UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

Amazon.com, Inc. and Amazon.com Services LLC.,

Petitioner

v.

LightGuide Inc.,

Patent Owner.

IPR2024-00130

U.S. Patent No. 9,658,614

DECLARATION OF JAMES L. MULLINS, Ph.D.

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I. INTRODUCTION

I, James L. Mullins, am above the age of majority and hereby declare under penalty of perjury:

1. I have been retained by counsel for Petitioners Amazon.com, Inc. and Amazon.com Services LLC to analyze and opine on the authenticity and public accessibility of certain documents referenced herein.

2. I am presently Dean Emeritus of Libraries and Esther Ellis Norton Professor Emeritus at Purdue University. My career as a professional and academic/researcher spanned more than 44 years, including library positions at Indiana University, Villanova University, Massachusetts Institute of Technology, and Purdue University. Appendix D is a true and correct copy of my curriculum vitae describing my background and experience.

3. In 2018, I founded the firm Prior Art Documentation Librarian Services, LLC, now located at 205 Saint Cuthbert, Williamsburg, VA 23188. Further information about my firm, Prior Art Documentation Librarian Services, LLC (PADLS), is available at www.priorartdoclib.com.

4. For my services in connection with this case, I bill at my usual and customary hourly fee of $275.00. I have no stake in the outcome of this proceeding

or any related litigation or administrative proceedings, and my compensation in no way depends on the substance of my testimony or the outcome of this proceeding.

5. As part of my preparation for completing this report, I have reviewed and considered the materials identified in this report.

II. QUALIFICATIONS

6. I received a Bachelor of Arts degree in History, Religion and Political Science in 1972 as well as a Master of Arts degree in Library Science in 1973, both from the University of Iowa. I received my Ph.D. in Academic Library Management in 1984 from Indiana University. Over forty-four years, I have held various positions, and I am considered a leader in the field of library and information sciences.

7. I am currently Dean Emeritus of Libraries and Esther Ellis Norton Professor Emeritus at Purdue University, 2018 – present. I was previously employed as follows:

i) Dean of Libraries and Esther Ellis Norton Professor, Purdue University, West Lafayette, IN, 2004 – 2017;

ii) Assistant/Associate Director for Administration, Massachusetts Institute of Technology (MIT) Libraries, Cambridge, MA 2000 – 2004;

iii) University Librarian and Director, Falvey Memorial Library, Villanova University, Villanova, PA, 1996 – 2000;

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iv) Director of Library Services, Indiana University South Bend, South Bend, IN, 1978 – 1996;

v) Part-time Instructor, School of Library and Information Science, Indiana University, Bloomington, IN, 1979 – 1996;

vi) Associate Law Librarian, and associated titles, Indiana University School of Law, Bloomington, IN, 1974 –1978;

vii) Catalog Librarian, Assistant Professor, Georgia Southern College (now University), Statesboro, GA, 1973, – 1974.

8. I am a member of the American Library Association ("ALA"), where I served as the chair of the Research Committee of the Association of College and Research Libraries ("ACRL"). My service to ALA included service on the editorial board of the most prominent library journal, *College and Research Libraries*. I also served on the Standards Committee, College Section of the ACRL, where I was instrumental in developing a re-issue of the *Standards for College Libraries* in 2000.

9. I am an author of numerous publications in the field of library science and have given presentations in library sciences at national and international conferences. During more than 44 years as an academic librarian and library science scholar, I have gained extensive experience with techniques and systems for cataloging and indexing printed materials in the library setting, including catalog records and online library management systems built using Machine-Readable

Cataloging ("MARC") standards. As an academic library administrator, I have had responsibility to ensure that students were educated to identify, locate, assess, and integrate information garnered from research library resources. I have also facilitated the research of faculty colleagues either directly or through the provision of and access to the requisite print and/or digital materials and services at the universities where I worked.

10. Based on my experience identified above and detailed in my curriculum vitae, which is attached hereto as Appendix C, I consider myself to be an expert in the field of library science and academic library administration. I have previously offered my opinions on the public accessibility and authenticity of documents in over 118 cases. I have been deposed in one case.

III. LEGAL STANDARDS

11. I am not a lawyer. My understanding of the legal standards to apply in reaching the conclusions in this declaration is based on discussions with counsel for Petitioner, my experience applying similar standards in other patent-related matters, and my reading of the documents related to this proceeding. In preparing this declaration, I have tried to faithfully apply these legal standards to the authenticity of the documents referenced herein and whether, when, and how these documents were publicly accessible.

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A. Authentication

12. I have been informed by counsel and understand that an item is considered authentic if there is sufficient evidence to support a finding that the item is what it is claimed to be by the proponent of the item. I have also been informed that authenticity can be established based on the properties of the item itself, such as the appearance, content, substance, internal patterns, or other distinctive characteristics of the item.

B. Public Accessibility

13. I have been informed by counsel and understand that a given reference qualifies as publicly accessible if it were disseminated or otherwise made available such that persons interested and ordinarily skilled in the relevant subject matter could locate it through the exercise of ordinary diligence.

14. I have been informed by counsel and understand that the determination of public accessibility under the foregoing standard rests on a case-by-case analysis of the facts particular to an individual publication. However, I also understand that one way that public accessibility can be shown is if a publication is cataloged and indexed by a library such that a person interested in the relevant subject matter could locate it. In other words, I understand that cataloging and indexing by a library, such that a person interested in the relevant subject matter could locate the reference, is sufficient to render it publicly accessible, though there are other ways that a given

reference may qualify as publicly accessible. One manner of sufficient indexing is indexing according to subject matter. I have been informed by counsel and understand that it is not necessary to prove someone actually looked at the reference in order to show it was publicly accessible by virtue of a library's cataloging and indexing thereof. I understand that cataloging and indexing of a particular printed publication can indicate that the publication is publicly accessible.

15. I also understand that there are other ways that a given reference may be deemed publicly accessible, including where that reference is cited by others in the field.

C. The Critical Date

16. I have been informed by counsel that for purposes of this declaration I should consider evidence of public accessibility prior to October 1, 2010. As described further below, I have concluded that each of the references discussed herein was publicly accessible, including to a Person of Ordinary Skill in the Art, prior to October 1, 2010.

D. The Person of Ordinary Skill in the Art

17. I have been informed by counsel that a person of ordinary skill in the art at the time of the inventions ("POSITA") is a hypothetical person who is presumed to be familiar with the relevant field and its literature at the time of the inventions.

This hypothetical person is also a person of ordinary creativity, capable of understanding the scientific principles applicable to the pertinent field.

18. In addition, I have been informed by counsel that as relevant to these proceedings, the POSITA would have the skills of one or more individuals with experience in the fields of interactive computer applications. These individuals would have at least a four-year degree in electrical engineering, mechanical engineering, computer science, or a closely related field, and at least a year of experience working in interactive computer applications with integrated cameras. Lack of work experience can be remedied by additional education, and vice versa.

IV. BACKGROUND OF LIBRARY CATALOG RECORDS AND OTHER RESOURCES

19. Some background on MARC formatted records, the Online Computer Library Center ("OCLC"), and WorldCat is helpful to understand the library catalog records discussed in this report. I am fully familiar with the library cataloging standard known as the MARC standard, which is an industry-wide standard method of storing and organizing library catalog information.[1] MARC practices have been

[1] The full text of the standard is available from the Library of Congress at http://www.loc.gov/marc/bibliographic/.

consistent since the MARC format was developed by the Library of Congress in the 1960s, and by the early 1970s became the U.S. national standard for disseminating bibliographic data. By the mid-1970s, the MARC format became the international standard, and it persists as such through the present. A MARC-compatible library is one that has a catalog consisting of individual MARC records for each of its items. The underlying MARC format underpins the online public access catalog ("OPAC") that is available to library users to locate a particular holding of a library. Today, MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries.[2] The MARC practices discussed below were in place during the time frames relevant to the documents referenced herein.

20. OCLC is a not-for-profit worldwide consortium of libraries. Similar to MARC standards, OCLC's practices have been consistent since the 1970s through the present. Accordingly, the OCLC practices discussed below were in place during the time frame discussed in my opinions section. OCLC was created "to establish,

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[2] Almost every major library in the world uses a catalog that is MARC-compatible. *See, e.g.,* Library of Congress, *MARC Standards Frequently Asked Questions (FAQ)*, available at https://www.loc.gov/marc/faq.html (last visited Jan. 24, 2018). "MARC is the acronym for MAchine-Readable Cataloging. It defines a data format that emerged from a Library of Congress-led initiative that began nearly forty years ago. It provides the mechanism by which computers exchange, use, and interpret bibliographic information, and its data elements make up the foundation of most library catalogs used today." *Id*. MARC is the ANSI/NISO Z39.2-1994 (reaffirmed 2009) standard for Information Interchange Format.

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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."[3] Among other services, OCLC and its members are responsible for maintaining the WorldCat database (http://www.worldcat.org/), used by libraries throughout the world.

21. Libraries worldwide use the machine-readable MARC format for catalog records. MARC-formatted records include a variety of subject access points based on the content of the document being cataloged. A MARC record for a particular work comprises 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. For example, a work's title is recorded in field 245, the primary author of the work is recorded in field 100, a work's

[3] OCLC Online Computer Library Center, Inc., Amended Articles of Incorporation of OCLC Online Computer Library Center, Inc., Third Article (OCLC, Dublin, Ohio) Revised June 23, 2017, available at https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf.

International Standard Book Number ("ISBN") is recorded in field 020, and the work's Library of Congress call number (assigned by the Library of Congress) is recorded in field 050. Some fields can contain subfields, which are indicated by letters. For example, a work's publication date is recorded in field 260 under the subfield "c."

22. The MARC Field 040, subfield "a," identifies the library or other entity that created the catalog record in the MARC format. MARC Field 008 identifies the date when this first MARC record was created.

23. MARC records also include several fields that include subject matter classification information. An overview of MARC record fields is available through the Library of Congress at http://www.loc.gov/marc/bibliographic/. For example, 6XX fields are termed "Subject Access Fields."[4] Among these, for example, is the 650 field; this is the "Subject Added Entry - Topical Term (R)" field. *See* http://www.loc.gov/marc/bibliographic/bd650.html. The 650 field is a "[s]ubject added entry in which the entry element is a topical term." *Id*. The 650 field entries "are assigned to a bibliographic record to provide access according to generally accepted thesaurus-building rules (e.g., *Library of Congress Subject Headings* (LCSH), *Medical Subject Headings* (MeSH))." *Id*. Thus, a researcher can easily

[4] *See* http://www.loc.gov/marc/bibliographic/bd6xx.html.

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discover material relevant to a topic of interest with a search using the terms employed in MARC Fields 6XX.

24. Further, MARC records include call numbers, which themselves include a classification number. For example, the 050 field is dedicated as the "Library of Congress Call Number (R)"[5] as assigned by the Library of Congress. A defined portion of the Library of Congress Call Number is the classification number; the "source of the classification number is *Library of Congress Classification* and the *LC Classification-Additions and Changes*." *Id*. (emphases in original). Thus, included in the 050 field is a subject matter classification. As an example: TK5105.59 indicates books on computer networks - security measures. When a local library assigns a classification number -- most often a Library of Congress derived classification number created by a local library cataloger, but sometimes a Dewey Decimal classification number such as, for example, "005.8, computer networks - security measures" -- that classification number appears in the 090 field. In either scenario, the MARC record includes a classification number in the call number field that represents a subject matter classification.

[5] *See* http://www.loc.gov/marc/bibliographic/bd050.html.

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25. The 9XX fields, which are not part of the standard MARC 21 format[6], were defined by OCLC for use by the Library of Congress in processing or holding notes for a local library, and for internal OCLC use. For example, the 955 field is reserved for use by the Library of Congress to track the progress of a new acquisition from the time it is submitted for Cataloging in Publication ("CIP") review until it is published and fully cataloged and publicly available for use within the Library of Congress. Fields 901-907, 910, and 945-949 have been defined by OCLC for local use and will pass OCLC validation. Fields 905 and 910 are often used by an individual library for internal processing purposes, for example, the date of cataloging and/or the initials of the cataloger.

26. *WorldCat* is the world's largest public online catalog. It is maintained by the OCLC, a not-for-profit international library consortium, and built with the records created by the thousands of libraries that are members of OCLC. OCLC provides bibliographic and abstract information to the public based on MARC-compliant records through its OCLC *WorldCat* database. *WorldCat* requires no knowledge of MARC tags and codes and does not require a login or password. *WorldCat* is easily accessible through the World Wide Web to all who wish to search it; there are no restrictions to be a member of a particular community, etc. The date a

[6] *See* https://www.oclc.org/bibformats/en/9xx.html.

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given catalog record was created (corresponding to the MARC Field 008) appears in some detailed *WorldCat* records as the Date of Entry but not necessarily all. *WorldCat* does not provide a view of the underlying MARC format for a specific *WorldCat* record. In order to see the underlying MARC format, the researcher must locate the book in a holding library listed among those shown in *WorldCat*, and search the online public catalog (OPAC) of a holding library. Whereas *WorldCat* records are widely available, the availability of library-specific MARC formatted records varies from library to library. When a specific library wishes to make the underlying MARC format available, there will be a link from the library's OPAC display, often identified as an option to click on the MARC record or use the librarian/staff view.

27. When a MARC record is created by the Library of Congress or an OCLC member institution, the date of creation for that record is automatically populated in the fixed field (008), with characters 00 through 05 in year, month, day format (YYMMDD).[7] Therefore, the MARC record creation date reflects the date on which the publication associated with the record was first cataloged. Thereafter, the local library's computer system may automatically update the date in field 005 every time the library updates the MARC record (e.g., to reflect that an item has been moved

[7] Some of the newer library catalog systems also include hour, minute, second (HHMMSS).

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to a different shelving location within the library, or a reload of the bibliographic data with the introduction of a new library management system that creates and manages the OPAC).

A. Monograph Publications

28. Monograph publications are written on a single topic, presented at length, and distinguished from an article. They include books, dissertations, proceedings of a conference, and technical reports. A library typically creates a catalog record when the monograph is acquired by the library. First, it will search the OCLC to determine if a record has already been created by the Library of Congress or another OCLC institution.

29. If a record is found in the OCLC, the record is downloaded into the library's management system, which typically includes the OPAC. Once the item is downloaded into the library's management system, the library adds its identifier to the OCLC database so when a search is completed on *WorldCat*, the library will be indicated as possessing the publication. Once a record is created in a library's management system, it is searchable and viewable through the library's OPAC, typically by author, title, and subject heading, at that library and from anywhere in the world through the internet by accessing that library's OPAC. The OPAC also connects with the circulation function of the library, which typically indicates whether the record is available, in circulation, etc., with its call number and location in a

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specific departmental/disciplinary library, if applicable. The OPAC not only provides immediate bibliographic access on-site, but it also facilitates the interlibrary loan process, which is when one publication is loaned from one library to another.

B. Periodical Publications

30. A periodical publication is a published work in a series, for example, a journal article. A library typically creates a catalog record for a periodical publication when the library receives its first issue. When the institution receives subsequent issues or volumes of the periodical, the issues or volumes are checked in, often using a date stamp; added to the institution's holding records; and made available very soon thereafter, normally within a few days of receipt or at most within a few weeks of receipt.

C. Cataloging / Indexing

31. A researcher may discover material relevant to a topic of interest in a variety of ways. One common means of discovery is to search for relevant information in an index of periodicals and other publications. Having found relevant material, the researcher will then normally obtain it online, look for it in libraries, or purchase it from a publisher, a bookstore, a document delivery service, or another provider.

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32. Indexing services use a wide variety of controlled vocabularies to provide subject access and other means of discovering the content of documents. The formats in which these access terms are presented vary from service to service.

33. Online indexing services commonly provide bibliographic information, abstracts, and full-text copies of the indexed publications, along with a list of the documents cited in the indexed publication. These services also often provide lists of publications that cite a given document. A citation of a document is evidence that the document was publicly available and in use by researchers no later than the publication date of the citing document. A few examples are provided below.

34. ***ACM Digital Library*** - Association for Computing Machinery. The ACM was founded in 1947 and is the world's largest scientific and educational computing society. The portal has two main sections: the ACM Digital Library and the ACM Guide to Computing Literature. The ACM Digital Library provides access to the journals, newsletters and conference proceedings of the organization. The Guide to Computing Literature is a bibliography of computing literature beginning in the 1950s with more than a million entries. *See* ACM Digital Library home page, available at https://dl.acm.org/.

35. ***CiteSeerx.*** – CiteSeer is an evolving scientific literature digital library and search engine that has focused primarily on literature in computer and information science. CiteSeer was developed in 1997 at the NEC Research Institute (now known

as NEC Laboratories America, Inc.) in Princeton, New Jersey. The service transitioned to Pennsylvania State University's College of Information Sciences and Technology in 2003. Since its inception, CiteSeer has grown to an index of over 750,000 documents and served over 1.5 million requests daily. *See* CiteSeer home page, available at http://csxstatic.ist.psu.edu/home.

36. ***Google Scholar*** - This web search engine indexes full text or metadata of scholarly literature, covering numerous formats and disciplines. The size of the database is not published by Google, but researchers have estimated that it contained approximately 160 million items in 2014. *See* Orduña-Malea, Enrique; Ayllón, Juan Manuel; Martín-Martín, Alberto; Delgado López-Cózar, Emilio, "About the size of Google Scholar: playing the numbers" Granada: EC3 Working Papers, 18:23 July 2014, available at https://arxiv.org/ftp/arxiv/papers/1407/1407.6239.pdf.

37. ***IEEE Xplore*** - The Institute of Electrical and Electronics Engineers is the world's largest organization for the advancement of technology with some 430,000 members in 160 countries. Known by its acronym IEEE, it has created a database, IEEE Xplore, that provides access to its hundreds of publications and those of its publishing partners. This includes the content of over 170 journals, more than 1,400 conference proceedings, some 5,100 technical standards, 2,000 eBooks and 400 educational courses. In all, more than 3 million documents, dating from 1872 on, are searchable and available for purchase either through subscription or individually.

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Many of these records are accessible via Google Scholar. *See* IEEE Xplore home page, available at https://ieeexplore.ieee.org/Xplore/home.jsp.

38. ***ResearchGate*** – ResearchGate is the professional network for scientists and researchers. Over 15 million members from all over the world use it to share, discover, and discuss research. *See* ResearchGate's "About" page, available at https://www.researchgate.net/about.

39. ***ScienceDirect*** – ScienceDirect is a website which provides subscription-based access to a large database of scientific and medical research. It hosts over 12 million pieces of content from 3,500 academic journals and 34,000 eBooks. The journals are grouped into four main sections: *Physical Sciences and Engineering*, *Life Sciences*, *Health Sciences*, and *Social Sciences and Humanities*. Article abstracts are freely available, but access to their full texts (in PDF and, for newer publications, also HTML) generally requires a subscription or pay-per-view purchase. *See* ScienceDirect webpage, available at https://www.elsevier.com/solutions/sciencedirect.

40. ***SPIE Digital Library*** - The SPIE Digital Library is the database of the International Society for Optical Engineering (originally the Society of Photographic Instrumentation Engineers). The technical papers, journals, eBooks, and conference proceedings of the organization are included in the database. More than 500,000 technical papers make up the database, with more than 18,000 new technical papers

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and 25 eBooks added each year. *See* SPIE Digital Library "About" page, available at https://www.spiedigitallibrary.org.

41. ***Springer Link*** - Springer Link provides researchers with access to millions of scientific documents from journals, books, series, protocols, reference works and proceedings. *See* SpringerLink home page, available at https://link.springer.com/.

42. ***Wisconsin TechSearch ("WTS")*** - WTS is a set of services offered by the University of Wisconsin Libraries. WTS offers an array of article delivery and research services to any individual or organization who requests the specialized skills of WTS staff in locating and retrieving information, regardless of whether the individual is affiliated with the University of Wisconsin. *See* WTS home page, available at https://wts.wisc.edu/.

V. OPINIONS REGARDING AUTHENTICITY AND PUBLIC ACCESSIBILITY OF REFERENCES

A. Exhibit 1007: Tamotsu Machino, Satoshi Iwaki, Hiroaki Kawata, Yoshimasa Yanagihara, Yoshito Nanjo, and Ken-ichiro Shimokura. "Remote-Collaboration System Using Mobile Robot with Camera and Projector." In Proceedings 2006 IEEE International Conference on Robotics and Automation, Orlando, Florida, May 15-18, 2006. ICRA 2006 on pages 4063-4068, published by IEEE Robotics and Automation Society, 2006 ("Machino").

43. I have been asked to opine on the authenticity and public accessibility of an article authored by Tomotsu Machino, et al., titled "Remote-Collaboration

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System Using Mobile Robot with Camera and Projector," published in *Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006* on pages 4063-4068 ("Machino"). These proceedings were published by the IEEE Robotics and Automation Society in 2006.

44. For consistency and clarification, Machino, when used in this report, refers not only to the Machino article but also to the publication in which it appears, *Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006.*

1. Authentication

45. I have evaluated the Machino reference in four ways: (1) by assessing a copy of Machino provided to me by counsel, Exhibit 1007; (2) by requesting a scan from Western University Libraries (London, Ontario) through WTS, appended to this declaration as Appendix A-1; (3) by accessing and assessing a download of Machino that I obtained from the *IEEE Xplore database* on April 25, 2023, enabled by my emeritus faculty status at Purdue University through the Purdue University Libraries, Appendix A-2; and (4) by retrieving and reviewing articles that cite Machino, published prior to October 1, 2010, discussed in Part V.A's section on public accessibility, *infra*.

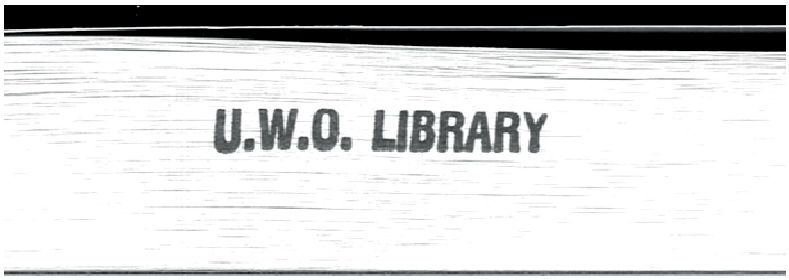
46. Appendix A-1 is a scan of the print copy of Machino owned by the Western University Libraries, obtained for me by WTS on April 11, 2023. Print

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copies of *Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006* are rare, because it was a ten-volume print set, published nearly at the same time as the digital version; libraries frequently opted for the digital version and did not acquire the print copy. However, as discussed further in Part V.A's section on public accessibility, *infra*, access to Machino was available through the digital version.

47. Appendix A-1 is composed of: title page of the 2006 International Conference on Robotics and Automation (ICRA), with a bar code partially obscuring the title that reads, "Western Libraries UWD", as shown below; title page of volume 9 of 10; verso of the title page for volume 9; a print of the fore edge of that reads, "U.W.O. Library", as shown below; Table of Contents on pages iii-lxvii; and the Machino article on pages 4063-4068.





48. The identifying ownership barcode and fore edge ownership stamp are consistent with library practice and procedure that I have observed during my career

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as a professional librarian. I have no cause for concern about the authenticity or accuracy of this ownership attribute. Machino was found within the custody of a library, the Western University Libraries, one of the most likely locations for an authentic publication to be located.

49. Evidence of the ownership of Machino by the Western University Libraries will be further explored and detailed below in section on public accessibility, *infra*.

50. Appendix A-2 is a download I made of Machino, enabled by my emeritus faculty position at Purdue University, through the Purdue University Libraries on April 25, 2023 from the *IEEE Xplore* at this URL: https://ieeexplore-ieee-org.ezproxy.lib.purdue.edu/stamp/stamp.jsp?tp=&arnumber=1642326. Machino is also available for a fee at this URL: https://ieeexplore.ieee.org/document/1642326.

51. I compared Appendix A-1 and Appendix A-2, and I found no difference between the two. I then compared Appendix A-1 and Appendix A-2 with Exhibit 1007, provided to me by counsel, and found no differences among the three. Given the above, I conclude that each of Exhibit 1007, Appendix A-1, and Appendix A-2 contains an authentic, true, and correct copy of Machino.

2. Public Accessibility

Amazon Ex. 1012.0027

52. Appendix A-3 is a true and correct copy of the *WorldCat* entry for Machino. I obtained Appendix A-3 by completing a search on *WorldCat* on May 9, 2023, by setting Williamsburg, Virginia as the geographical limiter. Only three holding libraries appear anywhere in the world: Western University, Canada; Technische Informationsbibliothek (TIB), Germany; and Kanagawa Institute of Technology, Japan.

53. Appendix A-3 shows that Machino is the document associated with this *WorldCat* entry, as verified by title (*2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006; Orlando, Florida, 15-19, 2006*) and ISBN (0780395050). Consistent with standard *WorldCat* practice, entry for these conference proceedings would have been created on or about July 14, 2006 at the time of original cataloging by a member library (as discussed below relative to the MARC record for the proceedings).

54. As a result, by 2010, Machino could have been located by searching for the title (*2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006; Orlando, Florida, 15-19*), and/or by searching the subject headings (e.g., *Automation; Automation-Congresses;* and/or *Robotics*).

55. By 2010, the search discussed above could have been performed anywhere in the world by anyone who accessed *WorldCat* and its predecessor database through an OCLC member library in the early 2000s.

Amazon Ex. 1012.0028

56. Appendix A-4 is a screen capture I made from the Western University Libraries OPAC (online catalog) on May 9, 2023. The document cataloged in this record is Machino as verified by the OPAC record fields including main title (*2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006; Orlando, Florida, 15-19, 2006*); publisher and publication (IEEE Robotics and Automation Society in 2006); and ISBN (0780395050).

57. Machino could have been located in the Western University Libraries OPAC by searching for title (*2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006; Orlando, Florida, 15-19, 2006*)*;* and/or subject headings (e.g., *Robotics – Congresses;* and/or *Automation-Congresses*).

58. Appendix A-10 is the MARC record that I downloaded from the Western University library OPAC. The 008 MARC field reads "008 060714s2006 njua b 101 0 eng d." This indicates that the proceedings including Machino were originally cataloged on July 14, 2006. It is unclear from the MARC record which library performed the original cataloging; nevertheless, on or around this date, the proceedings would have been added to *WorldCat*, as discussed above.

59. Appendix A-5 is a download from *IEEE Xplore* of the webpage that provides access to Machino. On Appendix A-5 toward the lower middle of the page it reads:

Amazon Ex. 1012.0029

Date of Conference: 15-19 May 2006

Date Added to IEEE *Xplore*: 26 June 2006

60. The date above of June 26, 2006, provides evidence that Machino was accessible and retrievable to anyone who had access to *IEEE Xplore* as of June 26, 2006 through a personal membership in IEEE, as well as to anyone who had access through a subscribing institution to *IEEE Xplore*, which most research libraries would provide.

61. Evidence that Machino was publicly accessible to researchers is confirmed by articles that cite Machino prior to October 1, 2010, thereby also confirming authenticity as an acceptable scholarly publication in the field.

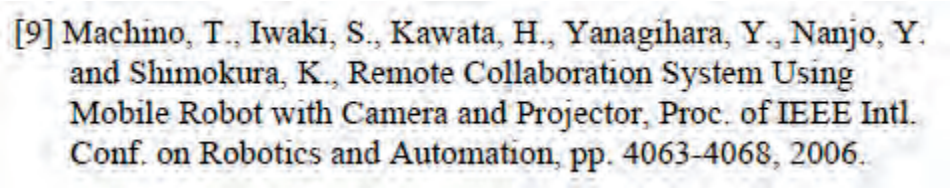
62. Appendix A-6 is a true and correct screen capture of the *Google Scholar* entries that cite Machino between the years 2007 and 2009. This citation list consists of six documents that cite Machino during that period of time. Three of these six documents are listed as follows: Appendix A-7, Park; Appendix A-8, Kawata; and Appendix A-9, Niitsuma. I completed the screen capture from *Google Scholar* on May 9, 2023, at this URL: https://scholar.google.com/scholar?hl=en&as_sdt=5%2C47&sciodt=0%2C47&cites=10317471256020941969&scipsc=&as_ylo=2007&as_yhi=2009.

63. Appendix A-7 is an article by Jongkyeong Park and Gerard Jounghyun Kim, titled "Robots with Projectors: An Alternative to Anthropomorphic HRI,"

published in *Proceedings of the 4th ACM/IEEE International Conference on Human Robot Interaction*, La Jolla, California, March 9-13, 2009 on pages 221-222. 2009 ("Park").

64. Park, Appendix A-7, was downloaded by me on April 25, 2023 from the *ACM Digital Library*, enabled by my emeritus faculty position at Purdue University, through the Purdue University Libraries at this URL: https://dl-acm-org.ezproxy.lib.purdue.edu/doi/abs/10.1145/1514095.1514146. Park is available for a fee at this URL: https://dl.acm.org/doi/abs/10.1145/1514095.1514146.

65. Appendix A-7, a true and correct copy of the Park paper, shows Machino as the 9th citation in the "References" on page 222, as shown below:


[9] Machino, T., Iwaki, S., Kawata, H., Yanagihara, Y., Nanjo, Y. and Shimokura, K., Remote Collaboration System Using Mobile Robot with Camera and Projector, Proc. of IEEE Intl. Conf. on Robotics and Automation, pp. 4063-4068, 2006.

66. The citation to Machino in Park is evidence that Machino was known, publicly accessible, and accepted as a scholarly reference when Park was presented as a paper at the *4th ACM/IEEE International Conference on Human Robot Interaction*, La Jolla, California, March 9-13, 2009, and later published in its proceedings.

67. Appendix A-8 is an article by Hiroaki Kawata, Yosuke Takano, Yoshiyuki Iwata, Naoyoshi Kanamaru, Ken-ichiro Shimokura and Yoshihiro Fujita, titled "Field Trial of Asynchronous Communication Using Network-Based

Amazon Ex. 1012.0031

Interactive Child Watch System for the Participation of Parents in Day-Care Activities," published in the *Proceedings, 2008 IEEE International Conference on Robotics and Automation*, Pasadena, CA, USA May 19 – 23, 2008, on pages 2558-2563 ("Kawata").

68. Appendix A-8, Kawata, was downloaded by me on April 25, 2023, from *IEEE Xplore*, enabled by my emeritus faculty position at Purdue University, through the Purdue University Libraries at this URL:

https://ieeexplore-ieee-org.ezproxy.lib.purdue.edu/stamp/stamp.jsp?tp=&arnumber=4543598.

Kawata is available for a fee at this URL:

https://ieeexplore.ieee.org/abstract/document/4543598.

69. Appendix A-8, a true and correct copy of the Kawata paper, shows Machino as the 7th citation in the "References" on page 2563, as shown below:

[7] T. Machino, et al. "Remote-Collaboration Sysytem Using Mobile Robot with Camera and Projector, " Proc. IEEE Int. Conf. on Robotics and Automation, 2006, pp. 4063- 4068.

70. The citation to Machino in Kawata is evidence that Machino was known, publicly accessible, and accepted as a scholarly reference when Kawata was presented as a paper at the *2008 IEEE International Conference on Robotics and Automation*, Pasadena, CA, USA, May 19 – 23, 2008.

Amazon Ex. 1012.0032

71. Appendix A-9 is an article by Mihoko Niitsuma and Hideki Hashimoto, titled "Spatial Memory for Collaboration Support System in Intelligent Space-User Identification Based on Spatial Memory," published in the proceedings of the *SICE Annual Conference 2007*, Takamatsu, Japan, September 17-20, 2007, on pages 3073-3079 ("Niitsuma").

72. Niitsuma, Appendix A-9, was obtained for me by the Purdue University Libraries Interlibrary Loan Department from the print copy owned by the University of Texas at Dallas on April 25, 2023. Niitsuma is available for a fee at this URL: https://ieeexplore.ieee.org/abstract/document/4421519.

73. Appendix A-9, a true and correct copy of the Niitsuma paper, shows Machino as the 5th citation in "References," on page 3079 as shown below:

> [5] Tamotsu Machino, Yoshito Nanjo, Yoshimasa Yanagihara, Hiroaki Kawata, Satoshi Iwaki and Ken-ichiro Shimokura, "A Remote-collaboration System using a Mobile Robot with a Camera and a Projector", Proc. 2006 IEEE Int. Conf. on Robotics and Automation, pp. 4063- 4068, 2006.

74. The citation to Machino in the Niitsuma article is evidence that Machino was known, publicly accessible, and accepted as a scholarly reference when Niitsuma was presented as a paper at the *SICE Annual Conference 2007*, Takamatsu, Japan, September 17-20, 2007, and subsequently published in its Proceedings.

Amazon Ex. 1012.0033

75. Based on the above, I conclude that Machino, submitted in this proceeding as Exhibit 1007, is an authentic document that was publicly accessible before October 1, 2010.

B. Exhibit 1011: Claudio Pinhanez, Rick Kjeldsen, Anthony Levas, Gopal Pingali, Mark Podlaseck, and Paul Chou. "Ubiquitous Interactive Graphics." IBM Research Report RC22495 (W0205-143) (2002). ("Pinhanez")

76. I have been asked to opine on the authenticity and public accessibility of a document authored by Claudio Pinhanez, et al., titled "Ubiquitous Interactive Graphics" and published as *IBM Research Report RC22495 (W0205-143)* in 2002 ("Pinhanez").

1. Authenticity

77. I have evaluated the Pinhanez reference several ways: (1) by assessing Exhibit 1011, provided to me by counsel; (2) by retrieving and assessing a copy of Pinhanez which I downloaded from the *CiteSeer* database, stewarded by the Penn State University, College of Information Science and Technology, appended to this declaration as Appendix B-1; (3) by accessing and verifying a copy of Pinhanez from the list of *IBM Research Reports* available through an open access website, Appendix B-2; (4) by retrieving and reviewing a download I made on May 11, 2023 of Pinhanez from the personal website of Claudio Pinhanez, Appendix B-4; and (4) retrieving and

Amazon Ex. 1012.0034

assessing articles that cite Pinhanez prior to October 1, 2010, discussed in the Public Accessibility section of Part V.B, *infra*.

78. Appendix B-1 is a copy of Pinhanez I downloaded from the *CiteSeer* database, stewarded by the Penn State University, College of Information Science and Technology. *CiteSeer* is a trusted academic research repository and as such would only provide access to authentic research documents. Appendix B-1 was downloaded by me on May 11, 2023 from this URL:

https://citeseerx.ist.psu.edu/pdf/391893bda0d70ab64e8b0ad90d375b80d9075970

79. Appendix B-2 is a bibliography of the publications of Claudio Pinhanez published between 1995 and 2020. It is downloaded from IBM Research at this URL:

https://researcher.watson.ibm.com/researcher/view_person_pubs.php?person=br-csantosp&t=1&mhsrc=ibmsearch_a&mhq=RC22495. The following citation is shown by scrolling to year 2002:

> Ubiquitous interactive graphics
> C. Pinhanez, R. Kjeldsen, T. Levas, G. Pingali, M. Podlaseck, P. Chou
> *IBM Research Report RC22495 (W0205-143)*, 2002

80. The hyperlink from the title in Appendix B-2, labeled "Ubiquitous interactive graphics," does not link to the document, only to a "404" missing link. However, the fact that Pinhanez is linked from the IBM Research Report website provides evidence that it is a research publication issued under the auspices of IBM.

Amazon Ex. 1012.0035

81. Appendix B-3 is the personal website of Claudio Pinhanez accessible at the URL http://www.pinhanez.com/claudio/. Appendix B-4 is a copy of Pinhanez I downloaded from Pinhanez's personal website at this URL: http://www.pinhanez.com/claudio/publications/rc22495.pdf.

82. Having compared Appendix B-1 and Appendix B-4, I found no difference between the two. I then compared Appendix B-1 and Appendix B-4 with Exhibit 1011, provided to me by counsel, and found no difference among the three. Given the above, I conclude that each of Exhibit 1011, Appendix B-1, and Appendix B-4 contains an authentic, true, and correct copy of Pinhanez.

2. Public Accessibility

83. To determine the public accessibility of Pinhanez, I researched articles that cite Pinhanez prior to October 1, 2010.

84. Appendix B-5 is a true and correct download of the *Google Scholar* entries that cite Pinhanez and were published between 2004 and 2007. The citation list in Appendix B-5 consists of 10 documents. Of those 10 documents which cite Pinhanez, 3 documents are as follows: Appendix B-6, Flagg; Appendix B-7, Bhasker; and Appendix B-8, Borkowski. I completed the download of this list of entries from *Google Scholar* on May 7, 2023, at this URL:

https://scholar.google.com/scholar?hl=en&as_sdt=5%2C47&sciodt=0%2C47&cites=8433351548041826889&scipsc=&as_ylo=2004&as_yhi=2007.

Amazon Ex. 1012.0036

85. Appendix B-6 is an article by Matthew Flagg and James M. Rehg titled "Projector-Guided Painting," published in the *Proceedings of the 19th Annual ACM Symposium on User Interface Software and Technology*, Montreux, Switzerland, October 15-18, 2006, on pages 235-243 ("Flagg").

86. Flagg was downloaded by me from the *ACM Digital Library* on April 25, 2023, enabled by my emeritus faculty position at Purdue University, through the Purdue University Libraries at this URL: https://dl-acm-org.ezproxy.lib.purdue.edu/doi/abs/10.1145/1166253.1166290. Flagg is available for a fee at this URL: https://dl.acm.org/doi/abs/10.1145/1166253.1166290.

87. Appendix B-6, Flagg, at page 243, shows Pinhanez in the References section, which lists citations, as shown below:

17. C. Pinhanez, R. Kjeldsen, T. Levas, G. Pingali, M. Podlaseck, and P. Chou. Ubiquitous Interactive Graphics. Technical Report RC22495 (W0205-143), IBM Research Report, May 2002.

88. The citation to Pinhanez-Ubiquitous in Flagg is evidence that Pinhanez was known and accepted as a scholarly reference when Flagg was presented as a paper at *19th Annual ACM Symposium on User Interface Software and Technology* in Montreux, Switzerland on October 15-18, 2006 and was subsequently published in its *Proceedings.*

89. Appendix B-7 is an article by E. Bhasker, R. Juang and A. Majumder titled "Registration Techniques for Using Imperfect and Partially Calibrated Devices

in Planar Multi-Projector Displays" published in *IEEE Transactions on Visualization and Computer Graphics*, volume 13, number 6, November – December 2007, on pages 1368-1375 ("Bhasker").

90. Bhasker was downloaded by me from *IEEE Xplore* on April 25, 2023, enabled by my emeritus faculty position at Purdue University, through the Purdue University Libraries at this URL: https://ieeexplore-ieee-org.ezproxy.lib.purdue.edu/stamp/stamp.jsp?tp=&arnumber=4376163&tag=1. Bhasker is available for a fee at this URL: https://ieeexplore.ieee.org/abstract/document/4376163/references#references.

91. Appendix B-7, Bhasker, at page 1375, shows Pinhanez as the 25th citation in its References, as shown below:

[25] C. S. Pinhanez, F. C. Kjeldsen, A. Levas, G. S. Pingali, M. E. Podlaseck, and P. B. Chou. Ubiquitous interactive graphics. Technical Report RC22495 (W0205-143), IBM Research, 2002.

92. The citation to Pinhanez in Bhasker is evidence that Pinhanez was known and accepted as a scholarly reference when Bhasker was published as a paper in *IEEE Transactions on Visualization and Computer Graphics*, volume 13, number 6, November – December 2007, on pages 1368-1375.

93. Appendix B-8 is an article by S. Borkowski, J. L. Crowley, J. Letessier and F. Berard, "User-Centric Design of a Vision System for Interactive Applications,"

Fourth IEEE International Conference on Computer Vision Systems (ICVS'06), New York, NY, USA, January 4-7, 2006 on pages [9-9] ("Borkowski").

94. Borkowski was downloaded by me from *IEEE Xplore* on April 26, 2023, enabled by my emeritus faculty position at Purdue University, through the Purdue University Libraries at this URL: https://ieeexplore-ieee-org.ezproxy.lib.purdue.edu/search/searchresult.jsp?searchWithin=%22Publication%20Number%22:10542&searchWithin=%22Document%20Title%22:User%20Centric%20Design%20of%20a%20Vision%20System%20for%20Interactive%20Applications. Borkowski is available for a fee at this URL: https://ieeexplore.ieee.org/abstract/document/1578697/references#references.

95. Appendix B-8, Borkowski, at page [9], shows Pinhanez as the 9th citation in its References, as shown below:

> [9] C. Pinhanez, R. Kjeldsen, T. Levas, G. Pingali, M. Podlaseck, and P. Chou. Ubiquitous interactive graphics. In *IBM Research Report RC22495 (W0205-143)*, May 2002.

96. The citation to Pinhanez in Borkowski is evidence that Pinhanez was known and accepted as a scholarly reference when Borkowski was presented as a paper at the *Fourth IEEE International Conference on Computer Vision Systems (ICVS'06)*, New York, NY, USA, January 4-7, 2006.

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97. Based on the above, I conclude that Pinhanez, submitted in this proceeding as Exhibit 1011, is an authentic document that was publicly accessible before October 1, 2010.

C. Exhibit 1008: David M. Kroenke and David J. Auer. *Database Processing: Fundamentals, Design, and Implementation*. Edition 11. Prentice-Hall, 2009. ("Kroenke")

1. Authentication

98. I have been asked to opine on the authenticity and public accessibility of a book authored by David M. Kroenke and David J. Auer, titled *Database Processing: Fundamentals, Design, and Implementation*, Edition 11, published by Prentice-Hall in 2009[8], comprised of 607 pages. ("Kroenke")

99. I have evaluated the Kroenke reference: (1) by assessing scans of a copy of Kroenke, Appendix C-1, Exhibit 1008, provided to me by counsel; (2) accessing and assessing a scan of Kroenke I obtained from the print copy owned by the Indiana University Bloomington Libraries, obtained by me at my request through the Purdue University Libraries Interlibrary Loan Department from Indiana University – Bloomington on October 24, 2023, Appendix C-2.

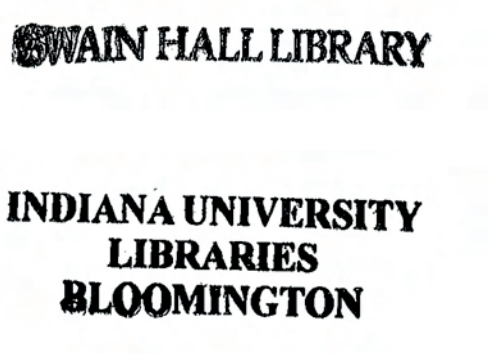
[8] As discussed below, although Kroenke lists a copyright date of 2010, according to U.S. Copyright Office records, Kroenke was in fact registered with the copyright office in 2009.

Amazon Ex. 1012.0040

100. Appendix C-1, Exhibit 1008, is a scan of Kroenke that includes the cover of *Database Processing: Fundamentals, Design, and Implementation*. Edition 11, by David M. Kroenke and David J. Auer*;* title page; verso of the title page (copyright); Contents (pages v-xvi); and additional pages.

101. Appendix C-2 is a scan of Kroenke that was obtained by me through the Purdue University Libraries Interlibrary Loan Department from Indiana University Libraries – Bloomington on October 23, 2023.

Appendix C-2 is comprised of: Cover; flyleaf page with a stamp that reads: "Swain Hall Library", as shown below; title page, with a stamp that reads: INDIANA UNIVERSITY LIBRARIES BLOOMINGTON", as shown below; verso of the title page (copyright): Brief Contents; and Contents, and pages v-xvi.



102. All identifying characteristics on Appendix C-2 are consistent with library practice and procedure that I have observed during my career as a professional librarian, specifically during my years as a librarian at Indiana University. I have no

cause for concern about the authenticity or accuracy of these identifying attributes. Appendix C-2 was found within the custody of a library, the Indiana University Bloomington Libraries, one of the most likely locations for an authentic publication.

103. After comparing Kroenke as it appeared in Appendix C-1 (Exhibit 1008) and Appendix C-2, I found no difference between the comparable pages in the two Appendices, specifically that both are Edition 11, and had the same copyright date and publisher. Therefore, based on finding Kroenke in print in a library – Indiana University – I opine that Kroenke, Edition 11, is an authentic document, and that Exhibit 1008 is an authentic and accurate copy of Kroenke.

104. Therefore, I conclude and affirm Kroenke (Exhibit 1008) is an authentic document.

2. Public Accessibility

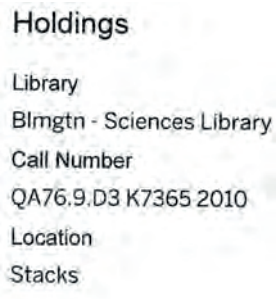
105. Appendix C-3 is a true and correct copy of the *WorldCat* entry for Kroenke, *Database Processing: Fundamentals, Design, and Implementation*. Edition 11. I obtained Appendix C-3 by completing a search on *WorldCat* on October 26, 2023. The document cataloged in this monographic (book) record is for *Database Processing: Fundamentals, Design, and Implementation*, Edition 11 as verified by title: *Database Processing: Fundamentals, Design, and Implementation,* Edition 11, Prentice-Hall.

106. When undertaking the search of *WorldCat* as described above using the geographical location of Indiana, the Indiana University Bloomington was among the 1040 libraries world-wide that hold Kroenke in one of its iterations.

107. *Database Processing: Fundamentals, Design, and Implementation*, Edition 11 could have been identified and located in a library in print by searching title: *Database Processing: Fundamentals, Design, and Implementation*; and/or by subject heading: *Database management.*

108. Appendix C-4 is a download I made on October 23, 2023 from the Indiana University Libraries OPAC (online catalog). The document cataloged in this record is a monographic record for: David M. Kroenke and David and J. Auer, *Database Processing: Fundamentals, Design, and Implementation*. Edition 11, Prentice-Hall.

109. Under "Holdings" it states: "Blmgtn – Sciences Library, Call Number QA76.9.D3K7365 2010 Location Stacks", as shown below.



110. Through my years of experience at Indiana University as a librarian and faculty member, I know that the designation "Blmgtn-Sciences Library" refers to the

Swain Hall Library. Kroenke could have been located by searching on the Indiana University Libraries OPAC for the title: *Database Processing: Fundamentals, Design, and Implementation* and/or searching subject heading: *Database management.*

111. There is no date on Appendix C-2 indicating when Indiana University Bloomington Libraries acquired and made Kroenke publicly accessible. Therefore, I have included Appendix C-5, the MARC record available through the Indiana University OPAC record under "Librarian View."

112. The MARC record underpins the public display in the online catalog. It provides additional information that is considered necessary for library operations but is not typically useful to a researcher. This is the case for the MARC 008 and MARC 005 Fields.

113. The MARC 008 Field indicates when the catalog record was created by the library that initially cataloged the book, typically the Library of Congress. The MARC 005 Field includes the date which the holding library (i.e., Indiana University) cataloged and entered the record into OCLC, *WorldCat,* and at the same time made it available through it own OPAC.

114. Within Appendix C-5, the MARC 008 reads as follows: "090313s maua b 001 0 Eng", as shown below. This indicates a date of: 09 = 2009, 03= March, 13

Amazon Ex. 1012.0044

= 13th (other digits provide further cataloging information). Therefore, March 13, 2009 is the date that the original library cataloged Kroenke.

115. In Appendix C-5 is the MARC 005 field reads " 200909060000.0", as shown below. This indicates the date on which Indiana University cataloged Kroenke, i.e., September 9, 2009 (the remaining digits are check digits for the computer).

116. Consistent with standard library policy and practice, Kroenke, *Database Processing: Fundamentals, Design, and Implementation*, Edition 11 would have been on the shelf in the Swain Hall Library, Indiana University Bloomington within a week to ten days after receipt by the library, that is, no later than September 19, 2009.

117. On the verso of the title page (copyright) the copyright shows as 2010, as shown below.

Copyright © 2010, 2006, 2004, 2000, 1998 Pearson Education, Inc., publishing as Prentice Hall, One Lake Street, Upper Saddle River, New Jersey 07458. All rights reserved. Manufactured in the United States

It is not uncommon for a publisher to state a later copyright date from when the book was published, especially if it is toward the end of the calendar year. This is often done to keep the book as 'current' as possible

118. To confirm my opinion that Kroenke was in fact published and publicly available in 2009, I consulted the online records of the United State Copyright

Office.[9] Those records are attached as Appendix C-6. I confirmed that this Copyright Office Record corresponds to Kroenke, because they both have the same ISBN of 0-13-230267-5. Appendix C-6 shows that Kroenke was registered with the U.S. Copyright Office on October 28, 2009. Appendix C-6 also claims that Kroenke has a "Date of Publication" of July 28, 2009. This further supports my opinion that Kroenke was publicly available no later than September 19, 2009.

3. Conclusion

119. I conclude that Kroenke, *Database Processing: Fundamentals, Design, and Implementation*, Edition 11 is an authentic document and would have been publicly accessible through the Indiana University Libraries, more likely than not, September 19, 2009.

[9] https://cocatalog.loc.gov/

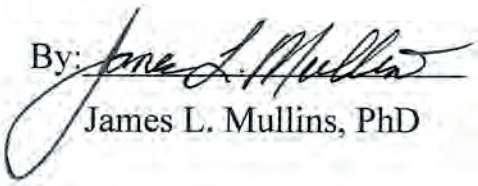
Amazon Ex. 1012.0046

VI. RIGHT TO SUPPLEMENT

120. I reserve the right to supplement my opinions in the future to respond to any arguments that Patent Owner or its expert(s) or counsel may raise, and to take into account new information as it becomes available to me.

121. I declare that all statements made herein of my knowledge are true, and that all statements made on information and belief are believed to be true, and that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Executed on: October 26, 2023

By: 

James L. Mullins, PhD

Amazon Ex. 1012.0047

Appendix A-1

Western Libraries U.W.O
Western Libraries
3 9006 03169711 5

2006 IEEE International Conference on Robotics and Automation (ICRA)

Orlando, Florida
15-19 May, 2006

Volume 9 of 10

IEEE

IEEE Catalog Number: 06CH37729
ISBN: 0-7803-9505-0

Amazon Ex. 1012.0049

2006 IEEE International Conference on Robotics and Automation (ICRA)

Orlando, Florida
15-19 May, 2006

Volume 9 of 10



IEEE Catalog Number: 06CH37729
ISBN: 0-7803-9505-0

Amazon Ex. 1012.0050

Proceedings 2006 IEEE International Conference on Robotics and Automation

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IEEE Catalog Number: 06CH37729
ISBN: 0-7803-9505-0
ISSN: 1050-4279
Library of Congress: 94-640158

Amazon Ex. 1012.0051

U.W.O. LIBRARY

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Nonlinear Control of Robotic Systems

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Remote-Collaboration System Using Mobile Robot with Camera and Projector

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***Abstract* - We have been studying a remote-collaboration system called SCOPE (sight collaboration by projection effect) featuring image projecting and capturing capabilities as implemented in a maintenance robot. With the help of SCOPE and a remote support person, an on-site worker can perform maintenance very efficiently. We propose a mobile SCOPE that can significantly expand the area of activity of the conventional SCOPE. To enable an on-site worker to share the field of view of a remote support person, we developed a technique for aligning the optical axes of a camera and a projector. We present experimental data that demonstrates the validity of our optomechanical design. Finally, we show that the mobile SCOPE enables workers to continuously share their field of view, no matter where the mobile SCOPE moves.**

Index Terms* - *Remote collaboration, Shared field of view, Mobile robot, Camera and projector, Tele-operation.

I. Introduction

To create a more efficient environment in which to perform remote maintenance over a network, we have been studying a new collaboration concept, called "robot-augmented communication" (RAC) [11]. In RAC, a maintenance robot and an on-site human worker, who may not be skilled in maintaining the target object, are assisted by a veteran operator of the object at a remote support center. RAC provides effective support for on-site workers by augmenting the communication ability of the remote support person with robotic functions that people do not have.

A prototype remote-collaboration system called SCOPE (sight collaboration by projection effect) was developed as a maintenance robot that was the first instance of RAC, which featured image projecting and capturing capability. This SCOPE system, equipped with a projector and a camera, enables a target object perceived in the field of view of a remote support person to be shared with an on-site worker. This function should dramatically shorten the time taken to perform maintenance operations.

However, this SCOPE system cannot move about in an on-site maintenance area. Generally, on-site maintenance areas include very large plant sites or huge industrial facilities, so mobility is indispensable. Therefore, we present a mobile SCOPE and discuss its key technological issues. A future scene of remote support using the mobile SCOPE is shown in Fig. 1. As far as we know, such a robotic system has never been reported before.

Numerous papers on real-space projection technology utilizing a camera and projector set have been published, mainly in the fields of augmented reality (AR), Computer Supported Cooperative Work (CSCW), and ubiquitous computing [1]-[5]. Almost all of these studies focused on applications inside a room in an office or home, so the equipment was spatially fixed to the room structure such as to a desk, ceiling, wall, or floor. Utilizing a head-mounted display [6] or hand-held projector [7] enables us to move about in an on-site maintenance area; however, the current size and weight of such devices make them too troublesome to wear and carry around. In that respect, mobile SCOPE can relieve the on-site worker from having to wear such heavy, bulky devices.

On the other hand, the addition of mobility to the SCOPE system will cause an inherent, serious problem with sharing the field of view in an actual space because the spatial relationship between the image frame of the camera and that of the projector will change depending on the distance between SCOPE and the target to be captured and projected. Therefore, one of the most important problems for a mobile SCOPE is to maintain a shared field of view, no matter where the SCOPE system moves. To overcome this problem, we describe a method, based on the use of an ingenious optomechanical structure, that enables the optical axis of the camera and that of the projector to be aligned.

After a brief introduction of our RAC concept and the

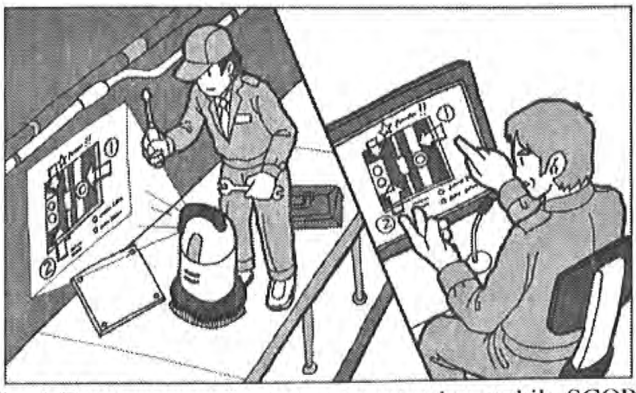


Fig. 1 Future scene of remote support using mobile SCOPE

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conventional SCOPE, we discuss requirements for the mobile SCOPE and its key technology for optical-axis alignment of the camera and the projector. Next, we provide experimental data on the evaluation of the optomechanical design of the mobile SCOPE. Finally, we describe implementing the mobile SCOPE with an optomechanical design that enables an on-site worker to share the field of view of a remote support person, no matter where the SCOPE moves.

II. Concept for New Collaboration between Robot and Human over Network

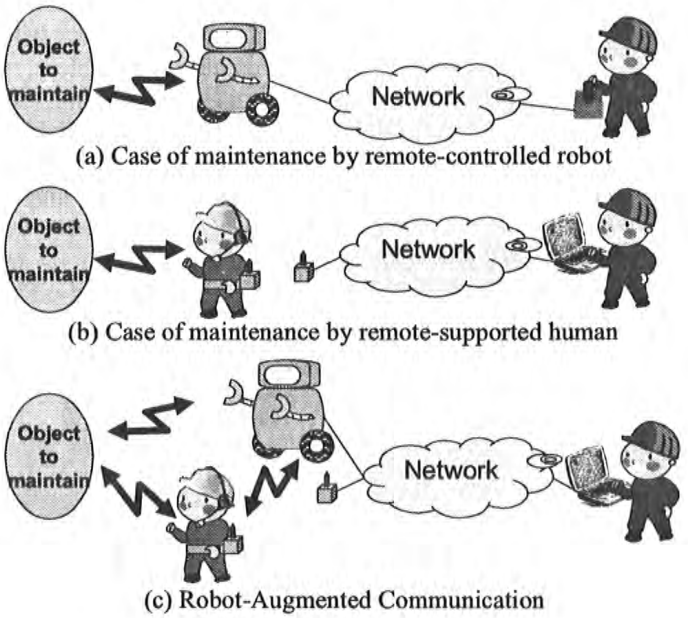
A. Robot-Augmented Communication

When no skilled workers are present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site [8] [9] (see Fig. 2(a) below) or dispatch an unskilled worker to the site and remotely instruct him/her to perform maintenance operations from a distance [6] [10] (see Fig. 2(b)). In Fig. 2(a), a robot that interacts with a maintenance object cooperates with and is controlled by a remote, skilled operator through a network. In Fig. 2(b), an unskilled worker and a skilled operator cooperate through a network, and the unskilled worker interacts with the maintenance object. Each of these two cases – namely, the robot or the person handling the on-site operation – has its advantages and disadvantages, as explained below.

(a) Remote-controlled robot: Robot function, e.g., in terms of power and information-processing capability, can surpass that of a human operator, but the current level of robot autonomy is low and cannot match the operation skill of a remote skilled worker.

(b) Remote-supported human: Generally, the decision-making capability of a person in response to site conditions is much better than that of a robot. However, sufficiently conveying the intentions of the remote support person, i.e., skilled operators, without putting undue stress on the unskilled worker is difficult under the present state of communication between unskilled on-site workers and skilled remote support workers. For example, due to the time delay of a network, the supporter's intention often cannot be transmitted rapidly and easily.

With the drawbacks of the above two approaches in mind and aiming at extending the skill and ideas of a remote support person to cover work sites, where specialized robotic functions such as high-level information processing are particularly applicable, we propose a new form of collaboration between robots and on-site workers who have high decision-making capability. We have extended communication by means of a robot's functions, so this collaboration setup is called "robot-augmented communication" (RAC). As shown in Fig. 2(c), RAC provides effective support by emphasizing the intentions of the remote support person through the robot. This is achieved by actively utilizing the interaction between an on-site worker and robot functions that cannot be performed by humans.



(a) Case of maintenance by remote-controlled robot

(b) Case of maintenance by remote-supported human

(c) Robot-Augmented Communication

Fig. 2 Setups for remote maintenance.

B. SCOPE: System for supporting a shared field of view in an actual space

We selected the function of projecting information in an actual space as a robot function that is intended to surpass the ability of humans. In this section, we introduce a remote-support system called SCOPE as the first instance of an RAC concept.

1) System overview

A schematic of the configuration of this system is shown in Fig. 3. At the on-site worker's location, a camera and a projector are integrated in one piece, and an incorporated stepping motor enables the camera's viewing field and projected images to rotate around the vertical axis of a camera and projector unit. To attain the capability of a "shared viewing field" as explained later, domains of the viewing field of the camera and that of the projector are adjusted so that they are aligned. An on-site worker can use a laser pointer as an input interface. We implemented a manipulation function

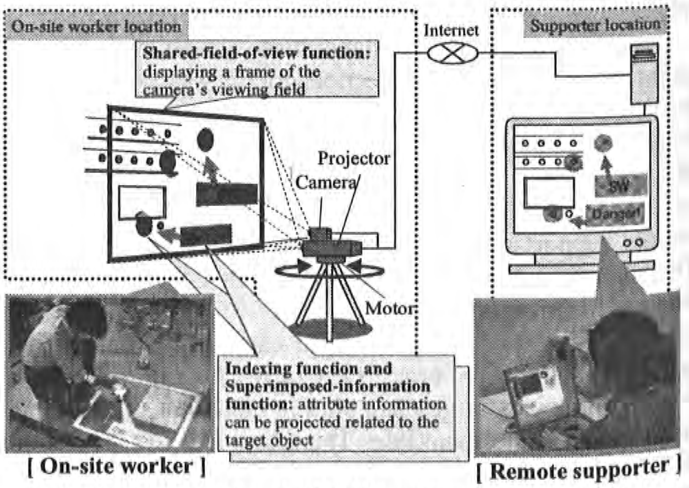


Fig. 3 SCOPE system.

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equivalent to the mouse on the client PC by applying image-recognition processing at the position of the laser pointer's spot.

2) Shared-field-of-view function

During collaborative operations at remote locations, a situation that often occurs is a remote support person verbally indicating relative directions like "on the right" to give instructions to an on-site worker. At such times, the remote support person's viewing field becomes essential information from the viewpoint of the on-site worker. In the SCOPE system, presenting the remote support person's viewing field to the on-site worker is possible by unifying the camera's viewing field and projector's projection area and displaying a frame of the camera's viewing field on the projected images.

3) Indexing function

Information needed for carrying out operations, "attribute information," is projected onto the target object as the occasion demands. This is like affixing notes on the target object with light. In the developed system, five kinds of information are conveyed: text, still images, video, sound, and program administration. The location of attributed information is indicated as a graphical image with a circular form. We call this mark a "projected image". By manipulating a projected image, one can also manipulate the display status of attribute information. At the on-site worker's location, the laser pointer is used to manipulate the projected image. At the supporter's location, the projected image is shown on a communication screen, which displays images transmitted from the on-site worker's location, and manipulated using the PC's mouse.

4) Superimposed-information function

In the SCOPE system, the camera/projector unit at the on-site worker's location can be manipulated from the supporter's location. The projected image and the attribute information are positioned on the target object by correcting the position of a projected image according to the movement of the camera and projector unit. This function enables the on-site worker to intuitively recognize the relationship between a stationary object in space and its attribute information.

5) Effectiveness of SCOPE for maintenance

The effectiveness of SCOPE was evaluated by experiments on two types of fundamental tasks, "comprehending the target object" and "transmitting instructions", involved in a typical maintenance operation. The experimental results indicate that shared-field-of-view, indexing, and superimposed-information functions are effective in shortening the time taken to perform the maintenance operation.

III. Hardware Design For a Mobile-type SCOPE

In this section, we discuss the hardware design of the mobile SCOPE in terms of user requirements and the conventional SCOPE technology. We use a planar mobile robot on which a camera-projector pair is mounted.

A. Requirements for utilizing SCOPE in an actual space

First, we assumed a very wide area with a flat floor in a huge indoor plant as the working environment of the mobile SCOPE. Therefore, we used a robot that has wheels with two degrees of freedom (DOF) of planar mobility. These DOF should be necessary for traveling in a wide working area and for avoiding projections, which are occluded by the on-site worker's body, between the robot and the object to be maintained.

B. Setup of projector and camera

We considered a projection plane approximately 4 × 4 m, about 1 – 3 m away from the mobile robot. A single small fixed projector cannot cover such a wide area, so pan-and-tilt rotational DOF are indispensable to broaden the projection coverage. On the other hand, rotation with respect to the optical axis is not needed because an on-site worker mainly works in a vertical standing position. We do not have to actively control the three translational DOF of the projector (one vertical and two horizontal) because we can relatively easily modify a projection image that has trapezoidal distortion caused by slanted projection on a flat plane. Based on the above discussion, we eventually designed a two-rotational-DOF projector on a 2-DOF planar mobile robot on wheels.

Many research studies have been performed on the autonomy of a mobile robot. For example, autonomous navigation technology such as path planning or SLAM (Simultaneous Localisation and Mapping) is a crucial issue that needs to be resolved for mobile robots. However, in the RAC concept, the present low level of mobile robot capabilities can be supplemented by human capabilities. On the other hand, the shared-field-of-view function of the mobile SCOPE has a fatal problem, as discussed in detail in the next section.

IV. Optomechanical Design

In this section, we discuss the layout for mounting a projector and camera on the mobile robot. First, we explain why aligning the optical axis of the projector and that of the camera is important, and we describe the optomechanical design for achieving this.

A. Issues in sharing field-of-view function of the mobile SCOPE

The basic functions of our mobile SCOPE include the following.

(1) Showing the remote support person's field of view by projecting the image frame of the camera

(2) Projecting various information on the viewing field as a shared area

(3) Enabling functions (1) and (2) in any place

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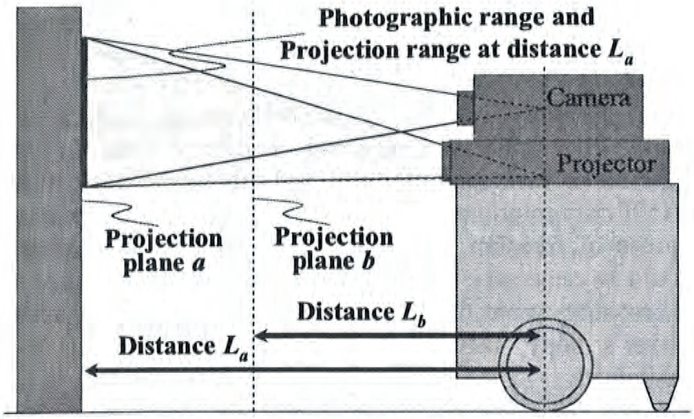


Fig. 4 Relationship between distance to projection plane, and photographic and projection ranges.

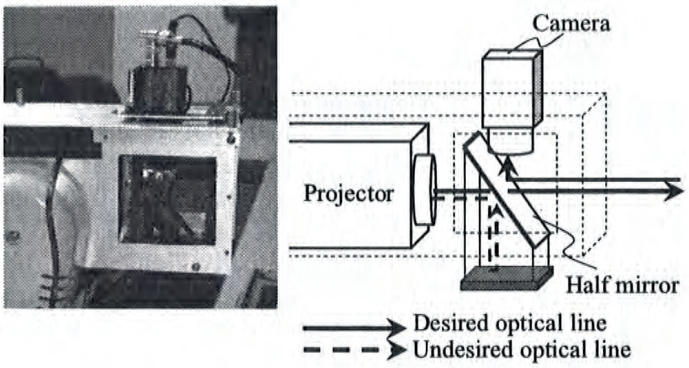


Fig. 5 Setup for aligning optical axes with half mirror.

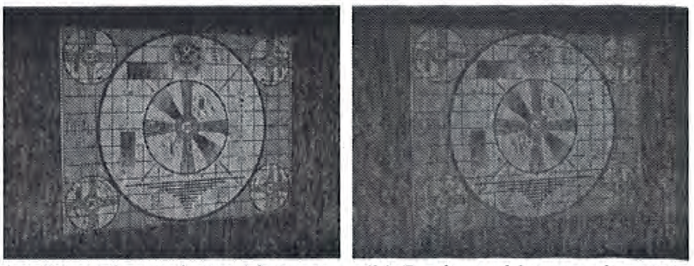
For the conventional SCOPE, we confirmed (1) and (2) by simply assembling the camera and projector so that their frames correctly overlapped on the projection plane. In this configuration, if the distance to the photographic plane (or the projection plane) is fixed, adjusting the orientations of the camera and projector only once is sufficient, which makes installation relatively easy. In the mobile SCOPE case, however, the distance is not fixed.

As shown in Fig. 4, if the camera's photographic range and the projector's projection range are the same at a projection plane located at distance L_a, then the photographic and projection ranges are not the same in projection plane b for distance L_b. To deal with this problem, one might normally have to develop one of the following.

(i) A hardware mechanism for automatically correcting the orientations of the camera and projector

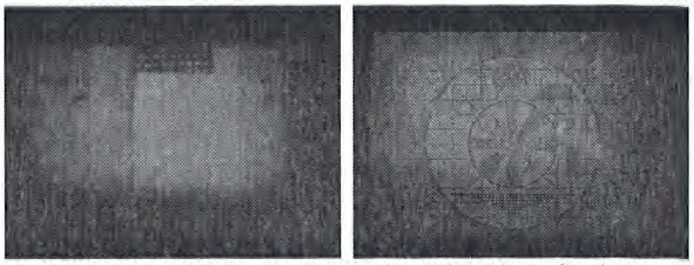
(ii) A real-time image-data-processing method that maintains the projected content within the visual field of the camera.

These are both very difficult and laborious to implement. Therefore, we propose another novel approach utilizing a half mirror.



(a) Directly projected image (b) Projected image through half-mirror

Fig. 6 Projected images on projection plane.



(a) Without black flock paper (b) With black flock paper

Fig. 7 Images captured by camera on SCOPE.

B. Aligning optical axes with a half mirror

To match the photographic range of the camera and the projection range of the projector independently of the distance to the subject, the ideal situation is for the focal point of the camera and the light source of the projector to be the same. However, this is impossible due to hardware restrictions. Therefore, we chose to achieve the same function by using a half mirror. First, as a preliminary investigation, we conducted an experiment using the equipment illustrated in Fig. 5.

Projected images on a projection plane without and with a half mirror, where the rate of reflection with respect to the rate of transmission, R:T, is 3:7, are shown in Figs. 6(a) and 6(b), respectively. The luminance of the projector is 1,500 lumens. These photographs were taken by another camera; they are images of what the on-site worker can see with the naked eye. Naturally, Fig. 6(b) is darker than Fig. 6(a).

Images captured by a camera on the mobile SCOPE are shown in Figs. 7(a) and (b). These are images of what the remote support person can see through the mobile SCOPE. If these images are completely the same as those in Fig. 6(b), the remote support person can see exactly what the on-site worker sees. However, they are clearly different, as is seen by comparing Figs. 6 and 7. In particular, Fig. 7(a) is extremely poor. An image of the black chassis passing through the half mirror is shown instead of the desired image. We call this phenomenon 'ghosting'. Ghosting occurs when the projector light that is reflected in the direction of the chassis is too bright. To delete the ghost image, we tried placing black flock paper on the chassis, and an image of that is shown in Fig. 7(b). The black flock paper reduces the ghosting. However, excess light still appeared in the camera image. The next section describes a method to eliminate this excess light.

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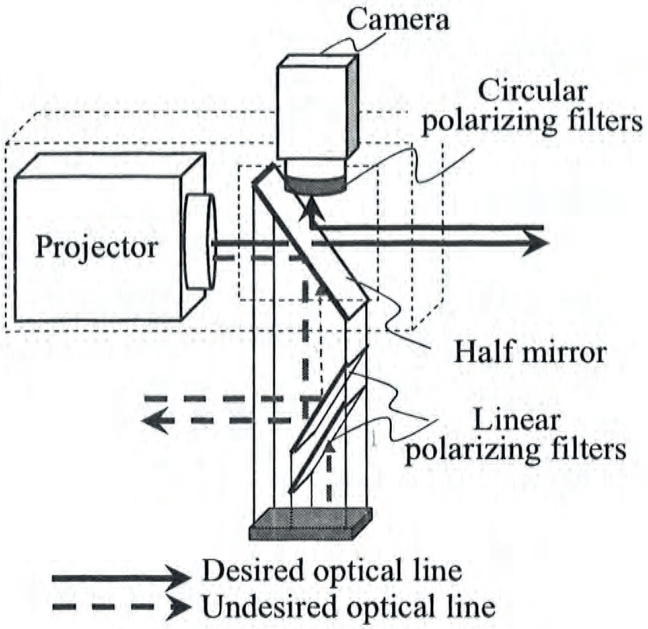
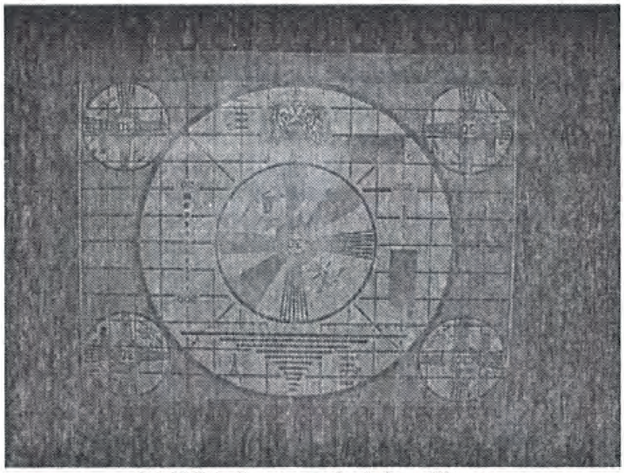
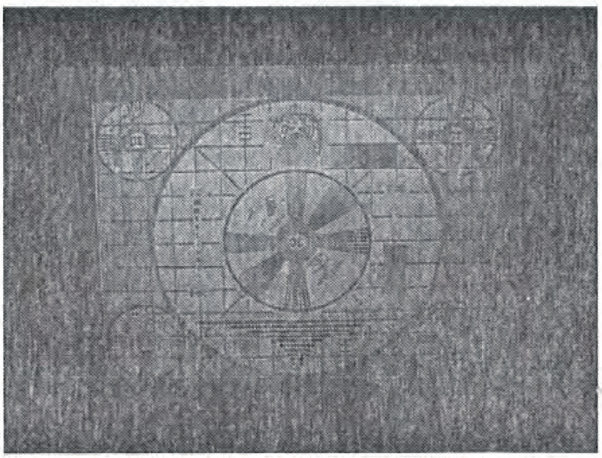


Fig. 8 Construction to eliminate ghost image.



(a) With linear polarizing filters



(b) With linear and circular filters

Fig. 9 Images captured by camera on SCOPE with polarizing filters.

C. Polarizing filters to eliminate the ghost image

We investigated ways to eliminate the excess light that passes through the half mirror and appears in the camera image. Utilizing polarizing filters is the key to solving this problem. The most effective configuration for eliminating the excess light is shown in Fig. 8. In this configuration, two linear polarizing filters reflect ambient light in the direction of the half mirror, and the circular polarizing filter blocks the light that has passed through the half mirror.

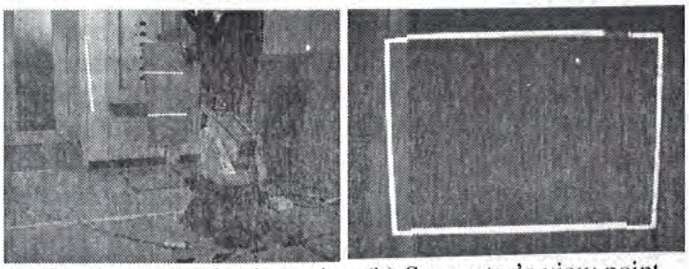
Images captured by the camera mounted on the SCOPE are shown in Fig. 9. They demonstrate the effectiveness of using polarizing filters. The result obtained when two linear polarizing filters were used is shown in Fig. 9(a). As the figure indicates, background image noise was cut by the linear polarization filters, compared with that of Fig. 7(b). However, the excess light that was reflected at the linear polarization filter and passed through the half mirror still appeared. The result obtained when two linear polarizing filters and a circular filter were used is shown in Fig. 9(b). The excess light from outside, which was present in Fig. 9(a), is reduced. This camera image can convey sufficient information about the on-site worker's site to a remote support person.

Photographs taken from the on-site worker's viewpoint and from the supporter's viewpoint, are shown in Figs. 10(a) and (b), respectively. Although the on-site worker's rectangular frame is extremely deformed by nonflat planes that consist of a cardboard and the background, the supporter's rectangular frame is almost the same as the rectangular frame of the projected image. This is evidence of the alignment of the optical axes of the camera and the projector.

From these experimental results, we confirmed the validity of our idea of using a half mirror and polarizing filters.

D. Implementation of mobile SCOPE

We unified a projector and a camera in the manner shown in Fig. 8 and mounted them on a mobile robot, Pioneer 3 manufactured by Active Media. A scene of remote support using the mobile SCOPE is shown in Figs. 11 and 12. Clearly, the viewing field of the remote supporter can be displayed in the on-site space. Aligning the optical axes enables sharing the field of view no matter where the mobile SCOPE moves. In this case, the position and orientation of the mobile SCOPE is controlled by the remote support person to find a target object or to avoid obstacles. Furthermore, the indexing and superimposed-information functions of the conventional



(a) On-site worker's viewpoint (b) Supporter's view point

Fig. 10 Result of aligning optical axes.

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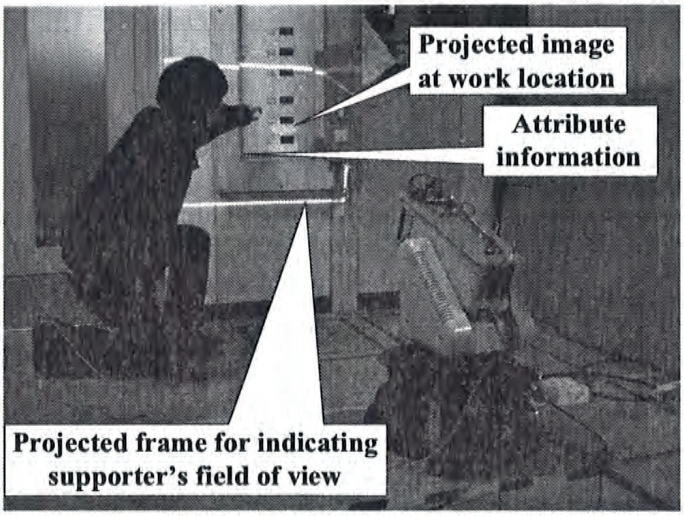


Fig. 11 Mobile SCOPE (on-site location).

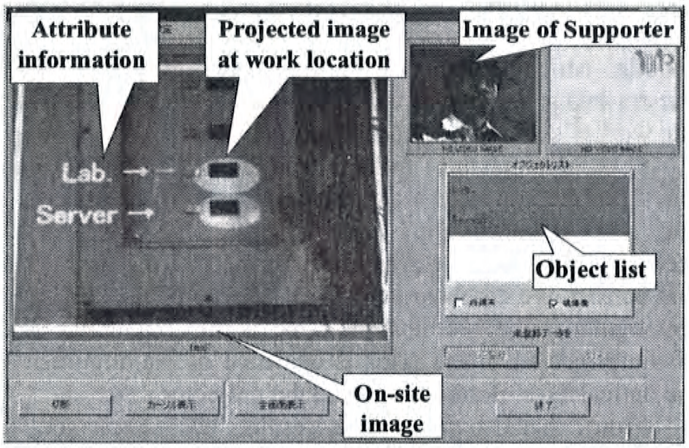


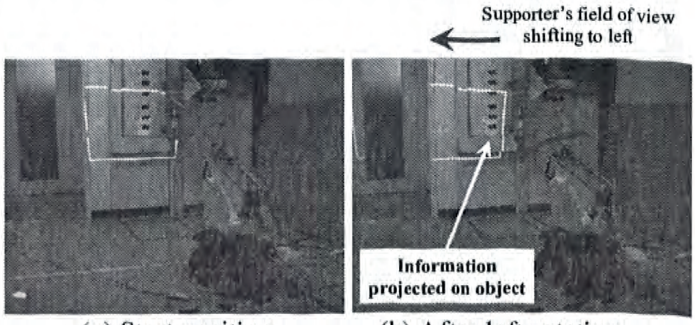
Fig. 12 Screen shot (supporter's location).

SCOPE were also implemented. Two photos indicate the result of automatic correction of the position of projected attribute information, as shown in Figs. 13(a) and (b).

V. Conclusion

To create a more efficient environment in which to perform remote maintenance over a network, we proposed a mobile SCOPE to significantly expand the field of activity. We developed a technique for aligning the optical axes of the camera and the projector to share the field of view between an on-site worker and a remote support person. Experimental data regarding the optomechanical design demonstrated the validity of our idea.

A conventional technique of many optomechanical systems uses a half mirror, such as that in a see-through head-mounted display. However, those systems are not relevant to the problems discussed in this paper such as "ghosting" because they do not use a bright light source like a projector.



(a) Start position (b) After left rotation

Fig. 13 Result of automatic correction of projected attribute information.

Therefore, a major contribution of this paper is the new finding of a new interdisciplinary research field covering AR and robotics. We plan to extend the autonomy functions of the mobile SCOPE to include obstacle avoidance or tracking target objects.

Acknowledgement

The authors gratefully acknowledge Takasuke Sonoyama for providing the illustration expressing a future scene of remote support using our mobile SCOPE.

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Appendix A-2

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Remote-Collaboration System Using Mobile Robot with Camera and Projector

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***Abstract* - We have been studying a remote-collaboration system called SCOPE (sight collaboration by projection effect) featuring image projecting and capturing capabilities as implemented in a maintenance robot. With the help of SCOPE and a remote support person, an on-site worker can perform maintenance very efficiently. We propose a mobile SCOPE that can significantly expand the area of activity of the conventional SCOPE. To enable an on-site worker to share the field of view of a remote support person, we developed a technique for aligning the optical axes of a camera and a projector. We present experimental data that demonstrates the validity of our optomechanical design. Finally, we show that the mobile SCOPE enables workers to continuously share their field of view, no matter where the mobile SCOPE moves.**

Index Terms* - *Remote collaboration, Shared field of view, Mobile robot, Camera and projector, Tele-operation.

I. Introduction

To create a more efficient environment in which to perform remote maintenance over a network, we have been studying a new collaboration concept, called "robot-augmented communication" (RAC) [11]. In RAC, a maintenance robot and an on-site human worker, who may not be skilled in maintaining the target object, are assisted by a veteran operator of the object at a remote support center. RAC provides effective support for on-site workers by augmenting the communication ability of the remote support person with robotic functions that people do not have.

A prototype remote-collaboration system called SCOPE (sight collaboration by projection effect) was developed as a maintenance robot that was the first instance of RAC, which featured image projecting and capturing capability. This SCOPE system, equipped with a projector and a camera, enables a target object perceived in the field of view of a remote support person to be shared with an on-site worker. This function should dramatically shorten the time taken to perform maintenance operations.

However, this SCOPE system cannot move about in an on-site maintenance area. Generally, on-site maintenance areas include very large plant sites or huge industrial facilities, so mobility is indispensable. Therefore, we present a mobile SCOPE and discuss its key technological issues. A future scene of remote support using the mobile SCOPE is shown in Fig. 1. As far as we know, such a robotic system has never been reported before.

Numerous papers on real-space projection technology utilizing a camera and projector set have been published, mainly in the fields of augmented reality (AR), Computer Supported Cooperative Work (CSCW), and ubiquitous computing [1]-[5]. Almost all of these studies focused on applications inside a room in an office or home, so the equipment was spatially fixed to the room structure such as to a desk, ceiling, wall, or floor. Utilizing a head-mounted display [6] or hand-held projector [7] enables us to move about in an on-site maintenance area; however, the current size and weight of such devices make them too troublesome to wear and carry around. In that respect, mobile SCOPE can relieve the on-site worker from having to wear such heavy, bulky devices.

On the other hand, the addition of mobility to the SCOPE system will cause an inherent, serious problem with sharing the field of view in an actual space because the spatial relationship between the image frame of the camera and that of the projector will change depending on the distance between SCOPE and the target to be captured and projected. Therefore, one of the most important problems for a mobile SCOPE is to maintain a shared field of view, no matter where the SCOPE system moves. To overcome this problem, we describe a method, based on the use of an ingenious optomechanical structure, that enables the optical axis of the camera and that of the projector to be aligned.

After a brief introduction of our RAC concept and the

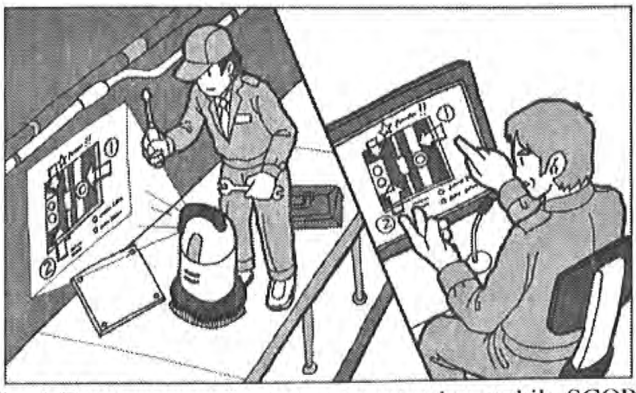


Fig. 1 Future scene of remote support using mobile SCOPE

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conventional SCOPE, we discuss requirements for the mobile SCOPE and its key technology for optical-axis alignment of the camera and the projector. Next, we provide experimental data on the evaluation of the optomechanical design of the mobile SCOPE. Finally, we describe implementing the mobile SCOPE with an optomechanical design that enables an on-site worker to share the field of view of a remote support person, no matter where the SCOPE moves.

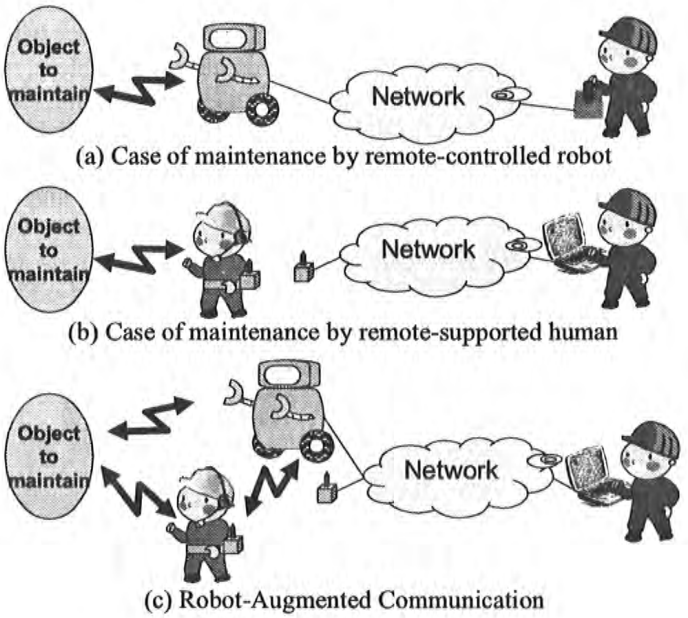
II. Concept for New Collaboration between Robot and Human over Network

A. Robot-Augmented Communication

When no skilled workers are present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site [8] [9] (see Fig. 2(a) below) or dispatch an unskilled worker to the site and remotely instruct him/her to perform maintenance operations from a distance [6] [10] (see Fig. 2(b)). In Fig. 2(a), a robot that interacts with a maintenance object cooperates with and is controlled by a remote, skilled operator through a network. In Fig. 2(b), an unskilled worker and a skilled operator cooperate through a network, and the unskilled worker interacts with the maintenance object. Each of these two cases – namely, the robot or the person handling the on-site operation – has its advantages and disadvantages, as explained below.

(a) Remote-controlled robot: Robot function, e.g., in terms of power and information-processing capability, can surpass that of a human operator, but the current level of robot autonomy is low and cannot match the operation skill of a remote skilled worker.

(b) Remote-supported human: Generally, the decision-making capability of a person in response to site conditions is much better than that of a robot. However, sufficiently conveying the intentions of the remote support person, i.e., skilled operators, without putting undue stress on the unskilled worker is difficult under the present state of communication between unskilled on-site workers and skilled remote support workers. For example, due to the time delay of a network, the supporter's intention often cannot be transmitted rapidly and easily.



(a) Case of maintenance by remote-controlled robot

(b) Case of maintenance by remote-supported human

(c) Robot-Augmented Communication

Fig. 2 Setups for remote maintenance.

With the drawbacks of the above two approaches in mind and aiming at extending the skill and ideas of a remote support person to cover work sites, where specialized robotic functions such as high-level information processing are particularly applicable, we propose a new form of collaboration between robots and on-site workers who have high decision-making capability. We have extended communication by means of a robot's functions, so this collaboration setup is called "robot-augmented communication" (RAC). As shown in Fig. 2(c), RAC provides effective support by emphasizing the intentions of the remote support person through the robot. This is achieved by actively utilizing the interaction between an on-site worker and robot functions that cannot be performed by humans.

B. SCOPE: System for supporting a shared field of view in an actual space

We selected the function of projecting information in an actual space as a robot function that is intended to surpass the ability of humans. In this section, we introduce a remote-support system called SCOPE as the first instance of an RAC concept.

1) System overview

A schematic of the configuration of this system is shown in Fig. 3. At the on-site worker's location, a camera and a projector are integrated in one piece, and an incorporated stepping motor enables the camera's viewing field and projected images to rotate around the vertical axis of a camera and projector unit. To attain the capability of a "shared viewing field" as explained later, domains of the viewing field of the camera and that of the projector are adjusted so that they are aligned. An on-site worker can use a laser pointer as an input interface. We implemented a manipulation function

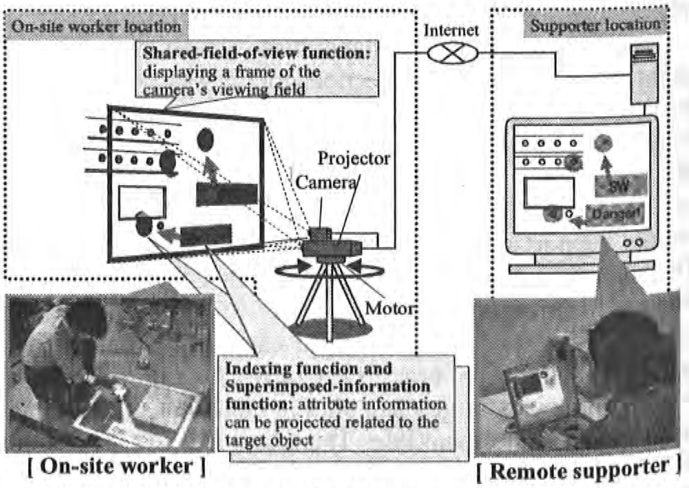


Fig. 3 SCOPE system.

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equivalent to the mouse on the client PC by applying image-recognition processing at the position of the laser pointer's spot.

2) Shared-field-of-view function

During collaborative operations at remote locations, a situation that often occurs is a remote support person verbally indicating relative directions like "on the right" to give instructions to an on-site worker. At such times, the remote support person's viewing field becomes essential information from the viewpoint of the on-site worker. In the SCOPE system, presenting the remote support person's viewing field to the on-site worker is possible by unifying the camera's viewing field and projector's projection area and displaying a frame of the camera's viewing field on the projected images.

3) Indexing function

Information needed for carrying out operations, "attribute information," is projected onto the target object as the occasion demands. This is like affixing notes on the target object with light. In the developed system, five kinds of information are conveyed: text, still images, video, sound, and program administration. The location of attributed information is indicated as a graphical image with a circular form. We call this mark a "projected image". By manipulating a projected image, one can also manipulate the display status of attribute information. At the on-site worker's location, the laser pointer is used to manipulate the projected image. At the supporter's location, the projected image is shown on a communication screen, which displays images transmitted from the on-site worker's location, and manipulated using the PC's mouse.

4) Superimposed-information function

In the SCOPE system, the camera/projector unit at the on-site worker's location can be manipulated from the supporter's location. The projected image and the attribute information are positioned on the target object by correcting the position of a projected image according to the movement of the camera and projector unit. This function enables the on-site worker to intuitively recognize the relationship between a stationary object in space and its attribute information.

5) Effectiveness of SCOPE for maintenance

The effectiveness of SCOPE was evaluated by experiments on two types of fundamental tasks, "comprehending the target object" and "transmitting instructions", involved in a typical maintenance operation. The experimental results indicate that shared-field-of-view, indexing, and superimposed-information functions are effective in shortening the time taken to perform the maintenance operation.

III. Hardware Design For a Mobile-type SCOPE

In this section, we discuss the hardware design of the mobile SCOPE in terms of user requirements and the conventional SCOPE technology. We use a planar mobile robot on which a camera-projector pair is mounted.

A. Requirements for utilizing SCOPE in an actual space

First, we assumed a very wide area with a flat floor in a huge indoor plant as the working environment of the mobile SCOPE. Therefore, we used a robot that has wheels with two degrees of freedom (DOF) of planar mobility. These DOF should be necessary for traveling in a wide working area and for avoiding projections, which are occluded by the on-site worker's body, between the robot and the object to be maintained.

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We considered a projection plane approximately 4 × 4 m, about 1 – 3 m away from the mobile robot. A single small fixed projector cannot cover such a wide area, so pan-and-tilt rotational DOF are indispensable to broaden the projection coverage. On the other hand, rotation with respect to the optical axis is not needed because an on-site worker mainly works in a vertical standing position. We do not have to actively control the three translational DOF of the projector (one vertical and two horizontal) because we can relatively easily modify a projection image that has trapezoidal distortion caused by slanted projection on a flat plane. Based on the above discussion, we eventually designed a two-rotational-DOF projector on a 2-DOF planar mobile robot on wheels.

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(3) Enabling functions (1) and (2) in any place

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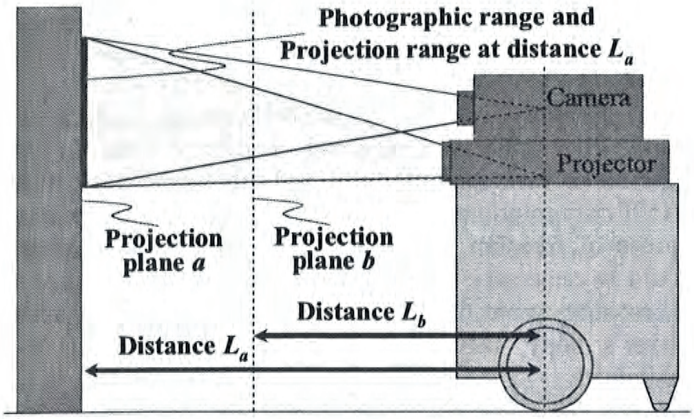


Fig. 4 Relationship between distance to projection plane, and photographic and projection ranges.

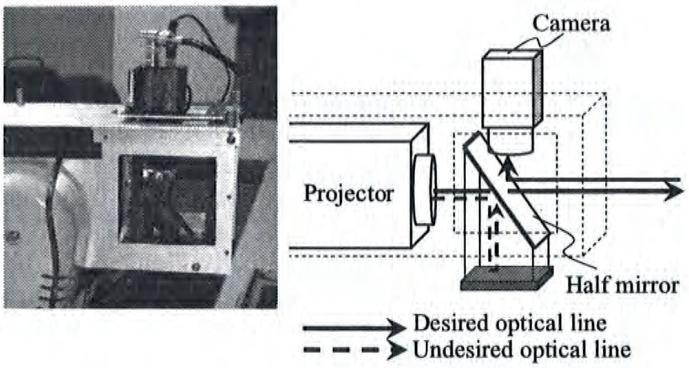


Fig. 5 Setup for aligning optical axes with half mirror.

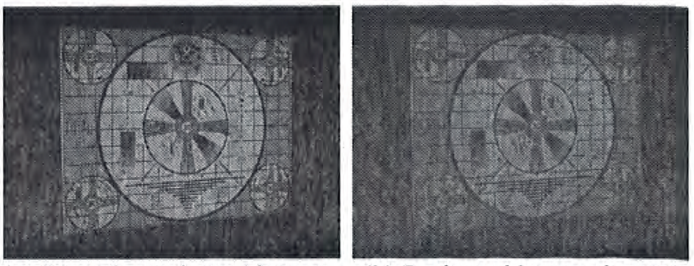
For the conventional SCOPE, we confirmed (1) and (2) by simply assembling the camera and projector so that their frames correctly overlapped on the projection plane. In this configuration, if the distance to the photographic plane (or the projection plane) is fixed, adjusting the orientations of the camera and projector only once is sufficient, which makes installation relatively easy. In the mobile SCOPE case, however, the distance is not fixed.

As shown in Fig. 4, if the camera's photographic range and the projector's projection range are the same at a projection plane located at distance L_a, then the photographic and projection ranges are not the same in projection plane b for distance L_b. To deal with this problem, one might normally have to develop one of the following.

(i) A hardware mechanism for automatically correcting the orientations of the camera and projector

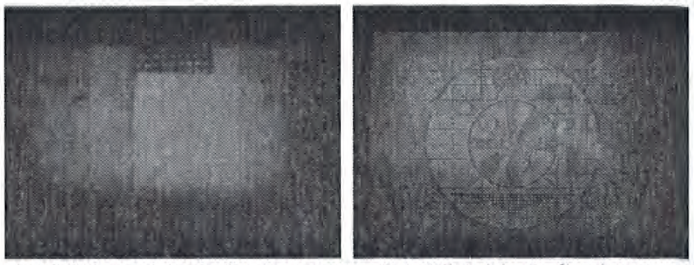
(ii) A real-time image-data-processing method that maintains the projected content within the visual field of the camera.

These are both very difficult and laborious to implement. Therefore, we propose another novel approach utilizing a half mirror.



(a) Directly projected image (b) Projected image through half-mirror

Fig. 6 Projected images on projection plane.



(a) Without black flock paper (b) With black flock paper

Fig. 7 Images captured by camera on SCOPE.

B. Aligning optical axes with a half mirror

To match the photographic range of the camera and the projection range of the projector independently of the distance to the subject, the ideal situation is for the focal point of the camera and the light source of the projector to be the same. However, this is impossible due to hardware restrictions. Therefore, we chose to achieve the same function by using a half mirror. First, as a preliminary investigation, we conducted an experiment using the equipment illustrated in Fig. 5.

Projected images on a projection plane without and with a half mirror, where the rate of reflection with respect to the rate of transmission, R:T, is 3:7, are shown in Figs. 6(a) and 6(b), respectively. The luminance of the projector is 1,500 lumens. These photographs were taken by another camera; they are images of what the on-site worker can see with the naked eye. Naturally, Fig. 6(b) is darker than Fig. 6(a).

Images captured by a camera on the mobile SCOPE are shown in Figs. 7(a) and (b). These are images of what the remote support person can see through the mobile SCOPE. If these images are completely the same as those in Fig. 6(b), the remote support person can see exactly what the on-site worker sees. However, they are clearly different, as is seen by comparing Figs. 6 and 7. In particular, Fig. 7(a) is extremely poor. An image of the black chassis passing through the half mirror is shown instead of the desired image. We call this phenomenon 'ghosting'. Ghosting occurs when the projector light that is reflected in the direction of the chassis is too bright. To delete the ghost image, we tried placing black flock paper on the chassis, and an image of that is shown in Fig. 7(b). The black flock paper reduces the ghosting. However, excess light still appeared in the camera image. The next section describes a method to eliminate this excess light.

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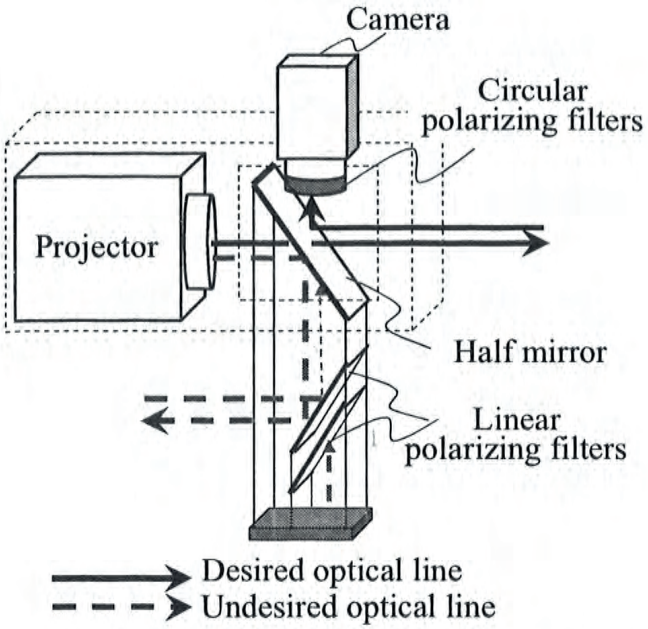
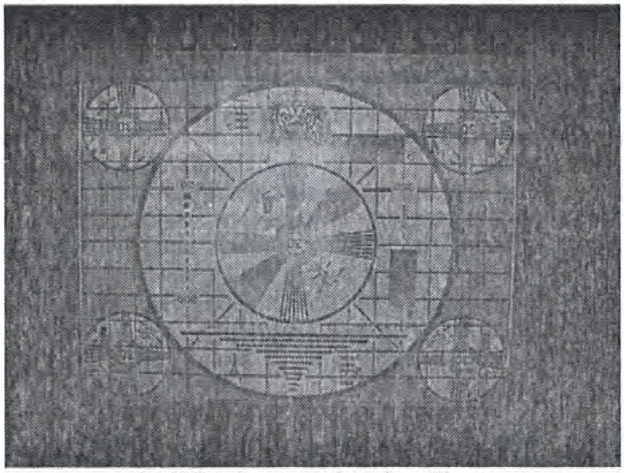
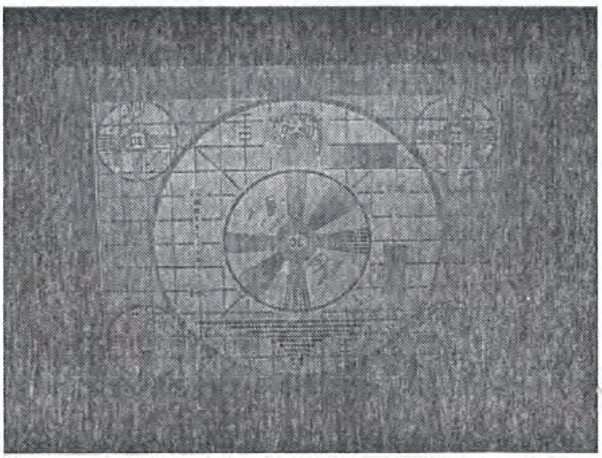


Fig. 8 Construction to eliminate ghost image.



(a) With linear polarizing filters



(b) With linear and circular filters

Fig. 9 Images captured by camera on SCOPE with polarizing filters.

C. Polarizing filters to eliminate the ghost image

We investigated ways to eliminate the excess light that passes through the half mirror and appears in the camera image. Utilizing polarizing filters is the key to solving this problem. The most effective configuration for eliminating the excess light is shown in Fig. 8. In this configuration, two linear polarizing filters reflect ambient light in the direction of the half mirror, and the circular polarizing filter blocks the light that has passed through the half mirror.

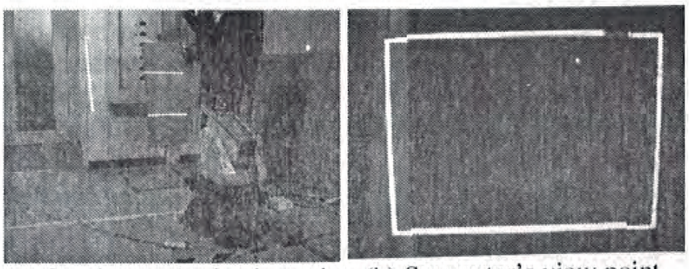
Images captured by the camera mounted on the SCOPE are shown in Fig. 9. They demonstrate the effectiveness of using polarizing filters. The result obtained when two linear polarizing filters were used is shown in Fig. 9(a). As the figure indicates, background image noise was cut by the linear polarization filters, compared with that of Fig. 7(b). However, the excess light that was reflected at the linear polarization filter and passed through the half mirror still appeared. The result obtained when two linear polarizing filters and a circular filter were used is shown in Fig. 9(b). The excess light from outside, which was present in Fig. 9(a), is reduced. This camera image can convey sufficient information about the on-site worker's site to a remote support person.

Photographs taken from the on-site worker's viewpoint and from the supporter's viewpoint, are shown in Figs. 10(a) and (b), respectively. Although the on-site worker's rectangular frame is extremely deformed by nonflat planes that consist of a cardboard and the background, the supporter's rectangular frame is almost the same as the rectangular frame of the projected image. This is evidence of the alignment of the optical axes of the camera and the projector.

From these experimental results, we confirmed the validity of our idea of using a half mirror and polarizing filters.

D. Implementation of mobile SCOPE

We unified a projector and a camera in the manner shown in Fig. 8 and mounted them on a mobile robot, Pioneer 3 manufactured by Active Media. A scene of remote support using the mobile SCOPE is shown in Figs. 11 and 12. Clearly, the viewing field of the remote supporter can be displayed in the on-site space. Aligning the optical axes enables sharing the field of view no matter where the mobile SCOPE moves. In this case, the position and orientation of the mobile SCOPE is controlled by the remote support person to find a target object or to avoid obstacles. Furthermore, the indexing and superimposed-information functions of the conventional



(a) On-site worker's viewpoint (b) Supporter's view point

Fig. 10 Result of aligning optical axes.

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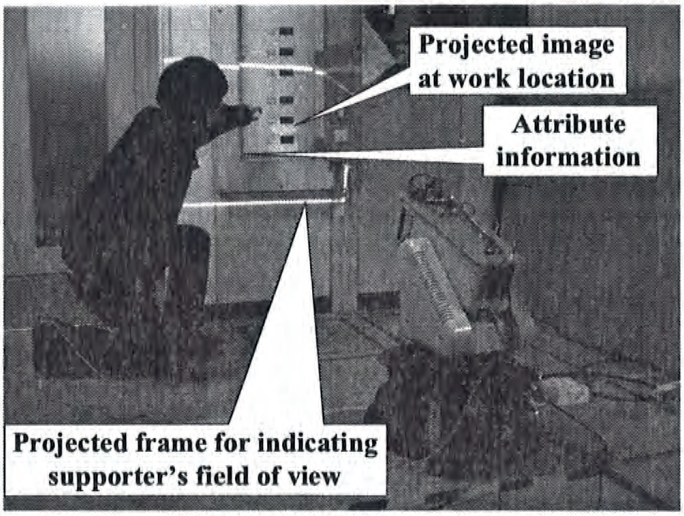


Fig. 11 Mobile SCOPE (on-site location).

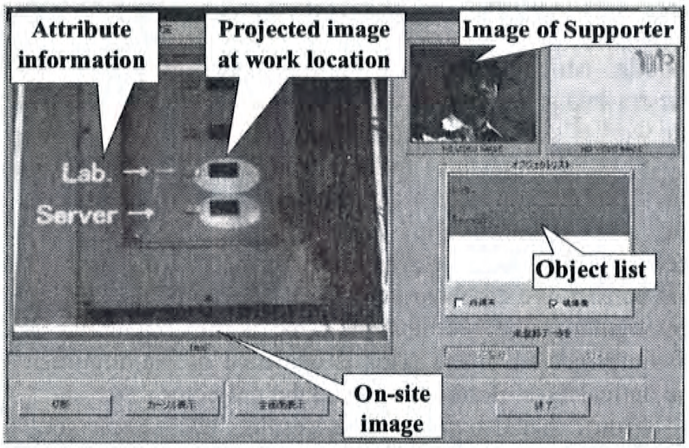


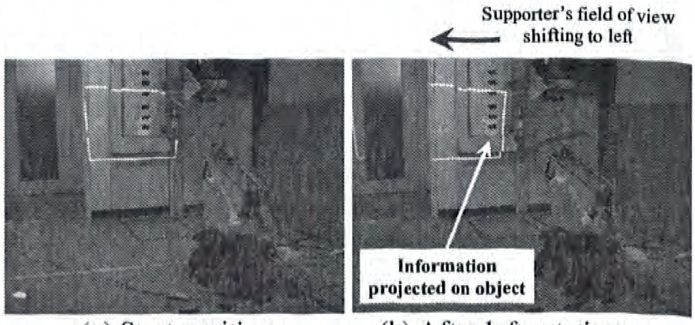
Fig. 12 Screen shot (supporter's location).

SCOPE were also implemented. Two photos indicate the result of automatic correction of the position of projected attribute information, as shown in Figs. 13(a) and (b).

V. Conclusion

To create a more efficient environment in which to perform remote maintenance over a network, we proposed a mobile SCOPE to significantly expand the field of activity. We developed a technique for aligning the optical axes of the camera and the projector to share the field of view between an on-site worker and a remote support person. Experimental data regarding the optomechanical design demonstrated the validity of our idea.

A conventional technique of many optomechanical systems uses a half mirror, such as that in a see-through head-mounted display. However, those systems are not relevant to the problems discussed in this paper such as "ghosting" because they do not use a bright light source like a projector.



(a) Start position (b) After left rotation

Fig. 13 Result of automatic correction of projected attribute information.

Therefore, a major contribution of this paper is the new finding of a new interdisciplinary research field covering AR and robotics. We plan to extend the autonomy functions of the mobile SCOPE to include obstacle avoidance or tracking target objects.

Acknowledgement

The authors gratefully acknowledge Takasuke Sonoyama for providing the illustration expressing a future scene of remote support using our mobile SCOPE.

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Orlando, Florida - May 2006

Remote-Collaboration System Using Mobile Robot with Camera and Projector

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***Abstract* - We have been studying a remote-collaboration system called SCOPE (sight collaboration by projection effect) featuring image projecting and capturing capabilities as implemented in a maintenance robot. With the help of SCOPE and a remote support person, an on-site worker can perform maintenance very efficiently. We propose a mobile SCOPE that can significantly expand the area of activity of the conventional SCOPE. To enable an on-site worker to share the field of view of a remote support person, we developed a technique for aligning the optical axes of a camera and a projector. We present experimental data that demonstrates the validity of our optomechanical design. Finally, we show that the mobile SCOPE enables workers to continuously share their field of view, no matter where the mobile SCOPE moves.**

Index Terms* - *Remote collaboration, Shared field of view, Mobile robot, Camera and projector, Tele-operation.

I. INTRODUCTION

To create a more efficient environment in which to perform remote maintenance over a network, we have been studying a new collaboration concept, called "robot-augmented communication" (RAC) [11]. In RAC, a maintenance robot and an on-site human worker, who may not be skilled in maintaining the target object, are assisted by a veteran operator of the object at a remote support center. RAC provides effective support for on-site workers by augmenting the communication ability of the remote support person with robotic functions that people do not have.

A prototype remote-collaboration system called SCOPE (sight collaboration by projection effect) was developed as a maintenance robot that was the first instance of RAC, which featured image projecting and capturing capability. This SCOPE system, equipped with a projector and a camera, enables a target object perceived in the field of view of a remote support person to be shared with an on-site worker. This function should dramatically shorten the time taken to perform maintenance operations.

However, this SCOPE system cannot move about in an on-site maintenance area. Generally, on-site maintenance areas include very large plant sites or huge industrial facilities, so mobility is indispensable. Therefore, we present a mobile SCOPE and discuss its key technological issues. A future scene of remote support using the mobile SCOPE is shown in Fig. 1. As far as we know, such a robotic system has never been reported before.

Numerous papers on real-space projection technology utilizing a camera and projector set have been published, mainly in the fields of augmented reality (AR), Computer Supported Cooperative Work (CSCW), and ubiquitous computing [1]-[5]. Almost all of these studies focused on applications inside a room in an office or home, so the equipment was spatially fixed to the room structure such as to a desk, ceiling, wall, or floor. Utilizing a head-mounted display [6] or hand-held projector [7] enables us to move about in an on-site maintenance area; however, the current size and weight of such devices make them too troublesome to wear and carry around. In that respect, mobile SCOPE can relieve the on-site worker from having to wear such heavy, bulky devices.

On the other hand, the addition of mobility to the SCOPE system will cause an inherent, serious problem with sharing the field of view in an actual space because the spatial relationship between the image frame of the camera and that of the projector will change depending on the distance between SCOPE and the target to be captured and projected. Therefore, one of the most important problems for a mobile SCOPE is to maintain a shared field of view, no matter where the SCOPE system moves. To overcome this problem, we describe a method, based on the use of an ingenious optomechanical structure, that enables the optical axis of the camera and that of the projector to be aligned.

After a brief introduction of our RAC concept and the



Fig. 1 Future scene of remote support using mobile SCOPE

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conventional SCOPE, we discuss requirements for the mobile SCOPE and its key technology for optical-axis alignment of the camera and the projector. Next, we provide experimental data on the evaluation of the optomechanical design of the mobile SCOPE. Finally, we describe implementing the mobile SCOPE with an optomechanical design that enables an on-site worker to share the field of view of a remote support person, no matter where the SCOPE moves.

II. Concept for New Collaboration between Robot and Human over Network

A. Robot-Augmented Communication

When no skilled workers are present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site [8] [9] (see Fig. 2(a) below) or dispatch an unskilled worker to the site and remotely instruct him/her to perform maintenance operations from a distance [6] [10] (see Fig. 2(b)). In Fig. 2(a), a robot that interacts with a maintenance object cooperates with and is controlled by a remote, skilled operator through a network. In Fig. 2(b), an unskilled worker and a skilled operator cooperate through a network, and the unskilled worker interacts with the maintenance object. Each of these two cases – namely, the robot or the person handling the on-site operation – has its advantages and disadvantages, as explained below.

(a) Remote-controlled robot: Robot function, e.g., in terms of power and information-processing capability, can surpass that of a human operator, but the current level of robot autonomy is low and cannot match the operation skill of a remote skilled worker.

(b) Remote-supported human: Generally, the decision-making capability of a person in response to site conditions is much better than that of a robot. However, sufficiently conveying the intentions of the remote support person, i.e., skilled operators, without putting undue stress on the unskilled worker is difficult under the present state of communication between unskilled on-site workers and skilled remote support workers. For example, due to the time delay of a network, the supporter's intention often cannot be transmitted rapidly and easily.

With the drawbacks of the above two approaches in mind and aiming at extending the skill and ideas of a remote support person to cover work sites, where specialized robotic functions such as high-level information processing are particularly applicable, we propose a new form of collaboration between robots and on-site workers who have high decision-making capability. We have extended communication by means of a robot's functions, so this collaboration setup is called "robot-augmented communication" (RAC). As shown in Fig. 2(c), RAC provides effective support by emphasizing the intentions of the remote support person through the robot. This is achieved by actively utilizing the interaction between an on-site worker and robot functions that cannot be performed by humans.

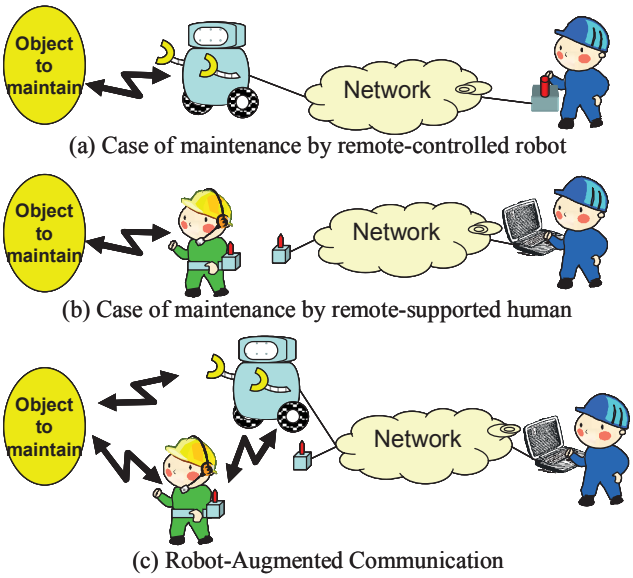


Fig. 2 Setups for remote maintenance.

B. SCOPE: System for supporting a shared field of view in an actual space

We selected the function of projecting information in an actual space as a robot function that is intended to surpass the ability of humans. In this section, we introduce a remote-support system called SCOPE as the first instance of an RAC concept.

1) System overview

A schematic of the configuration of this system is shown in Fig. 3. At the on-site worker's location, a camera and a projector are integrated in one piece, and an incorporated stepping motor enables the camera's viewing field and projected images to rotate around the vertical axis of a camera and projector unit. To attain the capability of a "shared viewing field" as explained later, domains of the viewing field of the camera and that of the projector are adjusted so that they are aligned. An on-site worker can use a laser pointer as an input interface. We implemented a manipulation function

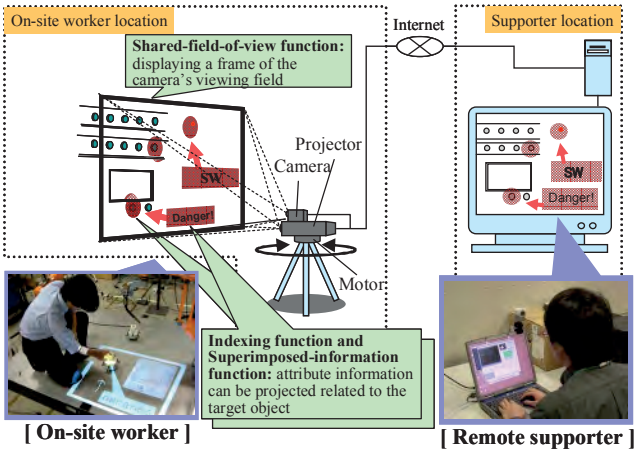


Fig. 3 SCOPE system.

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equivalent to the mouse on the client PC by applying image-recognition processing at the position of the laser pointer's spot.

2) Shared-field-of-view function

During collaborative operations at remote locations, a situation that often occurs is a remote support person verbally indicating relative directions like "on the right" to give instructions to an on-site worker. At such times, the remote support person's viewing field becomes essential information from the viewpoint of the on-site worker. In the SCOPE system, presenting the remote support person's viewing field to the on-site worker is possible by unifying the camera's viewing field and projector's projection area and displaying a frame of the camera's viewing field on the projected images.

3) Indexing function

Information needed for carrying out operations, "attribute information," is projected onto the target object as the occasion demands. This is like affixing notes on the target object with light. In the developed system, five kinds of information are conveyed: text, still images, video, sound, and program administration. The location of attributed information is indicated as a graphical image with a circular form. We call this mark a "projected image". By manipulating a projected image, one can also manipulate the display status of attribute information. At the on-site worker's location, the laser pointer is used to manipulate the projected image. At the supporter's location, the projected image is shown on a communication screen, which displays images transmitted from the on-site worker's location, and manipulated using the PC's mouse.

4) Superimposed-information function

In the SCOPE system, the camera/projector unit at the on-site worker's location can be manipulated from the supporter's location. The projected image and the attribute information are positioned on the target object by correcting the position of a projected image according to the movement of the camera and projector unit. This function enables the on-site worker to intuitively recognize the relationship between a stationary object in space and its attribute information.

5) Effectiveness of SCOPE for maintenance

The effectiveness of SCOPE was evaluated by experiments on two types of fundamental tasks, "comprehending the target object" and "transmitting instructions", involved in a typical maintenance operation. The experimental results indicate that shared-field-of-view, indexing, and superimposed-information functions are effective in shortening the time taken to perform the maintenance operation.

III. Hardware Design For a Mobile-type SCOPE

In this section, we discuss the hardware design of the mobile SCOPE in terms of user requirements and the conventional SCOPE technology. We use a planar mobile robot on which a camera-projector pair is mounted.

A. Requirements for utilizing SCOPE in an actual space

First, we assumed a very wide area with a flat floor in a huge indoor plant as the working environment of the mobile SCOPE. Therefore, we used a robot that has wheels with two degrees of freedom (DOF) of planar mobility. These DOF should be necessary for traveling in a wide working area and for avoiding projections, which are occluded by the on-site worker's body, between the robot and the object to be maintained.

B. Setup of projector and camera

We considered a projection plane approximately 4 × 4 m, about 1 – 3 m away from the mobile robot. A single small fixed projector cannot cover such a wide area, so pan-and-tilt rotational DOF are indispensable to broaden the projection coverage. On the other hand, rotation with respect to the optical axis is not needed because an on-site worker mainly works in a vertical standing position. We do not have to actively control the three translational DOF of the projector (one vertical and two horizontal) because we can relatively easily modify a projection image that has trapezoidal distortion caused by slanted projection on a flat plane. Based on the above discussion, we eventually designed a two-rotational-DOF projector on a 2-DOF planar mobile robot on wheels.

Many research studies have been performed on the autonomy of a mobile robot. For example, autonomous navigation technology such as path planning or SLAM (Simultaneous Localisation and Mapping) is a crucial issue that needs to be resolved for mobile robots. However, in the RAC concept, the present low level of mobile robot capabilities can be supplemented by human capabilities. On the other hand, the shared-field-of-view function of the mobile SCOPE has a fatal problem, as discussed in detail in the next section.

IV. Optomechanical Design

In this section, we discuss the layout for mounting a projector and camera on the mobile robot. First, we explain why aligning the optical axis of the projector and that of the camera is important, and we describe the optomechanical design for achieving this.

A. Issues in sharing field-of-view function of the mobile SCOPE

The basic functions of our mobile SCOPE include the following.

(1) Showing the remote support person's field of view by projecting the image frame of the camera

(2) Projecting various information on the viewing field as a shared area

(3) Enabling functions (1) and (2) in any place

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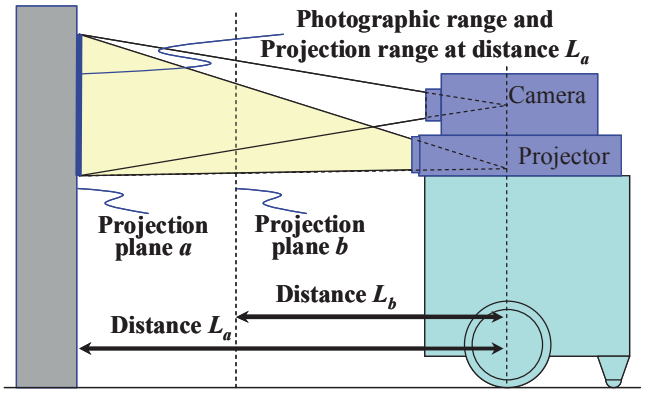


Fig. 4 Relationship between distance to projection plane, and photographic and projection ranges.

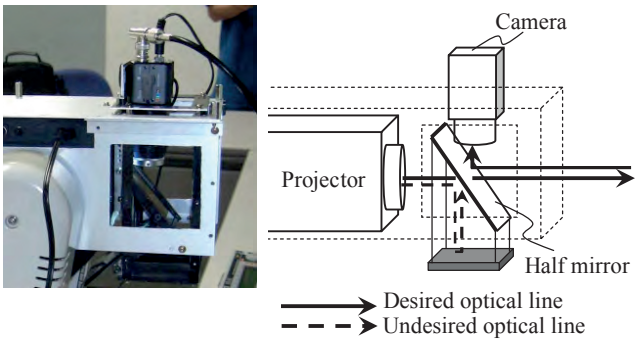


Fig. 5 Setup for aligning optical axes with half mirror.

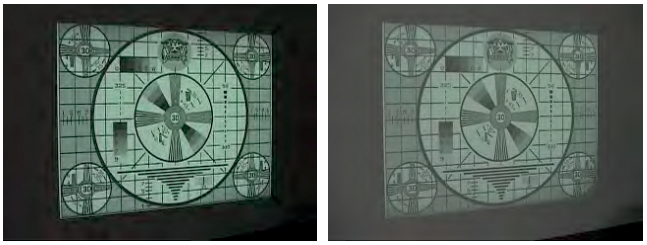
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As shown in Fig. 4, if the camera's photographic range and the projector's projection range are the same at a projection plane located at distance L_a, then the photographic and projection ranges are not the same in projection plane *b* for distance L_b. To deal with this problem, one might normally have to develop one of the following.

(i) A hardware mechanism for automatically correcting the orientations of the camera and projector

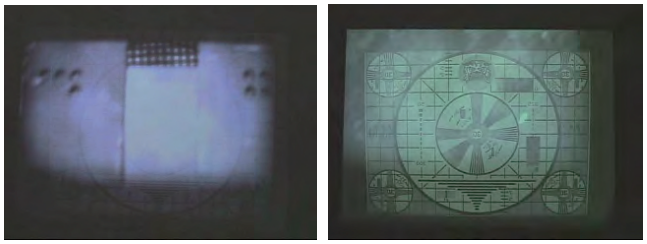
(ii) A real-time image-data-processing method that maintains the projected content within the visual field of the camera.

These are both very difficult and laborious to implement. Therefore, we propose another novel approach utilizing a half mirror.



(a) Directly projected image (b) Projected image through half-mirror

Fig. 6 Projected images on projection plane.



(a) Without black flock paper (b) With black flock paper

Fig. 7 Images captured by camera on SCOPE.

B. Aligning optical axes with a half mirror

To match the photographic range of the camera and the projection range of the projector independently of the distance to the subject, the ideal situation is for the focal point of the camera and the light source of the projector to be the same. However, this is impossible due to hardware restrictions. Therefore, we chose to achieve the same function by using a half mirror. First, as a preliminary investigation, we conducted an experiment using the equipment illustrated in Fig. 5.

Projected images on a projection plane without and with a half mirror, where the rate of reflection with respect to the rate of transmission, R:T, is 3:7, are shown in Figs. 6(a) and 6(b), respectively. The luminance of the projector is 1,500 lumens. These photographs were taken by another camera; they are images of what the on-site worker can see with the naked eye. Naturally, Fig. 6(b) is darker than Fig. 6(a).

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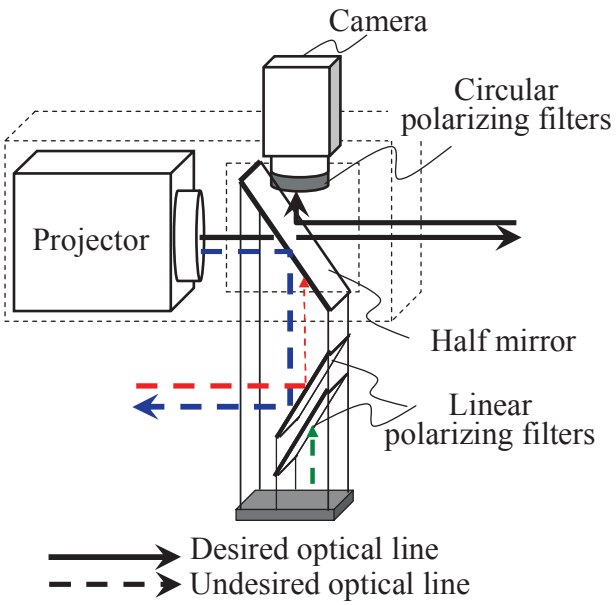
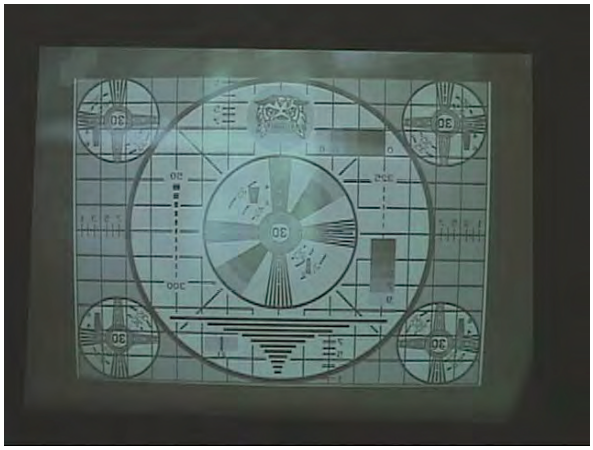
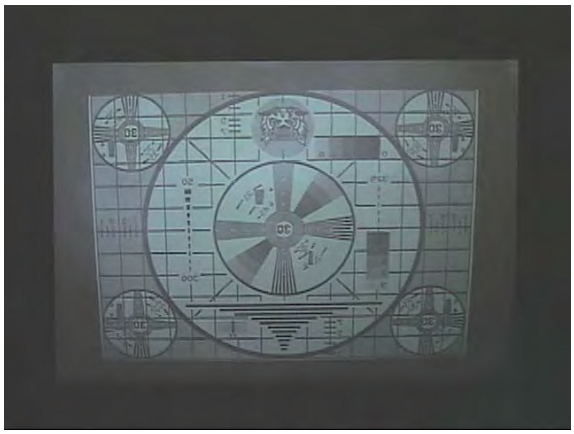


Fig. 8 Construction to eliminate ghost image.



(a) With linear polarizing filters



(b) With linear and circular filters

Fig. 9 Images captured by camera on SCOPE with polarizing filters.

C. Polarizing filters to eliminate the ghost image

We investigated ways to eliminate the excess light that passes through the half mirror and appears in the camera image. Utilizing polarizing filters is the key to solving this problem. The most effective configuration for eliminating the excess light is shown in Fig. 8. In this configuration, two linear polarizing filters reflect ambient light in the direction of the half mirror, and the circular polarizing filter blocks the light that has passed through the half mirror.

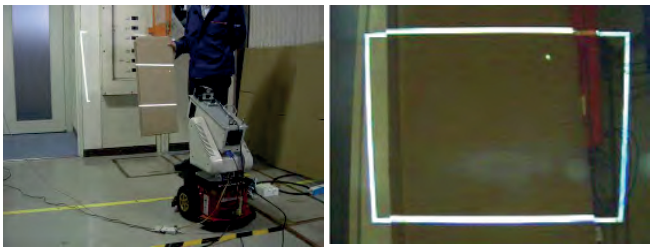
Images captured by the camera mounted on the SCOPE are shown in Fig. 9. They demonstrate the effectiveness of using polarizing filters. The result obtained when two linear polarizing filters were used is shown in Fig. 9(a). As the figure indicates, background image noise was cut by the linear polarization filters, compared with that of Fig. 7(b). However, the excess light that was reflected at the linear polarization filter and passed through the half mirror still appeared. The result obtained when two linear polarizing filters and a circular filter were used is shown in Fig. 9(b). The excess light from outside, which was present in Fig. 9(a), is reduced. This camera image can convey sufficient information about the on-site worker's site to a remote support person.

Photographs taken from the on-site worker's viewpoint and from the supporter's viewpoint, are shown in Figs. 10(a) and (b), respectively. Although the on-site worker's rectangular frame is extremely deformed by nonflat planes that consist of a cardboard and the background, the supporter's rectangular frame is almost the same as the rectangular frame of the projected image. This is evidence of the alignment of the optical axes of the camera and the projector.

From these experimental results, we confirmed the validity of our idea of using a half mirror and polarizing filters.

D. Implementation of mobile SCOPE

We unified a projector and a camera in the manner shown in Fig. 8 and mounted them on a mobile robot, Pioneer 3 manufactured by Active Media. A scene of remote support using the mobile SCOPE is shown in Figs. 11 and 12. Clearly, the viewing field of the remote supporter can be displayed in the on-site space. Aligning the optical axes enables sharing the field of view no matter where the mobile SCOPE moves. In this case, the position and orientation of the mobile SCOPE is controlled by the remote support person to find a target object or to avoid obstacles. Furthermore, the indexing and superimposed-information functions of the conventional



(a) On-site worker's viewpoint (b) Supporter's view point

Fig. 10 Result of aligning optical axes.

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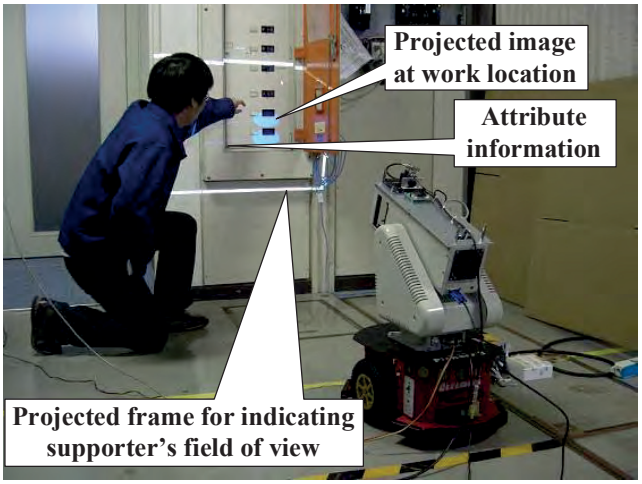


Fig. 11 Mobile SCOPE (on-site location).

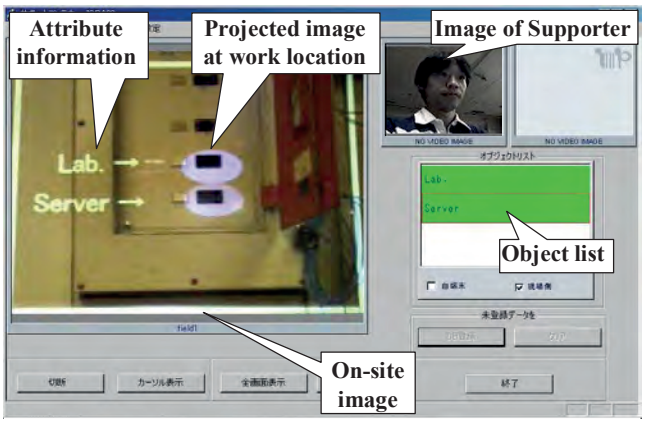


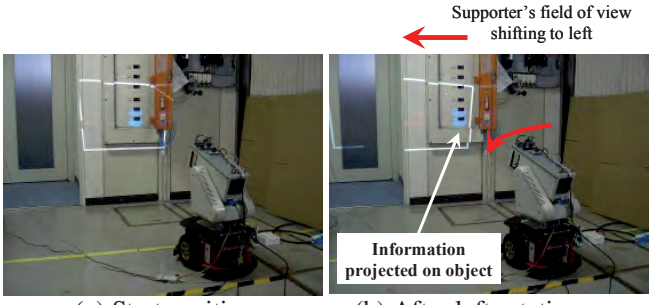
Fig. 12 Screen shot (supporter's location).

SCOPE were also implemented. Two photos indicate the result of automatic correction of the position of projected attribute information, as shown in Figs. 13(a) and (b).

V. Conclusion

To create a more efficient environment in which to perform remote maintenance over a network, we proposed a mobile SCOPE to significantly expand the field of activity. We developed a technique for aligning the optical axes of the camera and the projector to share the field of view between an on-site worker and a remote support person. Experimental data regarding the optomechanical design demonstrated the validity of our idea.

A conventional technique of many optomechanical systems uses a half mirror, such as that in a see-through head-mounted display. However, those systems are not relevant to the problems discussed in this paper such as "ghosting" because they do not use a bright light source like a projector.



(a) Start position (b) After left rotation

Fig. 13 Result of automatic correction of projected attribute information.

Therefore, a major contribution of this paper is the new finding of a new interdisciplinary research field covering AR and robotics. We plan to extend the autonomy functions of the mobile SCOPE to include obstacle avoidance or tracking target objects.

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Appendix A-3



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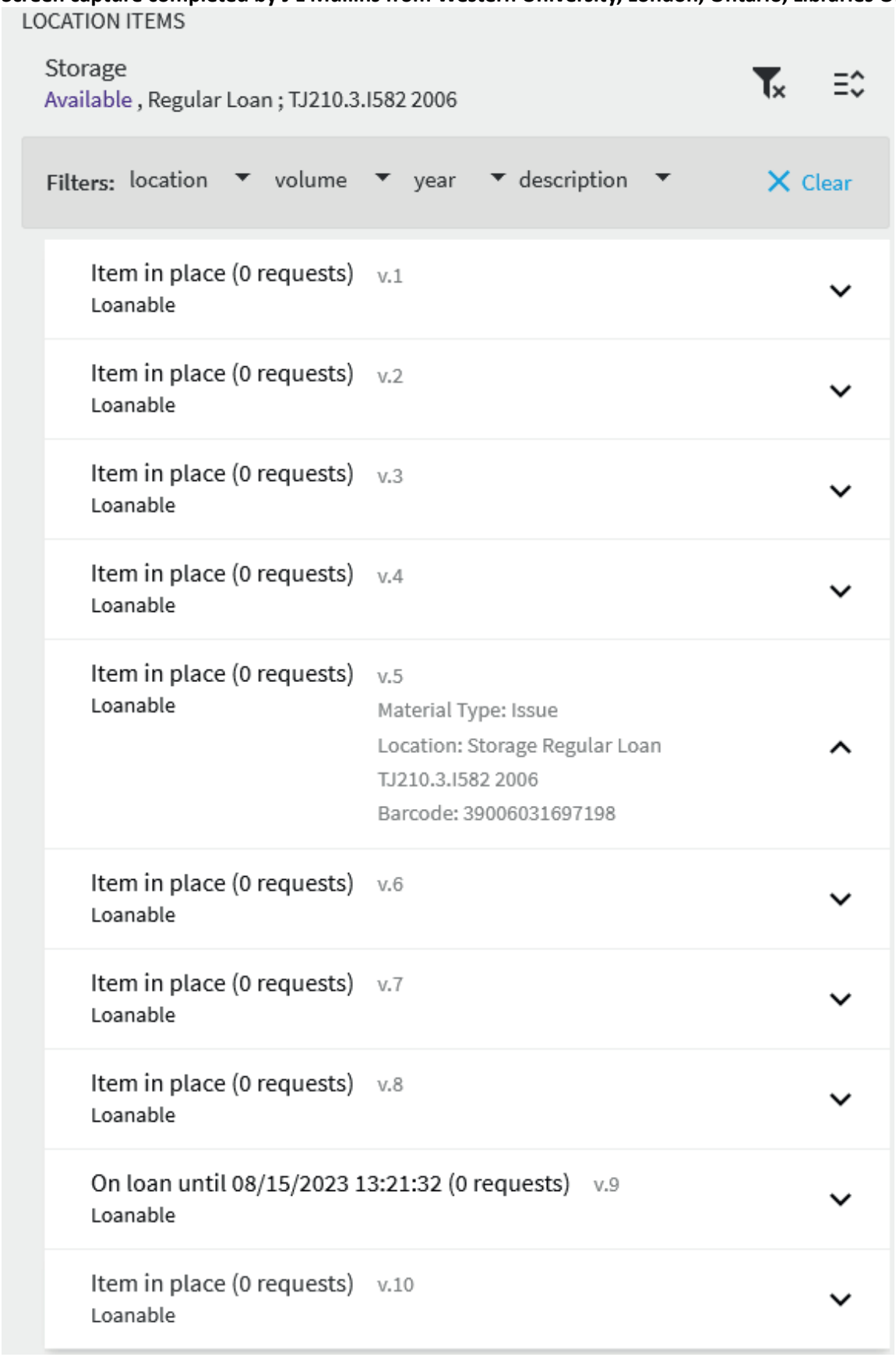
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Appendix A-5