this notion to include sonic effects, a real-time registered three dimensional (3D) sound could also be a paradigm of AR applications, and is termed augmented audio reality (AAR) (Cohen et al., 1993).

A few applications have applied 3D sounds in AR to enhance user experiences. Billinghurst et al. (1998) presented a prototype wearable communication space that uses spatial visual and audio cues to enhance communication between remote groups of people. The 'Listen Project' (Eckel et al., 2001) provides users with intuitive access to personalize and situated audio information spaces while they naturally explore everyday environments. It augments the physical environment through a dynamic sound-scape, which users experience over motion-tracked wireless headphones. The 'Magic Music Desk' (Zhou et al., 2002) registered virtual sound sources on fiducial markers from which 3D position information was retrieved by vision-based tracking method (Kato and Billinghurst, 1999). 'Touch space' (Cheok et al., 2004) applied different 3D sounds to represent different

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moving avatars in AR environment. Although there are quite a few AAR applications, the effectiveness of 3D sound in AAR has been rarely investigated. The particular research problems and questions that arise are:

1. Exact spatial 3D sound in virtual and augmented environments requires perceptual externalization of the sound source, which can only be brought about by using head related transfer functions (HRTFs) (Bill G, 1994) (these are tuned to each individual), reflections, reverberation, etc. (Wenzel, 1994) which might be too complex to be included in normal real time AR applications (which need to be a real time interactive system for any user without individual training). An alternative way to generate 3D sound is to use open source software development kits (SDKs) which have already incorporated the general HRTFs database and simple model of environment to generate 3D sound. The minimum requirement of these SDKs to generate 3D sound is to update the relative position of the virtual sound source to the head co-ordinate system. Thus, with such sound sources, a problem turns to be how can we track the sound source relative to user's head co-ordinate system.
2. How can we precisely register virtual sound sources in the physical world? More specifically, what kind of tracking method is suitable for obtaining precise position and orientation of the sound source in AR environments?
3. As 3D sound has been reported to improve depth perception (Mereu S, 1995) in 3D interfaces, will this argument stand in AR environment? If so, how can we investigate the effect of 3D sound? For example, what measures can be defined to quantify the performance of depth judgments?
4. Normally the space of AR environments is relatively small, and the attenuation of sound with distance in this small area can be too vague to be perceived. This is because in most 3D sound systems, the intensity of sound (a very strong distance cue) would follow incremental reductions of 6 DB for each successive position of doubled distance (Begault, 1994). This means that for small areas, the 3D sound hardly plays a role to provide a cue to the depth (or the distance of the frontal sound sources). In order to make 3D sound give a cue to depth in a small space, we need to exaggerate the intensity difference of 3D sound according to distance (depth) changes of the virtual sound sources. However, this leads to a new issue, which is to research if this exaggeration will ruin the realistic and immersive feeling which we have been focused on. It needs to be investigated what are the subjective feelings on this exaggeration to the human.
5. Does 3D sound still improve the task performances in AR environment? If so, what kind of tasks can be used to evaluate a user's performance and what measures can be applied to investigate the 3D sound's effect on improving task performance?
6. Does 3D sound play a significant role in collaborative AR environment? If so, how can we apply 3D sound and evaluate its role? In what ways will the subjective experience 'human presence and collaboration' in AR environments? Especially what will be the subjective experiences from the addition of 3D sound?

Recent software and hardware advances in AR and auditory interfaces enable us to integrate 3D sound into AR environments and study these interesting questions. Although the quality of 3D sound generated by software synthesizers (Loki Entertainment Software)

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is still to be examined by rigorous tests (Langendijk and Bronkhorst, 2000), the pre-tests taken by the developer and the user feedback from commercial applications have to some extend proved its fidelity. Our goal of this research is to do both quantitative and qualitative studies on the effectiveness of such software synthesized 3D sound in an AR environment. The outcomes of this research can have a useful impact on the development of AAR interfaces and the enhancement of AR environments for performing collaborative tasks such as co-operative teaching, training and gaming systems. Our contributions to the research topic are as follows:

1. *Depth perception in AR*: We investigated the impact of 3D sound on improving depth perception in AR systems with single-camera settings. We designed an experiment to measure the accuracy of depth judgment in the cases with and without 3D sound.
2. *Perceptual feeling of sound depth exaggeration*: In order to make full use of 3D sound's dimensional information in a relative small AR environment we exaggerated the intensity difference of virtual sound sources in different depths by multiplying an additional scalar factor. We investigated the subject's perceptual feeling to this exaggeration.
3. *Task analysis with AR sound*: We designed a searching task in another AR environment which requests the user to find a virtual character in the augmented scene; we investigated the impact of 3D sound on the task completion time.
4. *Collaboration and location with AR sound*: We applied a constant 3D sound on subject and task target to investigate the impact of 3D sound on the subject's feeling of 'human presence and collaboration' and the impact on 'locating correct augmented information'.

In Section 2, we discuss the general issues of developing AAR with 3D sound, and two different tracking methods for registering virtual 3D sound sources. The experimental goals and subjects are introduced in Section 3. The results of the experiments are then given and discussed in Section 4. The conclusions of the study are summarized in Section 5.

2. Development of AR environments with 3D sound for experimental analysis

2.1. General issues

Generating real 3D sound requires requires perceptual externalization of the sound source, which can only be brought about by using HRTFs (Bill G, 1994), reflections, reverberation, etc. (Wenzel, 1994) These HRTFs can be used to produce 3D sound effects from a linear convolution between sound signals and its corresponding spatial related impulse response (Wenzel et al., 1988) while the reflections and reverberations involve sophisticated modelling of environment. The individually derived HRTFs are better for individual users to provide more realistic sound experience. However, individual HRTFs are difficult for AR implementation due to the fact that AR systems are designed to be real time interactive systems that do not need individual user configuration. Thus our experiments were taken for randomized selected students. For easy implementation of 3D sound generation, several open source software development kits (SDKs), have been

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developed such as OpenAL (Loki Entertainment Software) and FMOD (L. Firelight Technologies). These use the general HRTFs database and modeling environment in a relative simple manner. However, as mentioned in Section 1, for AR systems 3D sound does not play a significant role to tell the depth (or the distance of the frontal sound sources) because most of actual AR spaces are relatively of small size (for example small office, tabletops, books, etc.).

Sound intensity has been shown to be a key cue in distance perception in humans. However, in the small physical spaces used in AR systems the human is only effectively provided with binaural cues from the synthesizer. Thus we try to also add the effect of intensity for the depth cue. Our approach is to exaggerate the intensity difference of sound sources in different depths by applying an additional scaling factor to the intensity of 3D sound generated by synthesizer. The intensity of the ith 3D sound V_i' is given by Eq. (1):

$$V_i' = (D_{\max} - D_i)V_i/D_{\max} \tag{1}$$

where D_i is the depth of the ith 3D sound source; V_i is the intensity of the ith 3D sound generated by synthesizer given the position of the ith sound source. $D_{\max}$ is the possible maximum distance of the sound sources which is subject to the space of different AR environments. We measured the space in our first and second experiments and the maximum distance was 1.5 and 5.5 m, respectively.

Apart from intensity, it is known that for distance perception the ratio of the energies of direct and reflected sound is of importance (Middlebrooks and Green, 1991; Bronkhorst and Houtgast, 1999). For objects farther away from the listener, coupling the decrease in virtual sound intensity with an increase in the 'reverberation' will lead to a more realistic perceptions. In order to focus on the main points with regards to AR sound we did not add the factor of reverberation, and left this issue for our future research.

In our first experiment the sound sources are always placed around 1.5 m away in the front of the listener. However, in a more general and complex AR environment like the second experimental environment, the listener can walk freely in a physical space where virtual sound sources can be very close to the left and the right side of the head. In this case, the head starts functioning as a sound barrier for high frequencies. Consequently, the (high-frequency) sound intensity will of course increase as the source approaches the head in the ear at the same side of the head but, due to the increasing barrier function, decrease in the ear at the other side of the head. It is reported that binaural cues play an important role in auditory distance perception for nearby sources (Brungart and Rabinowitz, 1999; Brungart, 1999). This fact plus our exaggeration process mentioned above causes a design problem of AAR when the listener is very close to or even overlaid on the virtual sound source. In this case the user can have very strange auditory experience and even get confused. This was confirmed in our experimental results which are shown below (Question 3 of Experiment 2 below).

2.2. Development of AR environments with 3D sound for experimental analysis

In the most common AR paradigm, the user wears a head mounted display (HMD) through which the user views the real world, either directly, or via a video camera attached

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to the front of the display Virtual objects are then superimposed on the real world. Early studies such as (Feiner et al., 1993) of this type simply overlaid two-dimensional text information on objects in the scene, but it has now become common to superimpose objects in three dimensions. The minimal requirements for this are that the position of the camera must be determined relative to the whole scene (or an object therein). The transformation matrix (TCM) between the scene and camera co-ordinates can then be used to generate the correct and seamless view of the virtual object. Given this TCM we can get the exact 3D position of the virtual object (virtual sound source) in the user's head co-ordinate system, which is the basic requirement of 3D sound synthesizer.

In our experiments, we applied the OpenAL (Loki Entertainment Software) to generate the 3D sound. Essential parameters needed are the virtual sound source's 3D position and its speed relative to the user's ear. More generally, the 3D position and speed of the virtual sound source and the position and orientation of user's head are needed. In the following parts we will introduce two tracking methods to solve this problem. However, since in our experiments the relative speed of head to virtual sound source is only as slow as 2 m s^{-1}, we ignored the Doppler Effect caused by their relative movement and thus we were only interested in their positions and orientations.

In our experiments, the final augmented virtual image was viewed through a Daeyang Cy-Visor DH-4400VP HMD, which presented the same 640×480 pixel image to both eyes. A PremaCam SCM series color security camera was attached to the front of this HMD. Our visual augmentation produced 25 images of 320×480 pixel resolution per second. To synchronize with the update of the visual scene, we updated the position of the virtual sound sources 25 times per second. The headphone on the HMD plays back the 3D sound generated by the computer. In this way, we provide an AR environment which is both visually and audibly augmented.

2.3. AR experimental environment implemented by vision-based tracking method

There have been many vision tracking methods for AR reported in recent years. In our first experiment, we used a precise vision-based toolkit for AR tracking (Kato and Billinghurst, 1999) reported by Kato and Billinghurst. It used image-processing technology to retrieve 3D position information from a fiducial marker. The 'ARGroove' (Poupyrev et al., 2000) applied this tracking method to get different position and orientation descriptions of the marker movements for which they defined different music. Our first AR experiment system used this tracking method to track the position of virtual sound source which is attached on fiducial marker.

The 3D position of the marker relative to camera can be obtained by computing the TCM from the camera co-ordinates to the 7 marker co-ordinates (Kato and Billinghurst, 1999). However, the 3D position of the marker we obtain is based on the camera co-ordinates. Thus, in order to obtain the 3D position of the marker in user's head co-ordinates (3D sound synthesizer's co-ordinates), simple translations from the camera to the center of user's inter-aural axis should be considered. As shown in Fig. 1, in order to attach the virtual sound source on the marker, the TCM from the 3D sound co-ordinates to marker co-ordinates could be calculated by simply applying translations to TCM obtained before. The 3D position of the marker in the 3D sound co-ordinates are then fed

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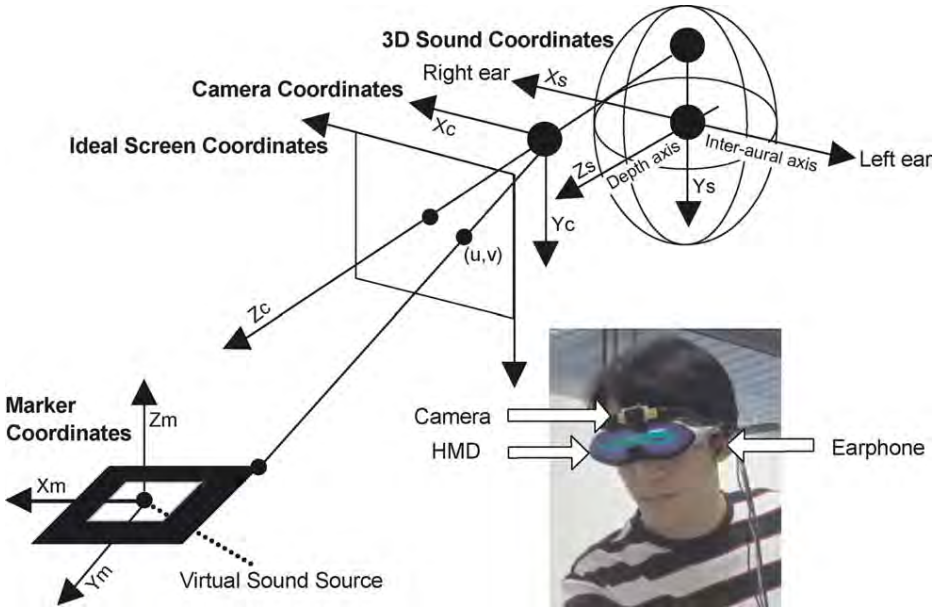


Fig. 1. In order to place a virtual object in the image of the three dimensional scene, the Euclidean transformation between the camera co-ordinates (X_c, Y_c, Z_c) and the marker co-ordinates (X_m, Y_m, Z_m) is estimated. This calculation is based on the imaged position of the corners of the square marker. The imaged position of one of these corners is depicted with pixel co-ordinates (u,v). To obtain the transformation matrix from the 3D sound co-ordinates to marker co-ordinates, translations should be taken from the camera co-ordinates to the 3D sound co-ordinates (X_s,Y_s,Z_s). The picture at the right bottom shows the physical setting of our single camera system where camera is mounted to the front of HMD and 3D sound plays back into the earphones.

into OpenAL (Loki Entertainment Software) for synthesis. Therefore, the 3D sound appears to emanate from the marker.

2.3.1. Depth confusion problem in single camera AR environment

In the most common AR paradigm, a single camera is used to capture the physical scenes (Billinghurst et al., 1998; Zhou et al., 2002; Kato and Billinghurst, 1999) This is not only because this setup is cheap but also because that it requires little computation cost and can be easily implemented. However, although this kind of AR environment setup enables the first-personal viewpoint, it cannot provide stereo video images for each eye, and this can lead to the difficulty of depth perception. Solving occlusion problems (Wloka and Anderson, 1995) or using stereo cameras can improve the depth perception problem. However, it requires more sophisticated settings (Stockburger, 1998) and more computational cost (Kanbara et al., 2000; Takagi et al., 2000). Thus, the low-cost single camera mono system is still widely used for AR applications.

Our objective is to find out whether 3D sounds could be helpful to improve depth perception in this commonly used lower-cost mono AR environment. Fig. 2 shows the depth confusion problem related to this kind of AR environment setup. We know that

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Fig. 2. The depth confusion problem in a single-camera AR setting. The left column shows the image sequences of a scene captured by a moving camera while the right column shows the augmented view seen by the user. (1) In the top left frame, two markers of different size are located in different depth which is hard to tell because of lacking cues. In the following frames, we know that the left marker is nearer to the camera with the cues obtained from the motion, background and lighting environment. (2) Right column shows that the augmented objects occlude everything behind them hence weaken the effect of motion cue. Without background information (in this special case, the objects are located on the same board), relative depth is hard to tell.

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human depth perception is based on both monocular cues and binocular cues. Binocular cues include parallax and ocular convergence, while monocular cues include interposition, relative (or familiar) size, linear perspective, texture gradient, light and shadows. The users' responses in our user study suggest that the depth of augmented object is hard to decide in this kind of mono AR environment setup.

This is because that the binocular cues do not work well due to the single-camera setting. Furthermore, because the augmented objects were rendered over the captured images, they appear to occlude everything behind them. To render the virtual objects to be faithful to the actual lighting conditions of the physical world is still a challenging problem. The correct display of shadow and texture gradient of the augmented objects needs the precise estimation of light sources (Kanbara and Yokoya, 2002). The occlusion problem of the augmented objects relative to the real object is also a difficult problem (Fuhrmann et al., 1999). Due to these difficulties, it is still not possible in real-time AR systems to have realistic virtual objects with respect to lighting, shadowing, and occlusion. Thus, our goal is to find out whether 3D sound can help in the judgment of depth, and if so, to what extend can it be helpful for AR.

We thus designed an experimental task which requires the subject to tell which of the augmented objects is closer (less deep) to her and we calculated the accuracy of the judgments. The subjects were required to give their judgment under the conditions of vision plus 3D sound and vision only. As will be seen in the sections below, the judgment accuracy was found to be significantly higher when 3D sound was applied.

2.4. AR experimental environment implemented by acoustic-inertial tracking method

The vision-based maker tracking method can register the virtual objects and virtual sound sources into the real scene precisely. However it has several short-comings as well. For example, the marker tracking algorithm is sensitive to the lighting environment. Also the requirement of keeping a marker in the scene all the time limits the user's movement as well as viewpoint and thus restricts the user to a relatively small space and a narrow angle of view. This drawback could be improved to some extent by using multi-marker tracking or natural feature tracking methods (Neumann and You, 1999). However, they still do not allow fully free head and body movements.

Some previous work used other methods for registering a virtual sound source in a larger space which allowed user's free movement. Makino et al. (1996) used the Global Positioning System (GPS) to locate the traveler within the environment. With differential correction by way of audio link from a GPS reference receiver in the local vicinity, localization is accurate to around 1 m under good conditions of reception. The listen project (Eckel et al., 2001) used motion-tracked wireless headphones to retrieve the position of the user in the environment. A similar method was applied by Schmandt (1998) where the head position is gained from a Polhemus sensor mounted on the headphones.

In our research system (Cheok et al., 2004; Wang et al., 2002), we use the InterSense IS-900 system (InterSense) for precise motion tracking. The IS-900 system is a hybrid acoustic-inertial six degree of freedom (6 DOF) position and orientation tracking system.

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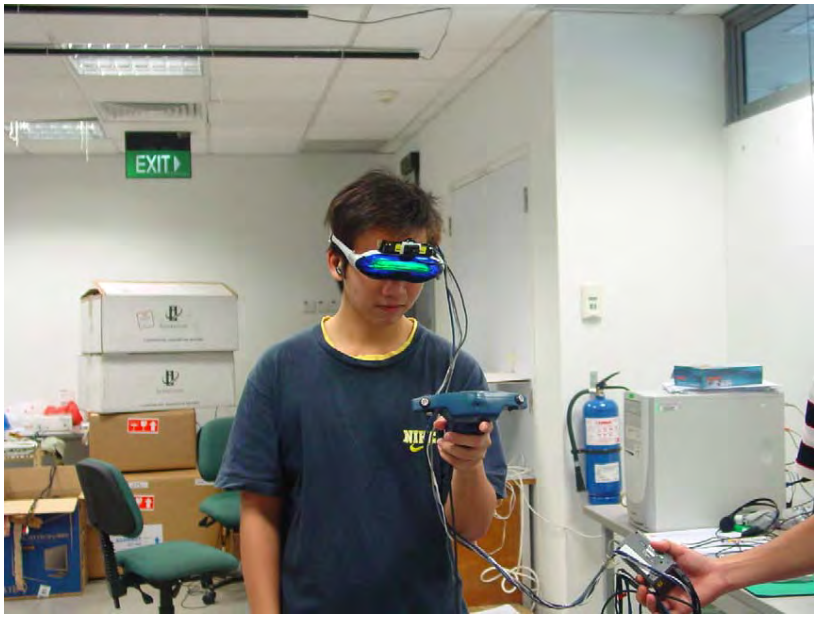


Fig. 3. The physical set-up of our acoustic-inertial tracking AR environment. On the ceiling there are six IS-900 SoniStrips which makes up a three meter by three meter area. A head tracker is mounted on the user's HMD and a camera is fixed on the head tracker. A wand tracker with four buttons and one joystick was held in the user's hand as an interaction device.

It tracks changes in orientation and position by integrating the outputs of its gyroscopes and accelerometers, and corrects drift by using a room-referenced ultrasonic time-of-flight range measuring system. It can obtain a resolution for position of 15 mm.

For the experimental system, as shown in Fig. 3, we mounted six IS-900 SoniStrips on the ceiling of a 3 meter by 3 meter space. This system can support up to four tracking stations. We used four tracking stations to track two users' heads and hands, respectively. A head tracker was mounted on the user's HMD and a camera is fixed on the head tracker. A wand tracker with four buttons and one joystick was held in the user's hand as an interaction device.

The system superimposes graphics on video sequences captured from the camera and displays the combined images on the HMD. We employed OpenAL (Loki Entertainment Software) for generating 3D sounds. Unlike the vision-based tracking method where we make the user's co-ordinates system as the reference, in this method, we used the IS-900 co-ordinates system as a reference while using the users' head position, orientation, and the virtual sound sources' 3D position as input parameters for the OpenAL software.

3. Experimental goals and subjects

Two experiments were taken in the two pre-mentioned AR environments, respectively. In the first experiment, our goal is to find out:

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1. Whether 3D sound helps depth perception and by how much.
2. Whether the exaggeration of intensity difference of 3D sound will be acceptable or unacceptable psychologically.

In the second experiment, our goal is to find out:

1. Whether 3D sound helps in task performance, or more specifically, whether it helps to shorten a searching task completion time and by how much.
2. Whether 3D sound gives more immersive and realistic perception to the users and whether it helps the subject to distinguish different objects in AR environments.
3. Whether 3D sound increases the feeling of 'human presence and collaboration'.

Both qualitative and quantitative studies were conducted in each experiment. The study took place over a four-week period in the summer of 2002.

Forty subjects (13 females and 27 males) were each paid Singapore $8 (approximately $4 USD) per hour to participate in this study. All the participants were undergraduate students at the National University of Singapore. Most of them were freshmen or juniors majoring in computer engineering. The subjects were on average 21.3 years old and had used computer for 8.7 years. They were asked to mark from 1 to 7 about how often (1 means very often while 7 means very seldom) do they use computers and how often do they play games. The averages were 1.7 and 4.5 respectively, which means that they often use computers, but play games only occasionally. All of the subjects reported clear-vision and normal hearing abilities.

Each subject performed both experiments. However in the second experiment, 20 subjects (seven females and thirteen males) were asked to conduct the searching task with the aid of 3D sound while the other 20 subjects (6 females and 14 males) conducted the same task without the 3D sound. Before doing the experiments, all the subjects were given a brief introduction about AR and the tasks to be performed. Each of the subjects was given five minutes to initially try on the HMD and experience the 3D sound effect. After the experiments, all subjects were given 25 min to finish a questionnaire based on the experiments finished.

4. Experimental results

In this section we present the details of the evaluation studies of 3D sound effect and performance in our two AR environments described before

4.1. Experiment of the impact of 3D sound on depth judgment

4.1.1. Design and procedures

In this experiment, we examined the effect of 3D sound on helping users to judge the relative depth of objects in an AR environment (Fig. 4) implemented by vision-based tracking method. Users were required to tell the relative depth of the two markers upon which virtual objects were augmented. In order to precisely position the markers, we used a white board to hold the markers. We set the height of user's chair so that the markers

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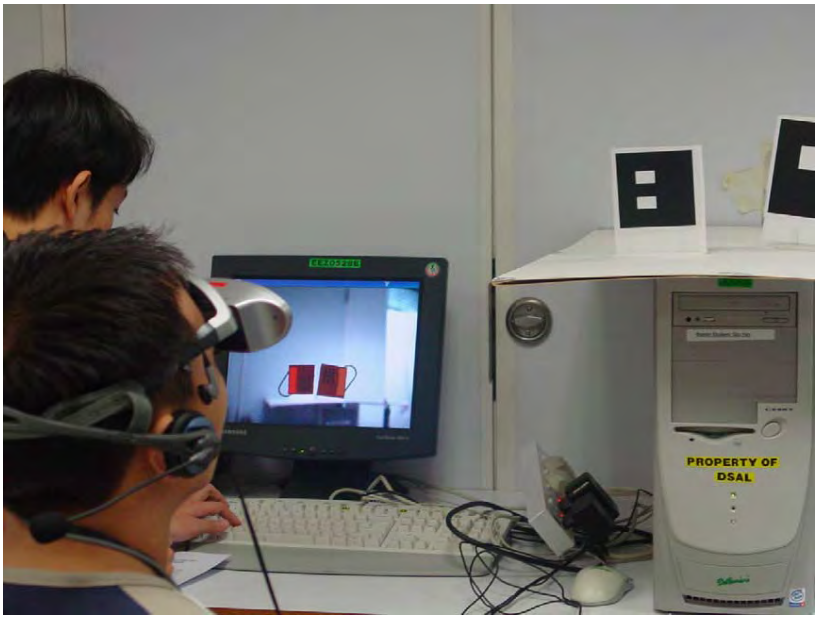


Fig. 4. The physical set-up of the experiment on depth judgment. The output of the computer VGA signal is send to a monitor and HMD for display by a video converter. The user can only see from HMD while the monitor is for the use of the experimentalist. Two virtual telephones with different colors are augmented onto different markers respectively. The size of augmented objects is adjusted to about the same by adjusting the position of marker. Users are required to tell the relative depth of the two objects in the cases of with and without 3D sound aided.

and the eyes were at the same height. By this way we eliminated the vertical vision cue to depth perception-as the relative position on the same plane can tell the relative depth. This makes sense in AR environment since the augmented objects are not necessarily located on the same plane, and thus this cue is not commonly available. The relative position of the two markers was chosen carefully so that the two markers seem to be approximately of the same size in the camera's view. As described in Section 2.3.1, this will cause depth confusion and hence we can carefully decide the effectiveness of adding 3D sound to the virtual objects.

A preliminary study (Mereu, 1995) indicated that visually impaired users can use the sound environments to perceive depth and position in a 3D application. We hence propose that 3D sound could also be helpful in AR environment for people to perceive depth. To test this hypothesis, we implemented 3D sound in our AR environment and measured the accuracy of relative depth judgment of subject.

4.1.2. User interfaces

As shown in Fig. 4, we augmented the same shape virtual telephone with a different color on each of the markers. The virtual telephones were augmented with a 3D telephone sound that was produced to emanate from each virtual telephone. As explained in

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Section 2, the intensity difference of 3D sound due to different depth of markers was exaggerated by a scaling factor. Subjects were asked to put on the headphone of HMD and perceive the difference of 3D sound when the marker was changed to different positions.

Every subject was required to perform 10 trials judging the relative depth of two telephones. Before every trial, the signal of the HMD is turned off so that the subject could not see how the markers were arranged. During that time, the user only sees black because the HMD is a nonoptical see through type. We placed the two different sized markers on the condition that the image size of the two objects are of about the same size, this can be observed by a monitor which is connected to the same VGA output as what the HMD is connected. Then the HMD is turned on and the subject was required to tell which telephone was nearer to him in the cases with and without 3D sound aided respectively. The possible answers are 'left', 'right' and 'uncertain'. We recorded the subjects' judgments and compared them with the correct answers for numerical analysis. We also asked some questions in the questionnaire for psychological analysis purpose.

4.1.3. Results

4.1.3.1. Performance.. The chart in Fig. 5 provides a visual summary of the results of the depth judgment experiment. Fig. 5 compares the number of correct relative depth judgments in 10 trials for 40 subjects in the cases with 3D sound and without 3D sound aided respectively. It can be seen that judgments with 3D sound aided lead to 2.5 times as accurate (70.25 versus 28.25%) as those without 3D sound added.

Our expectation of this experiment was to evaluate the impact of 3D sound on depth judging accuracy. Using a 0.05 significant level, a one-way ANalysis Of VAriance (ANOVA) (Stockburger D, 1998) of the individual correct judgment times of each user was used. In this experiment, we obtained $F(1,39)=129.55$; $p<0.001$ which declares the result to be statistically significant. Thus we conclude that 3D sound does significantly help to increase the number of times of correct depth judgments.

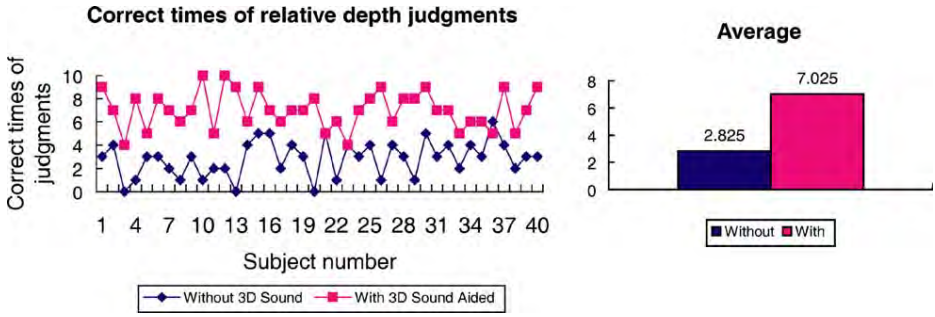


Fig. 5. Comparison of the correct depth judgment times of 40 subjects in ten trials in the cases of with and without 3D sound aided. From this chart we can see obviously that the accurate judgment times increase drastically by introducing 3D sound. The average of correct judgment times is increased from 2.825 to 7.025 by introducing 3D sound.

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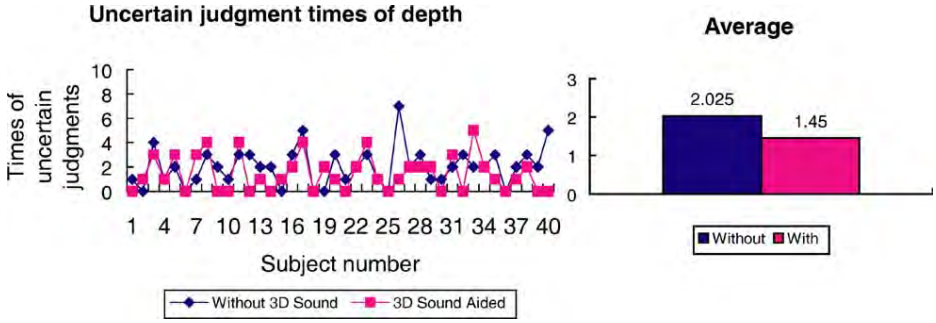


Fig. 6. Comparison of the uncertain judgments in the cases of with and without 3D sound aided. The average of uncertain judgment times is decreased from 2.025 to 1.45 by introducing 3D sound.

On the other hand, the addition of 3D sound decreases the uncertainty of relative depth judgment. Fig. 6 shows the comparison of uncertain judgment times between the cases of with and without 3D sound aided. The addition of 3D sound decreases the average uncertainty from $M=2.03$ to 1.45 times. A significant difference is found ($F(1,39)=4.24$; $p<0.05$). These results proved that the depth perception was significantly enhanced by 3D sound.

There was no significant difference found between the genders. For the correct judging times without 3D sound, males have a mean value of 2.67, females have a mean value of 3.15, $F(1,38)=0.9$; $p>0.1$. For the correct judging times with 3D sound aided, males have a mean value of 7.00, females have a mean value of 7:08, $F(1,38)=0:02$, $p>0.1$.

4.1.3.2. Questionnaire responses.. The purpose of the questionnaire is to examine how the subject qualitatively judges the relative depth of augmented objects and how difficult the task is. Apart from the quantitative results we obtain from the above experiments, it is advantageous to know the subjective feeling of users due to the addition of 3D sound, and the process of the sound intensity exaggeration. The main questions in questionnaire about this experiment were as follows:

1. When you were supposed to judge the relative depth of the two markers, what cues did you mainly use the depth of markers (multiple choices are possible)?
   A. brightness B. color C. size D. intuition E. background F. motion G. others
2. Do you think it is hard to tell the relative depth of two objects in this experiment without 3D sound? Please select your answer from the following choices:
   A. very hard B. hard C. medium D. easy E. very easy
3. Overall, do you think 3D sound helps you to make a correct decision?
   A. yes B. no C. uncertain
4. In real life situations, the intensity of sound doesn't change drastically when the sound source is moving within a short distance, say 100 mm. However, in our experiment we exaggerated this effect. Thus you perceived an obvious difference between the two markers when they were placed in a relative small different depth.

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Do you feel it is unintuitive that the depth scale of 3D sound in this experiment has been exaggerated? Please select from the following choices about how you feel:
A. very unintuitive B. unintuitive C. medium D. intuitive E. very intuitive F. did not notice at all

Question 1 allows multiple choices. Every choice given by the user will be counted as a single vote to the selected choice. Although different users might tick different numbers of choices, the vote diagram is not severely disturb qualitatively since our purpose is to find out what are the cues most users will use for judging depth. As shown in Fig. 7(a), the 'size' cue was given the first place (30 votes) of all the cues in our question. This partially explains why

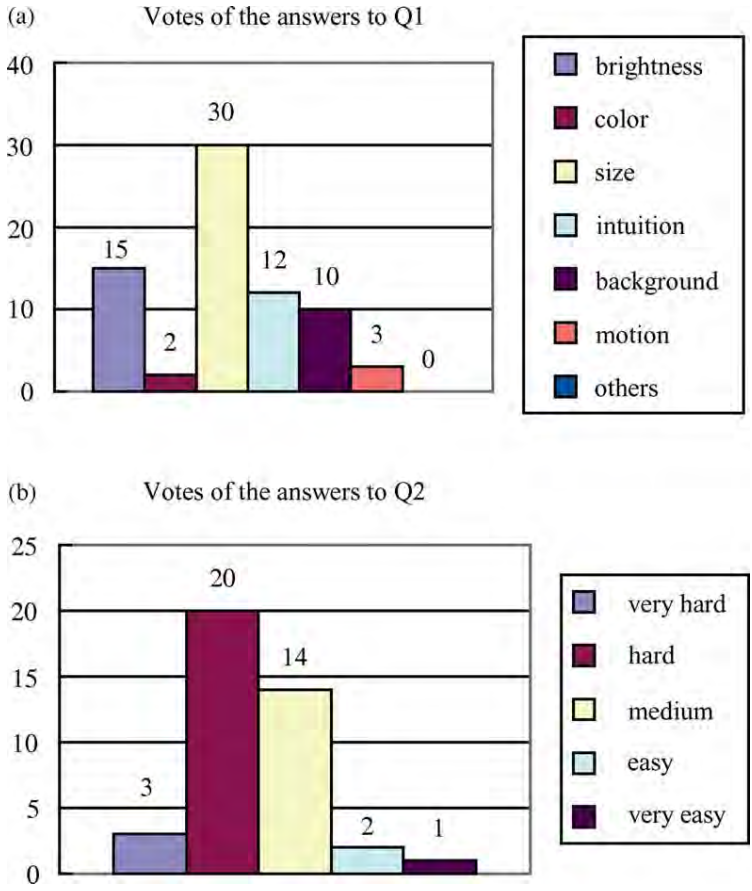


Fig. 7. Statistical charts of the answers to Question 1, 2 of Section 4.1.3 (a) The votes of the answers to question 1: When you were supposed to judge the relative depth of the two markers, what cues did you mainly use the depth of markers (can have multiple choices)? It can be seen from this chart that users are more likely to judge the depth of object by the size, brightness and the background cues. (b) The votes of the answers to question 2: Do you think it is hard to tell the relative depth of 2 objects in this experiment? It can be seen from this chart that it is hard to tell the relative depth of the two markers in our experimental AR environment.

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it is difficult for subjects to judge the relative depth when two markers are almost of the same size. Our setting of AR environment in this experiment restrained the effect of background (ten votes) and motion (three votes). The cue 'brightness' which reects the cue 'light and texture gradient' obtains the second highest votes (15 votes). This gives us a hint that in order to obtain good depth perception, it is also important to adjust the appearance of virtual object so that it fits its surrounding physical lighting environment.

However, in this experimental system, the brightness of the object is predefined when the model was created. Hence it brings more difficulties for depth judgment, and it can not provide the cue 'light and texture gradient'. Therefore, this suggests that in the future research we can adjust the brightness of augmented objects according to its lighting environment so as to achieve better depth perception.

In response to question 2, most subjects claimed that it is hard (three claimed very hard and 20 claimed hard) to judge the relative depth of objects in this experiment without the 3D sound cues. Fig. 7(b) gives the chart of this result. This psychological feeling is in accordance with the results shown in Fig. 5 where the accuracy of judgment is only 28.25% in average for tests without sound.

There is an interesting result from the answers to question 3. Only 19 subjects thought that 3D sound has helped them however, 6 subjects claimed 'no' and 15 subjects claimed 'uncertain', as shown in Fig. 8(a) (one subject somehow forgot to give the answer to this question, thus only 39 votes are appeared in this chart). This implies that the addition of 3D sound may have contributed to the depth perception (Fig. 5) although the subject may not psychologically feel it. While this result is quite interesting, more detailed and long term psychological investigation needs to be conducted before drawing any reliable conclusions.

In question 4, our prospect is to find out whether our exaggeration of 3D sound will lead to a degrading of the perceptual experience. The result (Fig. 8(b)) shows that only one subject claimed that it is 'very unintuitive' and six subjects claimed that it is 'unintuitive'. Nine subjects claimed 'medium', 12 subjects claimed 'intuitive' and one subject claimed 'very intuitive'. Moreover, 11 subjects claimed that they 'didn't notice at all'.

Although there is still a risk of losing the 'realistic experience' since the 3D sound environment is different from our everyday life, this result suggests that most of the users will still feel the virtual scene is intuitive psychologically if the exaggeration scale is properly chosen. This result is critical to the development of 3D sound system in AR environment since, unlike in pure VR system, normally the exaggeration is required, otherwise we may lose the information carried by one dimension of 3D sound-the depth. This occurs especially when the physical AR environment is as small as our experimental game system or even smaller, as in the desktop AR environment of the depth perception experiment.

4.2. Experiment of 3D sound's impact on task completion time and the feeling of 'human presence and collaboration'

4.2.1. Design and procedures

In the second experiment, we examined the effect of 3D sound in a larger AR environment in the form of a simple game Barfield (Barfield et al., 1997) identified three primary benefits of auditory spatial information displays as: relieving processing demands

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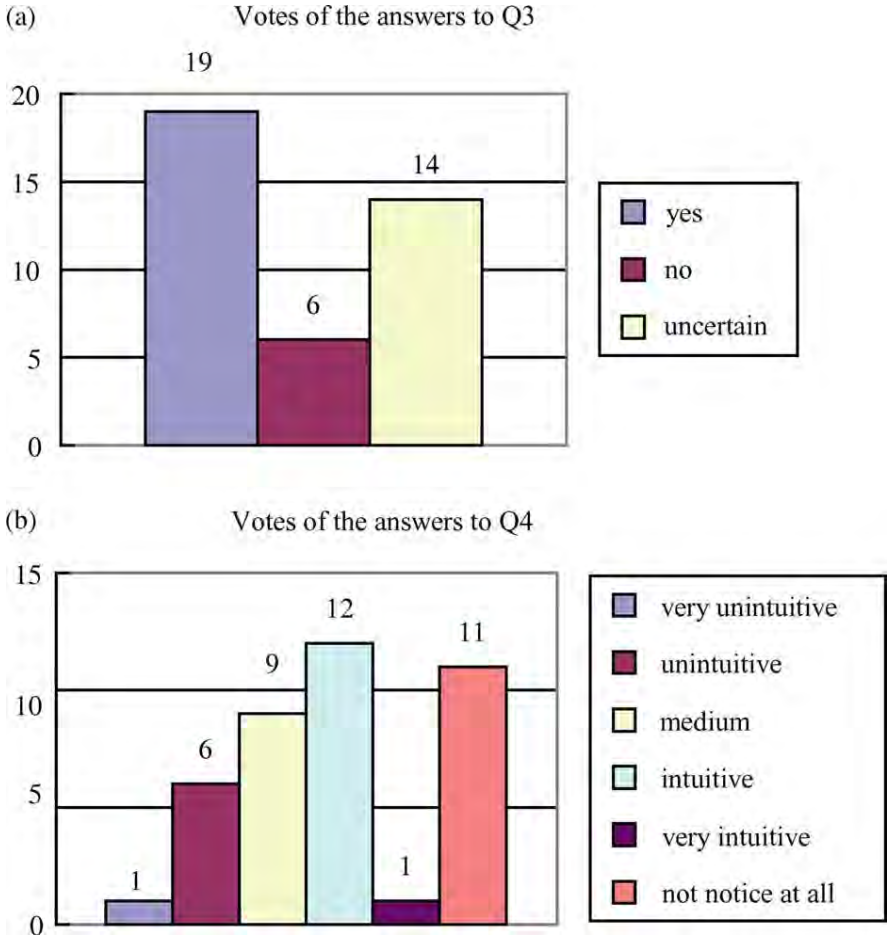


Fig. 8. Statistical charts of the answers to Question 3, 4 of Section 4.1.3. (a) The votes of the answers to question 3: Overall, do you think 3D sound help you to make a correct decision? (One subject somehow forgot to give answer to this question, thus only 39 votes are appeared in this chart). (b) The votes of the answers to question 4: In our every life, the intensity of sound doesn't change drastically when the sound source is moving within a short distance, say 100 mm. However, in our experiment we exaggerated this effect. Thus you perceived an obvious difference between the two markers when they were placed in a relative small different depth. Do you feel unintuitive that the depth scale of 3D sound in this experiment has been exaggerated?

on the visual modality, enhancing spatial awareness, and directing attention to important spatial events In our research system, we extend the benefits in this experiment by:

1. helping to localize an object in AR environment when the visual modality is weakened;
2. enhancing the feeling of human collaboration;
3. directing attention to different spatial objects or helping user to identify different spatial objects.

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4.2.2. User interface

Our experimental system allows two users to play a simple game at the same time The objective of this game is to rescue the princess who was captured by an evil witch. In this experimental game, three stages were used to for investigating the effects of 3D sound. In the first stage, users are allowed to walk around in a three by three meter region and to explore a virtual land augmented on the physical ground through a small rectangle virtual window displayed on the tracked wand. Fig. 9 shows the scrolling 3D landscape when the player is moving her hand. A small virtual plane is attached to the wand as an avatar for the user, as if the user is exploring the game space by manipulating the plane. The player is looking for the castle through the 'magic 3D window'. Two 3D sounds are applied in this stage and can be heard by both players. The first one is a 3D sound 'Help!' which was applied to the princess located inside the castle. The second sound is a constant buzz applied to the wand tracker of co-player as if it is generated by the engine of co-player's airplane. Each player can hypothetically localize his/her co-player by localizing the buzz sound.

In the first stage the player is allowed to become more and more familiar with the searching task and the perception of 3D sound. We purposely design this stage as a training process. When the player walks closer to the sound sources (the castle and the princess therein or the co-player), the sound becomes louder while it becomes softer

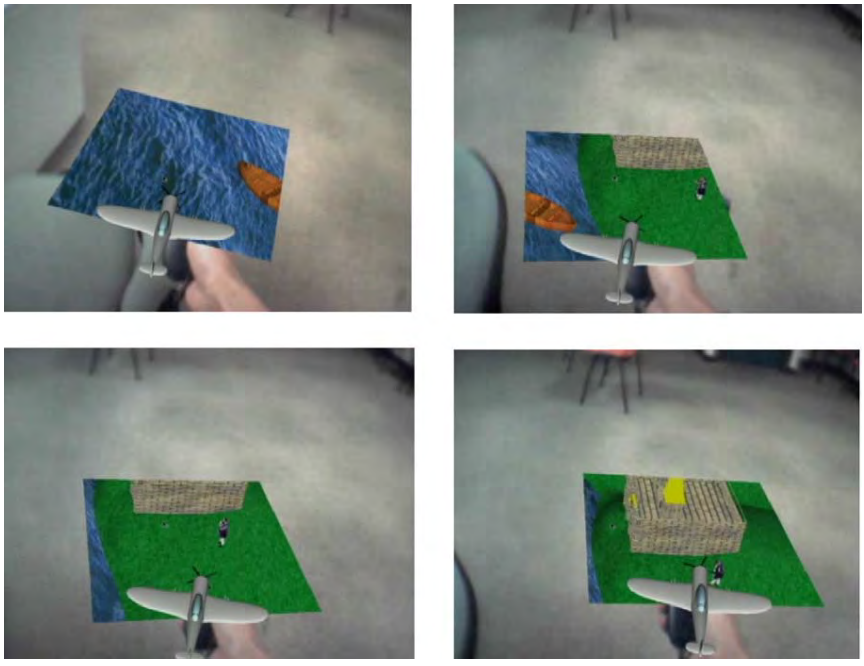


Fig. 9. Looking for the castle through a 'magic 3D window'. A virtual plane is augmented on the wand as an avatar for the user. A rectangle window is augmented in front of the wand through which the user can see the virtual land on the ground. When the user is moving around, the 3D landscape is also scrolled in the 'magic 3D window'. The user is looking down at the castle as if she is looking down from the sky in the airplane.

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when the player walks away from the castle. An exaggeration of the intensity difference described in Section 2 was undertaken here as well. Furthermore, it should be noted, when the player rotates her head or body, she can perceive that the sound source is also moving relative to her movements. We updated the position and orientation of the head tracker 25 times per second which allows a quite smooth feeling of sound source movement.

After the castle is found, players move to the second stage. They battle with a virtual witch who has captured the princess. The virtual witch is augmented in the physical world and is hovering in the experimental region. Players can move freely in the physical space to get the best shooting angle and position. They need to reload or transfer their bullets by putting their wands together which encourages the collaboration in the game, as shown in first two frames of Fig. 10. Apart from the sounds used in stage one, we applied the other two 3D sounds, the cry of witch when it is hit and the explosion sound when it is exploded after being shot for 10 times.

After destroying the witch, the players can fly into the virtual scene and rescue the princess from the castle. This enables a seamless transition from AR environment to VR environment. After the user flies into the virtual scene, she enters a virtual environment in which players can use joystick on the wand to move around, while they can turn over their head or body to change the direction of viewpoint. In this stage we still keep the princess's cry 'help' but we change the sound of co-player from a buzz of engine into a footstep sound. Both of the players can be either in AR or VR mode and can continuously be aware of each other by both vision and sound. Fig. 11 shows the views in this stage.

To examine the impact of 3D sound on task completion time and subjective feelings in this AR environment, 3D sounds were applied in this experimental game. Their functions are summarized as follows:

1. *Players' sounds*: A constant buzz sound is applied to the co-player's airplane when the users are exploring the augmented land. Since the plane is attached to the wand, the 3D positions can be easily obtained from the tracker in the wand. By applying this sound, the user can always hear where is the location of the co-player, even when the co-player is not visually in the scene. She can still roughly tell to what direction is her co-player located and whether the co-player is getting closer or further to her. This buzzing sound is changed into a footstep sound when the co-player enters the VR environment. The different sound gives the hint of whether the co-player is in the AR or VR environment as well.
2. *Human voice*: A constant human voice 'Help! Help!' is applied to the princess which is the target of the searching task. This sound helps the player to turn and face to the correct direction and walk to the correct location where she can see the princess through the small window.
3. *Entertainment sounds*: To make the game more entertaining, we also applied other sound effects. A shooting sound is played when user press the shooting button on the wand. A scream sound and an explosion sound were played when the witch is destroyed. A landing sound of engine is played when the user transits from AR environment to VR environment. A female voice saying 'congratulations' and some greeting words was played when the user finished her mission-find the princess and rescue her.

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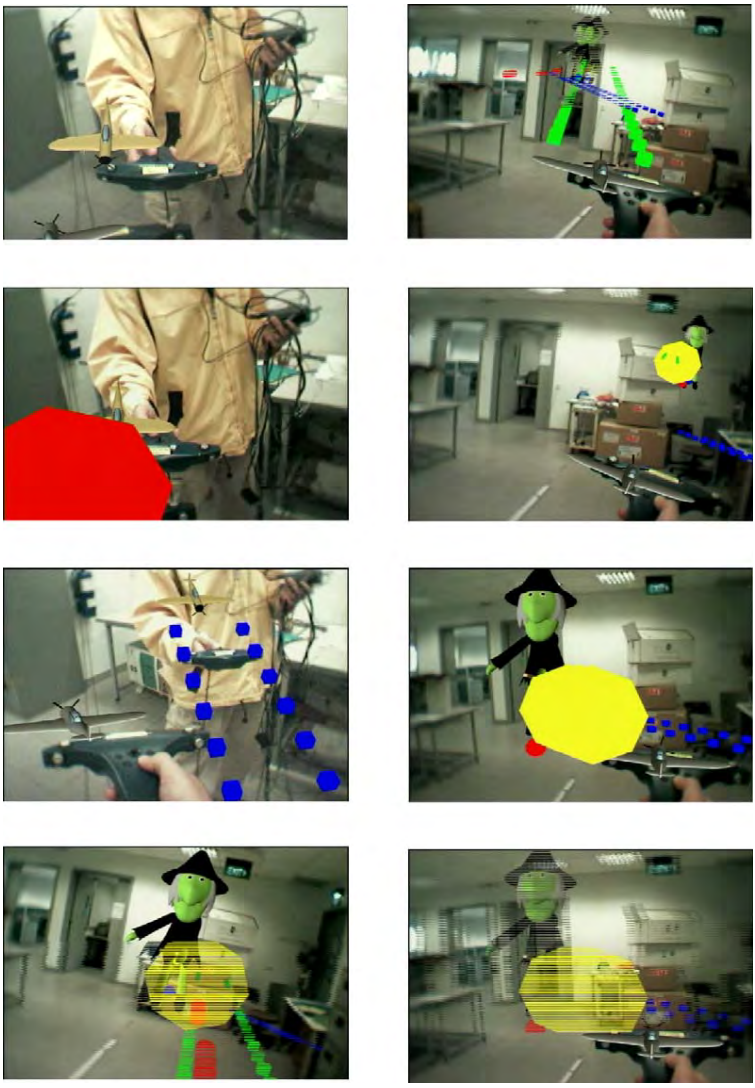


Fig. 10. Two users are collaboratively fighting the witch hovering around them in the physical experimental area. The user can see the augmented virtual witch in three dimensions through HMD. The two users need to reload or transfer their 'bullets' by putting their wands together as shown in the first two frames. When the user pressing a specific button on the wand, the airplane can fire bullets (blue and green dot lines in the subsequent frames). The position and orientation of the wand are used to decide trajectory of 'bullets' and whether the witch is shot or not. In the last frame, the witch disappeared after being shot for ten times.

In this experiment, we took both numerical and psychological studies of the subjects' responses. After the players finished the game missions, they probably have been familiar with the game, an additional task is required to perform in stage one. Instead of searching the castle, they need to search for the princess by walking around and scrolling

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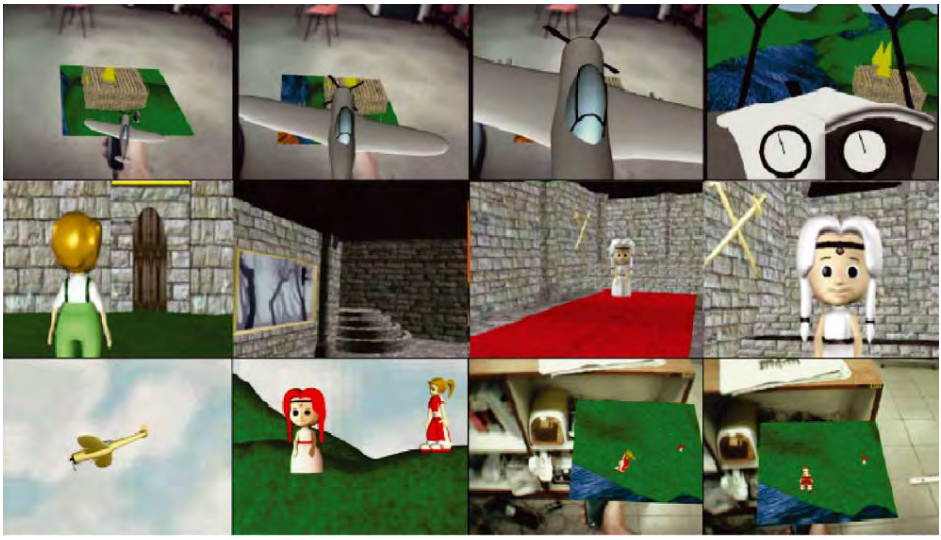


Fig. 11. Rescue the princess in the castle with co-player. (1) The first row shows the seamless transition from AR to VR that the user's airplane is 'flying into' and 'landing on' the VR world. (2) The second row shows one player's view when they are on the way to rescue the princess in the castle. The user uses the joystick to navigate however they can turn the body and head of the virtual character by physically turning their body and head. The footstep sound comes from the co-player and the 'Help!' scream of the princess can always be heard. (3) In the first frame of the third row, a user can physically look up in the sky to find her co-player who is still in AR mode (before flying into the VR mode). The user in the AR mode can still see the co-player and the princess by looking down to the land as if she is on the airplane. The second frame shows one player's view point when both of the players are in VR mode and come to the princess.

the window. The princess was taken outside the castle and was put at an open area on the land. Each subject was given a trial to see how the princess looks like in the small window. Then the princess was put at another position which is the same for all subjects. Every subject started from the same position and orientation in the space and began to search for the princess. The completion time of this searching task was recorded. Twenty subjects (7 females and 13 males) were asked to conduct the searching task with the aid of 'Help!' sound while the rest twenty subjects (6 females and 14 males) conducted the same task without any sound. Every subject performed this task only once either with or without sound aided. Apart from this numerical study, psychological studies were conducted by a linguistic questionnaire.

4.2.3. Results

4.2.3.1. Performance.. In this experiment the subjects performed a searching task as described in Section 4.2.2. The chart in Fig. 12 compares the completion time (in seconds) of the searching task for two groups in the cases with 3D sound and without 3D sound aided. The average task completion time of the group without 3D sound aided was 1.5 times as long (133.05 versus 88.1) as that with 3D sound aided. The effect of 3D sound on shorten the task completion time is significant, $F(1,38)=6.7$; $p<0.025$.

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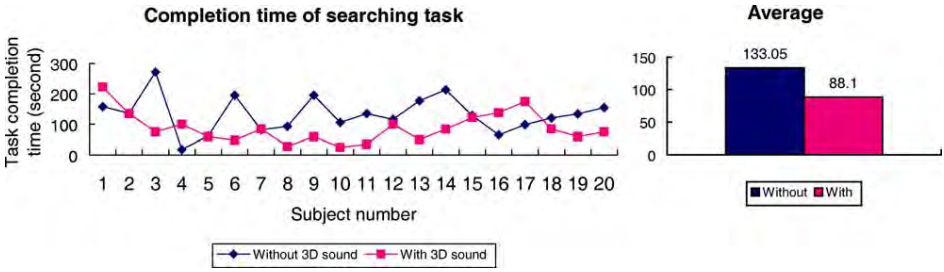


Fig. 12. The comparison of searching task completion time in the cases of with and without 3D sound aided. The average of completion time is shortened drastically from 133.05 to 88.1 s by introducing 3D sound.

No significant difference is found between the genders in this experiment as well. For the task completion time with 3D sound aided, males have a mean value of 88.4615, and females have a mean value of 87.43, $F(1,18)=0.0018$; $p>0.1$. For the task completion time without 3D sound aided, although females' mean value is higher than that of males' (166.33 versus 118.79), no significant difference is found at the significant level of 0.05, $F(1,18)=3.03$; $p>0.05$.

From the results given above we can see that, 3D sound helps significantly to shorten (about by half) the searching task completion time in this AR environment.

4.2.3.2. Questionnaire responses. The purpose of the questionnaire questions is to examine the impact of 3D sound on the subject's psychological feelings. We wanted to examine whether 3D sound improves the feeling of immersiveness and human presence and collaboration, whether it helps to identify spatial objects, and how much impact it has on these feeling. The main questions in questionnaire about this experiment were as follows:

1. Does 3D sound improve your perception of immersiveness in the AR environment? Do you think it is more realistic with 3D sound than without it? Why?
2. Does the 3D sound improve your feeling of human presence and collaboration as you can hear the sound coming from your collaborator at anytime?
3. Does the 3D sound help you to identify different information signals (spatial objects)?
4. Were you aware of your co-players in different places?
   A. always B. very often C. often D. barely E. never
5. What has helped your feeling of 'human presence and collaboration'? (can be multiple choices, please order the factors by the order of decreasing importance)
   A. small talk between co-players B. vision cues C. 3D Sound cues D. Others

According to question one, almost all subjects (39 of 40 subjects) claimed that 3D sound did improve the perception immersiveness. A total of 38 subjects claimed that it is more realistic with 3D sound, and one subject claimed 'a little better'. The main reasons they provided to support their viewpoint are as follows:

1. 'It is natural feeling and more realistic with 3D sound.'
2. 'You can feel the sound from all directions which gives a more 3D feeling.'

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3. 'You can tell where the collaborator is positioned, or to know the surrounding objects in the AR environment.'
4. 'The feeling is closer to real world and 3D sound helps to navigate.'
5. 'I can hear and judge distance from the object producing the sound.'

From these responses, we can find that 3D sound does play an important role complementing the visual AR environment. Although this result seems to be natural since the same conclusion has been drawn in virtual reality environment (VRE), it proves that this conclusion is still tenable in AR environment when the implementation method has been changed and especially when the interfaces preserve our social interactions which are weak in VR.

There were also negative comments. One subject suggested that there should be more background sound like noises to make it more realistic. The subject said, 'The sound field is too quiet to be realistic.' In fact, this is consistent with the argument given by Begault (Begault, 1994): "Even with non-spatial cues, one can tell something about the distance of different sounds and their context,…, but the inclusion of 3-D sound techniques and spatial reverberation cues can greatly increase the immersiveness of a simulation, as well as the overall quality and the available nuance in representing different environmental contexts".

The important result we obtained from the responses to question two is that 3D sound improves the feeling of 'human presence and collaboration' when the subject is performing this experimental task. In this question, 39 of 40 subjects answered 'yes'. Some of the comments were:

1. 'At least I can find whoever it is.'
2. 'The sound constantly reminds us of the presence of the collaborator.'
3. 'Yes, like someone is actually in the world with you.'
4. 'It is really interesting that you can turn to face him when the clop-clop is getting closer to you in your back.'

One interesting comment was that 'I can know whether he is still in the airplane or has landed down and walking around' (which meant that the user could know if the other player was in AR or VR modes). This is actually one function of sound which is serving as an auditory icon (Gaver, 1986). A good negative comment suggested that 'it can be improved by adding speech communication, because a running motor does not sound very human, so it is like an object somewhat'.

Apart from applying 3D sound to the collaborator, we also applied 3D sound to the princess who is the target of the task. The responses to question three suggest that 3D sound, when applied to different spatial objects (information signals) in AR environment, can help the user to identify different information carriers. In our experiment 36 subjects claimed that they can constantly be aware of both the other collaborator and the princess simultaneously. This result suggests that by introducing more than one 3D virtual source sources in AR environment, it is possible for the users to identify different meanings of them and to distinguish them by the localization of the sound sources. As one subject described, 'yes, very much so. For instance, if the collaborator sounds from the left

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earpiece and princess cries are heard at right earpiece, the directional news determines the positions of the collaborator and princess.'

However, one valuable criticism complained that 'the volume differs when you are far but when you are near I could not hear a difference especially in terms of direction', the other one complained that 'the sound sometimes seemed to be coming from all directions and I was uncertain whether to turn left/right, only when I was close did the volume increase, but in a jump, not gradually'. These comments points out the drawbacks of our exaggeration process of 3D sound intensity in this AR environment and also to some extend support the results of Brungart (Brungart and Rabinowitz, 1999; Brungart, 1999). We designed the auditory environment so that when the user becomes closer to the virtual sound source in the three by three meters region, the 3D sound intensity is exaggerated. This will be maximum intensity when the user is at the position of the virtual sound sources (distance to the object is zero). In this case, the binaural cues play a very important role for distance and direction perceptions. Because of the closeness to the object when near zero, even a slight movement of the user may cause a totally opposite feeling of the source direction (from left to right). When the movement is very fast, the intensity and sound direction may change rapidly. This problem can be partly solved by designing a better sound-scape. However the situation when the user is overlaid on the sound source is still a difficult problem unless we apply some physical constraints on the user's sound near to virtual sound sources.

Chart (a) and (b) in Fig. 13 shows the subjects' responses to question four and question five, respectively. We can see from chart (a) that nine of 40 subjects claimed that they were 'always' be aware of co-players while five subjects claimed 'very often' and 18 claimed 'often'. This leads to the improvement to the feeling of collaboration. A total of 39 subjects agreed that 3D sound did increase their feeling of collaboration from the result of question two.

To examine the importance of 3D sound among all cues, subjects were required to choose the cues they thought to have helped them and to order them by the importance. 3D sound cues obtained the highest votes (36 votes) among all the cues. Move importantly, a total of 14 subjects regarded 3D sound cues as the most important cue while 'small talk' and 'vision cues' only obtained five and four votes respectively. This result suggests that 3D sound does play a very important role in improving the subject's feeling of collaboration. It could even dominate among all possible cues in AR environment, especially when other cues are restrained by hardware settings, for example, angle of view is restrained by HMD in common AR system. In this situation, the visual cues are restrained due to the narrow viewpoint of HMD, and hence their effects on collaboration are limited. On the contrary, the 3D sound can be generated from any points in the AR space. When 3D sound is applied to the user and given different meaning at different situations, it can play the most important role to help the user's feeling of 'human presence and collaboration'.

5. Conclusions

The purpose of this work is to investigate the effectiveness of 3D sound in AR environments We designed two experimental AR environments to study the effectiveness

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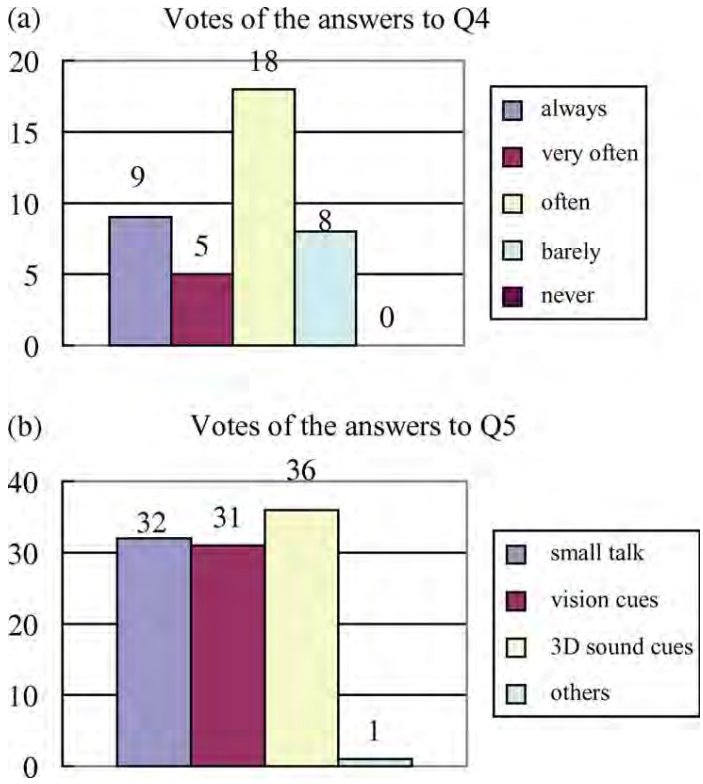


Fig. 13. Statistical charts of the answers to Question 4, 5 of Section 4.2.3. (a) The votes of the answers to question 4: Were you aware of your co-players in different places? We can see from the chart that in this AR environment, subjects can often be aware of co-player's position, however, this result is impossible if there was no 3D sound applied since the subject can only occasionally see co-player due to the narrow angle of view. (b) The votes of the answers to question 5: What has helped your feeling of 'human presence and collaboration'? It can be seen from this chart that 3D sound plays the most important role among all the cues. It gets even more votes than vision cues and voice communication cues.

both quantitatively and qualitatively. Two different tracking methods were applied to retrieve the 3D position of virtual sound sources. We examined the effects of 3D sound on improving depth perception and shortening task completion time. We also investigated 3D sound's effects on improving immersive and realistic perceptions, helping user to identify different spacial objects, and improving the subjective feeling of 'human presence and collaboration'.

The 3D sound generated by OpenAL (Loki Entertainment Software) applying HRTFs and simple modelling of environment is used in our experiments. Apart from its effects for the user on sound source localization, we tried to emphasize its effect on telling the depth (distance). Since intensity has been reported to be a key cue for distance perception, we exaggerated the intensity difference of sound sources in different depth by applying an additional scalar factor to the intensity of generated 3D sound. The user study result shows

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that it is still 'intuitive'. These methods to implement 3D sound in relative small AR environments provide a necessary foundation for the incorporation of 3D sound with visual AR environments.

However, our studies beg many additional questions. For example, how to set the intensity scale so that it can maximize 3D sound's ability to tell depth and meanwhile preserve realistic perception for users? Moreover, as reported, for distance perception not only the intensity but also a much stronger cue, the ratio of the energies of direct and reflected sound is of importance (Middlebrooks and Green, 1991; Bronkhorst and Houtgast, 1999). How will this ratio affect the depth perception in AAR? If the cues of background and drastic head movements are allowed, to what extend will 3D sound be effective to help depth judgment, comparing to other visual cues? When the binaural localization cues for nearby sources (Brungart and Rabinowitz, 1999; Brungart, 1999) are taken into account, how to design the sound-scape to 'display' the 3D sound correctly and intuitively when the user is very close to or even right overlapped on the sound source?

Although many questions remain unanswered, our studies show that the addition of 3D sound can be a very effective way to complement the user experiences in AR environments. It helps depth perception, task performance and facilitates collaborations between users. Moreover, it enables a more realistic environment and more immersive feeling of being inside a both visual and auditory augmented reality world.

Acknowledgements

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A wearable spatial conferencing space

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M. Billinghurst ; J. Bowskill ; M. Jessop ; J. Morphett All Authors

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Abstract:

Wearable computers provide constant access to computing and communications resources. In this paper we describe how the computing power of wearables can be used to provide spatialized 3D graphics and audio cues to aid communication. The result is a wearable augmented reality communication space with audio enabled avatars of the remote collaborators surrounding the user. The user can use natural head motions to attend to the remote collaborators, can communicate freely while being aware of other side conversations and can move through the communication space. In this way the conferencing space can support dozens of simultaneous users. Informal user studies suggest that wearable communication spaces may offer several advantages, both through the increase in the amount of information it is possible

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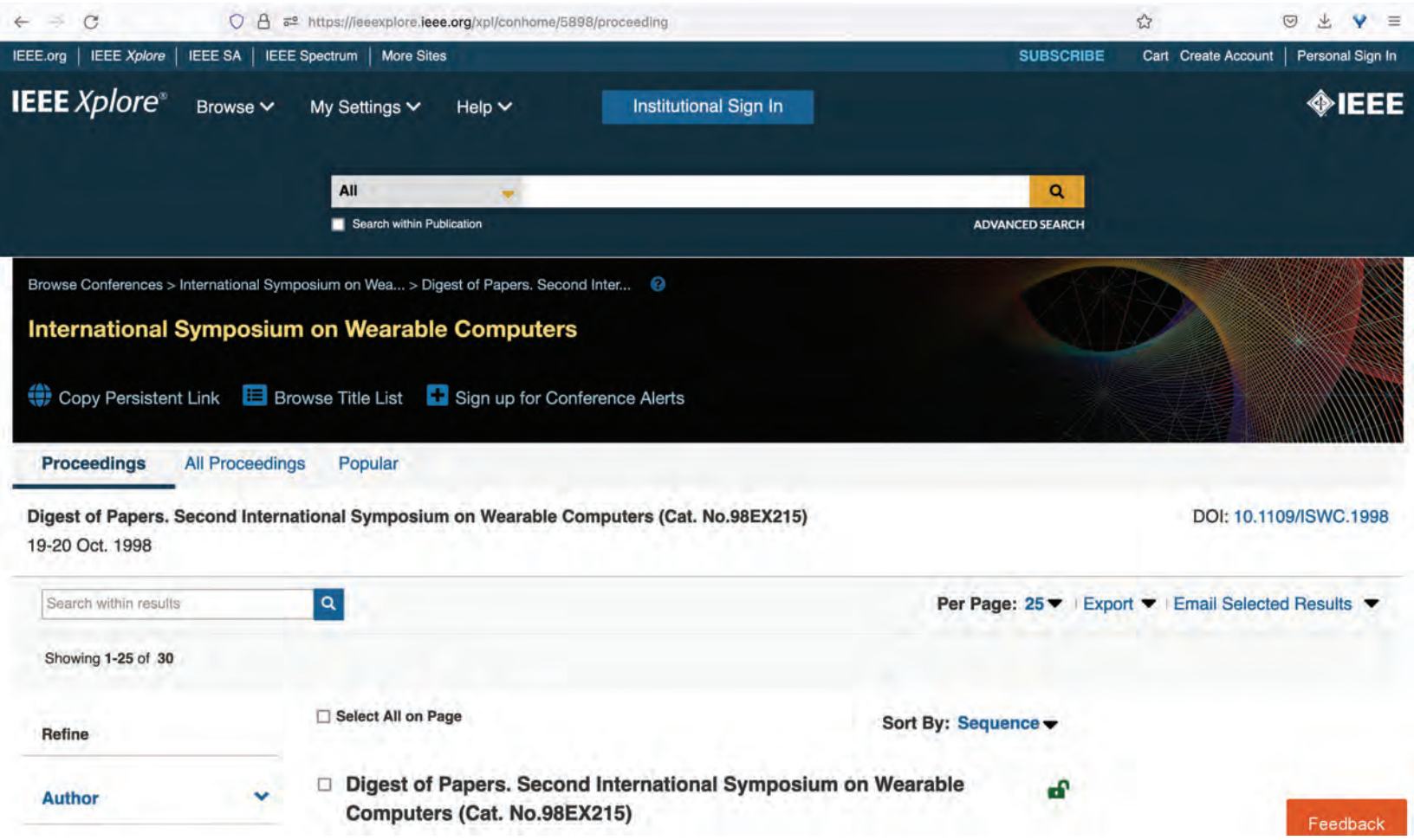
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The invention of the first wearable computer

E.O. Thorp

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A collaborative wearable system with remote sensing

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Publication Year: 1998 , Page(s): 10 - 17

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Development of a commercially successful wearable data collection system

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Publication Year: 1998 , Page(s): 18 - 24

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Adtranz: a mobile computing system for maintenance and collaboration

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Publication Year: 1998 , Page(s): 25 - 32

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Preliminary investigation of wearable computers for task guidance in aircraft inspection

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StartleCam: a cybernetic wearable camera

J. Healey; R.W. Picard

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Cited by: Papers (75) | Patents (51)

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Visual contextual awareness in wearable computing

T. Starner; B. Schiele; A. Pentland

Publication Year: 1998 , Page(s): 50 - 57

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G. Kortuem; Z. Segall; M. Bauer

Publication Year: 1998 , Page(s): 58 - 65

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▸ Abstract

☐ **Augment-able reality: situated communication through physical and digital spaces**

J. Rekimoto; Y. Ayatsuka; K. Hayashi

Publication Year: 1998 , Page(s): 68 - 75

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M. Billinghurst; J. Bowskill; M. Jessop; J. Morphett

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J. Pascoe

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Abstract

Handheld and bodyworn graphical displays: presented at the International Symposium on Wearable Computing (ISWC'98)

S.A. Lewis; G.D. Havey; B. Hanzal

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Speaking and listening on the run: design for wearable audio computing

N. Sawhney; C. Schmandt

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Design for wearability

F. Gemperle; C. Kasabach; J. Stivoric; M. Bauer; R. Martin

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Abstract

☐ **'WearCam' (The wearable camera): personal imaging systems for long-term use in wearable tetherless computer-mediated reality and personal photo/videographic memory prosthesis**

S. Mann

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Publication Year: 1998 , Page(s): 132 - 139

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▸ Abstract

☐ **A heat dissipation tutorial for wearable computers**

T. Starner; Y. Maguire

Publication Year: 1998 , Page(s): 140 - 148

Cited by: Papers (4)

▸ Abstract

☐ **Privacy, Wearable Computers, And Recording Technology**

H.B. Strub; K. Johnson; A. Allen; V. Belloni; T. Starner

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Message from the General Chair

Intelligence research has mostly been about how brains work, making autonomous machines, or creating a smart environments. But I believe that it is far more important to make *people* smarter. One can consider biochemistry or bio-implants, but the easiest avenue for improving intelligence is by augmenting the items we wear all the time: glasses, wrist watches, clothes, and shoes. High-tech wearables can potentially extend our senses, improve memory, aid social life, and even help us stay calm and collected. This goal of wearable intelligence is, to me, the central topic of this conference.

Today we see millions of users beginning to use truly portable electronic devices — plam-top computers, cell phones with internet connections. As technology progresses I expect that today's portable devices will naturally evolve into true wearables. Consider the history of glasses, watches, and radios, for instance, all of which evolved from hand-held, portable versions into true wearables. Similar evolutionary pressures will make today's' portables tomorrows wearables.

My hope is that these new wearable devices will make us smarter and improve our lives. They will certainly change our lives profoundly, because people relate to wearable devices very differently from other tools. Because wearables are with us constantly we tend to shape our personal habits and default social assumptions around them. Psychological studies show that the phrase "clothes make the man" is a deep truth; our self-perception and self-confidence change with our clothes. This echoes McLuhan's dictum "the medium is the message" — that is, how the new technology changes our lifestyle is more important than their information content or particular usage.

I believe that this conference series is a major step towards the goal of creating wearable intelligence aids that will improve human society. The first meeting, held last year in Cambridge MA, was one of the most successful first conferences' in IEEE history, and included a wearables design show that attracted overwhelming attention in the popular press [1].

This conference continues the excitement of that first meeting. One of the special features is a paper by Edward Thorp, which describes the development of what is almost certainly the first wearable computer. Another is the inclusion of a panel to consider the social impact of wearables, focusing on the topic of privacy.

Finally, I would like to acknowledge the efforts of the ISWC organizing committee, and especially its Chair, Randy Pausch. Without their numerous hours of dedicated service this symposium would not have been possible. I hope you enjoy this introduction to a new frontier in computing.



Alex (Sandy) Pentland

[1] http://www.media.mit.edu/Wearables/out-in-the-world

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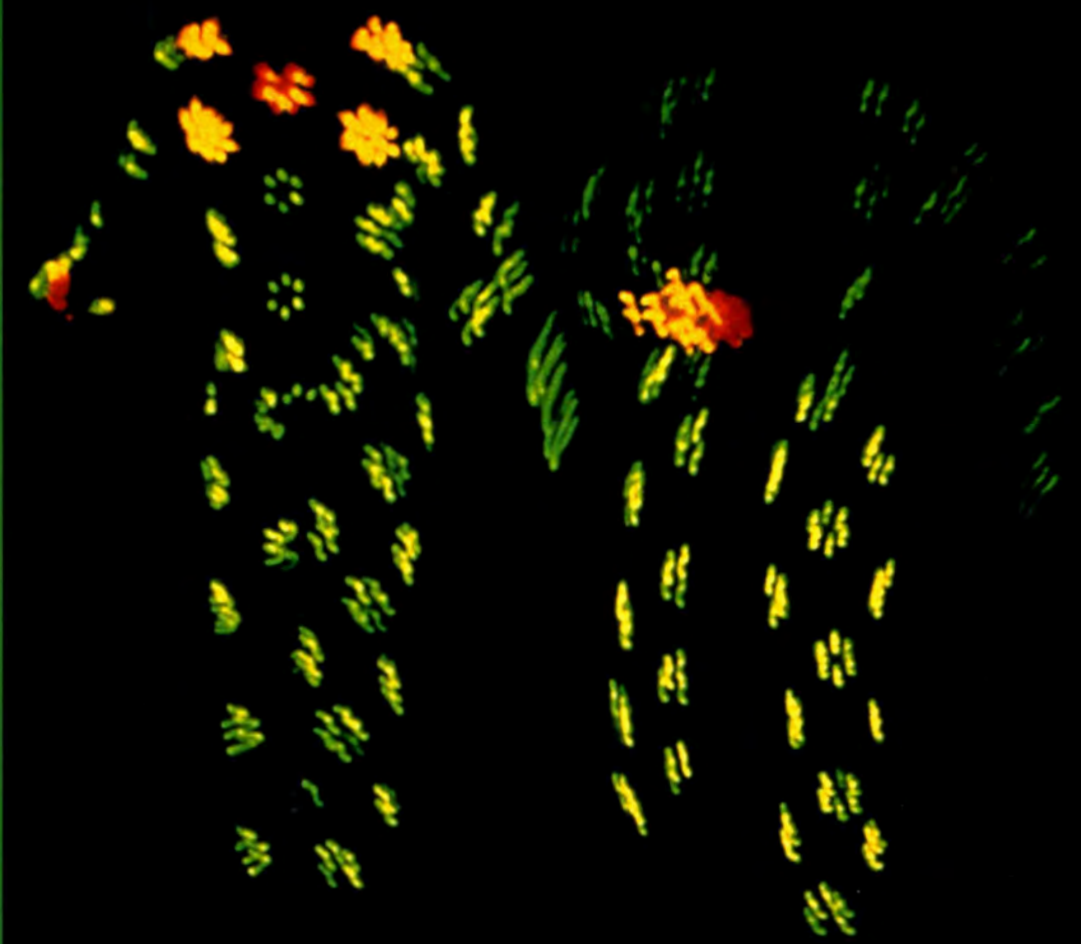
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A Wearable Spatial Conferencing Space

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Abstract

Wearable computers provide constant access to computing and communications resources. In this paper we describe how the computing power of wearables can be used to provide spatialized 3D graphics and audio cues to aid communication. The result is a wearable augmented reality communication space with audio enabled avatars of the remote collaborators surrounding the user. The user can use natural head motions to attend to the remote collaborators, can communicate freely while being aware of other side conversations and can move through the communication space. In this way the conferencing space can support dozens of simultaneous users. Informal user studies suggest that wearable communication spaces may offer several advantages, both through the increase in the amount of information it is possible to access and the naturalness of the interface.

1: Introduction

One of the broad trends emerging in human-computer interaction is the increasing portability of computing and communication facilities. However it remains an open question as to how computing can best be used to aid mobile communication.

Wearable computers are the most recent generation of portable machines. Worn on the body, they provide constant access to computing and communications resources. In general, a wearable computer may be defined as a computer that is subsumed into the personal space of the user, controlled by the wearer and has both operational and interactional constancy, i.e. is always on and always accessible [1]. Wearables are typically composed of a belt or back pack PC, see-though or see-around head mounted display (HMD), wireless communications hardware and an input device such as touchpad or chording keyboard. This configuration has been demonstrated in a number of real world applications including aircraft maintenance [2], navigational assistance [3] and vehicle mechanics [4]. In such applications wearables have dramatically improved user performance, halving task time in the case of vehicle inspection [4].

Many of the target application areas are those where the user could benefit from expert assistance. Network enabled wearable computers can be used as a communications device to enable remote experts to collaborate with the wearable user. In such situations the presence of remote experts have been found to significantly improve task performance [5], [6]. For example, Kuzuoka finds that a head mounted camera and display increases interaction efficiency in a remote collaborative object manipulation task [7]. However, most current collaborative wearable applications have only involved connections between one local and one remote user. The problem we are interested in is how a wearable computer can be used to support collaboration between multiple remote people. In particular we want to explore the following issues:

- What visual and audio enhancements can be used to aid communication?
- How can a collaborative communications space be created between users?
- How can remote users be represented in a wearable computing environment?

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These issues are becoming increasingly important as telephones incorporate more computing power and portable computers become more like telephones. A key issue is whether we need computer-mediated communication at all when a conference phone call may be just as effective. Prior work in the fields of teleconferencing and computer supported collaborative work addresses this question.

2: Background

Research on the roles of audio and visual cues in teleconferencing has produced mixed results. There have been many experiments conducted comparing face-to-face, audio and video, and audio only communication conditions. Sellen summarizes these by reporting that the main effect on collaborative performance is due to whether the collaboration was technologically mediated or not, not on the type of technology mediation used [8]. While people generally do not prefer the audio only condition, they are often able to perform tasks as effectively as in the audio and video condition, although in both cases they perform worse than face-to-face collaboration. Naturally this varies somewhat according to task. While face-to-face interaction is no better than speech-only for cognitive problem solving tasks [9], visual cues can be important in tasks requiring negotiation [10]. In general, the usefulness of video for transmitting non-verbal cues may be overestimated and video may be better used to show the communication availability of others or views of shared workspaces [11]. Even when users attempt non-verbal communication in a video conferencing environment their gestures must be exaggerated to be recognized as the equivalent face-to-face gestures [12].

Based on these results, and the fact that speech is the critical medium in teleconferencing experiments [13], it may be thought that audio alone should be suitable for a creating a shared communication space. An example of this, Thunderwire [14], was a purely audio system which allowed high quality audio conferencing between multiple participants at the flip of a switch. In a 3 month trial Hindus et. al. found that audio can be sufficient for a usable communication space. However several major problems were observed:

- Users were not able to easily tell who else was within the space.
- Users were not able to use visual cues to determine other's willingness to interact.

With more users it becomes increasingly difficult to discriminate between speakers and there is a higher incidence of speaker overlap and interruptions. These problems are typical of audio only spaces and suggest that while audio may be useful for small group interactions, it becomes less usable the more people present.

These shortcomings can be overcome through the use of visual and spatial cues. In face-to-face conversation, speech, gesture, body language and other non-verbal cues combine to show attention and interest. Simple versions of these cues can be replicated in desktop video conferencing. For example, the Passepartout [15] enhanced desktop conferencing tool includes visual representation of a conference table alongside shared documents and a text chat facility. The conference table includes icons of those people within the conference and simple cues, such as microphone on/off, which allow a participant's activity or interest to be inferred. However the absence of spatial cues in most video conferencing systems means that users often find it difficult to know when people are paying attention to them, to hold side conversations, and to establish eye contact [16].

Several video conferencing systems have attempted to provide spatial cues. The Hydra system uses multiple small monitors, one for each participant, positioned about the local user [17]. The user can easily attend to individual participants by turning to face the appropriate monitor and side conversations can be supported. The MAJIC system uses several wall projectors and a one way transmissive screen to create the illusion of several remote life-sized participants seated around the same real table [18]. Users can make eye contact and conduct parallel conversations. The MPEC prototype also supports spatial video conferencing and multi-party eye contact [19]. However a common disadvantage of these systems is that the users cannot control remote camera position and so their viewpoint and spatial relationships to the other participants is fixed, unlike in face-to-face collaboration. There are also many technical problems to be overcome before such systems scale to support large groups of participants.

Virtual reality can provide an alternative medium that allows groups of people to share the same communications space. British Telecom has demonstrated virtual conferencing in which many users can be represented as life like virtual avatars of themselves within virtual rooms [20]. Users can freely move through the space setting their own viewpoints and spatial relationships. In collaborative virtual environments (CVEs) spatial visual and audio cues can combine in natural ways to aid communication [21]. The well known "cocktail-party" effect shows that people can easily

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monitor several spatialized audio streams at once, selectively focusing on those of interest [22], [23]. Even a simple virtual avatar representation and spatial audio model enables users to discriminate between multiple speakers [24]. Spatialized interactions are particularly valuable for governing interactions between large groups of people; enabling crowds of people to inhabit the same virtual environment and interact in a way impossible in traditional video or audio conferencing [25].

3: A Wearable Communication Space

The results in the previous section suggest that an ideal wearable communications space should have three elements:

- High quality audio communication
- Visual representations of the collaborators
- An underlying spatial metaphor

One of the most important aspects of creating a collaborative communication interface is the visual and audio presentation of information. Most current wearable computers use see-through or see-around monoscopic head mounted displays with stereo headphones. With these displays information can be presented in a combination of three ways:

Head-stabilized - information is fixed to the users viewpoint and doesn't change as the user changes viewpoint orientation or position.

Body-stabilized - information is fixed relative to the users body position and varies as the user changes viewpoint orientation, but not as they change position. This requires the users viewpoint orientation to be tracked.

World-stabilized - information is fixed to real world locations and varies as the user changes viewpoint orientation and position. This requires the users viewpoint position and orientation to be tracked.

Body and World stabilized information display is attractive for a number of reasons. As Reichlen [26] demonstrates, a body-stabilized information space can overcome the resolution limitations of head mounted displays. In his work a user wears a head mounted display while seated on a rotating chair. By tracking head orientation the user experiences a hemispherical information surround - in effect a "hundred million pixel display". World-stabilized information presentation enables annotation of the real world with context dependent visual and audio data, creating information enriched environments [27]. This increases the intuitiveness of real world tasks. Despite these advantages, most current wearables only use head-stabilized information display.

In our work we have chosen to begin with the simplest form of body-stabilized display; one which uses one degree of orientation to give the user the impression they are surrounded by a virtual cylinder of visual and auditory information. Figures 1.0a and 1.0b contrast this with the traditional head stabilized wearable interface.



Figure 1.0a Head Stabilized Information Display



Figure 1.0b One Degree of Freedom Body-Stabilized Display

When using a head mounted display to navigate a cylindrical body-stabilized space, only the portion of the information space in its field of view can be seen. There are two ways the rest of the space can be viewed; by rotating the information space about the user's head, or tracking the user's head orientation as they look around the space. The first requires no additional hardware and

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can be done by mapping mouse, switch or voice input to direction and angle of rotation, while the second requires only a simple one degree of freedom tracker. The minimal hardware requirements make cylindrical spatial information displays particularly attractive. The cylindrical display is also very natural to use since most head and body motion is about the vertical axis, making it very difficult for the user to become disoriented.

In a previous paper we have found that users can locate information more rapidly with this type of information display than the more traditional head-stabilized wearable information space [28]. Sawhney and Schmandt also demonstrate how body-stabilized spatial audio can improve access to audio information on a wearable platform, allowing a user to browse up to three simultaneous audio streams [29].

With this display configuration a wearable conferencing space could be created that allows remote collaborators appear as virtual avatars distributed about the user (figure 2.0). The avatars could be live video streams and as they speak their audio streams spatialized in real time so that they appear to emit from the corresponding avatar.



Figure 2.0 A Spatial Conferencing Space.

Just as in face-to-face collaboration, users could turn to face the collaborators they wanted to talk to while still being aware of the other conversations taking place. The user could also move about the space enabling them to choose their own viewpoint and the spatial relationships between the collaborators. In this way the space could support dozens of simultaneous users, similar to current collaborative virtual environments. Since the displays are see-through or see-around the user could also see the real world at the same time, enabling the remote collaborators to help them with real world tasks. These remote users may also be using wearable computers and head mounted displays or could be interacting through a desktop workstation. The wearable conferencing space would also allow the faces of remote users to appear life-size, a crucial factor for establishing equal relationships in remote collaboration [30].

The technical requirements for such a conferencing space place it several years in the future, however in the remainder of this paper we describe a prototype we have developed which has many of the same features.

4: Implementation

Our research is initially focused on collaboration between a single wearable computer user and several desktop PC users. This situation might be encountered when a wearable user in the field is requesting help from remote deskbound experts. The aim is to develop a wearable interface to support medium sized meetings (5-6 people) in a manner that is natural and intuitive to use.

4.1: Hardware

The wearable computer we use is a custom built 586 PC 104 based computer with 20mb of RAM running Windows 95. Figure 3.0 shows a user wearing the display and computer.



Figure 3.0 The Wearable Hardware.

A hand held Logitech wireless radio trackball with three buttons is used as the primary input device. The display is a pair of Virtual i-O iglasses! converted into a monoscopic display by the removal of the left eyepiece.

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The Virtual i-O head mounted display can either be used in see-through or occluded mode, has a resolution of 262 by 230 pixels and a 26-degree field of view. The iglasses! also have a sourceless two-axis inclinometer and a magnetometer used as a three degree of freedom orientation tracker. A BreezeCom wireless LAN is used to give 2mb/s Internet access up to 500 feet from a base station. The wearable also has a soundBlaster compatible sound board with headmounted microphone. The desktop PCs are standard Pentium class machines with Internet connectivity and sound capability.

4.2: The Wearable Interface

Our wearable computer has no graphics acceleration hardware and limited wireless bandwidth so the interface is deliberately kept simple. The conferencing space runs as a full screen application that is initially blank until remote users connect. When users join the conferencing space they are represented by blocks with 128x128 pixel texture mapped static pictures of themselves on them. Each user determines the position and orientation of their own avatar in space, which changes as they move or look about environment. Although the resolution of the images is crude it is sufficient to identify who the speakers are and more importantly their spatial relationship to the wearable user. It is hoped that in the near future wearable computer CPU power and wireless bandwidth will be sufficient to support real time video texture mapping.

The wearable user has their head tracked so they can simply turn to face the speakers they are interested in. Users can also navigate through the space; by rolling the trackball forwards or backwards their viewpoint is moved forwards or backwards along the direction they are looking. Since the virtual images are superimposed on the real world, when the user rolls the trackball it appears to them as though they are moving the virtual space around them, rather than navigating through the space. Users are constrained to change viewpoint on the horizontal plane, just as in face-to-face conversations. The two different navigation methods (trackball motion, head tracking), match the different types of motion used in face to face communication; walking to join a join a group for conversation, and body orientation changes within a conversational group.

A radar display shows the location of the other users in the conferencing space, enabling users to find each other easily. Figure 4.0 shows the wearable interface from the wearable user's perspective. The interface was developed using Microsoft's Direct3D, DirectDraw and DirectInput libraries from the DirectX suite.

The wearable interface also supports 3D spatialized Internet telephony. When users connect to the conferencing space their audio is broadcast to all the other users in the space. This is spatialized according to the distance and direction between speaker and listener. As users face or move closer to different speakers the speaker volume changes due to the sound spatialisation. Since the speakers are constrained to remain in the same plane as the listener the audio spatialisation is considerably simplified. Audio culling is also used so that only the audio streams from the speakers closest to the listener are broadcast and spatialized. This significantly reduces the CPU load. The conferencing space uses custom developed telephony libraries that incorporate the Microsoft Direct Sound libraries.

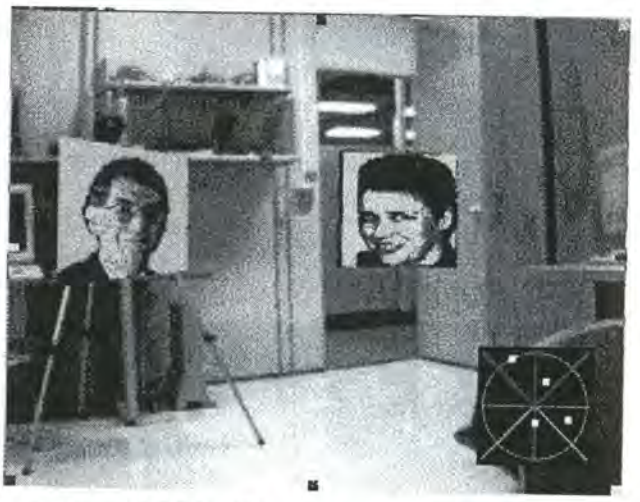


Figure 4.0 The User's View of the Wearable Conferencing Space

4.3: The Desktop interface

Users at a desktop workstation interact with the conferencing space through a similar interface as the wearable user, although in this case the application runs as a Windows application on the desktop. Users navigate through the space using the mouse. Mouse movements rotate head position when the left mouse button is held down, otherwise they translate the user backwards and forwards in space. Mapping avatar orientation to mouse movement means that the desktop interface is not quite as intuitive as the wearable interface. Users at the desktop machine wear headmounted microphones to talk into the conferencing space and listen through stereo headphones. Just as with the wearable interface, desktop users are aware of the spatial relationships between participants. When a participant turns and talks to someone else, the desktop user sees their avatar turn and face the person they're talking to.

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5: Distributed Software Architecture

The wearable and desktop interfaces are based around custom libraries for collaborative virtual environments being developed at British Telecom. When the wearable and desktop client applications are run TCP/IP multicast groups are created that enable the clients to communicate with each other through multicast sockets. The multicast protocol is an efficient mechanism for broadcasting data to multiple network nodes [31] and has been shown to scale well in large CVEs [32].

Communications within the conferencing space are routed through one of two multicast groups, as shown in figure 5.0. One is for transformational data representing an avatar's position and orientation plus any messaging data and the second for audio data. When users connect to the communication space they are assigned a unique identification tag, (ID). As a user moves through the space, their avatar's ID tag, positional and orientation information is broadcast onto the transformation multicast group. This transformational data flows at a rate of 10.0Kb/s per user. When received by each client in the group it is used to update the relevant avatar's position and orientation. The transformational information is also used in spatialising the user's audio stream relevant to the receiving user's position.

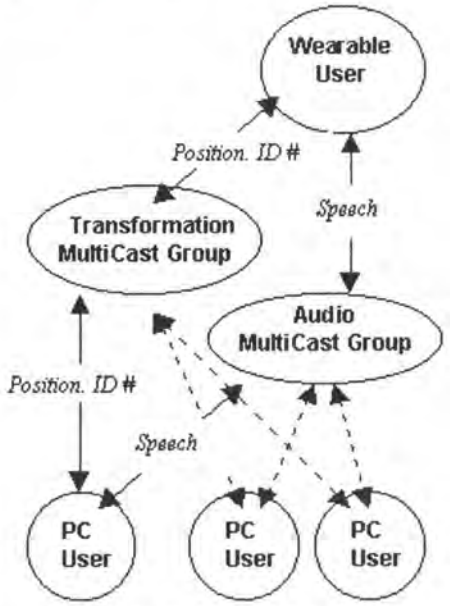


Figure 5.0 Distributed Software Architecture

Similarly when a user speaks, their speech is digitized and broadcast to the audio multicast group. When received by the other clients the senders IP address identifies the avatar that the audio belongs to and its position and orientation. The audio is then spatialized in real time. The audio is implemented utilizing Microsoft's Direct Sound technology. This allows for the capture of audio to a buffer, which can then be broadcast over the audio multicast group. Once received at a client computer the buffer can be played back through Direct Sound. In order for the audio to operate in full duplex mode it has to be captured at a rate of 8 bit 22KHz, resulting in a data rate 172Kb/s. All connections to the multicast groups are bi-directional and users can connect and disconnect at will without affecting other users in the conferencing space.

6: Initial User Experiences

In developing a wearable conferencing space we set out to explore the usefulness of spatial visual and audio cues compared to traditional portable communications devices, namely audio only collaboration with a mobile phone. We are in the process of conducting user trials to evaluate how the use of spatialized audio and visual representations affects communication between collaborators. Preliminary informal trials have found the following results:

Users are able to easily discriminate between three simultaneous speakers when their audio streams are spatialized, but not when non-spatialized audio is used. It is expected that this effect will become even more noticeable as the number of simultaneous participants is increased.

Participants preferred seeing a visual representation of their collaborators as opposed to just hearing their speech. Even though it was relatively poor quality the visual representation enabled them to see who is connected and the spatial relationship of the speakers. This allowed them to use some of the non-verbal cues commonly used in face-to-face communication such as gaze modulation and body motion. The radar display was useful for finding collaborators that were far away and barely visible.

Users found that they could continue doing real world tasks while talking to collaborators in the conferencing space and it was possible to move the conferencing space with the trackball so that collaborators weren't blocking critical portions of the users field of view.

The interface is easy and intuitive to use, although using the head tracking on the wearable was easier than the mouse only desktop interface.

However, as more users connect to the conferencing space the need to spatialize multiple audio streams puts a

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severe load on the CPU, slowing down the graphics and head tracking. This makes it difficult for the wearable user to conference with more than two or three people simultaneously. This problem will be reduced as faster CPUs and hardware support for 3D graphics become available for wearable computers. More severe spatial culling of the audio streams could also be used to overcome this limitation, through the coagulation of selected streams into a single spatial location, or removing the audio altogether.

7: Conclusions

We have presented a prototype wearable communication space that uses spatial visual and audio cues to enhance communication between remote groups of people. Our interface shows what is possible when computing and communications facilities are coupled together on a wearable platform. Preliminary results have found that users prefer using both the audio and visual cues together and that spatialized audio makes it easy for users to discriminate between speakers. This suggests that for some applications wearable computers may provide a useful alternative to traditional audio-only communication devices. We are currently conducting formal user studies to confirm these results and evaluate the effect of spatial cues on communication patterns. In the future we plan to investigate how the presence of spatialized video can further enhance communication. We will incorporate live video texture mapping into our interface, enabling users to see their remote collaborators as they speak. This will also allow users to send views of their workspace, improving collaboration on real-world tasks.

We believe that a wearable communications space can be used to support numerous collaborative applications in which some participants are either not sitting at desks or need mobility. A shared virtual environment facilitates audiovisual communications for groups of people with the added potential for embedded graphical, textual or audio information. A specific trait that we believe to be particularly important is that in an augmented communications space it is possible for the user to form effective cognitive maps by associating the annotated information with physical objects within their surroundings. We have demonstrated a body-stabilized system in which the communications space is located relative to the user themselves. With the ability to explicitly position object in the communications space relative to the user's real world location an exciting range of applications become possible. A user could, for example, choose to view avatars of conference participants overlaid and attached to a physical notice board. This represents a powerful vision of conferencing for all platforms; with remote video conferencing participants not in separate windows on a screen but spread around the user's environment, positioned in space where the user prefers.

8: Acknowledgements

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Appendix 1010C



CONFERENCE PROCEEDING

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Subjects	Portable computers -- Congresses > Mobile computing -- Congresses >
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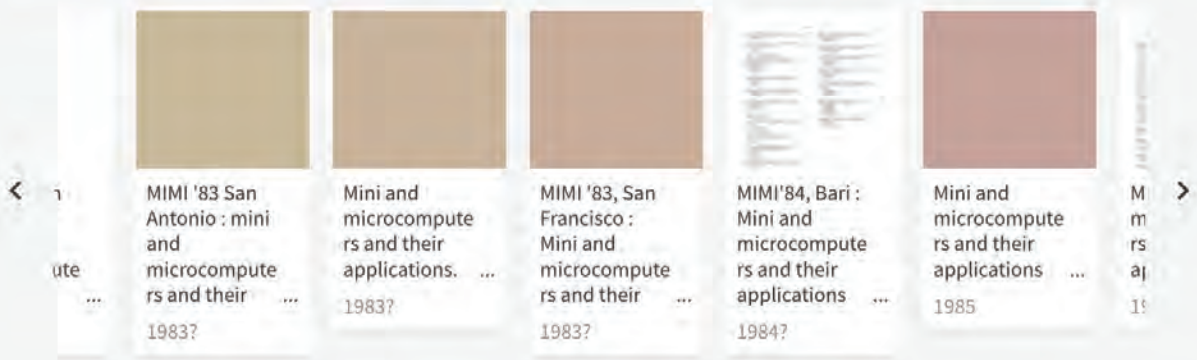
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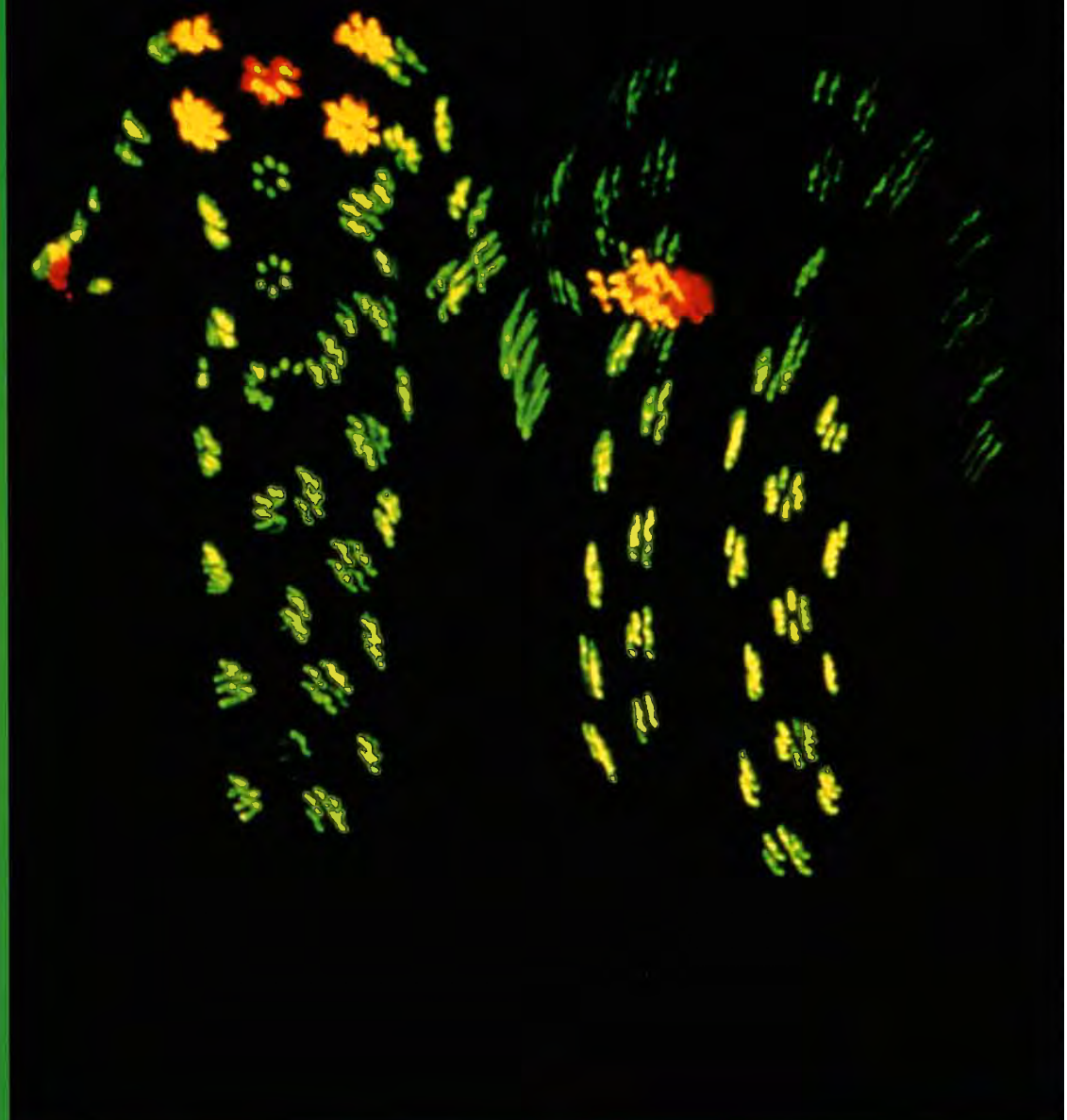
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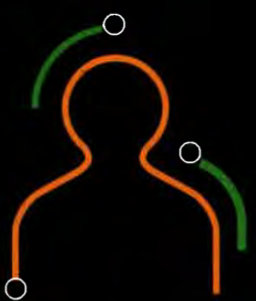
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October 19-20, 1998
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A Wearable Spatial Conferencing Space

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Abstract

Wearable computers provide constant access to computing and communications resources. In this paper we describe how the computing power of wearables can be used to provide spatialized 3D graphics and audio cues to aid communication. The result is a wearable augmented reality communication space with audio enabled avatars of the remote collaborators surrounding the user. The user can use natural head motions to attend to the remote collaborators, can communicate freely while being aware of other side conversations and can move through the communication space. In this way the conferencing space can support dozens of simultaneous users. Informal user studies suggest that wearable communication spaces may offer several advantages, both through the increase in the amount of information it is possible to access and the naturalness of the interface.

1: Introduction

One of the broad trends emerging in human-computer interaction is the increasing portability of computing and communication facilities. However it remains an open question as to how computing can best be used to aid mobile communication.

Wearable computers are the most recent generation of portable machines. Worn on the body, they provide constant access to computing and communications resources. In general, a wearable computer may be defined as a computer that is subsumed into the personal space of the user, controlled by the wearer and has both operational and interactional constancy, i.e. is always on and always accessible [1]. Wearables are typically composed of a belt or back pack PC, see-though or see-around head mounted display (HMD), wireless communications hardware and an input device such as touchpad or chording keyboard. This configuration has been demonstrated in a number of real world applications including aircraft maintenance [2], navigational assistance [3] and vehicle mechanics [4]. In such applications wearables have dramatically improved user performance, halving task time in the case of vehicle inspection [4].

Many of the target application areas are those where the user could benefit from expert assistance. Network enabled wearable computers can be used as a communications device to enable remote experts to collaborate with the wearable user. In such situations the presence of remote experts have been found to significantly improve task performance [5], [6]. For example, Kuzuoka finds that a head mounted camera and display increases interaction efficiency in a remote collaborative object manipulation task [7]. However, most current collaborative wearable applications have only involved connections between one local and one remote user. The problem we are interested in is how a wearable computer can be used to support collaboration between multiple remote people. In particular we want to explore the following issues:

- What visual and audio enhancements can be used to aid communication?
- How can a collaborative communications space be created between users?
- How can remote users be represented in a wearable computing environment?

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These issues are becoming increasingly important as telephones incorporate more computing power and portable computers become more like telephones. A key issue is whether we need computer-mediated communication at all when a conference phone call may be just as effective. Prior work in the fields of teleconferencing and computer supported collaborative work addresses this question.

2: Background

Research on the roles of audio and visual cues in teleconferencing has produced mixed results. There have been many experiments conducted comparing face-to-face, audio and video, and audio only communication conditions. Sellen summarizes these by reporting that the main effect on collaborative performance is due to whether the collaboration was technologically mediated or not, not on the type of technology mediation used [8]. While people generally do not prefer the audio only condition, they are often able to perform tasks as effectively as in the audio and video condition, although in both cases they perform worse than face-to-face collaboration. Naturally this varies somewhat according to task. While face-to-face interaction is no better than speech-only for cognitive problem solving tasks [9], visual cues can be important in tasks requiring negotiation [10]. In general, the usefulness of video for transmitting non-verbal cues may be overestimated and video may be better used to show the communication availability of others or views of shared workspaces [11]. Even when users attempt non-verbal communication in a video conferencing environment their gestures must be exaggerated to be recognized as the equivalent face-to-face gestures [12].

Based on these results, and the fact that speech is the critical medium in teleconferencing experiments [13], it may be thought that audio alone should be suitable for a creating a shared communication space. An example of this, Thunderwire [14], was a purely audio system which allowed high quality audio conferencing between multiple participants at the flip of a switch. In a 3 month trial Hindus et. al. found that audio can be sufficient for a usable communication space. However several major problems were observed:

- Users were not able to easily tell who else was within the space.
- Users were not able to use visual cues to determine other's willingness to interact.

With more users it becomes increasingly difficult to discriminate between speakers and there is a higher incidence of speaker overlap and interruptions. These problems are typical of audio only spaces and suggest that while audio may be useful for small group interactions, it becomes less usable the more people present.

These shortcomings can be overcome through the use of visual and spatial cues. In face-to-face conversation, speech, gesture, body language and other non-verbal cues combine to show attention and interest. Simple versions of these cues can be replicated in desktop video conferencing. For example, the Passepartout [15] enhanced desktop conferencing tool includes visual representation of a conference table alongside shared documents and a text chat facility. The conference table includes icons of those people within the conference and simple cues, such as microphone on/off, which allow a participant's activity or interest to be inferred. However the absence of spatial cues in most video conferencing systems means that users often find it difficult to know when people are paying attention to them, to hold side conversations, and to establish eye contact [16].

Several video conferencing systems have attempted to provide spatial cues. The Hydra system uses multiple small monitors, one for each participant, positioned about the local user [17]. The user can easily attend to individual participants by turning to face the appropriate monitor and side conversations can be supported. The MAJIC system uses several wall projectors and a one way transmissive screen to create the illusion of several remote life-sized participants seated around the same real table [18]. Users can make eye contact and conduct parallel conversations. The MPEC prototype also supports spatial video conferencing and multi-party eye contact [19]. However a common disadvantage of these systems is that the users cannot control remote camera position and so their viewpoint and spatial relationships to the other participants is fixed, unlike in face-to-face collaboration. There are also many technical problems to be overcome before such systems scale to support large groups of participants.

Virtual reality can provide an alternative medium that allows groups of people to share the same communications space. British Telecom has demonstrated virtual conferencing in which many users can be represented as life like virtual avatars of themselves within virtual rooms [20]. Users can freely move through the space setting their own viewpoints and spatial relationships. In collaborative virtual environments (CVEs) spatial visual and audio cues can combine in natural ways to aid communication [21]. The well known "cocktail-party" effect shows that people can easily

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monitor several spatialized audio streams at once, selectively focusing on those of interest [22], [23]. Even a simple virtual avatar representation and spatial audio model enables users to discriminate between multiple speakers [24]. Spatialized interactions are particularly valuable for governing interactions between large groups of people; enabling crowds of people to inhabit the same virtual environment and interact in a way impossible in traditional video or audio conferencing [25].

3: A Wearable Communication Space

The results in the previous section suggest that an ideal wearable communications space should have three elements:

- High quality audio communication
- Visual representations of the collaborators
- An underlying spatial metaphor

One of the most important aspects of creating a collaborative communication interface is the visual and audio presentation of information. Most current wearable computers use see-through or see-around monoscopic head mounted displays with stereo headphones. With these displays information can be presented in a combination of three ways:

Head-stabilized - information is fixed to the users viewpoint and doesn't change as the user changes viewpoint orientation or position.

Body-stabilized - information is fixed relative to the users body position and varies as the user changes viewpoint orientation, but not as they change position. This requires the users viewpoint orientation to be tracked.

World-stabilized - information is fixed to real world locations and varies as the user changes viewpoint orientation and position. This requires the users viewpoint position and orientation to be tracked.

Body and World stabilized information display is attractive for a number of reasons. As Reichlen [26] demonstrates, a body-stabilized information space can overcome the resolution limitations of head mounted displays. In his work a user wears a head mounted display while seated on a rotating chair. By tracking head orientation the user experiences a hemispherical information surround - in effect a "hundred million pixel display". World-stabilized information presentation enables annotation of the real world with context dependent visual and audio data, creating information enriched environments [27]. This increases the intuitiveness of real world tasks. Despite these advantages, most current wearables only use head-stabilized information display.

In our work we have chosen to begin with the simplest form of body-stabilized display; one which uses one degree of orientation to give the user the impression they are surrounded by a virtual cylinder of visual and auditory information. Figures 1.0a and 1.0b contrast this with the traditional head stabilized wearable interface.

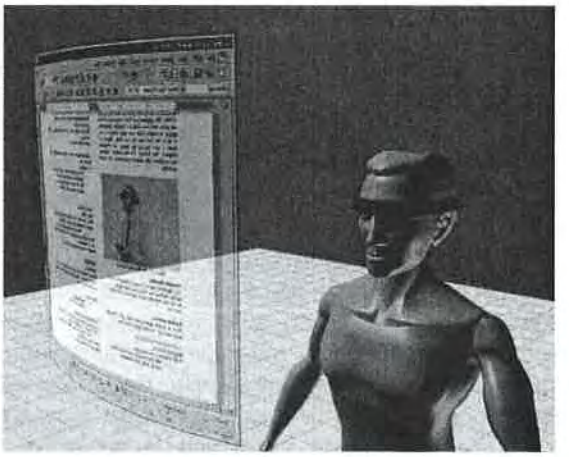


Figure 1.0a Head Stabilized Information Display



Figure 1.0b One Degree of Freedom Body-Stabilized Display

When using a head mounted display to navigate a cylindrical body-stabilized space, only the portion of the information space in its field of view can be seen. There are two ways the rest of the space can be viewed; by rotating the information space about the user's head, or tracking the user's head orientation as they look around the space. The first requires no additional hardware and

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can be done by mapping mouse, switch or voice input to direction and angle of rotation, while the second requires only a simple one degree of freedom tracker. The minimal hardware requirements make cylindrical spatial information displays particularly attractive. The cylindrical display is also very natural to use since most head and body motion is about the vertical axis, making it very difficult for the user to become disoriented.

In a previous paper we have found that users can locate information more rapidly with this type of information display than the more traditional head-stabilized wearable information space [28]. Sawhney and Schmandt also demonstrate how body-stabilized spatial audio can improve access to audio information on a wearable platform, allowing a user to browse up to three simultaneous audio streams [29].

With this display configuration a wearable conferencing space could be created that allows remote collaborators appear as virtual avatars distributed about the user (figure 2.0). The avatars could be live video streams and as they speak their audio streams spatialized in real time so that they appear to emit from the corresponding avatar.

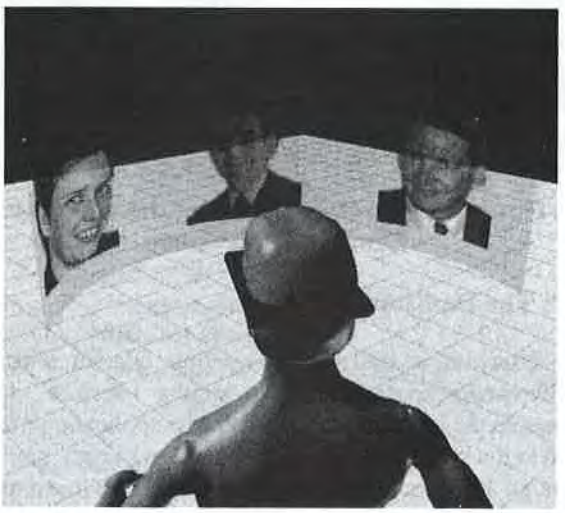


Figure 2.0 A Spatial Conferencing Space.

Just as in face-to-face collaboration, users could turn to face the collaborators they wanted to talk to while still being aware of the other conversations taking place. The user could also move about the space enabling them to choose their own viewpoint and the spatial relationships between the collaborators. In this way the space could support dozens of simultaneous users, similar to current collaborative virtual environments. Since the displays are see-through or see-around the user could also see the real world at the same time, enabling the remote collaborators to help them with real world tasks. These remote users may also be using wearable computers and head mounted displays or could be interacting through a desktop workstation. The wearable conferencing space would also allow the faces of remote users to appear life-size, a crucial factor for establishing equal relationships in remote collaboration [30].

The technical requirements for such a conferencing space place it several years in the future, however in the remainder of this paper we describe a prototype we have developed which has many of the same features.

4: Implementation

Our research is initially focused on collaboration between a single wearable computer user and several desktop PC users. This situation might be encountered when a wearable user in the field is requesting help from remote deskbound experts. The aim is to develop a wearable interface to support medium sized meetings (5-6 people) in a manner that is natural and intuitive to use.

4.1: Hardware

The wearable computer we use is a custom built 586 PC 104 based computer with 20mb of RAM running Windows 95. Figure 3.0 shows a user wearing the display and computer.



Figure 3.0 The Wearable Hardware.

A hand held Logitech wireless radio trackball with three buttons is used as the primary input device. The display is a pair of Virtual i-O iglasses! converted into a monoscopic display by the removal of the left eyepiece.

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The Virtual i-O head mounted display can either be used in see-through or occluded mode, has a resolution of 262 by 230 pixels and a 26-degree field of view. The iglasses! also have a sourceless two-axis inclinometer and a magnetometer used as a three degree of freedom orientation tracker. A BreezeCom wireless LAN is used to give 2mb/s Internet access up to 500 feet from a base station. The wearable also has a soundBlaster compatible sound board with headmounted microphone. The desktop PCs are standard Pentium class machines with Internet connectivity and sound capability.

4.2: The Wearable Interface

Our wearable computer has no graphics acceleration hardware and limited wireless bandwidth so the interface is deliberately kept simple. The conferencing space runs as a full screen application that is initially blank until remote users connect. When users join the conferencing space they are represented by blocks with 128x128 pixel texture mapped static pictures of themselves on them. Each user determines the position and orientation of their own avatar in space, which changes as they move or look about environment. Although the resolution of the images is crude it is sufficient to identify who the speakers are and more importantly their spatial relationship to the wearable user. It is hoped that in the near future wearable computer CPU power and wireless bandwidth will be sufficient to support real time video texture mapping.

The wearable user has their head tracked so they can simply turn to face the speakers they are interested in. Users can also navigate through the space; by rolling the trackball forwards or backwards their viewpoint is moved forwards or backwards along the direction they are looking. Since the virtual images are superimposed on the real world, when the user rolls the trackball it appears to them as though they are moving the virtual space around them, rather than navigating through the space. Users are constrained to change viewpoint on the horizontal plane, just as in face-to-face conversations. The two different navigation methods (trackball motion, head tracking), match the different types of motion used in face to face communication; walking to join a join a group for conversation, and body orientation changes within a conversational group.

A radar display shows the location of the other users in the conferencing space, enabling users to find each other easily. Figure 4.0 shows the wearable interface from the wearable user's perspective. The interface was developed using Microsoft's Direct3D, DirectDraw and DirectInput libraries from the DirectX suite.

The wearable interface also supports 3D spatialized Internet telephony. When users connect to the conferencing space their audio is broadcast to all the other users in the space. This is spatialized according to the distance and direction between speaker and listener. As users face or move closer to different speakers the speaker volume changes due to the sound spatialisation. Since the speakers are constrained to remain in the same plane as the listener the audio spatialisation is considerably simplified. Audio culling is also used so that only the audio streams from the speakers closest to the listener are broadcast and spatialized. This significantly reduces the CPU load. The conferencing space uses custom developed telephony libraries that incorporate the Microsoft Direct Sound libraries.

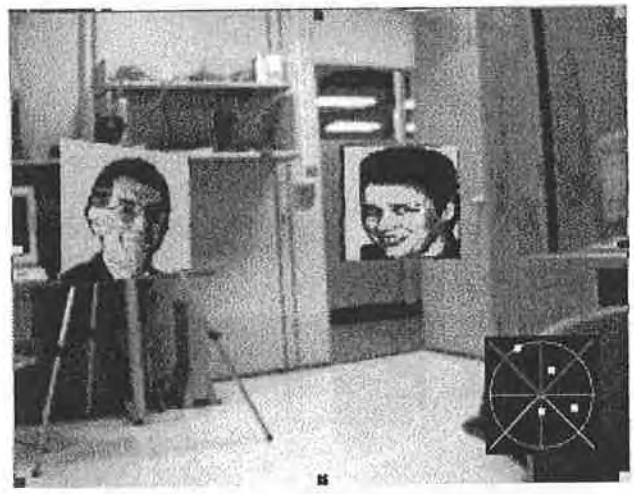


Figure 4.0 The User's View of the Wearable Conferencing Space

4.3: The Desktop interface

Users at a desktop workstation interact with the conferencing space through a similar interface as the wearable user, although in this case the application runs as a Windows application on the desktop. Users navigate through the space using the mouse. Mouse movements rotate head position when the left mouse button is held down, otherwise they translate the user backwards and forwards in space. Mapping avatar orientation to mouse movement means that the desktop interface is not quite as intuitive as the wearable interface. Users at the desktop machine wear headmounted microphones to talk into the conferencing space and listen through stereo headphones. Just as with the wearable interface, desktop users are aware of the spatial relationships between participants. When a participant turns and talks to someone else, the desktop user sees their avatar turn and face the person they're talking to.

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5: Distributed Software Architecture

The wearable and desktop interfaces are based around custom libraries for collaborative virtual environments being developed at British Telecom. When the wearable and desktop client applications are run TCP/IP multicast groups are created that enable the clients to communicate with each other through multicast sockets. The multicast protocol is an efficient mechanism for broadcasting data to multiple network nodes [31] and has been shown to scale well in large CVEs [32].

Communications within the conferencing space are routed through one of two multicast groups, as shown in figure 5.0. One is for transformational data representing an avatar's position and orientation plus any messaging data and the second for audio data. When users connect to the communication space they are assigned a unique identification tag, (ID). As a user moves through the space, their avatar's ID tag, positional and orientation information is broadcast onto the transformation multicast group. This transformational data flows at a rate of 10.0Kb/s per user. When received by each client in the group it is used to update the relevant avatar's position and orientation. The transformational information is also used in spatialising the user's audio stream relevant to the receiving user's position.

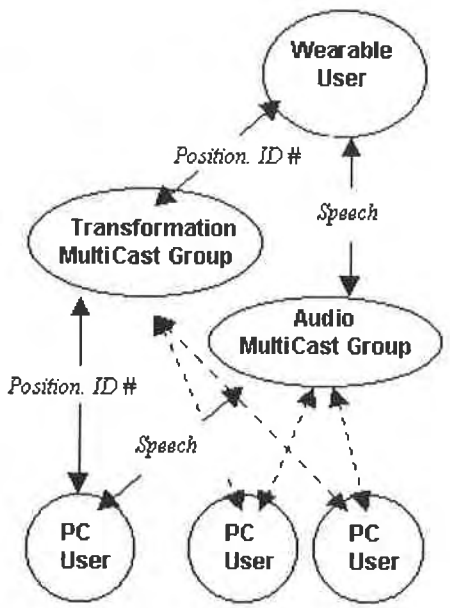


Figure 5.0 Distributed Software Architecture

Similarly when a user speaks, their speech is digitized and broadcast to the audio multicast group. When received by the other clients the senders IP address identifies the avatar that the audio belongs to and its position and orientation. The audio is then spatialized in real time. The audio is implemented utilizing Microsoft's Direct Sound technology. This allows for the capture of audio to a buffer, which can then be broadcast over the audio multicast group. Once received at a client computer the buffer can be played back through Direct Sound. In order for the audio to operate in full duplex mode it has to be captured at a rate of 8 bit 22KHz, resulting in a data rate 172Kb/s. All connections to the multicast groups are bi-directional and users can connect and disconnect at will without affecting other users in the conferencing space.

6: Initial User Experiences

In developing a wearable conferencing space we set out to explore the usefulness of spatial visual and audio cues compared to traditional portable communications devices, namely audio only collaboration with a mobile phone. We are in the process of conducting user trials to evaluate how the use of spatialized audio and visual representations affects communication between collaborators. Preliminary informal trials have found the following results:

Users are able to easily discriminate between three simultaneous speakers when their audio streams are spatialized, but not when non-spatialized audio is used. It is expected that this effect will become even more noticeable as the number of simultaneous participants is increased.

Participants preferred seeing a visual representation of their collaborators as opposed to just hearing their speech. Even though it was relatively poor quality the visual representation enabled them to see who is connected and the spatial relationship of the speakers. This allowed them to use some of the non-verbal cues commonly used in face-to-face communication such as gaze modulation and body motion. The radar display was useful for finding collaborators that were far away and barely visible.

Users found that they could continue doing real world tasks while talking to collaborators in the conferencing space and it was possible to move the conferencing space with the trackball so that collaborators weren't blocking critical portions of the users field of view.

The interface is easy and intuitive to use, although using the head tracking on the wearable was easier than the mouse only desktop interface.

However, as more users connect to the conferencing space the need to spatialize multiple audio streams puts a

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severe load on the CPU, slowing down the graphics and head tracking. This makes it difficult for the wearable user to conference with more than two or three people simultaneously. This problem will be reduced as faster CPUs and hardware support for 3D graphics become available for wearable computers. More severe spatial culling of the audio streams could also be used to overcome this limitation, through the coagulation of selected streams into a single spatial location, or removing the audio altogether.

7: Conclusions

We have presented a prototype wearable communication space that uses spatial visual and audio cues to enhance communication between remote groups of people. Our interface shows what is possible when computing and communications facilities are coupled together on a wearable platform. Preliminary results have found that users prefer using both the audio and visual cues together and that spatialized audio makes it easy for users to discriminate between speakers. This suggests that for some applications wearable computers may provide a useful alternative to traditional audio-only communication devices. We are currently conducting formal user studies to confirm these results and evaluate the effect of spatial cues on communication patterns. In the future we plan to investigate how the presence of spatialized video can further enhance communication. We will incorporate live video texture mapping into our interface, enabling users to see their remote collaborators as they speak. This will also allow users to send views of their workspace, improving collaboration on real-world tasks.

We believe that a wearable communications space can be used to support numerous collaborative applications in which some participants are either not sitting at desks or need mobility. A shared virtual environment facilitates audiovisual communications for groups of people with the added potential for embedded graphical, textual or audio information. A specific trait that we believe to be particularly important is that in an augmented communications space it is possible for the user to form effective cognitive maps by associating the annotated information with physical objects within their surroundings. We have demonstrated a body-stabilized system in which the communications space is located relative to the user themselves. With the ability to explicitly position object in the communications space relative to the user's real world location an exciting range of applications become possible. A user could, for example, choose to view avatars of conference participants overlaid and attached to a physical notice board. This represents a powerful vision of conferencing for all platforms; with remote video conferencing participants not in separate windows on a screen but spread around the user's environment, positioned in space where the user prefers.

8: Acknowledgements

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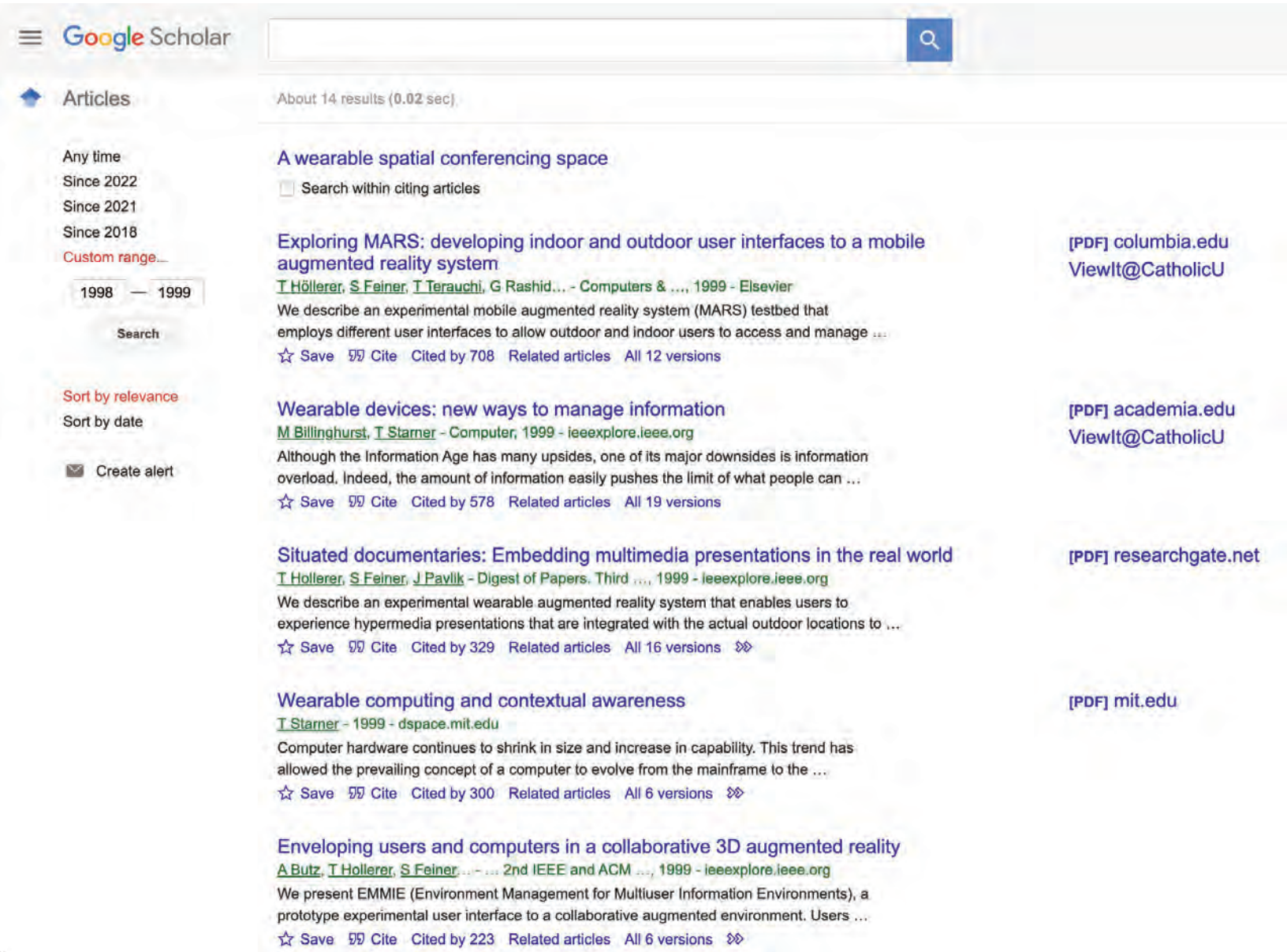
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An experimental study on the role of software synthesized 3D sound in augmented reality environments

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Abstract

Investigation of augmented reality (AR) environments has become a popular research topic for engineers, computer and cognitive scientists. Although application oriented studies focused on audio AR environments have been published, little work has been done to vigorously study and evaluate the important research questions of the effectiveness of 3D sound in the AR context, and to what extent the addition of 3D sound would contribute to the AR experience.

Thus, we have developed two AR environments and performed vigorous experiments with human subjects to study the effects of 3D sound in the AR context. The study concerns two scenarios. In the first scenario, one participant must use vision only and vision with 3D sound to judge the relative depth of augmented virtual objects. In the second scenario, two participants must co-operate to perform a joint task in a game-based AR environment.

Hence, the goals of this study are (1) to access the impact of 3D sound on depth perception in a single-camera AR environment, (2) to study the impact of 3D sound on task performance and the feeling of 'human presence and collaboration', (3) to better understand the role of 3D sound in human-computer and human–human interactions, (4) to investigate if gender can affect the impact of 3D sound in AR environments. The outcomes of this research can have a useful impact on the development of audio AR systems which provide more immersive, realistic and entertaining experiences by introducing 3D sound. Our results suggest that 3D sound in AR environment significantly improves the accuracy of depth judgment and improves task performance. Our results

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also suggest that 3D sound contributes significantly to the feeling of 'human presence and collaboration' and helps the subjects to 'identify spatial objects'.
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Keywords: 3D sound; Augmented reality; Depth perception; Localization of sound; Task performance; Collaboration; User studies

1. Introduction

Audio feedback, especially 3D sound, has proven itself to be an effective addition to human–computer interfaces in many studies. Sounds can be used to present information that would otherwise be difficult to convey through other means (Gaver et al. 1991). Moreover, 3D sound can convey location information for specific alerts or warnings. Also, 3D sound was reported to increase the immersive experience in virtual reality (VR) environments and hence provide a more realistic virtual environment (Begault 1994). Furthermore, the addition of 3D sound has been shown to increase the performance in active tasks (Wenzel, 1996; Avionique). In previous works, Mereu (1995) suggested that sound could improve depth perception in 3D interfaces. Makino et al. (1996) also indicated that spatialized sound from virtual acoustic display helps fast and accurate navigation. Additionally, simulations by Gaver et al. (1991) suggested that auditory icons can play a significant role in multiprocessing and collaborative system. Unlike VR in which extensive research has been carried on 3D sound, augmented reality (AR) aided by 3D sound is still a relative new research area.

AR, as placed on the reality–virtuality continuum (Milgram et al., 1994), refers to the incorporation of virtual computer graphics objects into a real world scene, or alternatively the inclusion of real world elements into a virtual environment. The former case is generally referred to as AR, and the latter as augmented virtuality. Azuma (1997) has defined three characteristics that are integral to an AR interface. First, it combines the real and the virtual. Second, it is interactive in real time. Third, it is registered in three dimensions. Although AR is often associated with visualization (starting with the first head-mounted display by Sutherland (1968)), augmentation is also possible in the aural domain (Cohen et al., 1993; Mynatt et al., 1997). If we extend this notion to include sonic effects, a real-time registered three dimensional (3D) sound could also be a paradigm of AR applications, and is termed augmented audio reality (AAR) (Cohen et al., 1993).

A few applications have applied 3D sounds in AR to enhance user experiences. Billinghurst et al. (1998) presented a prototype wearable communication space that uses spatial visual and audio cues to enhance communication between remote groups of people. The 'Listen Project' (Eckel et al., 2001) provides users with intuitive access to personalize and situated audio information spaces while they naturally explore everyday environments. It augments the physical environment through a dynamic sound-scape, which users experience over motion-tracked wireless headphones. The 'Magic Music Desk' (Zhou et al., 2002) registered virtual sound sources on fiducial markers from which 3D position information was retrieved by vision-based tracking method (Kato and Billinghurst, 1999). 'Touch space' (Cheok et al., 2004) applied different 3D sounds to represent different

moving avatars in AR environment. Although there are quite a few AAR applications, the effectiveness of 3D sound in AAR has been rarely investigated. The particular research problems and questions that arise are:

1. Exact spatial 3D sound in virtual and augmented environments requires perceptual externalization of the sound source, which can only be brought about by using head related transfer functions (HRTFs) (Bill G, 1994) (these are tuned to each individual), reflections, reverberation, etc. (Wenzel, 1994) which might be too complex to be included in normal real time AR applications (which need to be a real time interactive system for any user without individual training). An alternative way to generate 3D sound is to use open source software development kits (SDKs) which have already incorporated the general HRTFs database and simple model of environment to generate 3D sound. The minimum requirement of these SDKs to generate 3D sound is to update the relative position of the virtual sound source to the head co-ordinate system. Thus, with such sound sources, a problem turns to be how can we track the sound source relative to user's head co-ordinate system.
2. How can we precisely register virtual sound sources in the physical world? More specifically, what kind of tracking method is suitable for obtaining precise position and orientation of the sound source in AR environments?
3. As 3D sound has been reported to improve depth perception (Mereu S, 1995) in 3D interfaces, will this argument stand in AR environment? If so, how can we investigate the effect of 3D sound? For example, what measures can be defined to quantify the performance of depth judgments?
4. Normally the space of AR environments is relatively small, and the attenuation of sound with distance in this small area can be too vague to be perceived. This is because in most 3D sound systems, the intensity of sound (a very strong distance cue) would follow incremental reductions of 6 DB for each successive position of doubled distance (Begault, 1994). This means that for small areas, the 3D sound hardly plays a role to provide a cue to the depth (or the distance of the frontal sound sources). In order to make 3D sound give a cue to depth in a small space, we need to exaggerate the intensity difference of 3D sound according to distance (depth) changes of the virtual sound sources. However, this leads to a new issue, which is to research if this exaggeration will ruin the realistic and immersive feeling which we have been focused on. It needs to be investigated what are the subjective feelings on this exaggeration to the human.
5. Does 3D sound still improve the task performances in AR environment? If so, what kind of tasks can be used to evaluate a user's performance and what measures can be applied to investigate the 3D sound's effect on improving task performance?
6. Does 3D sound play a significant role in collaborative AR environment? If so, how can we apply 3D sound and evaluate its role? In what ways will the subjective experience 'human presence and collaboration' in AR environments? Especially what will be the subjective experiences from the addition of 3D sound?

Recent software and hardware advances in AR and auditory interfaces enable us to integrate 3D sound into AR environments and study these interesting questions. Although the quality of 3D sound generated by software synthesizers (Loki Entertainment Software)

is still to be examined by rigorous tests (Langendijk and Bronkhorst, 2000), the pre-tests taken by the developer and the user feedback from commercial applications have to some extend proved its fidelity. Our goal of this research is to do both quantitative and qualitative studies on the effectiveness of such software synthesized 3D sound in an AR environment. The outcomes of this research can have a useful impact on the development of AAR interfaces and the enhancement of AR environments for performing collaborative tasks such as co-operative teaching, training and gaming systems. Our contributions to the research topic are as follows:

1. *Depth perception in AR*: We investigated the impact of 3D sound on improving depth perception in AR systems with single-camera settings. We designed an experiment to measure the accuracy of depth judgment in the cases with and without 3D sound.
2. *Perceptual feeling of sound depth exaggeration*: In order to make full use of 3D sound's dimensional information in a relative small AR environment we exaggerated the intensity difference of virtual sound sources in different depths by multiplying an additional scalar factor. We investigated the subject's perceptual feeling to this exaggeration.
3. *Task analysis with AR sound*: We designed a searching task in another AR environment which requests the user to find a virtual character in the augmented scene; we investigated the impact of 3D sound on the task completion time.
4. *Collaboration and location with AR sound*: We applied a constant 3D sound on subject and task target to investigate the impact of 3D sound on the subject's feeling of 'human presence and collaboration' and the impact on 'locating correct augmented information'.

In Section 2, we discuss the general issues of developing AAR with 3D sound, and two different tracking methods for registering virtual 3D sound sources. The experimental goals and subjects are introduced in Section 3. The results of the experiments are then given and discussed in Section 4. The conclusions of the study are summarized in Section 5.

2. Development of AR environments with 3D sound for experimental analysis

2.1. General issues

Generating real 3D sound requires requires perceptual externalization of the sound source, which can only be brought about by using HRTFs (Bill G, 1994), reflections, reverberation, etc. (Wenzel, 1994) These HRTFs can be used to produce 3D sound effects from a linear convolution between sound signals and its corresponding spatial related impulse response (Wenzel et al., 1988) while the reflections and reverberations involve sophisticated modelling of environment. The individually derived HRTFs are better for individual users to provide more realistic sound experience. However, individual HRTFs are difficult for AR implementation due to the fact that AR systems are designed to be real time interactive systems that do not need individual user configuration. Thus our experiments were taken for randomized selected students. For easy implementation of 3D sound generation, several open source software development kits (SDKs), have been

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developed such as OpenAL (Loki Entertainment Software) and FMOD (L. Firelight Technologies). These use the general HRTFs database and modeling environment in a relative simple manner. However, as mentioned in Section 1, for AR systems 3D sound does not play a significant role to tell the depth (or the distance of the frontal sound sources) because most of actual AR spaces are relatively of small size (for example small office, tabletops, books, etc.).

Sound intensity has been shown to be a key cue in distance perception in humans. However, in the small physical spaces used in AR systems the human is only effectively provided with binaural cues from the synthesizer. Thus we try to also add the effect of intensity for the depth cue. Our approach is to exaggerate the intensity difference of sound sources in different depths by applying an additional scaling factor to the intensity of 3D sound generated by synthesizer. The intensity of the ith 3D sound V_i' is given by Eq. (1):

$$V_i' = (D_{\max} - D_i)V_i/D_{\max} \tag{1}$$

where D_i is the depth of the ith 3D sound source; V_i is the intensity of the ith 3D sound generated by synthesizer given the position of the ith sound source. $D_{\max}$ is the possible maximum distance of the sound sources which is subject to the space of different AR environments. We measured the space in our first and second experiments and the maximum distance was 1.5 and 5.5 m, respectively.

Apart from intensity, it is known that for distance perception the ratio of the energies of direct and reflected sound is of importance (Middlebrooks and Green, 1991; Bronkhorst and Houtgast, 1999). For objects farther away from the listener, coupling the decrease in virtual sound intensity with an increase in the 'reverberation' will lead to a more realistic perceptions. In order to focus on the main points with regards to AR sound we did not add the factor of reverberation, and left this issue for our future research.

In our first experiment the sound sources are always placed around 1.5 m away in the front of the listener. However, in a more general and complex AR environment like the second experimental environment, the listener can walk freely in a physical space where virtual sound sources can be very close to the left and the right side of the head. In this case, the head starts functioning as a sound barrier for high frequencies. Consequently, the (high-frequency) sound intensity will of course increase as the source approaches the head in the ear at the same side of the head but, due to the increasing barrier function, decrease in the ear at the other side of the head. It is reported that binaural cues play an important role in auditory distance perception for nearby sources (Brungart and Rabinowitz, 1999; Brungart, 1999). This fact plus our exaggeration process mentioned above causes a design problem of AAR when the listener is very close to or even overlaid on the virtual sound source. In this case the user can have very strange auditory experience and even get confused. This was confirmed in our experimental results which are shown below (Question 3 of Experiment 2 below).

2.2. Development of AR environments with 3D sound for experimental analysis

In the most common AR paradigm, the user wears a head mounted display (HMD) through which the user views the real world, either directly, or via a video camera attached

to the front of the display Virtual objects are then superimposed on the real world. Early studies such as (Feiner et al., 1993) of this type simply overlaid two-dimensional text information on objects in the scene, but it has now become common to superimpose objects in three dimensions. The minimal requirements for this are that the position of the camera must be determined relative to the whole scene (or an object therein). The transformation matrix (TCM) between the scene and camera co-ordinates can then be used to generate the correct and seamless view of the virtual object. Given this TCM we can get the exact 3D position of the virtual object (virtual sound source) in the user's head co-ordinate system, which is the basic requirement of 3D sound synthesizer.

In our experiments, we applied the OpenAL (Loki Entertainment Software) to generate the 3D sound. Essential parameters needed are the virtual sound source's 3D position and its speed relative to the user's ear. More generally, the 3D position and speed of the virtual sound source and the position and orientation of user's head are needed. In the following parts we will introduce two tracking methods to solve this problem. However, since in our experiments the relative speed of head to virtual sound source is only as slow as 2 m s^{-1}, we ignored the Doppler Effect caused by their relative movement and thus we were only interested in their positions and orientations.

In our experiments, the final augmented virtual image was viewed through a Daeyang Cy-Visor DH-4400VP HMD, which presented the same 640×480 pixel image to both eyes. A PremaCam SCM series color security camera was attached to the front of this HMD. Our visual augmentation produced 25 images of 320×480 pixel resolution per second. To synchronize with the update of the visual scene, we updated the position of the virtual sound sources 25 times per second. The headphone on the HMD plays back the 3D sound generated by the computer. In this way, we provide an AR environment which is both visually and audibly augmented.

2.3. AR experimental environment implemented by vision-based tracking method

There have been many vision tracking methods for AR reported in recent years. In our first experiment, we used a precise vision-based toolkit for AR tracking (Kato and Billinghurst, 1999) reported by Kato and Billinghurst. It used image-processing technology to retrieve 3D position information from a fiducial marker. The 'ARGroove' (Poupyrev et al., 2000) applied this tracking method to get different position and orientation descriptions of the marker movements for which they defined different music. Our first AR experiment system used this tracking method to track the position of virtual sound source which is attached on fiducial marker.

The 3D position of the marker relative to camera can be obtained by computing the TCM from the camera co-ordinates to the 7 marker co-ordinates (Kato and Billinghurst, 1999). However, the 3D position of the marker we obtain is based on the camera co-ordinates. Thus, in order to obtain the 3D position of the marker in user's head co-ordinates (3D sound synthesizer's co-ordinates), simple translations from the camera to the center of user's inter-aural axis should be considered. As shown in Fig. 1, in order to attach the virtual sound source on the marker, the TCM from the 3D sound co-ordinates to marker co-ordinates could be calculated by simply applying translations to TCM obtained before. The 3D position of the marker in the 3D sound co-ordinates are then fed

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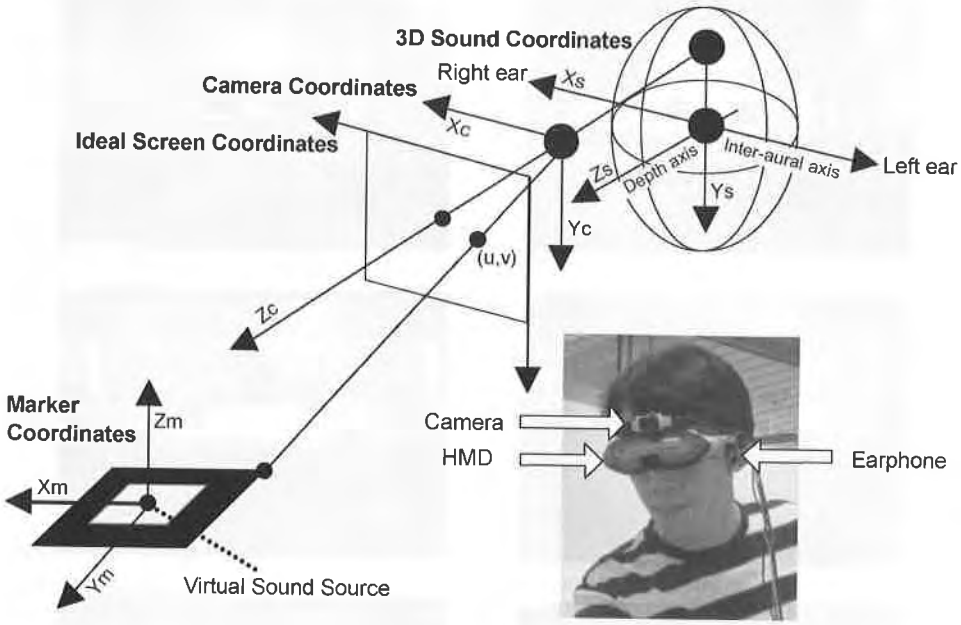


Fig. 1. In order to place a virtual object in the image of the three dimensional scene, the Euclidean transformation between the camera co-ordinates (X_c, Y_c, Z_c) and the marker co-ordinates (X_m, Y_m, Z_m) is estimated. This calculation is based on the imaged position of the corners of the square marker. The imaged position of one of these corners is depicted with pixel co-ordinates (u,v). To obtain the transformation matrix from the 3D sound co-ordinates to marker co-ordinates, translations should be taken from the camera co-ordinates to the 3D sound co-ordinates (X_s,Y_s,Z_s). The picture at the right bottom shows the physical setting of our single camera system where camera is mounted to the front of HMD and 3D sound plays back into the earphones.

into OpenAL (Loki Entertainment Software) for synthesis. Therefore, the 3D sound appears to emanate from the marker.

2.3.1. Depth confusion problem in single camera AR environment

In the most common AR paradigm, a single camera is used to capture the physical scenes (Billinghurst et al., 1998; Zhou et al., 2002; Kato and Billinghurst, 1999) This is not only because this setup is cheap but also because that it requires little computation cost and can be easily implemented. However, although this kind of AR environment setup enables the first-personal viewpoint, it cannot provide stereo video images for each eye, and this can lead to the difficulty of depth perception. Solving occlusion problems (Wloka and Anderson, 1995) or using stereo cameras can improve the depth perception problem. However, it requires more sophisticated settings (Stockburger, 1998) and more computational cost (Kanbara et al., 2000; Takagi et al., 2000). Thus, the low-cost single camera mono system is still widely used for AR applications.

Our objective is to find out whether 3D sounds could be helpful to improve depth perception in this commonly used lower-cost mono AR environment. Fig. 2 shows the depth confusion problem related to this kind of AR environment setup. We know that

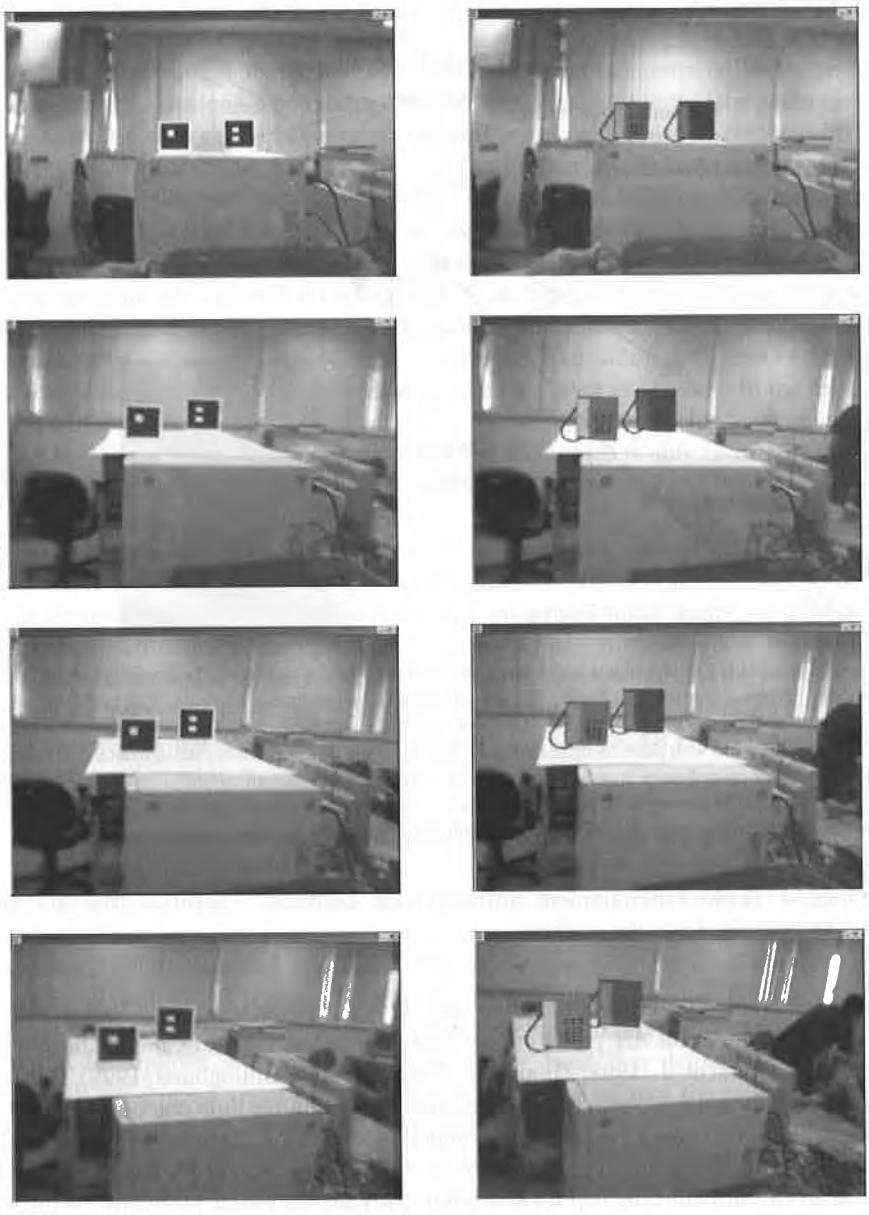


Fig. 2. The depth confusion problem in a single-camera AR setting. The left column shows the image sequences of a scene captured by a moving camera while the right column shows the augmented view seen by the user. (1) In the top left frame, two markers of different size are located in different depth which is hard to tell because of lacking cues. In the following frames, we know that the left marker is nearer to the camera with the cues obtained from the motion, background and lighting environment. (2) Right column shows that the augmented objects occlude everything behind them hence weaken the effect of motion cue. Without background information (in this special case, the objects are located on the same board), relative depth is hard to tell.

human depth perception is based on both monocular cues and binocular cues. Binocular cues include parallax and ocular convergence, while monocular cues include interposition, relative (or familiar) size, linear perspective, texture gradient, light and shadows. The users' responses in our user study suggest that the depth of augmented object is hard to decide in this kind of mono AR environment setup.

This is because that the binocular cues do not work well due to the single-camera setting. Furthermore, because the augmented objects were rendered over the captured images, they appear to occlude everything behind them. To render the virtual objects to be faithful to the actual lighting conditions of the physical world is still a challenging problem. The correct display of shadow and texture gradient of the augmented objects needs the precise estimation of light sources (Kanbara and Yokoya, 2002). The occlusion problem of the augmented objects relative to the real object is also a difficult problem (Fuhrmann et al., 1999). Due to these difficulties, it is still not possible in real-time AR systems to have realistic virtual objects with respect to lighting, shadowing, and occlusion. Thus, our goal is to find out whether 3D sound can help in the judgment of depth, and if so, to what extend can it be helpful for AR.

We thus designed an experimental task which requires the subject to tell which of the augmented objects is closer (less deep) to her and we calculated the accuracy of the judgments. The subjects were required to give their judgment under the conditions of vision plus 3D sound and vision only. As will be seen in the sections below, the judgment accuracy was found to be significantly higher when 3D sound was applied.

2.4. AR experimental environment implemented by acoustic-inertial tracking method

The vision-based maker tracking method can register the virtual objects and virtual sound sources into the real scene precisely. However it has several short-comings as well. For example, the marker tracking algorithm is sensitive to the lighting environment. Also the requirement of keeping a marker in the scene all the time limits the user's movement as well as viewpoint and thus restricts the user to a relatively small space and a narrow angle of view. This drawback could be improved to some extent by using multi-marker tracking or natural feature tracking methods (Neumann and You, 1999). However, they still do not allow fully free head and body movements.

Some previous work used other methods for registering a virtual sound source in a larger space which allowed user's free movement. Makino et al. (1996) used the Global Positioning System (GPS) to locate the traveler within the environment. With differential correction by way of audio link from a GPS reference receiver in the local vicinity, localization is accurate to around 1 m under good conditions of reception. The listen project (Eckel et al., 2001) used motion-tracked wireless headphones to retrieve the position of the user in the environment. A similar method was applied by Schmandt (1998) where the head position is gained from a Polhemus sensor mounted on the headphones.

In our research system (Cheok et al., 2004; Wang et al., 2002), we use the InterSense IS-900 system (InterSense) for precise motion tracking. The IS-900 system is a hybrid acoustic-inertial six degree of freedom (6 DOF) position and orientation tracking system.

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Fig. 3. The physical set-up of our acoustic-inertial tracking AR environment. On the ceiling there are six IS-900 SoniStrips which makes up a three meter by three meter area. A head tracker is mounted on the user's HMD and a camera is fixed on the head tracker. A wand tracker with four buttons and one joystick was held in the user's hand as an interaction device.

It tracks changes in orientation and position by integrating the outputs of its gyroscopes and accelerometers, and corrects drift by using a room-referenced ultrasonic time-of-flight range measuring system. It can obtain a resolution for position of 15 mm.

For the experimental system, as shown in Fig. 3, we mounted six IS-900 SoniStrips on the ceiling of a 3 meter by 3 meter space. This system can support up to four tracking stations. We used four tracking stations to track two users' heads and hands, respectively. A head tracker was mounted on the user's HMD and a camera is fixed on the head tracker. A wand tracker with four buttons and one joystick was held in the user's hand as an interaction device.

The system superimposes graphics on video sequences captured from the camera and displays the combined images on the HMD. We employed OpenAL (Loki Entertainment Software) for generating 3D sounds. Unlike the vision-based tracking method where we make the user's co-ordinates system as the reference, in this method, we used the IS-900 co-ordinates system as a reference while using the users' head position, orientation, and the virtual sound sources' 3D position as input parameters for the OpenAL software.

3. Experimental goals and subjects

Two experiments were taken in the two pre-mentioned AR environments, respectively. In the first experiment, our goal is to find out:

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1. Whether 3D sound helps depth perception and by how much.
2. Whether the exaggeration of intensity difference of 3D sound will be acceptable or unacceptable psychologically.

In the second experiment, our goal is to find out:

1. Whether 3D sound helps in task performance, or more specifically, whether it helps to shorten a searching task completion time and by how much.
2. Whether 3D sound gives more immersive and realistic perception to the users and whether it helps the subject to distinguish different objects in AR environments.
3. Whether 3D sound increases the feeling of 'human presence and collaboration'.

Both qualitative and quantitative studies were conducted in each experiment. The study took place over a four-week period in the summer of 2002.

Forty subjects (13 females and 27 males) were each paid Singapore $8 (approximately $4 USD) per hour to participate in this study. All the participants were undergraduate students at the National University of Singapore. Most of them were freshmen or juniors majoring in computer engineering. The subjects were on average 21.3 years old and had used computer for 8.7 years. They were asked to mark from 1 to 7 about how often (1 means very often while 7 means very seldom) do they use computers and how often do they play games. The averages were 1.7 and 4.5 respectively, which means that they often use computers, but play games only occasionally. All of the subjects reported clear-vision and normal hearing abilities.

Each subject performed both experiments. However in the second experiment, 20 subjects (seven females and thirteen males) were asked to conduct the searching task with the aid of 3D sound while the other 20 subjects (6 females and 14 males) conducted the same task without the 3D sound. Before doing the experiments, all the subjects were given a brief introduction about AR and the tasks to be performed. Each of the subjects was given five minutes to initially try on the HMD and experience the 3D sound effect. After the experiments, all subjects were given 25 min to finish a questionnaire based on the experiments finished.

4. Experimental results

In this section we present the details of the evaluation studies of 3D sound effect and performance in our two AR environments described before

4.1. Experiment of the impact of 3D sound on depth judgment

4.1.1. Design and procedures

In this experiment, we examined the effect of 3D sound on helping users to judge the relative depth of objects in an AR environment (Fig. 4) implemented by vision-based tracking method. Users were required to tell the relative depth of the two markers upon which virtual objects were augmented. In order to precisely position the markers, we used a white board to hold the markers. We set the height of user's chair so that the markers



Fig. 4. The physical set-up of the experiment on depth judgment. The output of the computer VGA signal is send to a monitor and HMD for display by a video converter. The user can only see from HMD while the monitor is for the use of the experimentalist. Two virtual telephones with different colors are augmented onto different markers respectively. The size of augmented objects is adjusted to about the same by adjusting the position of marker. Users are required to tell the relative depth of the two objects in the cases of with and without 3D sound aided.

and the eyes were at the same height. By this way we eliminated the vertical vision cue to depth perception-as the relative position on the same plane can tell the relative depth. This makes sense in AR environment since the augmented objects are not necessarily located on the same plane, and thus this cue is not commonly available. The relative position of the two markers was chosen carefully so that the two markers seem to be approximately of the same size in the camera's view. As described in Section 2.3.1, this will cause depth confusion and hence we can carefully decide the effectiveness of adding 3D sound to the virtual objects.

A preliminary study (Mereu, 1995) indicated that visually impaired users can use the sound environments to perceive depth and position in a 3D application. We hence propose that 3D sound could also be helpful in AR environment for people to perceive depth. To test this hypothesis, we implemented 3D sound in our AR environment and measured the accuracy of relative depth judgment of subject.

4.1.2. User interfaces

As shown in Fig. 4, we augmented the same shape virtual telephone with a different color on each of the markers. The virtual telephones were augmented with a 3D telephone sound that was produced to emanate from each virtual telephone. As explained in

Section 2, the intensity difference of 3D sound due to different depth of markers was exaggerated by a scaling factor. Subjects were asked to put on the headphone of HMD and perceive the difference of 3D sound when the marker was changed to different positions.

Every subject was required to perform 10 trials judging the relative depth of two telephones. Before every trial, the signal of the HMD is turned off so that the subject could not see how the markers were arranged. During that time, the user only sees black because the HMD is a nonoptical see through type. We placed the two different sized markers on the condition that the image size of the two objects are of about the same size, this can be observed by a monitor which is connected to the same VGA output as what the HMD is connected. Then the HMD is turned on and the subject was required to tell which telephone was nearer to him in the cases with and without 3D sound aided respectively. The possible answers are 'left', 'right' and 'uncertain'. We recorded the subjects' judgments and compared them with the correct answers for numerical analysis. We also asked some questions in the questionnaire for psychological analysis purpose.

4.1.3. Results

4.1.3.1. Performance.. The chart in Fig. 5 provides a visual summary of the results of the depth judgment experiment. Fig. 5 compares the number of correct relative depth judgments in 10 trials for 40 subjects in the cases with 3D sound and without 3D sound aided respectively. It can be seen that judgments with 3D sound aided lead to 2.5 times as accurate (70.25 versus 28.25%) as those without 3D sound added.

Our expectation of this experiment was to evaluate the impact of 3D sound on depth judging accuracy. Using a 0.05 significant level, a one-way ANalysis Of VAriance (ANOVA) (Stockburger D, 1998) of the individual correct judgment times of each user was used. In this experiment, we obtained $F(1,39)=129.55$; $p<0.001$ which declares the result to be statistically significant. Thus we conclude that 3D sound does significantly help to increase the number of times of correct depth judgments.

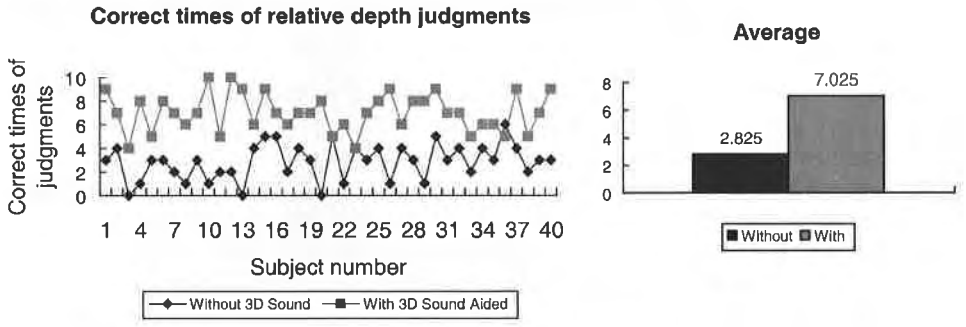


Fig. 5. Comparison of the correct depth judgment times of 40 subjects in ten trials in the cases of with and without 3D sound aided. From this chart we can see obviously that the accurate judgment times increase drastically by introducing 3D sound. The average of correct judgment times is increased from 2.825 to 7.025 by introducing 3D sound.

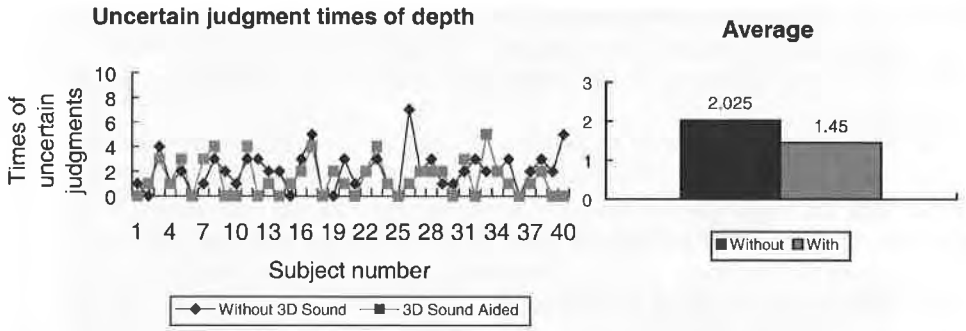


Fig. 6. Comparison of the uncertain judgments in the cases of with and without 3D sound aided. The average of uncertain judgment times is decreased from 2.025 to 1.45 by introducing 3D sound.

On the other hand, the addition of 3D sound decreases the uncertainty of relative depth judgment. Fig. 6 shows the comparison of uncertain judgment times between the cases of with and without 3D sound aided. The addition of 3D sound decreases the average uncertainty from $M=2.03$ to 1.45 times. A significant difference is found ($F(1,39)=4.24$; $p<0.05$). These results proved that the depth perception was significantly enhanced by 3D sound.

There was no significant difference found between the genders. For the correct judging times without 3D sound, males have a mean value of 2.67, females have a mean value of 3.15, $F(1,38)=0.9$; $p>0.1$. For the correct judging times with 3D sound aided, males have a mean value of 7.00, females have a mean value of 7:08, $F(1,38)=0:02$, $p>0.1$.

4.1.3.2. Questionnaire responses.. The purpose of the questionnaire is to examine how the subject qualitatively judges the relative depth of augmented objects and how difficult the task is. Apart from the quantitative results we obtain from the above experiments, it is advantageous to know the subjective feeling of users due to the addition of 3D sound, and the process of the sound intensity exaggeration. The main questions in questionnaire about this experiment were as follows:

1. When you were supposed to judge the relative depth of the two markers, what cues did you mainly use the depth of markers (multiple choices are possible)?
   A. brightness B. color C. size D. intuition E. background F. motion G. others
2. Do you think it is hard to tell the relative depth of two objects in this experiment without 3D sound? Please select your answer from the following choices:
   A. very hard B. hard C. medium D. easy E. very easy
3. Overall, do you think 3D sound helps you to make a correct decision?
   A. yes B. no C. uncertain
4. In real life situations, the intensity of sound doesn't change drastically when the sound source is moving within a short distance, say 100 mm. However, in our experiment we exaggerated this effect. Thus you perceived an obvious difference between the two markers when they were placed in a relative small different depth.

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Do you feel it is unintuitive that the depth scale of 3D sound in this experiment has been exaggerated? Please select from the following choices about how you feel:
A. very unintuitive B. unintuitive C. medium D. intuitive E. very intuitive F. did not notice at all

Question 1 allows multiple choices. Every choice given by the user will be counted as a single vote to the selected choice. Although different users might tick different numbers of choices, the vote diagram is not severely disturb qualitatively since our purpose is to find out what are the cues most users will use for judging depth. As shown in Fig. 7(a), the 'size' cue was given the first place (30 votes) of all the cues in our question. This partially explains why

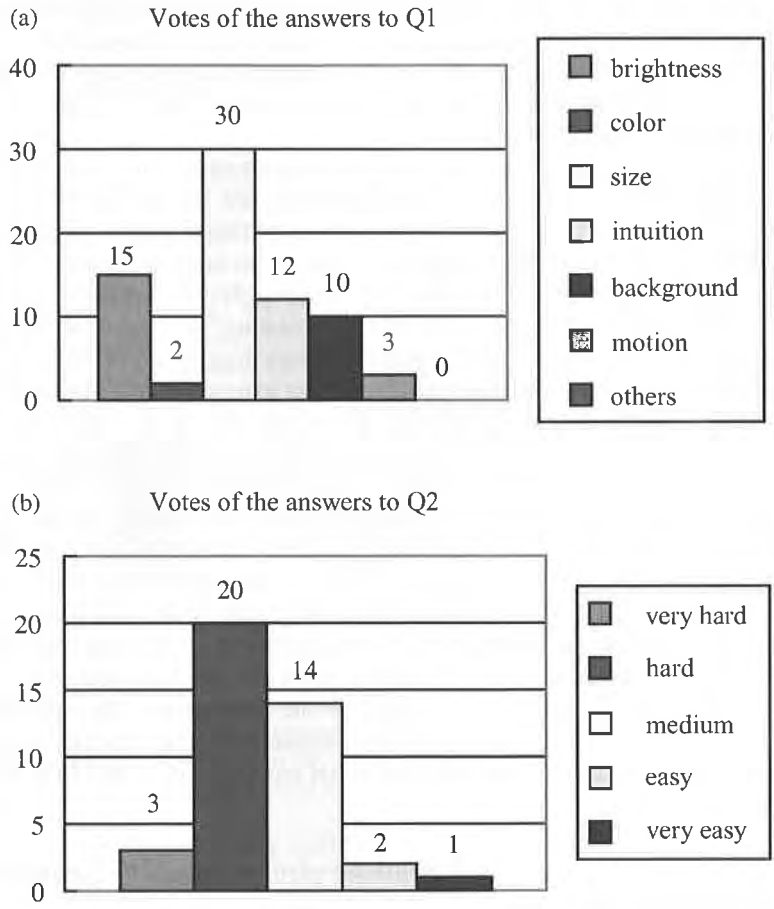


Fig. 7. Statistical charts of the answers to Question 1, 2 of Section 4.1.3 (a) The votes of the answers to question 1: When you were supposed to judge the relative depth of the two markers, what cues did you mainly use the depth of markers (can have multiple choices)? It can be seen from this chart that users are more likely to judge the depth of object by the size, brightness and the background cues. (b) The votes of the answers to question 2: Do you think it is hard to tell the relative depth of 2 objects in this experiment? It can be seen from this chart that it is hard to tell the relative depth of the two markers in our experimental AR environment.

it is difficult for subjects to judge the relative depth when two markers are almost of the same size. Our setting of AR environment in this experiment restrained the effect of background (ten votes) and motion (three votes). The cue 'brightness' which reects the cue 'light and texture gradient' obtains the second highest votes (15 votes). This gives us a hint that in order to obtain good depth perception, it is also important to adjust the appearance of virtual object so that it fits its surrounding physical lighting environment.

However, in this experimental system, the brightness of the object is predefined when the model was created. Hence it brings more difficulties for depth judgment, and it can not provide the cue 'light and texture gradient'. Therefore, this suggests that in the future research we can adjust the brightness of augmented objects according to its lighting environment so as to achieve better depth perception.

In response to question 2, most subjects claimed that it is hard (three claimed very hard and 20 claimed hard) to judge the relative depth of objects in this experiment without the 3D sound cues. Fig. 7(b) gives the chart of this result. This psychological feeling is in accordance with the results shown in Fig. 5 where the accuracy of judgment is only 28.25% in average for tests without sound.

There is an interesting result from the answers to question 3. Only 19 subjects thought that 3D sound has helped them however, 6 subjects claimed 'no' and 15 subjects claimed 'uncertain', as shown in Fig. 8(a) (one subject somehow forgot to give the answer to this question, thus only 39 votes are appeared in this chart). This implies that the addition of 3D sound may have contributed to the depth perception (Fig. 5) although the subject may not psychologically feel it. While this result is quite interesting, more detailed and long term psychological investigation needs to be conducted before drawing any reliable conclusions.

In question 4, our prospect is to find out whether our exaggeration of 3D sound will lead to a degrading of the perceptual experience. The result (Fig. 8(b)) shows that only one subject claimed that it is 'very unintuitive' and six subjects claimed that it is 'unintuitive'. Nine subjects claimed 'medium', 12 subjects claimed 'intuitive' and one subject claimed 'very intuitive'. Moreover, 11 subjects claimed that they 'didn't notice at all'.

Although there is still a risk of losing the 'realistic experience' since the 3D sound environment is different from our everyday life, this result suggests that most of the users will still feel the virtual scene is intuitive psychologically if the exaggeration scale is properly chosen. This result is critical to the development of 3D sound system in AR environment since, unlike in pure VR system, normally the exaggeration is required, otherwise we may lose the information carried by one dimension of 3D sound-the depth. This occurs especially when the physical AR environment is as small as our experimental game system or even smaller, as in the desktop AR environment of the depth perception experiment.

4.2. Experiment of 3D sound's impact on task completion time and the feeling of 'human presence and collaboration'

4.2.1. Design and procedures

In the second experiment, we examined the effect of 3D sound in a larger AR environment in the form of a simple game Barfield (Barfield et al., 1997) identified three primary benefits of auditory spatial information displays as: relieving processing demands

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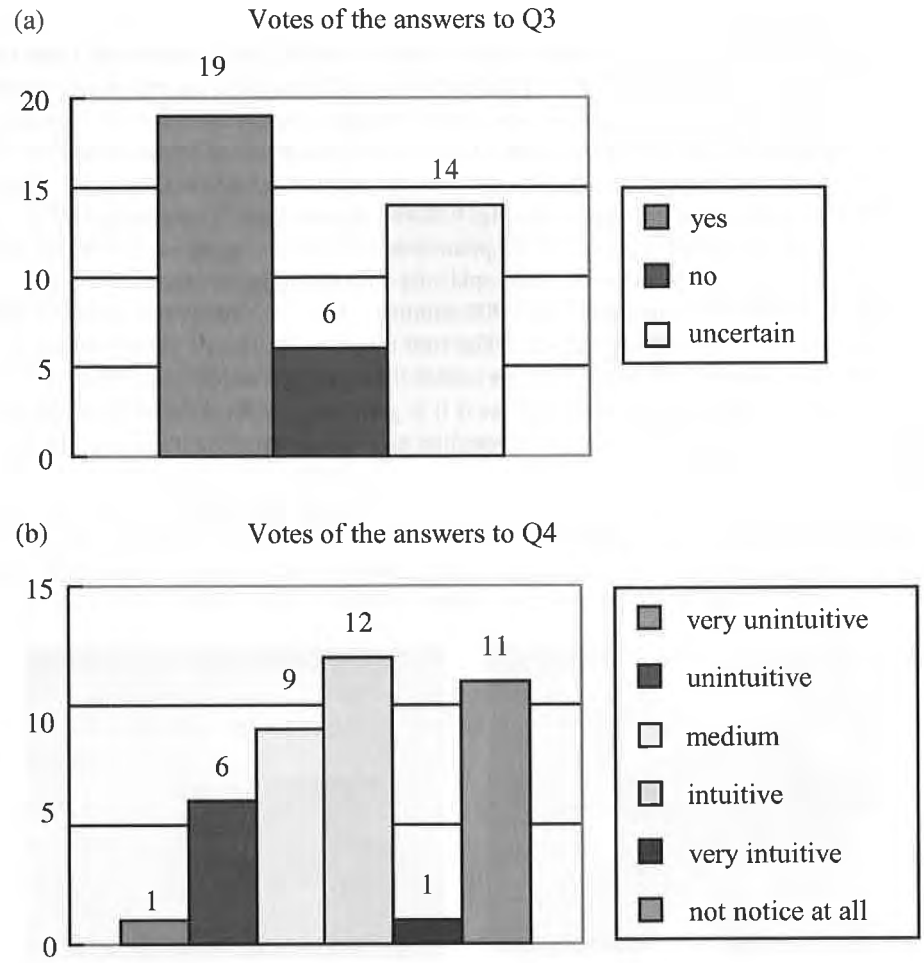


Fig. 8. Statistical charts of the answers to Question 3, 4 of Section 4.1.3. (a) The votes of the answers to question 3: Overall, do you think 3D sound help you to make a correct decision? (One subject somehow forgot to give answer to this question, thus only 39 votes are appeared in this chart). (b) The votes of the answers to question 4: In our every life, the intensity of sound doesn't change drastically when the sound source is moving within a short distance, say 100 mm. However, in our experiment we exaggerated this effect. Thus you perceived an obvious difference between the two markers when they were placed in a relative small different depth. Do you feel unintuitive that the depth scale of 3D sound in this experiment has been exaggerated?

on the visual modality, enhancing spatial awareness, and directing attention to important spatial events In our research system, we extend the benefits in this experiment by:

1. helping to localize an object in AR environment when the visual modality is weakened;
2. enhancing the feeling of human collaboration;
3. directing attention to different spatial objects or helping user to identify different spatial objects.

4.2.2. User interface

Our experimental system allows two users to play a simple game at the same time The objective of this game is to rescue the princess who was captured by an evil witch. In this experimental game, three stages were used to for investigating the effects of 3D sound. In the first stage, users are allowed to walk around in a three by three meter region and to explore a virtual land augmented on the physical ground through a small rectangle virtual window displayed on the tracked wand. Fig. 9 shows the scrolling 3D landscape when the player is moving her hand. A small virtual plane is attached to the wand as an avatar for the user, as if the user is exploring the game space by manipulating the plane. The player is looking for the castle through the 'magic 3D window'. Two 3D sounds are applied in this stage and can be heard by both players. The first one is a 3D sound 'Help!' which was applied to the princess located inside the castle. The second sound is a constant buzz applied to the wand tracker of co-player as if it is generated by the engine of co-player's airplane. Each player can hypothetically localize his/her co-player by localizing the buzz sound.

In the first stage the player is allowed to become more and more familiar with the searching task and the perception of 3D sound. We purposely design this stage as a training process. When the player walks closer to the sound sources (the castle and the princess therein or the co-player), the sound becomes louder while it becomes softer

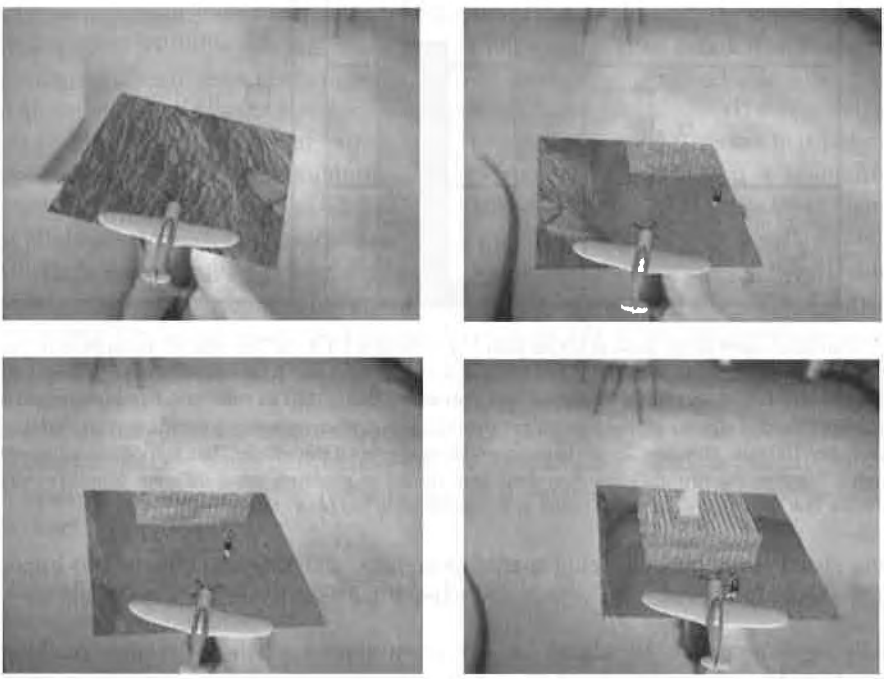


Fig. 9. Looking for the castle through a 'magic 3D window'. A virtual plane is augmented on the wand as an avatar for the user. A rectangle window is augmented in front of the wand through which the user can see the virtual land on the ground. When the user is moving around, the 3D landscape is also scrolled in the 'magic 3D window'. The user is looking down at the castle as if she is looking down from the sky in the airplane.

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when the player walks away from the castle. An exaggeration of the intensity difference described in Section 2 was undertaken here as well. Furthermore, it should be noted, when the player rotates her head or body, she can perceive that the sound source is also moving relative to her movements. We updated the position and orientation of the head tracker 25 times per second which allows a quite smooth feeling of sound source movement.

After the castle is found, players move to the second stage. They battle with a virtual witch who has captured the princess. The virtual witch is augmented in the physical world and is hovering in the experimental region. Players can move freely in the physical space to get the best shooting angle and position. They need to reload or transfer their bullets by putting their wands together which encourages the collaboration in the game, as shown in first two frames of Fig. 10. Apart from the sounds used in stage one, we applied the other two 3D sounds, the cry of witch when it is hit and the explosion sound when it is exploded after being shot for 10 times.

After destroying the witch, the players can fly into the virtual scene and rescue the princess from the castle. This enables a seamless transition from AR environment to VR environment. After the user flies into the virtual scene, she enters a virtual environment in which players can use joystick on the wand to move around, while they can turn over their head or body to change the direction of viewpoint. In this stage we still keep the princess's cry 'help' but we change the sound of co-player from a buzz of engine into a footstep sound. Both of the players can be either in AR or VR mode and can continuously be aware of each other by both vision and sound. Fig. 11 shows the views in this stage.

To examine the impact of 3D sound on task completion time and subjective feelings in this AR environment, 3D sounds were applied in this experimental game. Their functions are summarized as follows:

1. *Players' sounds*: A constant buzz sound is applied to the co-player's airplane when the users are exploring the augmented land. Since the plane is attached to the wand, the 3D positions can be easily obtained from the tracker in the wand. By applying this sound, the user can always hear where is the location of the co-player, even when the co-player is not visually in the scene. She can still roughly tell to what direction is her co-player located and whether the co-player is getting closer or further to her. This buzzing sound is changed into a footstep sound when the co-player enters the VR environment. The different sound gives the hint of whether the co-player is in the AR or VR environment as well.
2. *Human voice*: A constant human voice 'Help! Help!' is applied to the princess which is the target of the searching task. This sound helps the player to turn and face to the correct direction and walk to the correct location where she can see the princess through the small window.
3. *Entertainment sounds*: To make the game more entertaining, we also applied other sound effects. A shooting sound is played when user press the shooting button on the wand. A scream sound and an explosion sound were played when the witch is destroyed. A landing sound of engine is played when the user transits from AR environment to VR environment. A female voice saying 'congratulations' and some greeting words was played when the user finished her mission-find the princess and rescue her.

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Fig. 10. Two users are collaboratively fighting the witch hovering around them in the physical experimental area. The user can see the augmented virtual witch in three dimensions through HMD. The two users need to reload or transfer their 'bullets' by putting their wands together as shown in the first two frames. When the user pressing a specific button on the wand, the airplane can fire bullets (blue and green dot lines in the subsequent frames). The position and orientation of the wand are used to decide trajectory of 'bullets' and whether the witch is shot or not. In the last frame, the witch disappeared after being shot for ten times.

In this experiment, we took both numerical and psychological studies of the subjects' responses. After the players finished the game missions, they probably have been familiar with the game, an additional task is required to perform in stage one. Instead of searching the castle, they need to search for the princess by walking around and scrolling

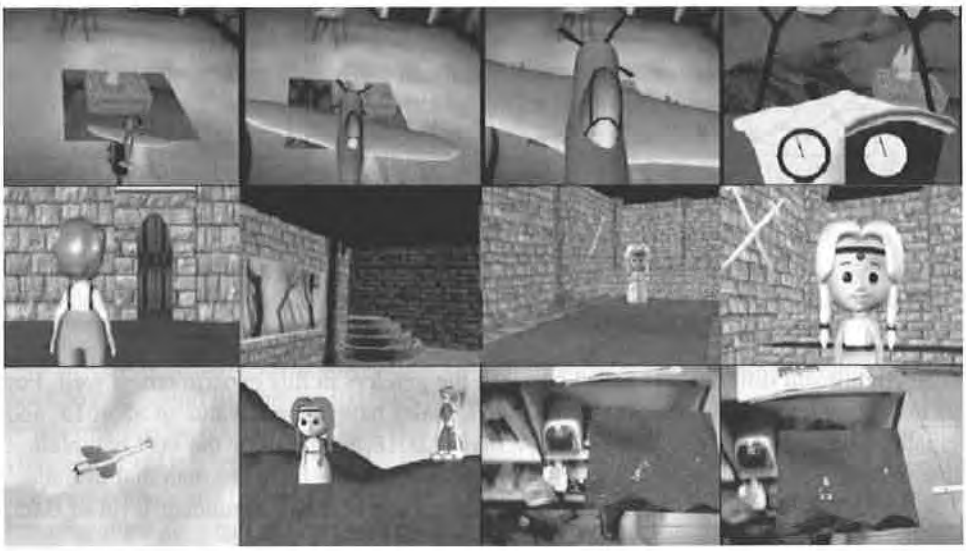


Fig. 11. Rescue the princess in the castle with co-player. (1) The first row shows the seamless transition from AR to VR that the user's airplane is 'flying into' and 'landing on' the VR world. (2) The second row shows one player's view when they are on the way to rescue the princess in the castle. The user uses the joystick to navigate however they can turn the body and head of the virtual character by physically turning their body and head. The footstep sound comes from the co-player and the 'Help!' scream of the princess can always be heard. (3) In the first frame of the third row, a user can physically look up in the sky to find her co-player who is still in AR mode (before flying into the VR mode). The user in the AR mode can still see the co-player and the princess by looking down to the land as if she is on the airplane. The second frame shows one player's view point when both of the players are in VR mode and come to the princess.

the window. The princess was taken outside the castle and was put at an open area on the land. Each subject was given a trial to see how the princess looks like in the small window. Then the princess was put at another position which is the same for all subjects. Every subject started from the same position and orientation in the space and began to search for the princess. The completion time of this searching task was recorded. Twenty subjects (7 females and 13 males) were asked to conduct the searching task with the aid of 'Help!' sound while the rest twenty subjects (6 females and 14 males) conducted the same task without any sound. Every subject performed this task only once either with or without sound aided. Apart from this numerical study, psychological studies were conducted by a linguistic questionnaire.

4.2.3. Results

4.2.3.1. Performance.. In this experiment the subjects performed a searching task as described in Section 4.2.2. The chart in Fig. 12 compares the completion time (in seconds) of the searching task for two groups in the cases with 3D sound and without 3D sound aided. The average task completion time of the group without 3D sound aided was 1.5 times as long (133.05 versus 88.1) as that with 3D sound aided. The effect of 3D sound on shorten the task completion time is significant, $F(1,38)=6.7$; $p<0.025$.

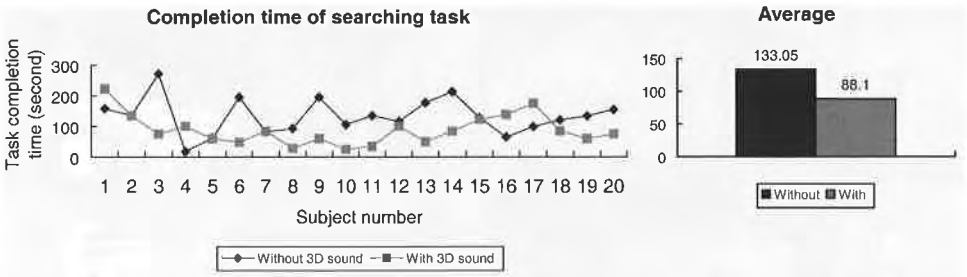


Fig. 12. The comparison of searching task completion time in the cases of with and without 3D sound aided. The average of completion time is shortened drastically from 133.05 to 88.1 s by introducing 3D sound.

No significant difference is found between the genders in this experiment as well. For the task completion time with 3D sound aided, males have a mean value of 88.4615, and females have a mean value of 87.43, $F(1,18)=0.0018$; $p>0.1$. For the task completion time without 3D sound aided, although females' mean value is higher than that of males' (166.33 versus 118.79), no significant difference is found at the significant level of 0.05, $F(1,18)=3.03$; $p>0.05$.

From the results given above we can see that, 3D sound helps significantly to shorten (about by half) the searching task completion time in this AR environment.

4.2.3.2. Questionnaire responses. The purpose of the questionnaire questions is to examine the impact of 3D sound on the subject's psychological feelings. We wanted to examine whether 3D sound improves the feeling of immersiveness and human presence and collaboration, whether it helps to identify spatial objects, and how much impact it has on these feeling. The main questions in questionnaire about this experiment were as follows:

1. Does 3D sound improve your perception of immersiveness in the AR environment? Do you think it is more realistic with 3D sound than without it? Why?
2. Does the 3D sound improve your feeling of human presence and collaboration as you can hear the sound coming from your collaborator at anytime?
3. Does the 3D sound help you to identify different information signals (spatial objects)?
4. Were you aware of your co-players in different places?
   A. always B. very often C. often D. barely E. never
5. What has helped your feeling of 'human presence and collaboration'? (can be multiple choices, please order the factors by the order of decreasing importance)
   A. small talk between co-players B. vision cues C. 3D Sound cues D. Others

According to question one, almost all subjects (39 of 40 subjects) claimed that 3D sound did improve the perception immersiveness. A total of 38 subjects claimed that it is more realistic with 3D sound, and one subject claimed 'a little better'. The main reasons they provided to support their viewpoint are as follows:

1. 'It is natural feeling and more realistic with 3D sound.'
2. 'You can feel the sound from all directions which gives a more 3D feeling.'

3. 'You can tell where the collaborator is positioned, or to know the surrounding objects in the AR environment.'
4. 'The feeling is closer to real world and 3D sound helps to navigate.'
5. 'I can hear and judge distance from the object producing the sound.'

From these responses, we can find that 3D sound does play an important role complementing the visual AR environment. Although this result seems to be natural since the same conclusion has been drawn in virtual reality environment (VRE), it proves that this conclusion is still tenable in AR environment when the implementation method has been changed and especially when the interfaces preserve our social interactions which are weak in VR.

There were also negative comments. One subject suggested that there should be more background sound like noises to make it more realistic. The subject said, 'The sound field is too quiet to be realistic.' In fact, this is consistent with the argument given by Begault (Begault, 1994): "Even with non-spatial cues, one can tell something about the distance of different sounds and their context,..., but the inclusion of 3-D sound techniques and spatial reverberation cues can greatly increase the immersiveness of a simulation, as well as the overall quality and the available nuance in representing different environmental contexts".

The important result we obtained from the responses to question two is that 3D sound improves the feeling of 'human presence and collaboration' when the subject is performing this experimental task. In this question, 39 of 40 subjects answered 'yes'. Some of the comments were:

1. 'At least I can find whoever it is.'
2. 'The sound constantly reminds us of the presence of the collaborator.'
3. 'Yes, like someone is actually in the world with you.'
4. 'It is really interesting that you can turn to face him when the clop-clop is getting closer to you in your back.'

One interesting comment was that 'I can know whether he is still in the airplane or has landed down and walking around' (which meant that the user could know if the other player was in AR or VR modes). This is actually one function of sound which is serving as an auditory icon (Gaver, 1986). A good negative comment suggested that 'it can be improved by adding speech communication, because a running motor does not sound very human, so it is like an object somewhat'.

Apart from applying 3D sound to the collaborator, we also applied 3D sound to the princess who is the target of the task. The responses to question three suggest that 3D sound, when applied to different spatial objects (information signals) in AR environment, can help the user to identify different information carriers. In our experiment 36 subjects claimed that they can constantly be aware of both the other collaborator and the princess simultaneously. This result suggests that by introducing more than one 3D virtual source sources in AR environment, it is possible for the users to identify different meanings of them and to distinguish them by the localization of the sound sources. As one subject described, 'yes, very much so. For instance, if the collaborator sounds from the left

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earpiece and princess cries are heard at right earpiece, the directional news determines the positions of the collaborator and princess.'

However, one valuable criticism complained that 'the volume differs when you are far but when you are near I could not hear a difference especially in terms of direction', the other one complained that 'the sound sometimes seemed to be coming from all directions and I was uncertain whether to turn left/right, only when I was close did the volume increase, but in a jump, not gradually'. These comments points out the drawbacks of our exaggeration process of 3D sound intensity in this AR environment and also to some extend support the results of Brungart (Brungart and Rabinowitz, 1999; Brungart, 1999). We designed the auditory environment so that when the user becomes closer to the virtual sound source in the three by three meters region, the 3D sound intensity is exaggerated. This will be maximum intensity when the user is at the position of the virtual sound sources (distance to the object is zero). In this case, the binaural cues play a very important role for distance and direction perceptions. Because of the closeness to the object when near zero, even a slight movement of the user may cause a totally opposite feeling of the source direction (from left to right). When the movement is very fast, the intensity and sound direction may change rapidly. This problem can be partly solved by designing a better sound-scape. However the situation when the user is overlaid on the sound source is still a difficult problem unless we apply some physical constraints on the user's sound near to virtual sound sources.

Chart (a) and (b) in Fig. 13 shows the subjects' responses to question four and question five, respectively. We can see from chart (a) that nine of 40 subjects claimed that they were 'always' be aware of co-players while five subjects claimed 'very often' and 18 claimed 'often'. This leads to the improvement to the feeling of collaboration. A total of 39 subjects agreed that 3D sound did increase their feeling of collaboration from the result of question two.

To examine the importance of 3D sound among all cues, subjects were required to choose the cues they thought to have helped them and to order them by the importance. 3D sound cues obtained the highest votes (36 votes) among all the cues. Move importantly, a total of 14 subjects regarded 3D sound cues as the most important cue while 'small talk' and 'vision cues' only obtained five and four votes respectively. This result suggests that 3D sound does play a very important role in improving the subject's feeling of collaboration. It could even dominate among all possible cues in AR environment, especially when other cues are restrained by hardware settings, for example, angle of view is restrained by HMD in common AR system. In this situation, the visual cues are restrained due to the narrow viewpoint of HMD, and hence their effects on collaboration are limited. On the contrary, the 3D sound can be generated from any points in the AR space. When 3D sound is applied to the user and given different meaning at different situations, it can play the most important role to help the user's feeling of 'human presence and collaboration'.

5. Conclusions

The purpose of this work is to investigate the effectiveness of 3D sound in AR environments We designed two experimental AR environments to study the effectiveness

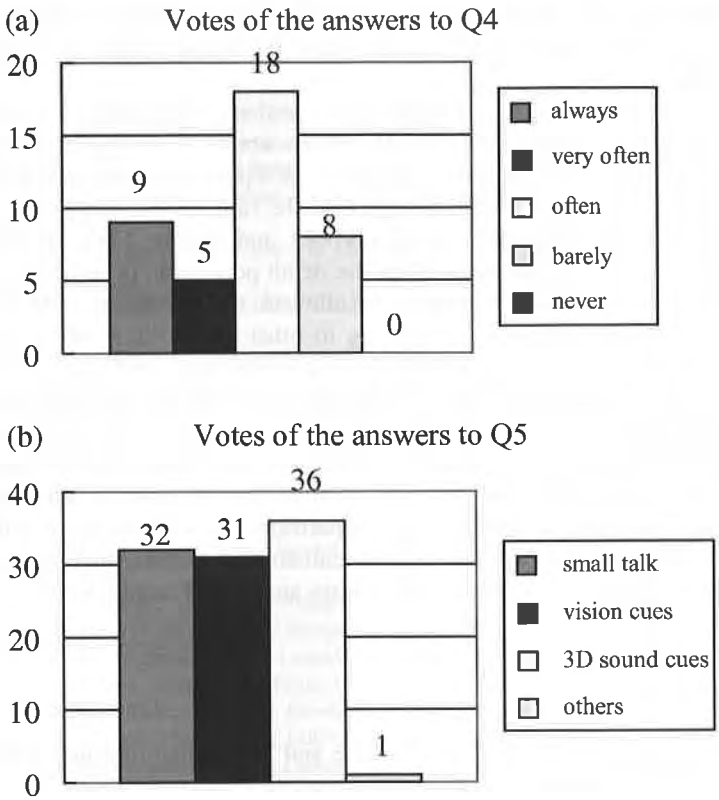


Fig. 13. Statistical charts of the answers to Question 4, 5 of Section 4.2.3. (a) The votes of the answers to question 4: Were you aware of your co-players in different places? We can see from the chart that in this AR environment, subjects can often be aware of co-player's position, however, this result is impossible if there was no 3D sound applied since the subject can only occasionally see co-player due to the narrow angle of view. (b) The votes of the answers to question 5: What has helped your feeling of 'human presence and collaboration'? It can be seen from this chart that 3D sound plays the most important role among all the cues. It gets even more votes than vision cues and voice communication cues.

both quantitatively and qualitatively. Two different tracking methods were applied to retrieve the 3D position of virtual sound sources. We examined the effects of 3D sound on improving depth perception and shortening task completion time. We also investigated 3D sound's effects on improving immersive and realistic perceptions, helping user to identify different spacial objects, and improving the subjective feeling of 'human presence and collaboration'.

The 3D sound generated by OpenAL (Loki Entertainment Software) applying HRTFs and simple modelling of environment is used in our experiments. Apart from its effects for the user on sound source localization, we tried to emphasize its effect on telling the depth (distance). Since intensity has been reported to be a key cue for distance perception, we exaggerated the intensity difference of sound sources in different depth by applying an additional scalar factor to the intensity of generated 3D sound. The user study result shows

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that it is still 'intuitive'. These methods to implement 3D sound in relative small AR environments provide a necessary foundation for the incorporation of 3D sound with visual AR environments.

However, our studies beg many additional questions. For example, how to set the intensity scale so that it can maximize 3D sound's ability to tell depth and meanwhile preserve realistic perception for users? Moreover, as reported, for distance perception not only the intensity but also a much stronger cue, the ratio of the energies of direct and reflected sound is of importance (Middlebrooks and Green, 1991; Bronkhorst and Houtgast, 1999). How will this ratio affect the depth perception in AAR? If the cues of background and drastic head movements are allowed, to what extend will 3D sound be effective to help depth judgment, comparing to other visual cues? When the binaural localization cues for nearby sources (Brungart and Rabinowitz, 1999; Brungart, 1999) are taken into account, how to design the sound-scape to 'display' the 3D sound correctly and intuitively when the user is very close to or even right overlapped on the sound source?

Although many questions remain unanswered, our studies show that the addition of 3D sound can be a very effective way to complement the user experiences in AR environments. It helps depth perception, task performance and facilitates collaborations between users. Moreover, it enables a more realistic environment and more immersive feeling of being inside a both visual and auditory augmented reality world.

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An experimental study on the role of software synthesized 3D sound in augmented reality environments

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Abstract

Investigation of augmented reality (AR) environments has become a popular research topic for engineers, computer and cognitive scientists. Although application oriented studies focused on audio AR environments have been published, little work has been done to vigorously study and evaluate the important research questions of the effectiveness of 3D sound in the AR context, and to what extent the addition of 3D sound would contribute to the AR experience.

Thus, we have developed two AR environments and performed vigorous experiments with human subjects to study the effects of 3D sound in the AR context. The study concerns two scenarios. In the first scenario, one participant must use vision only and vision with 3D sound to judge the relative depth of augmented virtual objects. In the second scenario, two participants must co-operate to perform a joint task in a game-based AR environment.

Hence, the goals of this study are (1) to access the impact of 3D sound on depth perception in a single-camera AR environment, (2) to study the impact of 3D sound on task performance and the feeling of 'human presence and collaboration', (3) to better understand the role of 3D sound in human-computer and human–human interactions, (4) to investigate if gender can affect the impact of 3D sound in AR environments. The outcomes of this research can have a useful impact on the development of audio AR systems which provide more immersive, realistic and entertaining experiences by introducing 3D sound. Our results suggest that 3D sound in AR environment significantly improves the accuracy of depth judgment and improves task performance. Our results

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also suggest that 3D sound contributes significantly to the feeling of 'human presence and collaboration' and helps the subjects to 'identify spatial objects'.
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Keywords: 3D sound; Augmented reality; Depth perception; Localization of sound; Task performance; Collaboration; User studies

1. Introduction

Audio feedback, especially 3D sound, has proven itself to be an effective addition to human–computer interfaces in many studies. Sounds can be used to present information that would otherwise be difficult to convey through other means (Gaver et al. 1991). Moreover, 3D sound can convey location information for specific alerts or warnings. Also, 3D sound was reported to increase the immersive experience in virtual reality (VR) environments and hence provide a more realistic virtual environment (Begault 1994). Furthermore, the addition of 3D sound has been shown to increase the performance in active tasks (Wenzel, 1996; Avionique). In previous works, Mereu (1995) suggested that sound could improve depth perception in 3D interfaces. Makino et al. (1996) also indicated that spatialized sound from virtual acoustic display helps fast and accurate navigation. Additionally, simulations by Gaver et al. (1991) suggested that auditory icons can play a significant role in multiprocessing and collaborative system. Unlike VR in which extensive research has been carried on 3D sound, augmented reality (AR) aided by 3D sound is still a relative new research area.

AR, as placed on the reality–virtuality continuum (Milgram et al., 1994), refers to the incorporation of virtual computer graphics objects into a real world scene, or alternatively the inclusion of real world elements into a virtual environment. The former case is generally referred to as AR, and the latter as augmented virtuality. Azuma (1997) has defined three characteristics that are integral to an AR interface. First, it combines the real and the virtual. Second, it is interactive in real time. Third, it is registered in three dimensions. Although AR is often associated with visualization (starting with the first head-mounted display by Sutherland (1968)), augmentation is also possible in the aural domain (Cohen et al., 1993; Mynatt et al., 1997). If we extend this notion to include sonic effects, a real-time registered three dimensional (3D) sound could also be a paradigm of AR applications, and is termed augmented audio reality (AAR) (Cohen et al., 1993).

A few applications have applied 3D sounds in AR to enhance user experiences. Billinghurst et al. (1998) presented a prototype wearable communication space that uses spatial visual and audio cues to enhance communication between remote groups of people. The 'Listen Project' (Eckel et al., 2001) provides users with intuitive access to personalize and situated audio information spaces while they naturally explore everyday environments. It augments the physical environment through a dynamic sound-scape, which users experience over motion-tracked wireless headphones. The 'Magic Music Desk' (Zhou et al., 2002) registered virtual sound sources on fiducial markers from which 3D position information was retrieved by vision-based tracking method (Kato and Billinghurst, 1999). 'Touch space' (Cheok et al., 2004) applied different 3D sounds to represent different

moving avatars in AR environment. Although there are quite a few AAR applications, the effectiveness of 3D sound in AAR has been rarely investigated. The particular research problems and questions that arise are:

1. Exact spatial 3D sound in virtual and augmented environments requires perceptual externalization of the sound source, which can only be brought about by using head related transfer functions (HRTFs) (Bill G, 1994) (these are tuned to each individual), reflections, reverberation, etc. (Wenzel, 1994) which might be too complex to be included in normal real time AR applications (which need to be a real time interactive system for any user without individual training). An alternative way to generate 3D sound is to use open source software development kits (SDKs) which have already incorporated the general HRTFs database and simple model of environment to generate 3D sound. The minimum requirement of these SDKs to generate 3D sound is to update the relative position of the virtual sound source to the head co-ordinate system. Thus, with such sound sources, a problem turns to be how can we track the sound source relative to user's head co-ordinate system.
2. How can we precisely register virtual sound sources in the physical world? More specifically, what kind of tracking method is suitable for obtaining precise position and orientation of the sound source in AR environments?
3. As 3D sound has been reported to improve depth perception (Mereu S, 1995) in 3D interfaces, will this argument stand in AR environment? If so, how can we investigate the effect of 3D sound? For example, what measures can be defined to quantify the performance of depth judgments?
4. Normally the space of AR environments is relatively small, and the attenuation of sound with distance in this small area can be too vague to be perceived. This is because in most 3D sound systems, the intensity of sound (a very strong distance cue) would follow incremental reductions of 6 DB for each successive position of doubled distance (Begault, 1994). This means that for small areas, the 3D sound hardly plays a role to provide a cue to the depth (or the distance of the frontal sound sources). In order to make 3D sound give a cue to depth in a small space, we need to exaggerate the intensity difference of 3D sound according to distance (depth) changes of the virtual sound sources. However, this leads to a new issue, which is to research if this exaggeration will ruin the realistic and immersive feeling which we have been focused on. It needs to be investigated what are the subjective feelings on this exaggeration to the human.
5. Does 3D sound still improve the task performances in AR environment? If so, what kind of tasks can be used to evaluate a user's performance and what measures can be applied to investigate the 3D sound's effect on improving task performance?
6. Does 3D sound play a significant role in collaborative AR environment? If so, how can we apply 3D sound and evaluate its role? In what ways will the subjective experience 'human presence and collaboration' in AR environments? Especially what will be the subjective experiences from the addition of 3D sound?

Recent software and hardware advances in AR and auditory interfaces enable us to integrate 3D sound into AR environments and study these interesting questions. Although the quality of 3D sound generated by software synthesizers (Loki Entertainment Software)

is still to be examined by rigorous tests (Langendijk and Bronkhorst, 2000), the pre-tests taken by the developer and the user feedback from commercial applications have to some extend proved its fidelity. Our goal of this research is to do both quantitative and qualitative studies on the effectiveness of such software synthesized 3D sound in an AR environment. The outcomes of this research can have a useful impact on the development of AAR interfaces and the enhancement of AR environments for performing collaborative tasks such as co-operative teaching, training and gaming systems. Our contributions to the research topic are as follows:

1. *Depth perception in AR*: We investigated the impact of 3D sound on improving depth perception in AR systems with single-camera settings. We designed an experiment to measure the accuracy of depth judgment in the cases with and without 3D sound.
2. *Perceptual feeling of sound depth exaggeration*: In order to make full use of 3D sound's dimensional information in a relative small AR environment we exaggerated the intensity difference of virtual sound sources in different depths by multiplying an additional scalar factor. We investigated the subject's perceptual feeling to this exaggeration.
3. *Task analysis with AR sound*: We designed a searching task in another AR environment which requests the user to find a virtual character in the augmented scene; we investigated the impact of 3D sound on the task completion time.
4. *Collaboration and location with AR sound*: We applied a constant 3D sound on subject and task target to investigate the impact of 3D sound on the subject's feeling of 'human presence and collaboration' and the impact on 'locating correct augmented information'.

In Section 2, we discuss the general issues of developing AAR with 3D sound, and two different tracking methods for registering virtual 3D sound sources. The experimental goals and subjects are introduced in Section 3. The results of the experiments are then given and discussed in Section 4. The conclusions of the study are summarized in Section 5.

2. Development of AR environments with 3D sound for experimental analysis

2.1. General issues

Generating real 3D sound requires. requires perceptual externalization of the sound source, which can only be brought about by using HRTFs (Bill G, 1994), reflections, reverberation, etc. (Wenzel, 1994) These HRTFs can be used to produce 3D sound effects from a linear convolution between sound signals and its corresponding spatial related impulse response (Wenzel et al., 1988) while the reflections and reverberations involve sophisticated modelling of environment. The individually derived HRTFs are better for individual users to provide more realistic sound experience. However, individual HRTFs are difficult for AR implementation due to the fact that AR systems are designed to be real time interactive systems that do not need individual user configuration. Thus our experiments were taken for randomized selected students. For easy implementation of 3D sound generation, several open source software development kits (SDKs), have been

developed such as OpenAL (Loki Entertainment Software) and FMOD (L. Firelight Technologies). These use the general HRTFs database and modeling environment in a relative simple manner. However, as mentioned in Section 1, for AR systems 3D sound does not play a significant role to tell the depth (or the distance of the frontal sound sources) because most of actual AR spaces are relatively of small size (for example small office, tabletops, books, etc.).

Sound intensity has been shown to be a key cue in distance perception in humans. However, in the small physical spaces used in AR systems the human is only effectively provided with binaural cues from the synthesizer. Thus we try to also add the effect of intensity for the depth cue. Our approach is to exaggerate the intensity difference of sound sources in different depths by applying an additional scaling factor to the intensity of 3D sound generated by synthesizer. The intensity of the ith 3D sound V_i' is given by Eq. (1):

$$V_i' = (D_{\max} - D_i)V_i/D_{\max} \tag{1}$$

where D_i is the depth of the ith 3D sound source; V_i is the intensity of the ith 3D sound generated by synthesizer given the position of the ith sound source. $D_{\max}$ is the possible maximum distance of the sound sources which is subject to the space of different AR environments. We measured the space in our first and second experiments and the maximum distance was 1.5 and 5.5 m, respectively.

Apart from intensity, it is known that for distance perception the ratio of the energies of direct and reflected sound is of importance (Middlebrooks and Green, 1991; Bronkhorst and Houtgast, 1999). For objects farther away from the listener, coupling the decrease in virtual sound intensity with an increase in the 'reverberation' will lead to a more realistic perceptions. In order to focus on the main points with regards to AR sound we did not add the factor of reverberation, and left this issue for our future research.

In our first experiment the sound sources are always placed around 1.5 m away in the front of the listener. However, in a more general and complex AR environment like the second experimental environment, the listener can walk freely in a physical space where virtual sound sources can be very close to the left and the right side of the head. In this case, the head starts functioning as a sound barrier for high frequencies. Consequently, the (high-frequency) sound intensity will of course increase as the source approaches the head in the ear at the same side of the head but, due to the increasing barrier function, decrease in the ear at the other side of the head. It is reported that binaural cues play an important role in auditory distance perception for nearby sources (Brungart and Rabinowitz, 1999; Brungart, 1999). This fact plus our exaggeration process mentioned above causes a design problem of AAR when the listener is very close to or even overlaid on the virtual sound source. In this case the user can have very strange auditory experience and even get confused. This was confirmed in our experimental results which are shown below (Question 3 of Experiment 2 below).

2.2. Development of AR environments with 3D sound for experimental analysis

In the most common AR paradigm, the user wears a head mounted display (HMD) through which the user views the real world, either directly, or via a video camera attached

to the front of the display Virtual objects are then superimposed on the real world. Early studies such as (Feiner et al., 1993) of this type simply overlaid two-dimensional text information on objects in the scene, but it has now become common to superimpose objects in three dimensions. The minimal requirements for this are that the position of the camera must be determined relative to the whole scene (or an object therein). The transformation matrix (TCM) between the scene and camera co-ordinates can then be used to generate the correct and seamless view of the virtual object. Given this TCM we can get the exact 3D position of the virtual object (virtual sound source) in the user's head co-ordinate system, which is the basic requirement of 3D sound synthesizer.

In our experiments, we applied the OpenAL (Loki Entertainment Software) to generate the 3D sound. Essential parameters needed are the virtual sound source's 3D position and its speed relative to the user's ear. More generally, the 3D position and speed of the virtual sound source and the position and orientation of user's head are needed. In the following parts we will introduce two tracking methods to solve this problem. However, since in our experiments the relative speed of head to virtual sound source is only as slow as 2 m s^{-1}, we ignored the Doppler Effect caused by their relative movement and thus we were only interested in their positions and orientations.

In our experiments, the final augmented virtual image was viewed through a Daeyang Cy-Visor DH-4400VP HMD, which presented the same 640×480 pixel image to both eyes. A PremaCam SCM series color security camera was attached to the front of this HMD. Our visual augmentation produced 25 images of 320×480 pixel resolution per second. To synchronize with the update of the visual scene, we updated the position of the virtual sound sources 25 times per second. The headphone on the HMD plays back the 3D sound generated by the computer. In this way, we provide an AR environment which is both visually and audibly augmented.

2.3. AR experimental environment implemented by vision-based tracking method

There have been many vision tracking methods for AR reported in recent years. In our first experiment, we used a precise vision-based toolkit for AR tracking (Kato and Billinghurst, 1999) reported by Kato and Billinghurst. It used image-processing technology to retrieve 3D position information from a fiducial marker. The 'ARGroove' (Poupyrev et al., 2000) applied this tracking method to get different position and orientation descriptions of the marker movements for which they defined different music. Our first AR experiment system used this tracking method to track the position of virtual sound source which is attached on fiducial marker.

The 3D position of the marker relative to camera can be obtained by computing the TCM from the camera co-ordinates to the 7 marker co-ordinates (Kato and Billinghurst, 1999). However, the 3D position of the marker we obtain is based on the camera co-ordinates. Thus, in order to obtain the 3D position of the marker in user's head co-ordinates (3D sound synthesizer's co-ordinates), simple translations from the camera to the center of user's inter-aural axis should be considered. As shown in Fig. 1, in order to attach the virtual sound source on the marker, the TCM from the 3D sound co-ordinates to marker co-ordinates could be calculated by simply applying translations to TCM obtained before. The 3D position of the marker in the 3D sound co-ordinates are then fed

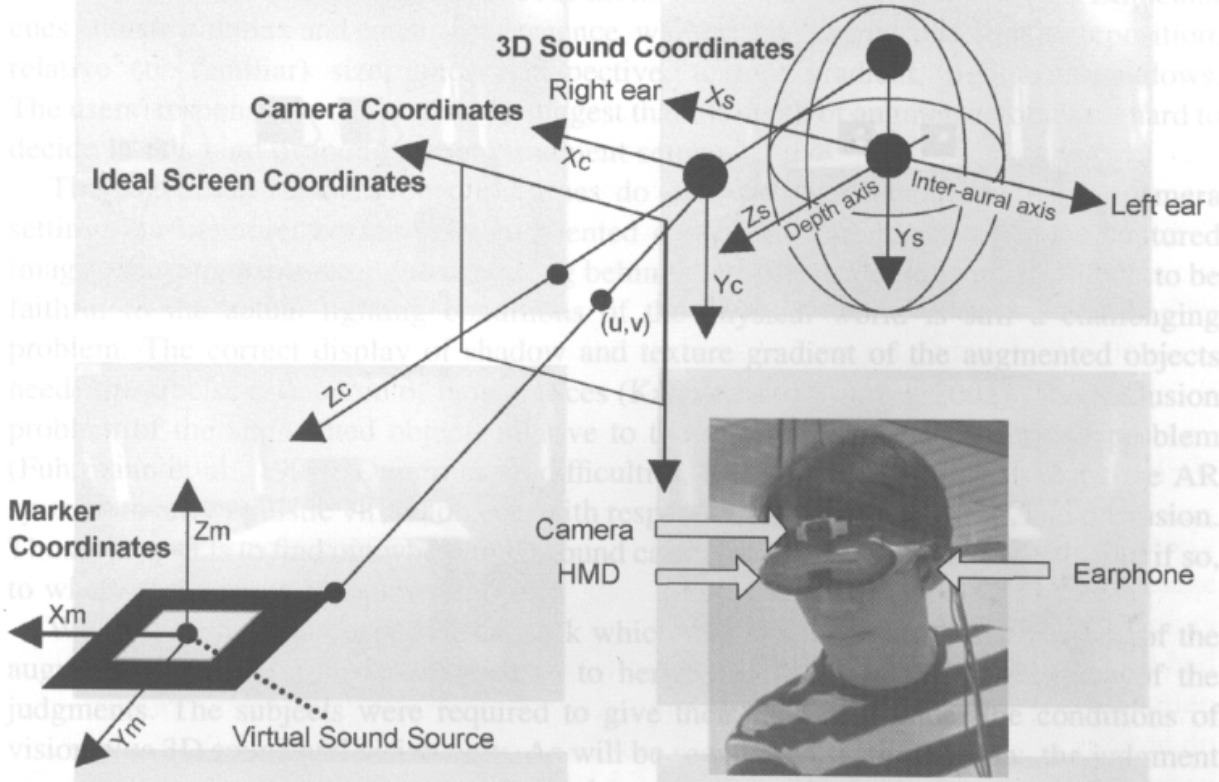


Fig. 1. In order to place a virtual object in the image of the three dimensional scene, the Euclidean transformation between the camera co-ordinates (X_c, Y_c, Z_c) and the marker co-ordinates (X_m, Y_m, Z_m) is estimated. This calculation is based on the imaged position of the corners of the square marker. The imaged position of one of these corners is depicted with pixel co-ordinates (u,v). To obtain the transformation matrix from the 3D sound co-ordinates to marker co-ordinates, translations should be taken from the camera co-ordinates to the 3D sound co-ordinates (X_s,Y_s,Z_s). The picture at the right bottom shows the physical setting of our single camera system where camera is mounted to the front of HMD and 3D sound plays back into the earphones.

into OpenAL (Loki Entertainment Software) for synthesis. Therefore, the 3D sound appears to emanate from the marker.

2.3.1. Depth confusion problem in single camera AR environment

In the most common AR paradigm, a single camera is used to capture the physical scenes (Billinghurst et al., 1998; Zhou et al., 2002; Kato and Billinghurst, 1999) This is not only because this setup is cheap but also because that it requires little computation cost and can be easily implemented. However, although this kind of AR environment setup enables the first-personal viewpoint, it cannot provide stereo video images for each eye, and this can lead to the difficulty of depth perception. Solving occlusion problems (Wloka and Anderson, 1995) or using stereo cameras can improve the depth perception problem. However, it requires more sophisticated settings (Stockburger, 1998) and more computational cost (Kanbara et al., 2000; Takagi et al., 2000). Thus, the low-cost single camera mono system is still widely used for AR applications.

Our objective is to find out whether 3D sounds could be helpful to improve depth perception in this commonly used lower-cost mono AR environment. Fig. 2 shows the depth confusion problem related to this kind of AR environment setup. We know that

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Fig. 2. The depth confusion problem in a single-camera AR setting. The left column shows the image sequences of a scene captured by a moving camera while the right column shows the augmented view seen by the user. (1) In the top left frame, two markers of different size are located in different depth which is hard to tell because of lacking cues. In the following frames, we know that the left marker is nearer to the camera with the cues obtained from the motion, background and lighting environment. (2) Right column shows that the augmented objects occlude everything behind them hence weaken the effect of motion cue. Without background information (in this special case, the objects are located on the same board), relative depth is hard to tell.

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human depth perception is based on both monocular cues and binocular cues. Binocular cues include parallax and ocular convergence, while monocular cues include interposition, relative (or familiar) size, linear perspective, texture gradient, light and shadows. The users' responses in our user study suggest that the depth of augmented object is hard to decide in this kind of mono AR environment setup.

This is because that the binocular cues do not work well due to the single-camera setting. Furthermore, because the augmented objects were rendered over the captured images, they appear to occlude everything behind them. To render the virtual objects to be faithful to the actual lighting conditions of the physical world is still a challenging problem. The correct display of shadow and texture gradient of the augmented objects needs the precise estimation of light sources (Kanbara and Yokoya, 2002). The occlusion problem of the augmented objects relative to the real object is also a difficult problem (Fuhrmann et al., 1999). Due to these difficulties, it is still not possible in real-time AR systems to have realistic virtual objects with respect to lighting, shadowing, and occlusion. Thus, our goal is to find out whether 3D sound can help in the judgment of depth, and if so, to what extend can it be helpful for AR.

We thus designed an experimental task which requires the subject to tell which of the augmented objects is closer (less deep) to her and we calculated the accuracy of the judgments. The subjects were required to give their judgment under the conditions of vision plus 3D sound and vision only. As will be seen in the sections below, the judgment accuracy was found to be significantly higher when 3D sound was applied.

2.4. AR experimental environment implemented by acoustic-inertial tracking method

The vision-based maker tracking method can register the virtual objects and virtual sound sources into the real scene precisely. However it has several short-comings as well. For example, the marker tracking algorithm is sensitive to the lighting environment. Also the requirement of keeping a marker in the scene all the time limits the user's movement as well as viewpoint and thus restricts the user to a relatively small space and a narrow angle of view. This drawback could be improved to some extent by using multi-marker tracking or natural feature tracking methods (Neumann and You, 1999). However, they still do not allow fully free head and body movements.

Some previous work used other methods for registering a virtual sound source in a larger space which allowed user's free movement. Makino et al. (1996) used the Global Positioning System (GPS) to locate the traveler within the environment. With differential correction by way of audio link from a GPS reference receiver in the local vicinity, localization is accurate to around 1 m under good conditions of reception. The listen project (Eckel et al., 2001) used motion-tracked wireless headphones to retrieve the position of the user in the environment. A similar method was applied by Schmandt (1998) where the head position is gained from a Polhemus sensor mounted on the headphones.

In our research system (Cheok et al., 2004; Wang et al., 2002), we use the InterSense IS-900 system (InterSense) for precise motion tracking. The IS-900 system is a hybrid acoustic-inertial six degree of freedom (6 DOF) position and orientation tracking system.

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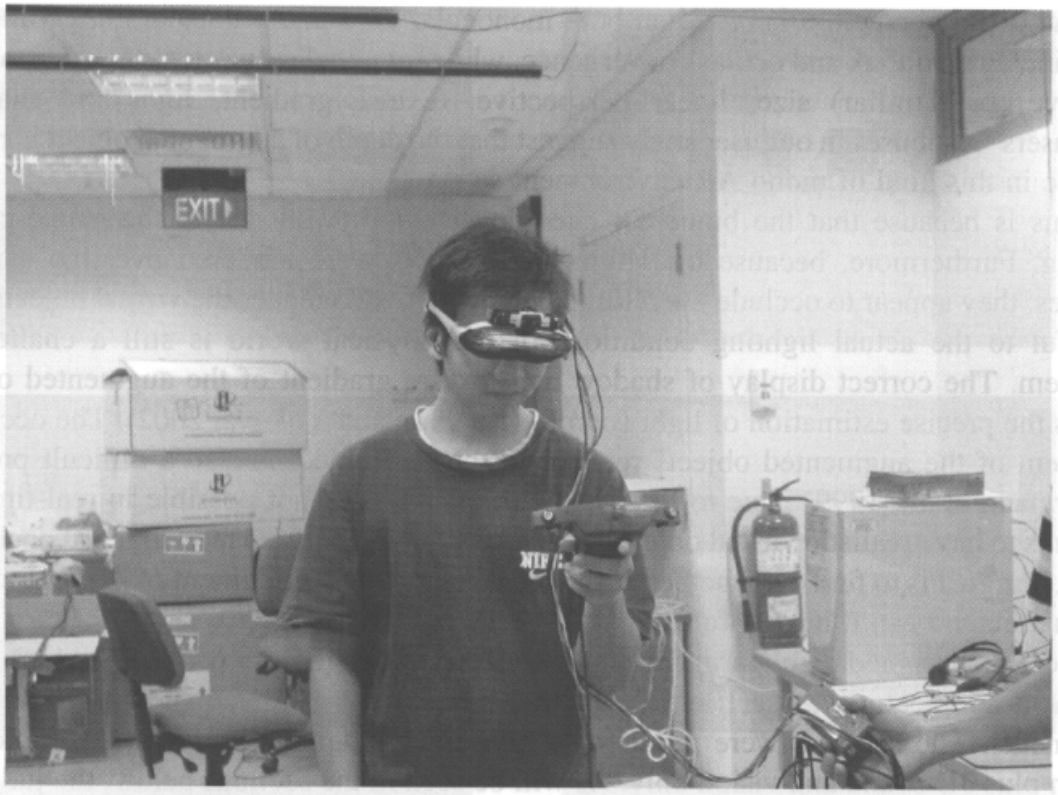


Fig. 3. The physical set-up of our acoustic-inertial tracking AR environment. On the ceiling there are six IS-900 SoniStrips which makes up a three meter by three meter area. A head tracker is mounted on the user's HMD and a camera is fixed on the head tracker. A wand tracker with four buttons and one joystick was held in the user's hand as an interaction device.

It tracks changes in orientation and position by integrating the outputs of its gyroscopes and accelerometers, and corrects drift by using a room-referenced ultrasonic time-of-flight range measuring system. It can obtain a resolution for position of 15 mm.

For the experimental system, as shown in Fig. 3, we mounted six IS-900 SoniStrips on the ceiling of a 3 meter by 3 meter space. This system can support up to four tracking stations. We used four tracking stations to track two users' heads and hands, respectively. A head tracker was mounted on the user's HMD and a camera is fixed on the head tracker. A wand tracker with four buttons and one joystick was held in the user's hand as an interaction device.

The system superimposes graphics on video sequences captured from the camera and displays the combined images on the HMD. We employed OpenAL (Loki Entertainment Software) for generating 3D sounds. Unlike the vision-based tracking method where we make the user's co-ordinates system as the reference, in this method, we used the IS-900 co-ordinates system as a reference while using the users' head position, orientation, and the virtual sound sources' 3D position as input parameters for the OpenAL software.

3. Experimental goals and subjects

Two experiments were taken in the two pre-mentioned AR environments, respectively. In the first experiment, our goal is to find out:

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1. Whether 3D sound helps depth perception and by how much.
2. Whether the exaggeration of intensity difference of 3D sound will be acceptable or unacceptable psychologically.

In the second experiment, our goal is to find out:

1. Whether 3D sound helps in task performance, or more specifically, whether it helps to shorten a searching task completion time and by how much.
2. Whether 3D sound gives more immersive and realistic perception to the users and whether it helps the subject to distinguish different objects in AR environments.
3. Whether 3D sound increases the feeling of 'human presence and collaboration'.

Both qualitative and quantitative studies were conducted in each experiment. The study took place over a four-week period in the summer of 2002.

Forty subjects (13 females and 27 males) were each paid Singapore $8 (approximately $4 USD) per hour to participate in this study. All the participants were undergraduate students at the National University of Singapore. Most of them were freshmen or juniors majoring in computer engineering. The subjects were on average 21.3 years old and had used computer for 8.7 years. They were asked to mark from 1 to 7 about how often (1 means very often while 7 means very seldom) do they use computers and how often do they play games. The averages were 1.7 and 4.5 respectively, which means that they often use computers, but play games only occasionally. All of the subjects reported clear-vision and normal hearing abilities.

Each subject performed both experiments. However in the second experiment, 20 subjects (seven females and thirteen males) were asked to conduct the searching task with the aid of 3D sound while the other 20 subjects (6 females and 14 males) conducted the same task without the 3D sound. Before doing the experiments, all the subjects were given a brief introduction about AR and the tasks to be performed. Each of the subjects was given five minutes to initially try on the HMD and experience the 3D sound effect. After the experiments, all subjects were given 25 min to finish a questionnaire based on the experiments finished.

4. Experimental results

In this section we present the details of the evaluation studies of 3D sound effect and performance in our two AR environments described before

4.1. Experiment of the impact of 3D sound on depth judgment

4.1.1. Design and procedures

In this experiment, we examined the effect of 3D sound on helping users to judge the relative depth of objects in an AR environment (Fig. 4) implemented by vision-based tracking method. Users were required to tell the relative depth of the two markers upon which virtual objects were augmented. In order to precisely position the markers, we used a white board to hold the markers. We set the height of user's chair so that the markers

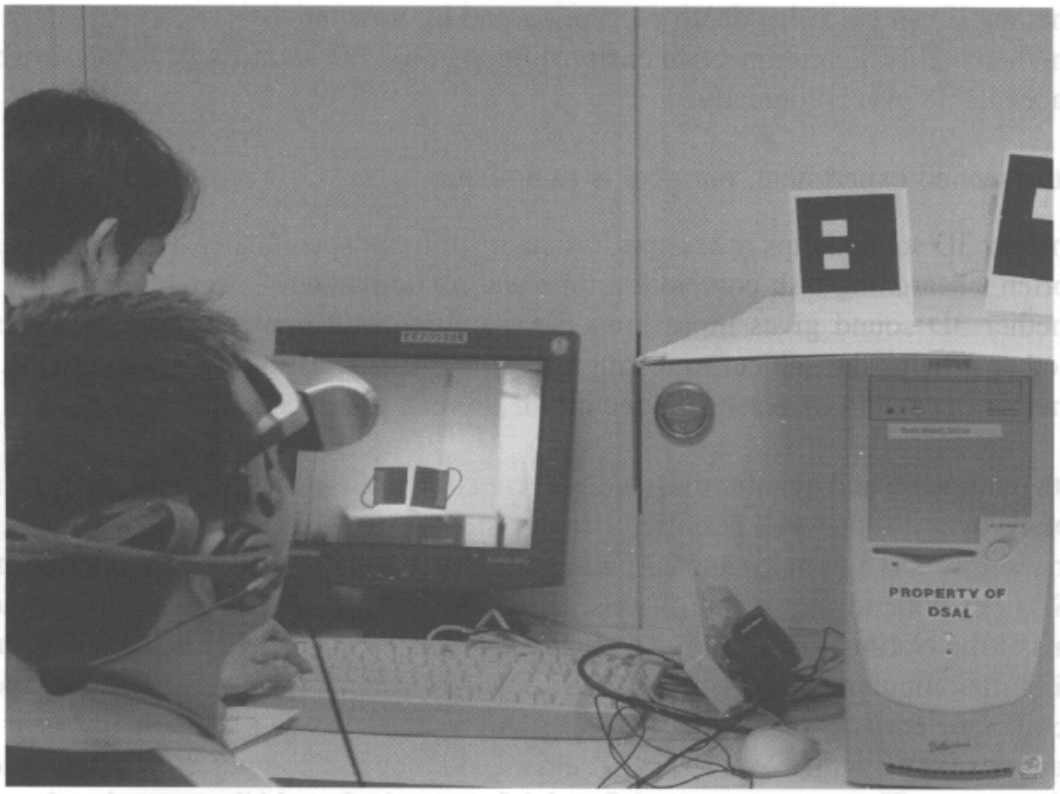


Fig. 4. The physical set-up of the experiment on depth judgment. The output of the computer VGA signal is send to a monitor and HMD for display by a video converter. The user can only see from HMD while the monitor is for the use of the experimentalist. Two virtual telephones with different colors are augmented onto different markers respectively. The size of augmented objects is adjusted to about the same by adjusting the position of marker. Users are required to tell the relative depth of the two objects in the cases of with and without 3D sound aided.

and the eyes were at the same height. By this way we eliminated the vertical vision cue to depth perception-as the relative position on the same plane can tell the relative depth. This makes sense in AR environment since the augmented objects are not necessarily located on the same plane, and thus this cue is not commonly available. The relative position of the two markers was chosen carefully so that the two markers seem to be approximately of the same size in the camera's view. As described in Section 2.3.1, this will cause depth confusion and hence we can carefully decide the effectiveness of adding 3D sound to the virtual objects.

A preliminary study (Mereu, 1995) indicated that visually impaired users can use the sound environments to perceive depth and position in a 3D application. We hence propose that 3D sound could also be helpful in AR environment for people to perceive depth. To test this hypothesis, we implemented 3D sound in our AR environment and measured the accuracy of relative depth judgment of subject.

4.1.2. User interfaces

As shown in Fig. 4, we augmented the same shape virtual telephone with a different color on each of the markers. The virtual telephones were augmented with a 3D telephone sound that was produced to emanate from each virtual telephone. As explained in

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Section 2, the intensity difference of 3D sound due to different depth of markers was exaggerated by a scaling factor. Subjects were asked to put on the headphone of HMD and perceive the difference of 3D sound when the marker was changed to different positions.

Every subject was required to perform 10 trials judging the relative depth of two telephones. Before every trial, the signal of the HMD is turned off so that the subject could not see how the markers were arranged. During that time, the user only sees black because the HMD is a nonoptical see through type. We placed the two different sized markers on the condition that the image size of the two objects are of about the same size, this can be observed by a monitor which is connected to the same VGA output as what the HMD is connected. Then the HMD is turned on and the subject was required to tell which telephone was nearer to him in the cases with and without 3D sound aided respectively. The possible answers are 'left', 'right' and 'uncertain'. We recorded the subjects' judgments and compared them with the correct answers for numerical analysis. We also asked some questions in the questionnaire for psychological analysis purpose.

4.1.3. Results

4.1.3.1. Performance.. The chart in Fig. 5 provides a visual summary of the results of the depth judgment experiment. Fig. 5 compares the number of correct relative depth judgments in 10 trials for 40 subjects in the cases with 3D sound and without 3D sound aided respectively. It can be seen that judgments with 3D sound aided lead to 2.5 times as accurate (70.25 versus 28.25%) as those without 3D sound added.

Our expectation of this experiment was to evaluate the impact of 3D sound on depth judging accuracy. Using a 0.05 significant level, a one-way ANalysis Of VAriance (ANOVA) (Stockburger D, 1998) of the individual correct judgment times of each user was used. In this experiment, we obtained $F(1,39)=129.55$; $p<0.001$ which declares the result to be statistically significant. Thus we conclude that 3D sound does significantly help to increase the number of times of correct depth judgments.

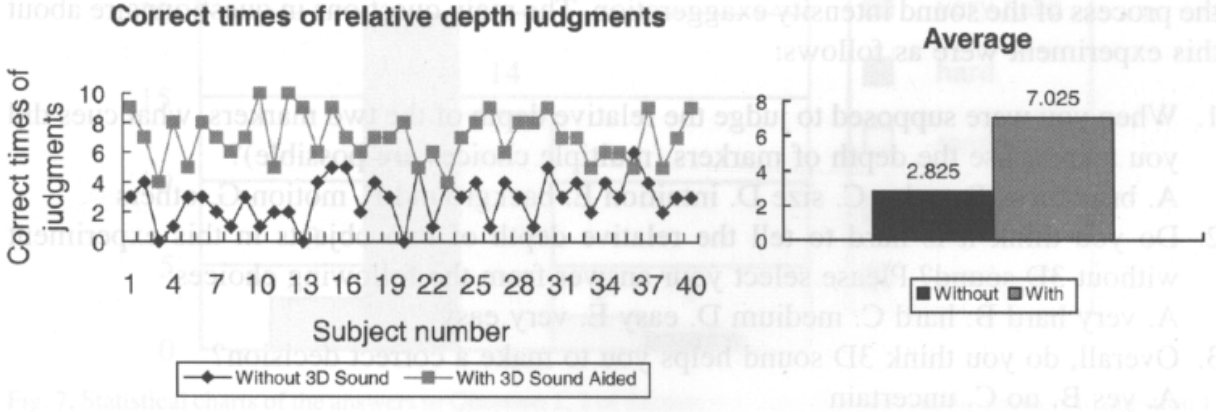


Fig. 5. Comparison of the correct depth judgment times of 40 subjects in ten trials in the cases of with and without 3D sound aided. From this chart we can see obviously that the accurate judgment times increase drastically by introducing 3D sound. The average of correct judgment times is increased from 2.825 to 7.025 by introducing 3D sound.

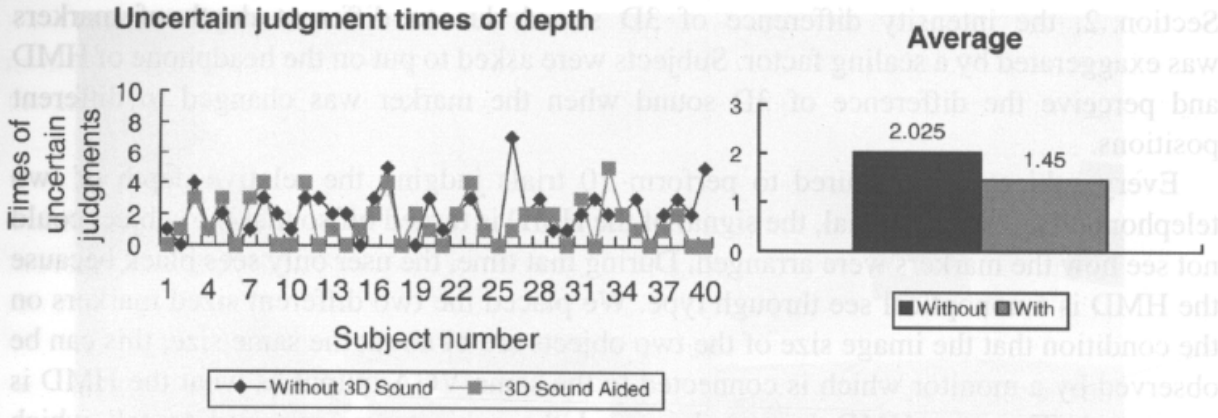


Fig. 6. Comparison of the uncertain judgments in the cases of with and without 3D sound aided. The average of uncertain judgment times is decreased from 2.025 to 1.45 by introducing 3D sound.

On the other hand, the addition of 3D sound decreases the uncertainty of relative depth judgment. Fig. 6 shows the comparison of uncertain judgment times between the cases of with and without 3D sound aided. The addition of 3D sound decreases the average uncertainty from $M=2.03$ to 1.45 times. A significant difference is found ($F(1,39)=4.24$; $p<0.05$). These results proved that the depth perception was significantly enhanced by 3D sound.

There was no significant difference found between the genders. For the correct judging times without 3D sound, males have a mean value of 2.67, females have a mean value of 3.15, $F(1,38)=0.9$; $p>0.1$. For the correct judging times with 3D sound aided, males have a mean value of 7.00, females have a mean value of 7:08, $F(1,38)=0:02$, $p>0.1$.

4.1.3.2. Questionnaire responses.. The purpose of the questionnaire is to examine how the subject qualitatively judges the relative depth of augmented objects and how difficult the task is. Apart from the quantitative results we obtain from the above experiments, it is advantageous to know the subjective feeling of users due to the addition of 3D sound, and the process of the sound intensity exaggeration. The main questions in questionnaire about this experiment were as follows:

1. When you were supposed to judge the relative depth of the two markers, what cues did you mainly use the depth of markers (multiple choices are possible)?
   A. brightness B. color C. size D. intuition E. background F. motion G. others
2. Do you think it is hard to tell the relative depth of two objects in this experiment without 3D sound? Please select your answer from the following choices:
   A. very hard B. hard C. medium D. easy E. very easy
3. Overall, do you think 3D sound helps you to make a correct decision?
   A. yes B. no C. uncertain
4. In real life situations, the intensity of sound doesn't change drastically when the sound source is moving within a short distance, say 100 mm. However, in our experiment we exaggerated this effect. Thus you perceived an obvious difference between the two markers when they were placed in a relative small different depth.

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Do you feel it is unintuitive that the depth scale of 3D sound in this experiment has been exaggerated? Please select from the following choices about how you feel:
A. very unintuitive B. unintuitive C. medium D. intuitive E. very intuitive F. did not notice at all

Question 1 allows multiple choices. Every choice given by the user will be counted as a single vote to the selected choice. Although different users might tick different numbers of choices, the vote diagram is not severely disturb qualitatively since our purpose is to find out what are the cues most users will use for judging depth. As shown in Fig. 7(a), the 'size' cue was given the first place (30 votes) of all the cues in our question. This partially explains why

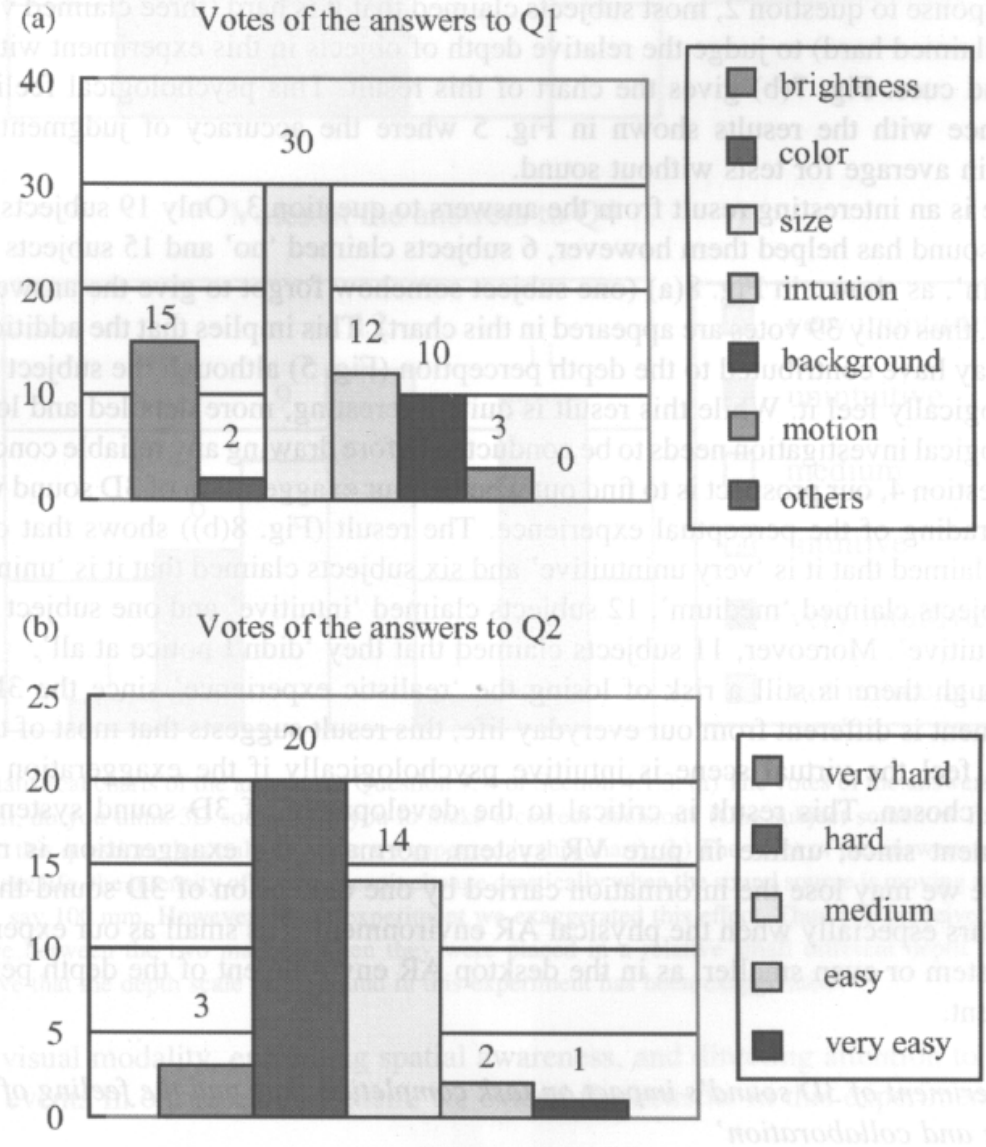


Fig. 7. Statistical charts of the answers to Question 1, 2 of Section 4.1.3 (a) The votes of the answers to question 1: When you were supposed to judge the relative depth of the two markers, what cues did you mainly use the depth of markers (can have multiple choices)? It can be seen from this chart that users are more likely to judge the depth of object by the size, brightness and the background cues. (b) The votes of the answers to question 2: Do you think it is hard to tell the relative depth of 2 objects in this experiment? It can be seen from this chart that it is hard to tell the relative depth of the two markers in our experimental AR environment.

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it is difficult for subjects to judge the relative depth when two markers are almost of the same size. Our setting of AR environment in this experiment restrained the effect of background (ten votes) and motion (three votes). The cue 'brightness' which reects the cue 'light and texture gradient' obtains the second highest votes (15 votes). This gives us a hint that in order to obtain good depth perception, it is also important to adjust the appearance of virtual object so that it fits its surrounding physical lighting environment.

However, in this experimental system, the brightness of the object is predefined when the model was created. Hence it brings more difficulties for depth judgment, and it can not provide the cue 'light and texture gradient'. Therefore, this suggests that in the future research we can adjust the brightness of augmented objects according to its lighting environment so as to achieve better depth perception.

In response to question 2, most subjects claimed that it is hard (three claimed very hard and 20 claimed hard) to judge the relative depth of objects in this experiment without the 3D sound cues. Fig. 7(b) gives the chart of this result. This psychological feeling is in accordance with the results shown in Fig. 5 where the accuracy of judgment is only 28.25% in average for tests without sound.

There is an interesting result from the answers to question 3. Only 19 subjects thought that 3D sound has helped them however, 6 subjects claimed 'no' and 15 subjects claimed 'uncertain', as shown in Fig. 8(a) (one subject somehow forgot to give the answer to this question, thus only 39 votes are appeared in this chart). This implies that the addition of 3D sound may have contributed to the depth perception (Fig. 5) although the subject may not psychologically feel it. While this result is quite interesting, more detailed and long term psychological investigation needs to be conducted before drawing any reliable conclusions.

In question 4, our prospect is to find out whether our exaggeration of 3D sound will lead to a degrading of the perceptual experience. The result (Fig. 8(b)) shows that only one subject claimed that it is 'very unintuitive' and six subjects claimed that it is 'unintuitive'. Nine subjects claimed 'medium', 12 subjects claimed 'intuitive' and one subject claimed 'very intuitive'. Moreover, 11 subjects claimed that they 'didn't notice at all'.

Although there is still a risk of losing the 'realistic experience' since the 3D sound environment is different from our everyday life, this result suggests that most of the users will still feel the virtual scene is intuitive psychologically if the exaggeration scale is properly chosen. This result is critical to the development of 3D sound system in AR environment since, unlike in pure VR system, normally the exaggeration is required, otherwise we may lose the information carried by one dimension of 3D sound-the depth. This occurs especially when the physical AR environment is as small as our experimental game system or even smaller, as in the desktop AR environment of the depth perception experiment.

4.2. Experiment of 3D sound's impact on task completion time and the feeling of 'human presence and collaboration'

4.2.1. Design and procedures

In the second experiment, we examined the effect of 3D sound in a larger AR environment in the form of a simple game Barfield (Barfield et al., 1997) identified three primary benefits of auditory spatial information displays as: relieving processing demands

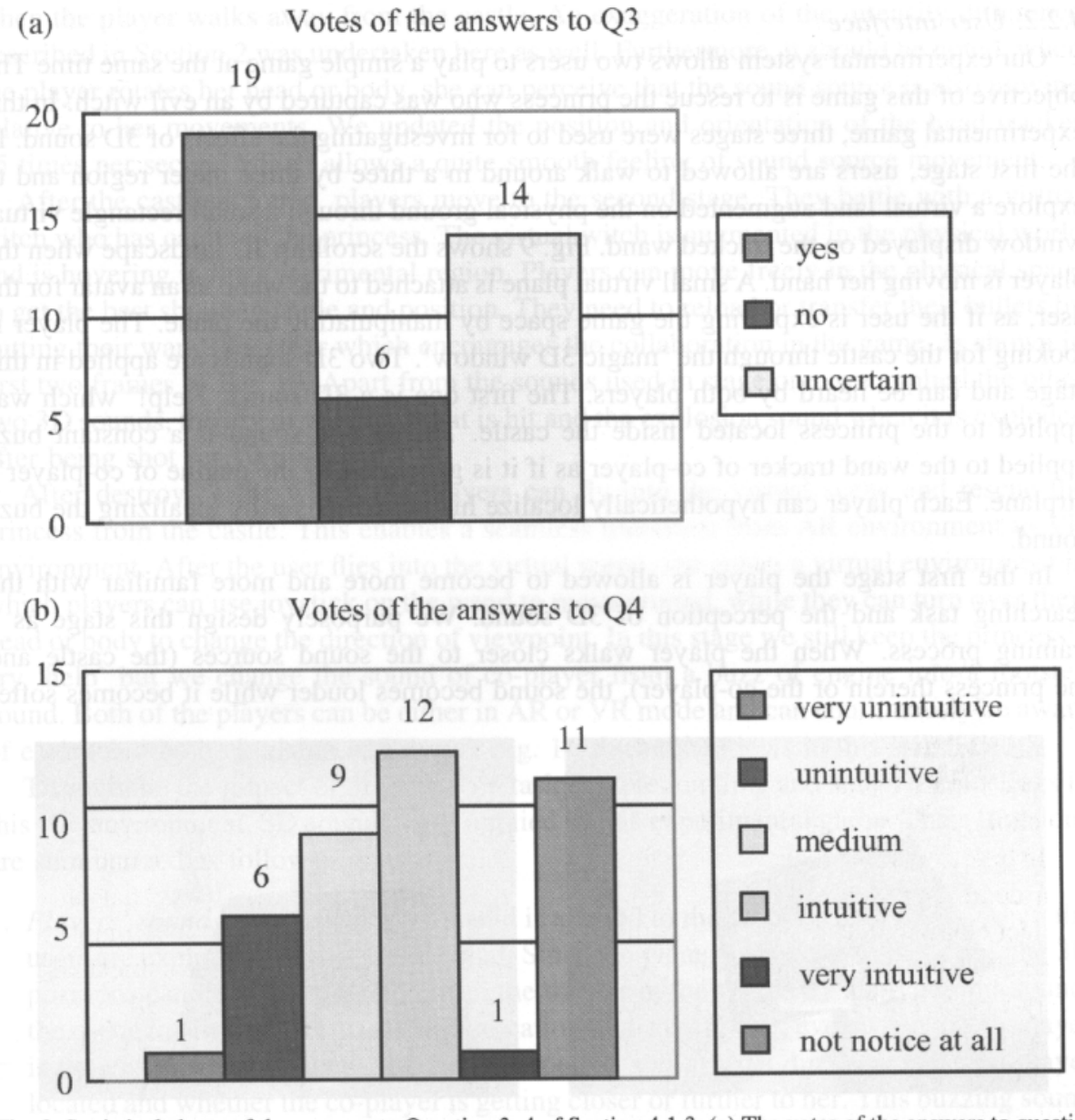


Fig. 8. Statistical charts of the answers to Question 3, 4 of Section 4.1.3. (a) The votes of the answers to question 3: Overall, do you think 3D sound help you to make a correct decision? (One subject somehow forgot to give answer to this question, thus only 39 votes are appeared in this chart). (b) The votes of the answers to question 4: In our every life, the intensity of sound doesn't change drastically when the sound source is moving within a short distance, say 100 mm. However, in our experiment we exaggerated this effect. Thus you perceived an obvious difference between the two markers when they were placed in a relative small different depth. Do you feel unintuitive that the depth scale of 3D sound in this experiment has been exaggerated?

on the visual modality, enhancing spatial awareness, and directing attention to important spatial events In our research system, we extend the benefits in this experiment by:

1. helping to localize an object in AR environment when the visual modality is weakened;
2. enhancing the feeling of human collaboration;
3. directing attention to different spatial objects or helping user to identify different spatial objects.

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4.2.2. User interface

Our experimental system allows two users to play a simple game at the same time The objective of this game is to rescue the princess who was captured by an evil witch. In this experimental game, three stages were used to for investigating the effects of 3D sound. In the first stage, users are allowed to walk around in a three by three meter region and to explore a virtual land augmented on the physical ground through a small rectangle virtual window displayed on the tracked wand. Fig. 9 shows the scrolling 3D landscape when the player is moving her hand. A small virtual plane is attached to the wand as an avatar for the user, as if the user is exploring the game space by manipulating the plane. The player is looking for the castle through the 'magic 3D window'. Two 3D sounds are applied in this stage and can be heard by both players. The first one is a 3D sound 'Help!' which was applied to the princess located inside the castle. The second sound is a constant buzz applied to the wand tracker of co-player as if it is generated by the engine of co-player's airplane. Each player can hypothetically localize his/her co-player by localizing the buzz sound.

In the first stage the player is allowed to become more and more familiar with the searching task and the perception of 3D sound. We purposely design this stage as a training process. When the player walks closer to the sound sources (the castle and the princess therein or the co-player), the sound becomes louder while it becomes softer

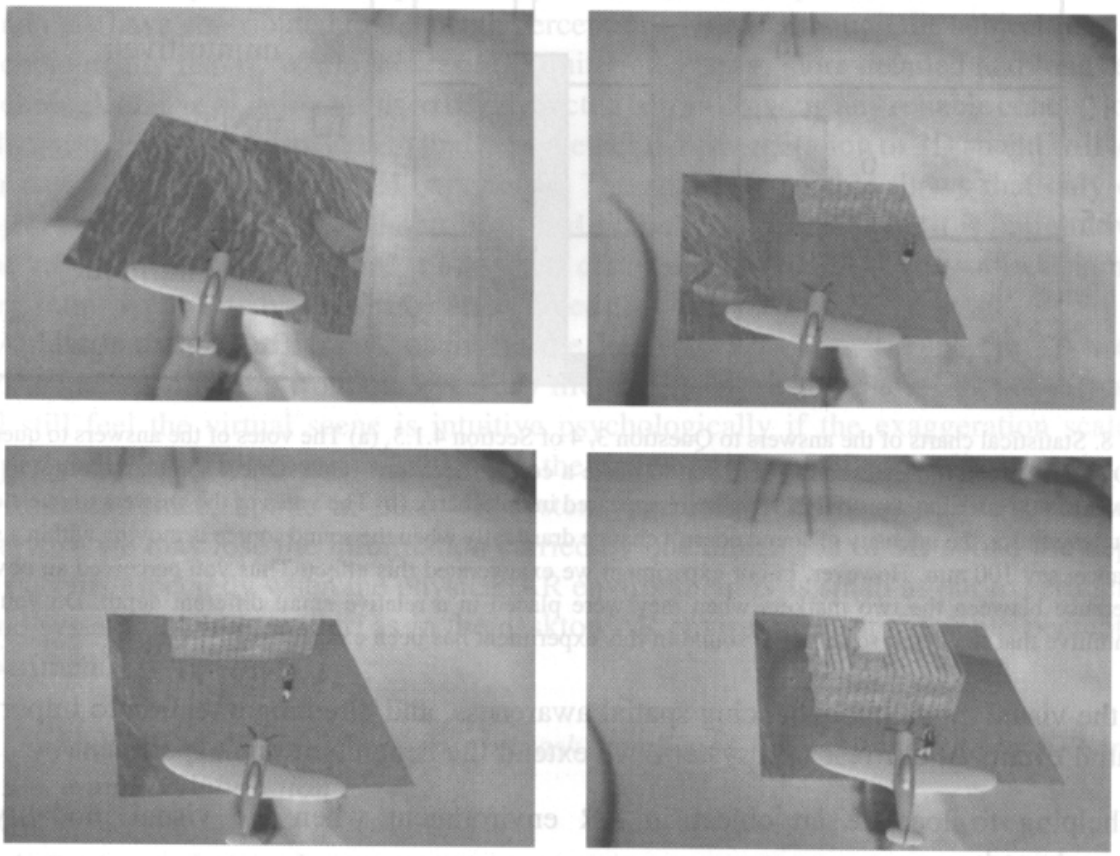


Fig. 9. Looking for the castle through a 'magic 3D window'. A virtual plane is augmented on the wand as an avatar for the user. A rectangle window is augmented in front of the wand through which the user can see the virtual land on the ground. When the user is moving around, the 3D landscape is also scrolled in the 'magic 3D window'. The user is looking down at the castle as if she is looking down from the sky in the airplane.

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when the player walks away from the castle. An exaggeration of the intensity difference described in Section 2 was undertaken here as well. Furthermore, it should be noted, when the player rotates her head or body, she can perceive that the sound source is also moving relative to her movements. We updated the position and orientation of the head tracker 25 times per second which allows a quite smooth feeling of sound source movement.

After the castle is found, players move to the second stage. They battle with a virtual witch who has captured the princess. The virtual witch is augmented in the physical world and is hovering in the experimental region. Players can move freely in the physical space to get the best shooting angle and position. They need to reload or transfer their bullets by putting their wands together which encourages the collaboration in the game, as shown in first two frames of Fig. 10. Apart from the sounds used in stage one, we applied the other two 3D sounds, the cry of witch when it is hit and the explosion sound when it is exploded after being shot for 10 times.

After destroying the witch, the players can fly into the virtual scene and rescue the princess from the castle. This enables a seamless transition from AR environment to VR environment. After the user flies into the virtual scene, she enters a virtual environment in which players can use joystick on the wand to move around, while they can turn over their head or body to change the direction of viewpoint. In this stage we still keep the princess's cry 'help' but we change the sound of co-player from a buzz of engine into a footstep sound. Both of the players can be either in AR or VR mode and can continuously be aware of each other by both vision and sound. Fig. 11 shows the views in this stage.

To examine the impact of 3D sound on task completion time and subjective feelings in this AR environment, 3D sounds were applied in this experimental game. Their functions are summarized as follows:

1. *Players' sounds*: A constant buzz sound is applied to the co-player's airplane when the users are exploring the augmented land. Since the plane is attached to the wand, the 3D positions can be easily obtained from the tracker in the wand. By applying this sound, the user can always hear where is the location of the co-player, even when the co-player is not visually in the scene. She can still roughly tell to what direction is her co-player located and whether the co-player is getting closer or further to her. This buzzing sound is changed into a footstep sound when the co-player enters the VR environment. The different sound gives the hint of whether the co-player is in the AR or VR environment as well.
2. *Human voice*: A constant human voice 'Help! Help!' is applied to the princess which is the target of the searching task. This sound helps the player to turn and face to the correct direction and walk to the correct location where she can see the princess through the small window.
3. *Entertainment sounds*: To make the game more entertaining, we also applied other sound effects. A shooting sound is played when user press the shooting button on the wand. A scream sound and an explosion sound were played when the witch is destroyed. A landing sound of engine is played when the user transits from AR environment to VR environment. A female voice saying 'congratulations' and some greeting words was played when the user finished her mission-find the princess and rescue her.

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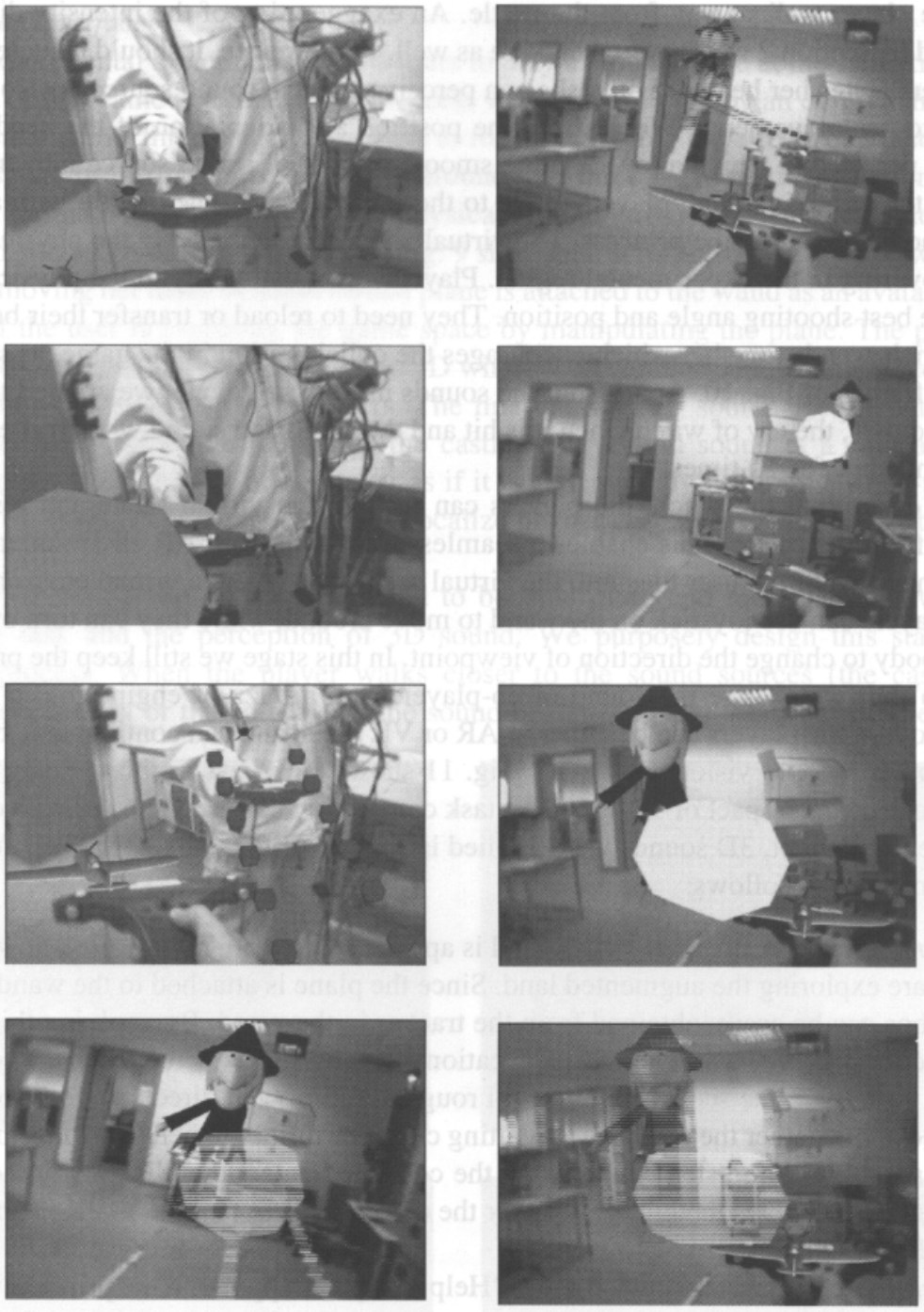


Fig. 10. Two users are collaboratively fighting the witch hovering around them in the physical experimental area. The user can see the augmented virtual witch in three dimensions through HMD. The two users need to reload or transfer their 'bullets' by putting their wands together as shown in the first two frames. When the user pressing a specific button on the wand, the airplane can fire bullets (blue and green dot lines in the subsequent frames). The position and orientation of the wand are used to decide trajectory of 'bullets' and whether the witch is shot or not. In the last frame, the witch disappeared after being shot for ten times.

In this experiment, we took both numerical and psychological studies of the subjects' responses. After the players finished the game missions, they probably have been familiar with the game, an additional task is required to perform in stage one. Instead of searching the castle, they need to search for the princess by walking around and scrolling

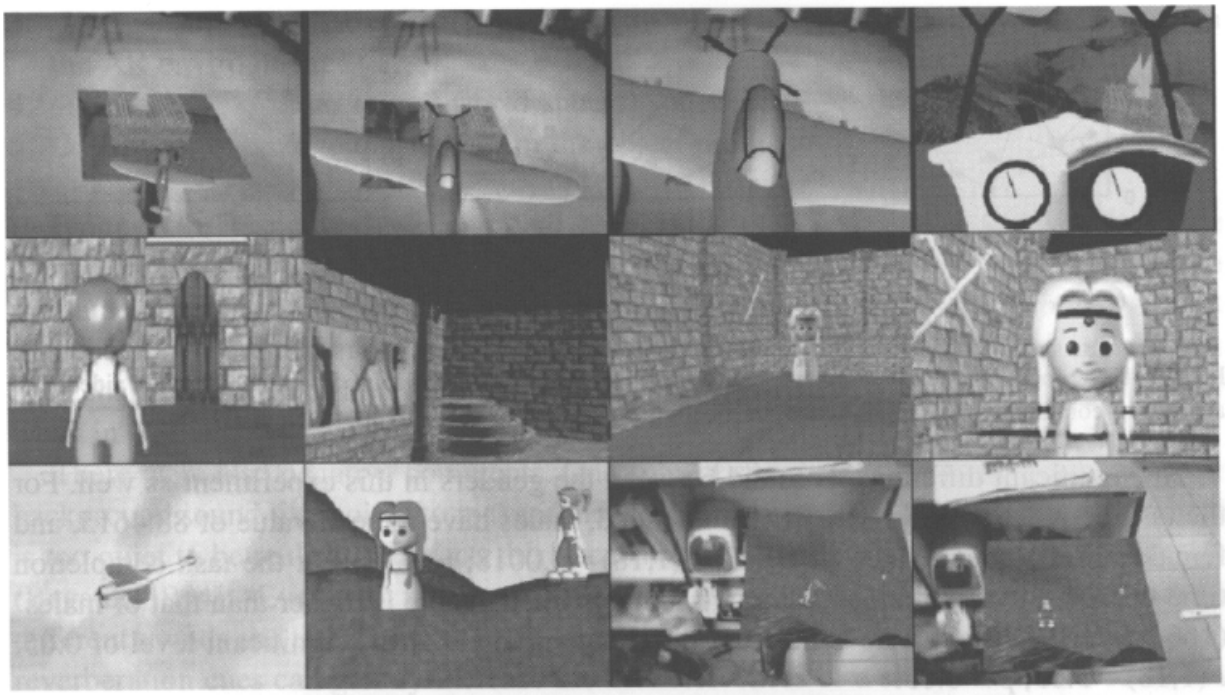


Fig. 11. Rescue the princess in the castle with co-player. (1) The first row shows the seamless transition from AR to VR that the user's airplane is 'flying into' and 'landing on' the VR world. (2) The second row shows one player's view when they are on the way to rescue the princess in the castle. The user uses the joystick to navigate however they can turn the body and head of the virtual character by physically turning their body and head. The footstep sound comes from the co-player and the 'Help!' scream of the princess can always be heard. (3) In the first frame of the third row, a user can physically look up in the sky to find her co-player who is still in AR mode (before flying into the VR mode). The user in the AR mode can still see the co-player and the princess by looking down to the land as if she is on the airplane. The second frame shows one player's view point when both of the players are in VR mode and come to the princess.

the window. The princess was taken outside the castle and was put at an open area on the land. Each subject was given a trial to see how the princess looks like in the small window. Then the princess was put at another position which is the same for all subjects. Every subject started from the same position and orientation in the space and began to search for the princess. The completion time of this searching task was recorded. Twenty subjects (7 females and 13 males) were asked to conduct the searching task with the aid of 'Help!' sound while the rest twenty subjects (6 females and 14 males) conducted the same task without any sound. Every subject performed this task only once either with or without sound aided. Apart from this numerical study, psychological studies were conducted by a linguistic questionnaire.

4.2.3. Results

4.2.3.1. Performance.. In this experiment the subjects performed a searching task as described in Section 4.2.2. The chart in Fig. 12 compares the completion time (in seconds) of the searching task for two groups in the cases with 3D sound and without 3D sound aided. The average task completion time of the group without 3D sound aided was 1.5 times as long (133.05 versus 88.1) as that with 3D sound aided. The effect of 3D sound on shorten the task completion time is significant, $F(1,38)=6.7$; $p<0.025$.

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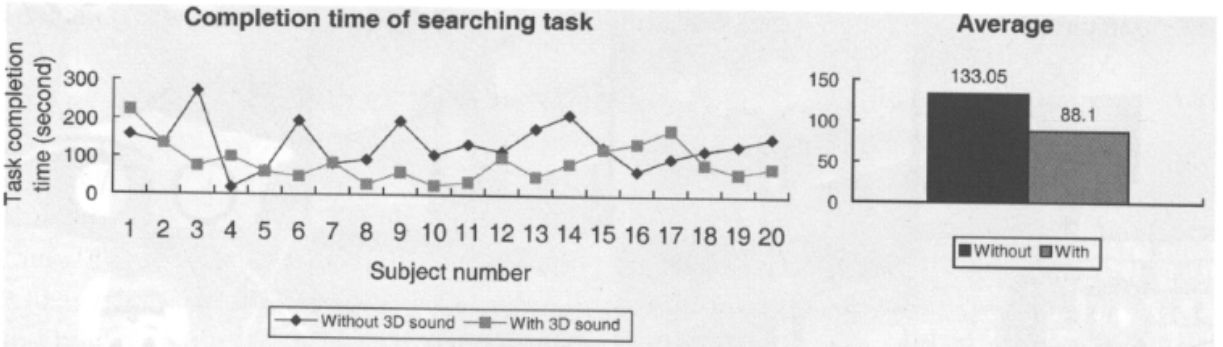


Fig. 12. The comparison of searching task completion time in the cases of with and without 3D sound aided. The average of completion time is shortened drastically from 133.05 to 88.1 s by introducing 3D sound.

No significant difference is found between the genders in this experiment as well. For the task completion time with 3D sound aided, males have a mean value of 88.4615, and females have a mean value of 87.43, $F(1,18)=0.0018$; $p>0.1$. For the task completion time without 3D sound aided, although females' mean value is higher than that of males' (166.33 versus 118.79), no significant difference is found at the significant level of 0.05, $F(1,18)=3.03$; $p>0.05$.

From the results given above we can see that, 3D sound helps significantly to shorten (about by half) the searching task completion time in this AR environment.

4.2.3.2. Questionnaire responses. The purpose of the questionnaire questions is to examine the impact of 3D sound on the subject's psychological feelings. We wanted to examine whether 3D sound improves the feeling of immersiveness and human presence and collaboration, whether it helps to identify spatial objects, and how much impact it has on these feeling. The main questions in questionnaire about this experiment were as follows:

1. Does 3D sound improve your perception of immersiveness in the AR environment? Do you think it is more realistic with 3D sound than without it? Why?
2. Does the 3D sound improve your feeling of human presence and collaboration as you can hear the sound coming from your collaborator at anytime?
3. Does the 3D sound help you to identify different information signals (spatial objects)?
4. Were you aware of your co-players in different places?
   A. always B. very often C. often D. barely E. never
5. What has helped your feeling of 'human presence and collaboration'? (can be multiple choices, please order the factors by the order of decreasing importance)
   A. small talk between co-players B. vision cues C. 3D Sound cues D. Others

According to question one, almost all subjects (39 of 40 subjects) claimed that 3D sound did improve the perception immersiveness. A total of 38 subjects claimed that it is more realistic with 3D sound, and one subject claimed 'a little better'. The main reasons they provided to support their viewpoint are as follows:

1. 'It is natural feeling and more realistic with 3D sound.'
2. 'You can feel the sound from all directions which gives a more 3D feeling.'

3. 'You can tell where the collaborator is positioned, or to know the surrounding objects in the AR environment.'
4. 'The feeling is closer to real world and 3D sound helps to navigate.'
5. 'I can hear and judge distance from the object producing the sound.'

From these responses, we can find that 3D sound does play an important role complementing the visual AR environment. Although this result seems to be natural since the same conclusion has been drawn in virtual reality environment (VRE), it proves that this conclusion is still tenable in AR environment when the implementation method has been changed and especially when the interfaces preserve our social interactions which are weak in VR.

There were also negative comments. One subject suggested that there should be more background sound like noises to make it more realistic. The subject said, 'The sound field is too quiet to be realistic.' In fact, this is consistent with the argument given by Begault (Begault, 1994): "Even with non-spatial cues, one can tell something about the distance of different sounds and their context,..., but the inclusion of 3-D sound techniques and spatial reverberation cues can greatly increase the immersiveness of a simulation, as well as the overall quality and the available nuance in representing different environmental contexts".

The important result we obtained from the responses to question two is that 3D sound improves the feeling of 'human presence and collaboration' when the subject is performing this experimental task. In this question, 39 of 40 subjects answered 'yes'. Some of the comments were:

1. 'At least I can find whoever it is.'
2. 'The sound constantly reminds us of the presence of the collaborator.'
3. 'Yes, like someone is actually in the world with you.'
4. 'It is really interesting that you can turn to face him when the clop-clop is getting closer to you in your back.'

One interesting comment was that 'I can know whether he is still in the airplane or has landed down and walking around' (which meant that the user could know if the other player was in AR or VR modes). This is actually one function of sound which is serving as an auditory icon (Gaver, 1986). A good negative comment suggested that 'it can be improved by adding speech communication, because a running motor does not sound very human, so it is like an object somewhat'.

Apart from applying 3D sound to the collaborator, we also applied 3D sound to the princess who is the target of the task. The responses to question three suggest that 3D sound, when applied to different spatial objects (information signals) in AR environment, can help the user to identify different information carriers. In our experiment 36 subjects claimed that they can constantly be aware of both the other collaborator and the princess simultaneously. This result suggests that by introducing more than one 3D virtual source sources in AR environment, it is possible for the users to identify different meanings of them and to distinguish them by the localization of the sound sources. As one subject described, 'yes, very much so. For instance, if the collaborator sounds from the left

earpiece and princess cries are heard at right earpiece, the directional news determines the positions of the collaborator and princess.'

However, one valuable criticism complained that 'the volume differs when you are far but when you are near I could not hear a difference especially in terms of direction', the other one complained that 'the sound sometimes seemed to be coming from all directions and I was uncertain whether to turn left/right, only when I was close did the volume increase, but in a jump, not gradually'. These comments points out the drawbacks of our exaggeration process of 3D sound intensity in this AR environment and also to some extend support the results of Brungart (Brungart and Rabinowitz, 1999; Brungart, 1999). We designed the auditory environment so that when the user becomes closer to the virtual sound source in the three by three meters region, the 3D sound intensity is exaggerated. This will be maximum intensity when the user is at the position of the virtual sound sources (distance to the object is zero). In this case, the binaural cues play a very important role for distance and direction perceptions. Because of the closeness to the object when near zero, even a slight movement of the user may cause a totally opposite feeling of the source direction (from left to right). When the movement is very fast, the intensity and sound direction may change rapidly. This problem can be partly solved by designing a better sound-scape. However the situation when the user is overlaid on the sound source is still a difficult problem unless we apply some physical constraints on the user's sound near to virtual sound sources.

Chart (a) and (b) in Fig. 13 shows the subjects' responses to question four and question five, respectively. We can see from chart (a) that nine of 40 subjects claimed that they were 'always' be aware of co-players while five subjects claimed 'very often' and 18 claimed 'often'. This leads to the improvement to the feeling of collaboration. A total of 39 subjects agreed that 3D sound did increase their feeling of collaboration from the result of question two.

To examine the importance of 3D sound among all cues, subjects were required to choose the cues they thought to have helped them and to order them by the importance. 3D sound cues obtained the highest votes (36 votes) among all the cues. Move importantly, a total of 14 subjects regarded 3D sound cues as the most important cue while 'small talk' and 'vision cues' only obtained five and four votes respectively. This result suggests that 3D sound does play a very important role in improving the subject's feeling of collaboration. It could even dominate among all possible cues in AR environment, especially when other cues are restrained by hardware settings, for example, angle of view is restrained by HMD in common AR system. In this situation, the visual cues are restrained due to the narrow viewpoint of HMD, and hence their effects on collaboration are limited. On the contrary, the 3D sound can be generated from any points in the AR space. When 3D sound is applied to the user and given different meaning at different situations, it can play the most important role to help the user's feeling of 'human presence and collaboration'.

5. Conclusions

The purpose of this work is to investigate the effectiveness of 3D sound in AR environments We designed two experimental AR environments to study the effectiveness

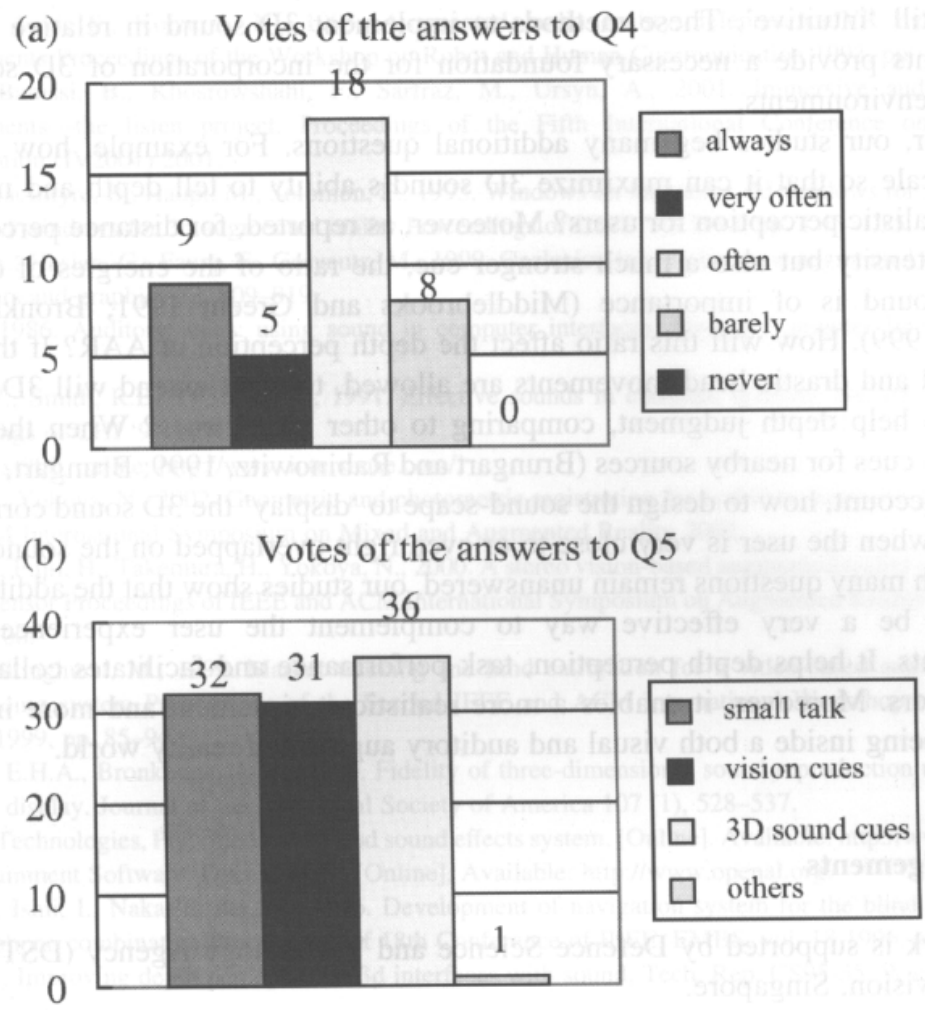


Fig. 13. Statistical charts of the answers to Question 4, 5 of Section 4.2.3. (a) The votes of the answers to question 4: Were you aware of your co-players in different places? We can see from the chart that in this AR environment, subjects can often be aware of co-player's position, however, this result is impossible if there was no 3D sound applied since the subject can only occasionally see co-player due to the narrow angle of view. (b) The votes of the answers to question 5: What has helped your feeling of 'human presence and collaboration'? It can be seen from this chart that 3D sound plays the most important role among all the cues. It gets even more votes than vision cues and voice communication cues.

both quantitatively and qualitatively. Two different tracking methods were applied to retrieve the 3D position of virtual sound sources. We examined the effects of 3D sound on improving depth perception and shortening task completion time. We also investigated 3D sound's effects on improving immersive and realistic perceptions, helping user to identify different spacial objects, and improving the subjective feeling of 'human presence and collaboration'.

The 3D sound generated by OpenAL (Loki Entertainment Software) applying HRTFs and simple modelling of environment is used in our experiments. Apart from its effects for the user on sound source localization, we tried to emphasize its effect on telling the depth (distance). Since intensity has been reported to be a key cue for distance perception, we exaggerated the intensity difference of sound sources in different depth by applying an additional scalar factor to the intensity of generated 3D sound. The user study result shows

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that it is still 'intuitive'. These methods to implement 3D sound in relative small AR environments provide a necessary foundation for the incorporation of 3D sound with visual AR environments.

However, our studies beg many additional questions. For example, how to set the intensity scale so that it can maximize 3D sound's ability to tell depth and meanwhile preserve realistic perception for users? Moreover, as reported, for distance perception not only the intensity but also a much stronger cue, the ratio of the energies of direct and reflected sound is of importance (Middlebrooks and Green, 1991; Bronkhorst and Houtgast, 1999). How will this ratio affect the depth perception in AAR? If the cues of background and drastic head movements are allowed, to what extend will 3D sound be effective to help depth judgment, comparing to other visual cues? When the binaural localization cues for nearby sources (Brungart and Rabinowitz, 1999; Brungart, 1999) are taken into account, how to design the sound-scape to 'display' the 3D sound correctly and intuitively when the user is very close to or even right overlapped on the sound source?

Although many questions remain unanswered, our studies show that the addition of 3D sound can be a very effective way to complement the user experiences in AR environments. It helps depth perception, task performance and facilitates collaborations between users. Moreover, it enables a more realistic environment and more immersive feeling of being inside a both visual and auditory augmented reality world.

Acknowledgements

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Citations to Zhou, 2006-2010 (in chronological order)

Cunningham, S., Grout, V., & Hebblewhite, R. (2006, October). Computer game audio: the unappreciated scholar of the half-life generation. *Audio-Mostly 2006,* pp. 9-14.

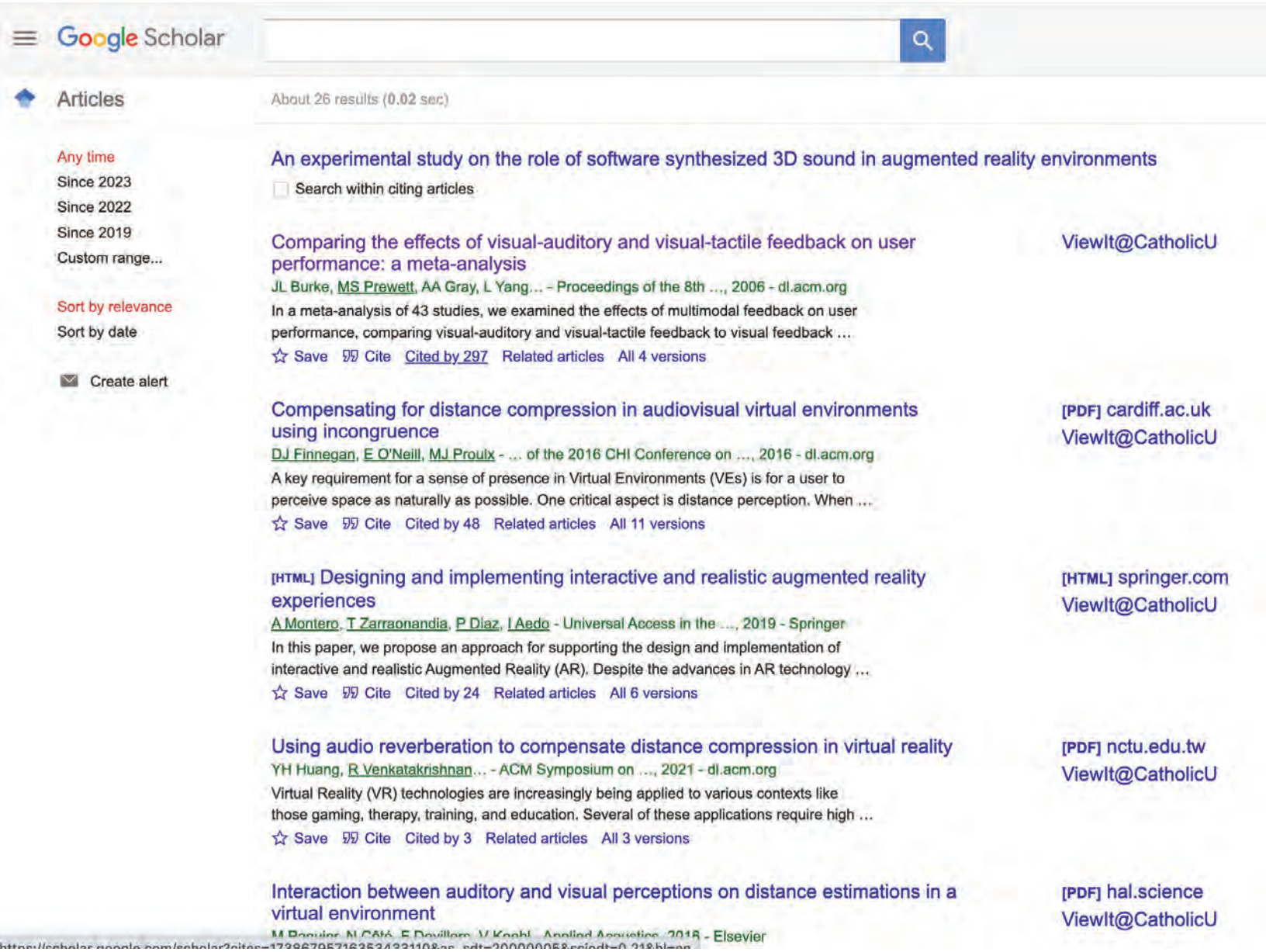
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Yu, L. C., Hsia, H. P., Yi, L. J., & Chia, L. H. (2010, June). Study on Augmented Reality as a Teaching Aid for Handicapped Children. In *Advanced Measurement and Test—Proceedings of 2010 International Conference on Advanced Measurement and Test (AMT 2010)*.


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[PDF] L'analyse ergonomique des besoins en amont de la conception de technologies émergentes

[PDF] academia.edu

M Anastassova - 2008 - academia.edu

Je remercie tout particulièrement M. Jean-Marie Burkhardt, Maître de Conférences à l'Unité Ergonomie–Comportement & Interactions de l'Université Paris V, pour ses nombreux ...

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Study on augmented reality as a teaching aid for handicapped children

ViewIt@CatholicU

CY Lin, PH Hung, JY Lin, HC Lun - Key Engineering Materials, 2010 - Trans Tech Publ

This study looked at the use of augmented reality to combine real scenery with virtual sound to improve the interactivity of teaching aid and provide handicapped children with a more ...

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[PDF] Study on Augmented Reality as a Teaching Aid for Handicapped Children

[PDF] psu.edu

LINC Yu, HP Hsia, LINJ Yi, LUNH Chia - Advanced Measurement and Test ..., 2010 - Citeseer

This study looked at the use of augmented reality to combine real scenery with virtual sound to improve the interactivity of teaching aid and provide handicapped children with a more ...

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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

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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)

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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

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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)

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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)

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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)

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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.
```


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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
```


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```
                        $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

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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.

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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

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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

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$v -- Volume number

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

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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

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856 Electronic location and access
9XX Reserved for local use. (They are used by vendors, systems, or individual libraries to exchange additional data)

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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

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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")

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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*

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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

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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

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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

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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

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