

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

3SHAPE A/S AND 3SHAPE INC.
Petitioners

v.

MEDIT CORPORATION
Patent Owner

Case No. IPR2024-01268
U.S. PATENT NO. 9,191,648

DECLARATION OF INGRID HSIEH-YEE, PH.D.

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I. Introduction

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

1. Except where I have been informed by counsel regarding certain legal issues, as indicated below, I have personal knowledge of all of the matters about which I testify in this declaration.

2. I have been retained as an independent expert witness on behalf of 3Shape A/S and 3Shape Inc. (“3SHAPE”) to evaluate the authenticity and public availability of certain printed publications (identified below) which I am told will be submitted in connection with an *inter partes* review (IPR) proceeding before the United States Patent and Trademark Office.

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

A. Qualifications and Professional Experience

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

5. I was a professor in the Department of Library and Information Science at the Catholic University of America for 32 years and was conferred the title of

Professor Emerita in December 2022. I have experience working in an academic library, a medical library, and a legislative library. I hold a Ph.D. and a Masters in Library and Information Studies from the University of Wisconsin-Madison.

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

B. MARC, OCLC & Library Catalogs

7. I am very familiar with a library cataloging encoding standard known as the “Machine-Readable Cataloging” standard, also known as “MARC,” which became the national standard for sharing bibliographic data in the United States by 1971 and the international standard by 1973. MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries. Experts in my field would reasonably rely upon MARC records when forming their opinions.

8. A MARC record consists of several fields, each of them contains specific data about the work. Each field is identified by a standardized, unique, three-digit code corresponding to the type of data that follows. **Appendix B** is a true and correct copy of Parts VII to X of “Understanding MARC Bibliographic: Machine-Readable Cataloging” (<http://www.loc.gov/marc/umb/um07to10.html>) from the Library of Congress that explains commonly used MARC fields. For example, the personal author of a work is recorded in Field 100, the title is recorded in Field 245, publisher information is recorded in Field 260, the physical volume and characteristics of a publication are recorded in Field 300, and topical subjects are recorded in Fields 650.

9. I am very familiar with library cataloging and processing practices and the relationships between OCLC (Online Computer Library Center) and library

catalogs, and how libraries create and share their records to help the public discover and access information.

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

11. OCLC members can contribute original cataloging records in MARC to the system or derive cataloging records from existing records, an activity referred to as “copy cataloging.” When an OCLC participating institution acquires a work, it can create an original MARC record for the work in OCLC’s Connexion system (a system for catalogers to create and share MARC records), and the system will automatically generate a code for the date of record creation in the yymmdd format, and the creating library’s OCLC symbol is recorded in subfield “a” of the 040 field. Once the MARC record is in Connexion, it becomes available to other OCLC members for adoption to their local online catalogs (*i.e.*, copy cataloging).

12. After a MARC record is created in Connexion, it also becomes searchable and viewable on WorldCat, which is a free web portal for users to explore more than 10,000 libraries worldwide. Records in WorldCat, however, are not presented in MARC fields. Instead, the data elements are labeled to help users interpret the records. Thus, the information stored in MARC records in Connexion is available to the interested public through the user-friendly WorldCat web portal.

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

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

14. Libraries create MARC records for works they acquire, including books, serials, motion pictures, and publications in other formats. MARC records are representations of materials held by libraries and are critical for the discovery and access to those materials. Monograph cataloging is fairly common in libraries, and most libraries make a newly cataloged monograph available to the public soon after the cataloging work is completed, usually within a week. Libraries can create original cataloging records or use an existing record in OCLC to create a copy cataloging record. As soon as the cataloging record is completed, it is added to the library’s online catalog for users. If the record is an original record, it is also entered into OCLC WorldCat. If it is a copy cataloging record, the library’s holding symbol

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

15. The cataloging of serials and the serial check-in process are discussed here to show how libraries usually provide access to newly received serial issues. According to the glossary of the *RDA: Resource Description and Access* cataloging standard, a serial is “a mode of issuance of a manifestation issued in successive parts, usually bearing numbering, that has no predetermined conclusion. A serial includes a periodical, monographic series, newspaper, etc.” Because publishers of serials usually make new serial issues available successively, a customary cataloging practice is to create one bibliographic record for each serial, and the serial record (encoded in MARC) typically provides information on the beginning date and frequency of the serial, not the dates of individual issues. In other words, libraries typically do not create MARC records for individual issues of a serial. Instead, they rely on a serial check-in system to track the receipt of new issues. A common check-in practice is to date stamp a new issue when it arrives. This practice has become automated since the late 1990s, and libraries now vary in how they share the receipt date of a new serial issue with the public. Some libraries use a date stamp, some affix a label to indicate the receipt date, some pencil in the receipt date, and some do not provide the information to the public.

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

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

- Google Scholar (<https://scholar.google.com/>)
- Internet Archive (<https://archive.org/>)
- Online catalog of the University of California Berkeley Library
(<https://www.lib.berkeley.edu/>)
- Online catalog of the University of Washington Libraries
(<https://lib.uw.edu/>)

- Online catalog of the Yale University Library
(<https://library.yale.edu/>)
- WorldCat (<https://search.worldcat.org/>)

C. Scope of This Declaration

18. I have been asked to offer opinions on the authenticity and public availability dates of the following documents:

- (1) Estépar, R. S. J., Brun, A., & Westin, C. F. (2004). Robust generalized total least squares iterative closest point registration. In *Medical Image Computing and Computer-Assisted Intervention—MICCAI 2004: 7th International Conference, Saint-Malo, France, September 26-29, 2004. Proceedings, Part I*, pp. 234-241, Springer Berlin Heidelberg, **EX1008** (“Estépar”);
- (2) Szeliski, R. (2006). *Image Alignment and Stitching: A Tutorial, Foundations and Trends in Computer Graphics and Vision*, vol. 2, issue 1, pp. 1-104, **EX1009** (“Szeliski”).

19. I am rendering my expert opinion on the authenticity of the documents referenced herein and on whether such documents were publicly available and published. I provide my opinion on when and how the documents were publicly disseminated or otherwise made publicly available to the extent that persons interested and ordinarily skilled in the subject matter or art, exercising reasonable

diligence, could have located and retrieved this document.

20. I am informed by counsel 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. I am also informed that authenticity can be established based on the contents of the documents themselves, such as the appearance, content, substance, internal patterns, protocols followed or other distinctive characteristics of the item.

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

22. I have been informed by counsel that U.S. Patent No. 9,191, 648 (“the ’648 Patent”) was filed on August 20, 2013 and claims a priority date of February 22, 2011. I have assessed public accessibility of the documents referenced below as of the claimed priority date of February 22, 2011.

D. Person of Ordinary Skill in the Arts

23. I am told by counsel that the subject matter of the IPR proceeding involves three-dimensional imaging techniques and systems that can be used, for example, in medical and dentistry applications.

24. I have been informed by counsel that a “person of ordinary skill in the art at the time of the invention” (POSITA) is a hypothetical person who is presumed to be familiar with the relevant field, presumed to be aware of all pertinent art, and thinks along conventional wisdom in the art. This hypothetical person is also a person of ordinary creativity, capable of understanding the scientific principles and literature applicable to the pertinent field.

25. I am told by counsel that a POSITA, for purposes of the IPR proceeding, would have at least (1) a bachelor’s degree in electrical engineering, computer engineering, computer science, or an equivalent field, as well as at least two to three years of industry or research experience with computer vision/graphics making use of three-dimensional virtual models; or (2) a master’s degree in electrical engineering, computer engineering, computer science, or an equivalent field with a focus in making use of three-dimensional virtual models in the area of computer vision/graphics.

26. It is my opinion that such a person would have been actively engaged in learning about the field, for example, through formal instruction and bibliographic

resources. By at least February 22, 2011, such a person would have had access to a vast array of print and electronic resources, including at least those resources referenced below.

E. Evidence Considered in Forming My Opinions

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

- (1) The documents referenced above in Section I.C;
- (2) Copy of *Estépar* obtained from the publisher Springer at https://link.springer.com/content/pdf/10.1007/978-3-540-30135-6_29.pdf, **Appendix 1008A**;
- (3) Publisher's webpage for *Estépar*, available at https://link.springer.com/chapter/10.1007/978-3-540-30135-6_29, **Appendix 1008B**;
- (4) Bibliographic and MARC records for *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2004* that contains *Estépar*, available at <https://search.library.yale.edu/catalog/6709697> from the online catalog of the Yale University Library, **Appendix 1008C**;

- (5) Online catalog of the Yale University Library archived by Internet Archive on October 21, 2002, available at <https://web.archive.org/web/20021021221107/http://orbis.library.yale.edu/cgi-bin/Pwebrecon.cgi?DB=local&PAGE=First>, **Appendix 1008D**;
- (6) Bibliographic and MARC records for *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2004* that contains *Estépar*, available at https://search.library.berkeley.edu/permalink/01UCS_BER/10rhv18/alma991043486999706532 from the online catalog of the University of California Berkeley Library, **Appendix 1008E**;
- (7) The library home page and online catalog of the University of California Berkeley Library archived by Internet Archive on October 1, 2004, available at <https://web.archive.org/web/20041001083013/https://www.lib.berkeley.edu/> and <https://web.archive.org/web/20041001084337/http://sunsite5.berkeley.edu:8000/>, respectively, **Appendix 1008F**;
- (8) Citations to *Estépar*, obtained from Google Scholar, **Appendix**

1008G;

- (9) Publisher's webpage for *Szeliski*, available at <https://www.nowpublishers.com/article/Details/CGV-009>, and an extract of *Szeliski* obtained from <https://www.nowpublishers.com/article/DownloadSummary/CGV-009> from the publisher, **Appendix 1009A;**
- (10) Library copy of the front matter of *Szeliski*, obtained from the Yale University Library, **Appendix 1009B;**
- (11) Bibliographic and MARC records for *Szeliski*, available at <https://search.library.yale.edu/catalog/7927620> from the online catalog of the Yale University Library, **Appendix 1009C;**
- (12) Online catalog of the Yale University Library archived by Internet Archive on October 21, 2002, available at <https://web.archive.org/web/20021021221107/http://orbis.library.yale.edu/cgi-bin/Pwebrecon.cgi?DB=local&PAGE=First>, **Appendix 1009D;**
- (13) Bibliographic and MARC records for *Szeliski*, available at https://orbiscascade-washington.primo.exlibrisgroup.com/permalink/01ALLIANCE_U

W/1juclfo/alma99123702650001452 from the online catalog of the University of Washington Libraries, **Appendix 1009E**;

- (14) Online catalog of the University of Washington Libraries archived by Internet Archive on May 25, 2006, available at <https://web.archive.org/web/20060525191432/http://catalog.lib.washington.edu/search~/>, **Appendix 1009F**;

- (15) Publisher's webpage for *Foundations and Trends in Computer Graphics and Vision* archived by Internet Archive on March 7, 2007, and available at <https://web.archive.org/web/20070307074531/http://www.nowpublishers.com/>, and the publisher's webpage for *Szeliski* archived by Internet Archive on March 3, 2007, and available at <https://web.archive.org/web/20070303052646/http://www.nowpublishers.com/product.aspx?product=CGV&doi=0600000009>, **Appendix 1009G**;

- (16) Citations to *Szeliski*, obtained from Google Scholar, **Appendix 1009H**.

II. Authenticity and Public Availability of *Estépar* (EX1008)

A. Authentication

28. **EX1008** is a true and correct copy of “Robust generalized total least squares iterative closest point registration,” (“*Estépar*”), by Estépar et al. in *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2004: 7th International Conference, Saint-Malo, France, September 26-29, 2004, Proceedings*, (“*MICCAI 2004*”), Part I, pp. 234-241, LNCS 3216, that I obtained from the Yale University Library. When I began researching this article, I searched WorldCat for records for *MICCAI 2004* that contains *Estépar*, and a record at <https://search.worldcat.org/title/56617014> shows the Yale University Library is one of 246 libraries holding this work. After verifying the holdings information in this library’s online catalog, I requested a scan copy of *Estépar* from the library through a document delivery service. This library copy is presented as **EX1008** in this declaration.

29. Page 1 is the cover that carries a Yale University Library barcode and shows this copy is Part 1 of the *MICCAI 2004* conference proceedings, which is “LNCS 3216,” and Springer is the publisher. Page 2 shows a library stamp of “Yale University Library, Engineering and Applied Science Library.” Page 3 is the series title page that shows *MICCAI 2004* is volume 3216 of *Lecture Notes in Computer Science*. Page 4 is the title page that shows three editors, title, conference

information, and publisher. Page 5 is the copyright page that shows *MICCAI 2004* has a 2004 copyright date and Springer-Verlag Berlin Heidelberg holds the copyright. This page shows the Library of Congress Control Number (LCCN) assigned to this work is “2004111954” and the ISBN of this work is “3-540-22976-0.” This page also shows a hand-written call number of “ENG N QA76 A1 L43 3216 (LC).” Pages 6 to 15 are the table of contents of “LNCS 3216: MICCAI 2004 Proceedings, Part I” and page 8 (internal page XV) shows *Estépar* is included in “Segmentation I” and begins on internal page 234. Pages 16 to 31 are the table of contents of Part II of *MICCAI 2004*.

30. Page 32 (internal page [234]) is the first page of *Estépar* that shows the title, authors, and abstract. The bottom of this page shows *Estépar* appears in *MICCAI 2004*, which was edited by C. Barillot, D.R. Haynor, and P. Hellier, and published as volume 3216 of the LNCS series. This page also shows *Estépar* runs from pages 234 to 241, has a 2004 copyright date, and the publisher holds the copyright. **EX1008** shows *Estépar* has four parts and a total of eight pages, including 12 equations, three figures, one table, and 10 references.

31. To authenticate **EX1008**, I searched Google Scholar for information on *Estépar*, and a record led me to the publisher’s webpage for this article at https://link.springer.com/chapter/10.1007/978-3-540-30135-6_29, which included a link for users to “Download to read the full chapter text.” I then followed this link

to obtain a copy of *Estépar* (https://link.springer.com/content/pdf/10.1007/978-3-540-30135-6_29.pdf). This publisher copy is presented as **Appendix 1008A** in this declaration.

32. Appendix 1008A has a total of eight pages, including 12 equations, three figures, one table, and 10 references. I have closely compared the library copy (**EX1008**) with the publisher copy (**Appendix 1008A**) and found them to contain the same *Estépar* article. The difference is the Yale University copy (**EX1008**) includes the front matter of *MICCAI 2004*.

33. Appendix 1008B is the publisher's webpage for *Estépar* that I obtained from https://link.springer.com/chapter/10.1007/978-3-540-30135-6_29. Page 1 shows the title and authors of this article, identifies *Estépar* as a conference paper that appears from pages 234 to 241 of *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2004*, which is volume 3216 of the *Lecture Notes in Computer Science* series. Pages 1 and 2 show the abstract, which is the same as the abstract in **EX1008**. Pages 3 and 4 show 10 references, which are the same as the references in **EX1008**, but presented in a slightly different citation style. Page 5 shows *Estépar* has a 2004 copyright date and the publisher holds the copyright. It also shows the DOI of this article. The authors, title, abstract, the article's relationship to *MICCAI 2004*, the LNCS series information, and the references on

this publisher webpage match the information contained in **EX1008** and confirm *MICCAI 2004* that contains *Estépar* is available at the Yale University Library.

34. EX1008 is in a condition that creates no suspicion about its authenticity. Specifically, this Yale University Library copy of *Estépar* is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. In addition, this copy has the same content for *Estépar* as the copy obtained from the publisher (**Appendix 1008A**). Furthermore, bibliographic details contained in **EX1008** are the same as those presented on the publisher's webpage for this article (**Appendix 1008B**). Based on my analysis of **EX1008**, **Appendix 1008A**, and **Appendix 1008B**, it is my opinion that **EX1008** is authentic.

B. Yale University Library Records

35. To determine when *MICCAI 2004* that contains *Estépar* became publicly accessible at libraries, I obtained the bibliographic and MARC records for *MICCAI 2004* from the online catalog of the Yale University Library. I personally located, identified, and obtained these records. They are the type of record experts in my field would reasonably rely upon when forming their opinions.

36. Appendix 1008C is a true and correct copy of the bibliographic and MARC records for *MICCAI 2004*. Pages 1 to 4 are the bibliographic record that shows the conference name, title, ISBNs, publisher, physical description, format,

language, series, bibliography, subjects, editors, and bookmark of this record. The “Added to Catalog” field shows the record for *MICCAI 2004* was added to the online catalog of the Yale University Library on “October 13, 2004.”

37. Pages 5 and 6 are the MARC record. The first six digits of Field 008 show the record was first created on “041001” (*i.e.*, October 1, 2004). Subfield “a” of Field 040 shows “OHX” (*i.e.*, Harrassowitz of Wiesbaden, Germany, an OCLC commercial partner) created the original record. Subfield “d” of Field 040 shows “CtY” (*i.e.*, Yale University Library) modified the original record. Fields 008 and 040 inform my opinion that the Yale University Library used the original MARC record created on October 1, 2004, by Harrassowitz as the basis for their copy cataloging record and added the modified record to their online catalog on October 13, 2004, making *MICCAI 2004* discoverable from that date on.

38. Field 010 shows the Library of Congress Control Number. Field 020 shows the ISBN of volume 1. Field 111 shows the authorized form of the conference name is used as the author of this work. Field 245 shows the title, subtitle and editors. Field 260 shows the publisher and year of publication. Field 300 shows physical details. Field 440 shows the series title. Field 504 shows a note of references and index. Three Fields 700 show the editors are included in the MARC record to help users discover this work. The Library of Congress Control Number, ISBN for

volume 1, conference name, title, publisher, series, and editors match the information contained in **EX1008**, confirming this record represents *MICCAI 2004*.

39. Subjects are represented by six Library of Congress subject headings, with “Imaging systems in medicine |x Data processing” (“|x” indicates a topical subdivision), “Image analysis |x Data processing,” “Image processing |x Digital techniques,” “Operations, Surgical |x Data processing,” “Medicine |x Data processing,” and “Diagnostic imaging |x Data processing” as the main topics, each followed by “Congresses” as a form subdivision encoded in subfield “v” to indicate the main topics are treated at a conference. These subject headings enable users to conduct subject searches to discover *MICCAI 2004*.

40. The original MARC record includes a Library of Congress Classification numbers in Field 050, but that number is not used at the Yale University Library for *MICCAI 2004*. Field 902 shows that the library uses “QA76 A1 L43 3216-3217” as the call number for this work at their shelving facility.

41. Appendix 1008C shows the Yale University Library completed their copy cataloging work for *MICCAI 2004* and added the record to their online catalog on October 13, 2004, making *MICCAI 2004* discoverable from that date on. As of that date, interested users would have been able to discover *MICCAI 2004* by the conference name, title, series title, editors, ISBNs, and LCCN. In addition, they would have been able to conduct subject searches to discover this work.

42. A common library practice is to process a newly cataloged book promptly for public access, usually within a week after the cataloging work is completed. It is therefore my opinion that, from October 13, 2004 on, *MICCAI 2004* that contains *Estépar* was discoverable, and the physical volumes, after processing, would have been publicly accessible by October 20, 2004, at the Yale University Library. If workload at the time caused some delay, the physical copy would have been publicly accessible no later than November 13, 2004.

43. As evidence that the online catalog of the Yale University Library was in operation when the MARC record for *MICCAI 2004* was added to the library catalog, I searched Internet Archive for records. **Appendix 1008D** is a true and correct copy of “Orbis, Yale University Library Catalog” archived by Internet Archive. I personally located, identified, and obtained this copy. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

44. Page 1 of **Appendix 1008D** is a screen capture of a Wayback Machine calendar that shows the library online catalog was archived on October 21, 2002, and available at <https://web.archive.org/web/20021021221107/http://orbis.library.yale.edu/cgi-bin/Pwebrecon.cgi?DB=local&PAGE=First>. Pages 2 and 3 are the PDF of this archived copy that shows, as of October 21, 2002, users could discover Orbis on the Internet and search the catalog by title, journal, author, keyword, ranked keyword,

subject, call number, and uniform title, and a “Search Help” was available to help users explore the online catalog. **Appendix 1008D** shows that the online catalog of the Yale University Library was in operation before the copy cataloging record for *MICCAI 2004* was added to the online catalog on October 13, 2004.

C. University of California Berkeley Library Records

45. **Appendix 1008E** is a true and correct copy of the bibliographic and MARC records for *MICCAI 2004* that I obtained from the University of California Berkeley Library. I personally located, identified, and obtained these records to further demonstrate the public availability of *MICCAI 2004* at libraries. They are the type of record experts in my field would reasonably rely upon when forming their opinions.

46. Pages 1 to 4 are the bibliographic record that shows *MICCAI 2004* is a conference proceeding, and the University of California Berkeley Library holds the print copy and also provides access to the online version. Details of the record include creator, title, other title, format, creation date, publisher, series, reference and index note, contributors, and ISBNs. These details match the information presented in **EX1008**, confirming this record represents *MICCAI 2004*.

47. Pages 5 to 7 are the MARC record. The first six digits of Field 008 shows the original MARC record was created on “041001” (*i.e.*, October 1, 2004). Subfield “a” shows NLM (*i.e.*, the National Library of Medicine) created the record,

and Field 042 shows this is an “NLMcopc” (meaning copy cataloging record of the National Library of Medicine). Subfield “d” shows OHX (*i.e.*, Harrassowitz) created the record that was modified by NLM. Field 968 is a local field and the “Addate” subfield shows *MICCAI 2004* was added to the library collection on “041105” (*i.e.*, November 5, 2004.” Field 996 is another local field and the “CatDate” shows the cataloging record date is “11-05-04” (*i.e.*, November 5, 2004). Data from Field 008, 040, 968, and 996 inform my opinion that the National Library of Medicine created a copy cataloging record for *MICCAI 2004* based on the record created by Harrassowitz on October 1, 2004. After the NLM copy cataloging record was completed, the University of California Berkeley Library used the NLM record to create their copy cataloging record on November 5, 2004, making *MICCAI 2004* discoverable in their online catalog from that date on.

48. Since the Yale University Library MARC record (**Appendix 1008C**) and the University of California Berkeley MARC record (**Appendix 1008E**) were based on the same record created by Harrassowitz on October 1, 2004, the two records have many fields in common, including the LCCN (Field 010), the ISBNs for the print version (Fields 020), Conference name (Field 111), title (Field 245), publisher (Field 260), physical description (Field 300), series (Fields 440, 490, 830), editors (Fields 700), and similar subject headings (Fields 650). These data elements in the MARC record make *MICCAI 2004* discoverable in the online catalog of the

University of California Berkeley Library. Interested users would have been able to search for this work by the conference name, title, variant title, LCCN, ISBNs, series title, and editors. They would also have been able to conduct subject searches to locate *MICCAI 2004*.

49. As evidence that the University of California Berkeley Library had an online catalog in operation in 2004 when the copy cataloging record for *MICCAI 2004* was completed and became searchable, I searched Internet Archive for records of the library catalog. **Appendix 1008F** is a true and correct copy of the library home page and the online catalog archived by Internet Archive in 2004. I personally located, identified, and obtained these records. They are the type of record experts in my field would reasonably rely upon when forming their opinions. I used screen captures to produce this appendix.

50. Page 1 is a screen capture of the library home page archived by Internet Archive on October 1, 2004, and available at <https://web.archive.org/web/20041001083013/https://www.lib.berkeley.edu/>. The “Library Catalogs” column shows that, as of October 1, 2004, users could search the UCB-Pathfinder catalog and the ALL UC-MELVYL system, and a Guide to Library catalogs was available.

51. Page 2 is a screen capture of Pathfinder, which is the UCB Library Catalog, and this copy was archived by Internet Archive on October 1, 2004, and

available

at

<https://web.archive.org/web/20041001084337/http://sunsite5.berkeley.edu:8000/>.

This archived copy of Pathfinder shows that, as of October 1, 2004, users could explore the library catalog by title keyword(s), title phrase, personal author phrase, subject keyword(s), corporate author keyword(s), conference keyword(s), and call number phrase. They could also limit their searches by location or format to make the search results more manageable. **Appendix 1008F** shows that, on October 1, 2004, the online catalog of the University of California Berkeley Library was in operation. Users could discover the catalog from the library home page or directly on the Internet. **Appendix 1008F** shows that users would have been able to use the online catalog to discover *MICCAI 2004* when the library record was created on November 5, 2004.

D. Usage Record

52. Actual usage of a publication is reflected by other publications that make reference to it. I used Google Scholar to review citations to *Estépar* and compile a list of citations to demonstrate usage. **Appendix 1008G** presents six citations published from 2005 to 2007, and shows the earliest citation appeared in June 2005.

E. Summary of My Opinion on *Estépar*

53. The copy of *Estépar* from the Yale University Library (**EX1008**) is authentic because it contains no signs to raise suspicion about its authenticity, and the content of *Estépar* in this copy is the same as the content in the publisher copy (**Appendix 1008A**). In addition, the front matter of **EX1008** contains the same bibliographic details presented on the publisher's webpage for *Estépar* (**Appendix 1008B**). The records from the Yale University Library (**Appendix 1008C**) show their MARC record for *MICCAI 2004* was a copy cataloging record that was added to the catalog on October 13, 2004. Thus, based on this record, *Estépar* (**EX1008**) was publicly discoverable no later than October 13, 2004. In addition, an archived record of the library's online catalog (**Appendix 1008D**) shows that by October 21, 2002, users could discover and use the online catalog on the Internet, and that means when the copy cataloging record for *MICCAI 2004* was added to the library catalog in October 2004, users would have been able to use the online catalog to discover *MICCAI 2004*. The records from the University of California Berkeley Library (**Appendix 1008E**) show their copy cataloging record was created on November 5, 2004. Thus, based on this record, *Estépar* (**EX1008**) was publicly discoverable no later than November 5, 2004. In addition, an archived record of their library home page and catalog (**Appendix 1008F**) show that by October 1, 2004, users would have been able to discover and use the online catalog on the Internet. This means

that when the copy cataloging record for *MICCAI 2004* was created on November 5, 2004, users would have been able to use the online catalog to discover it.

54. Based on the documents and records I have analyzed, it is my opinion that *MICCAI 2004*, which contains *Estépar (EX1008)*, would have been discoverable on October 13, 2004, at the Yale University Library. The physical copy, after processing, was publicly accessible no later than November 13, 2004, at this library. *MICCAI 2004* would have been discoverable at the University of California Berkeley Library from November 5, 2004 on. The physical copy, after processing, was publicly accessible no later than December 5, 2004, at this library. Citation records (**Appendix 1008G**) show the earliest citation appeared in June 2005. Thus, *Estépar (EX1008)* was published and publicly accessible as early as November 13, 2004 and no later than December 5, 2004 at libraries.

III. Authenticity and Public Availability of *Szeliski* (EX1009)

A. Authentication

55. **EX1009** is a true and correct copy of *Image Alignment and Stitching: A Tutorial*, (“*Szeliski*”), by R. Szeliski, *Foundations and Trends in Computer Graphics and Vision*, vol. 2, issue 1, pp. 1-104, that I obtained from the publisher. When I began my research on *Szeliski* I searched Google Scholar for records and a record led me to the publisher’s webpage for this work at <https://www.nowpublishers.com/article/Details/CGV-009>. I then followed the

instructions on this webpage to obtain a PDF copy. This publisher copy is presented as **EX1009** in this declaration.

56. EX1009 has a total of 119 pages. Page 1 is the half title page. Page 3 is the title page that shows the title, author, and NOW of Boston and Delft as the publisher. Page 4 is the copyright page that shows this work has a 2006 copyright date and the author holds the copyright. It also shows the ISBN of this work is “1-933019-04-2” and the Library of Congress Control Number (LCCN) assigned to this work is “2006938728.” The top of this page shows this work is part of the *Foundations and Trends in Computer Graphics and Vision* series, and page 5 shows this work is “Volume 2 Issue 1, 2006” of the series. Page 6 is the series information. Page 8 shows the title, author, abstract, series title and numbering, pagination (“1-104”), copyright date, DOI (“10.1561/06000000009”), and publisher of *Szeliski*. Pages 9 and 10 are the table of contents. **EX1009** shows *Szeliski* has seven chapters, including equations, figures (some in color), tables, and 227 references (listed from pages 95 to 109).

57. EX1009 is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, the text on each page appears to flow seamlessly from one page to the next, and there are no visible alterations to the document. In addition, this copy is in the custody of the

publisher, where if it is authentic, it is likely to be found. I therefore see no reason to question the authenticity of **EX1009**.

B. Yale University Library Copy

58. More details of *Szeliski* are available from the publisher. **Appendix 1009A** is a true and correct copy of the publisher's webpage for *Szeliski* (<https://www.nowpublishers.com/article/Details/CGV-009>) and an extract provided by the publisher free of charge at <https://www.nowpublishers.com/article/DownloadSummary/CGV-009>. Page 1 shows the title, author, suggested citation, copyright date ("2006"), subjects, and "02 Jan 2007" as the publication date. Page 2 shows the abstract, DOI, chapter headings, book description, and a book cover. Pages 3 to 28 are the extract that indicates the full text is available at <http://dx.doi.org/10.1561/06000000009>. The extract includes the half title page, title page, copyright page, series title and numbering page, series information page, abstract page, table of contents, and pages 1 to 3, and 227 references on pages 95 to 109.

59. As evidence that *Szeliski* is publicly available at libraries, I searched WorldCat for records on *Szeliski* and a WorldCat record (<https://search.worldcat.org/title/86078426>) identifies the Yale University Library as one of the 70 holding libraries. After the holdings information was verified, I obtained a copy of the front matter of *Szeliski* from this library through a document

delivery service. This library copy is presented as **Appendix 1009B** in this declaration.

60. The Yale University Library was not able to scan the entire work of *Szeliski* for me due to copyright restrictions, so I obtained the front matter of this work instead. **Appendix 1009B** is a true and correct copy of the front matter of *Szeliski*. Page 1 is the cover that shows the title, author, series title, publisher, a Yale University Library barcode, and a call number label of “ENGN TA1637 .S93 2006 (LC).” Page 2 shows a library stamp of “Yale University Library, Engineering and Applied Science Library.” Page 3 is the half title page, page 4 is the title page, page 5 is the copyright page that shows a hand-written call number, page 6 is the series title and numbering page, page 7 is the series information page, page 8 is the abstract page, pages 9 and 10 are the table of contents that shows *Szeliski* includes seven chapters and the list of references begins on page 95.

61. I have closely compared the Yale University Library copy of the front matter of *Szeliski* (**Appendix 1009B**) with the front matter of the publisher copy (**EX1009**) and the extract provided by the publisher (**Appendix 1009A**), and found the front matter in these three copies to be identical, confirming *Szeliski*, which is *Foundations and Trends in Computer Graphics and Vision* vol. 2, issue 1 (2006), 1-104, is available at the Yale University Library.

C. Yale University Library Records

62. To determine when *Szeliski* became publicly accessible at the Yale University Library, I obtained the bibliographic and MARC records for this work from the online catalog of the library. I personally located, identified, and obtained these records. They are the type of record experts in my field would reasonably rely upon when forming their opinions.

63. **Appendix 1009C** is a true and correct copy of the bibliographic and MARC records for *Szeliski* from the Yale University Library. Pages 1 to 3 are the bibliographic record that shows the author, title, ISBNs, publisher, physical description, note, format, language, bibliography, subjects, and bookmark of this record. The “Added to Catalog” field shows the record for *Szeliski* was added to the online catalog of the Yale University Library on “September 04, 2007.”

64. Page 4 is the MARC record. The first six digits of Field 008 show the record was first created on “070320” (*i.e.*, March 20, 2007). Subfield “a” of Field 040 shows “WAU” (*i.e.*, the University of Washington Libraries), created the original record. Subfield “d” of Field 040 shows “CtY” (*i.e.*, Yale University Library) modified the original record to create their copy cataloging record. Field 907 is a local note field that shows the cataloging record was added to the catalog on “2007-09-04” (*i.e.*, September 4, 2007). Fields 008, 040, and 907 inform my opinion that the Yale University Library used

the original MARC record created on March 20, 2007, by the University of Washington Libraries to create their copy cataloging record and entered the record into their online catalog on September 4, 2007, making *Szeliski* discoverable in their online catalog from that date on.

65. Field 010 shows the Library of Congress Control Number (LCCN). Field 020 shows the ISBNs. Field 100 shows the author. Field 245 shows the title, subtitle and author. Field 260 shows the publisher and copyright date. Field 300 shows physical details. Field 500 explains *Szeliski* was published as volume 2 issue 1 (2006) of the series. Field 504 shows the references appear from pages 95 to 109. Field 730 shows the series title is included to help users discover this work. The LCCN, ISBNs, author, title, publisher, and series title and numbering match the information contained in **EX1009**, confirming this record represents *Szeliski*.

66. Subjects are represented by two Library of Congress subject headings: “Imaging processing |x Digital techniques |x Mathematical models” (“|x” indicates a topical subdivision), and “Imaging processing |x Digital techniques |x Mathematics.” These subject headings enable users to conduct subject searches to discover *Szeliski*.

67. The original MARC record includes a Library of Congress Classification numbers in Field 050, but that number is not used by the Yale

University Library for *Szeliski*. Field 902 shows that the library uses “TA1637 .S93 2006 (LC)” as the call number for this work at their shelving facility.

68. **Appendix 1009C** shows the Yale University Library completed their copy cataloging work for *Szeliski* and added the record to their online catalog on September 4, 2007, making this work discoverable from that date on. As of that date, interested users would have been able to discover *Szeliski* by the title, author, series, LCCN, and ISBNs. In addition, they would have been able to conduct subject searches to discover this work.

69. A common library practice is to process a newly cataloged book promptly for public access, usually within a week after the cataloging work is completed. It is therefore my opinion that, from September 4, 2007 on, *Szeliski* was discoverable, and the physical copy, after processing, would have been publicly accessible by September 11, 2007, at the Yale University Library. If workload at the time caused some delay, the physical copy would have been publicly accessible no later than October 4, 2007.

70. As evidence that the online catalog of the Yale University Library was in operation when the MARC record for *Szeliski* was added to the library catalog, I searched Internet Archive for records. **Appendix 1009D** is a true and correct copy of “Orbis, Yale University Library Catalog” archived by Internet Archive. I personally located, identified, and obtained this copy. This is the type of record

experts in my field would reasonably rely upon when forming their opinions.

71. Page 1 of **Appendix 1009D** is a screen capture of a Wayback Machine calendar that shows the library online catalog was archived on October 21, 2002, and available at <https://web.archive.org/web/20021021221107/http://orbis.library.yale.edu/cgi-bin/Pwebrecon.cgi?DB=local&PAGE=First>. Pages 2 and 3 are the PDF of this archived copy that shows, as of October 21, 2002, users could discover Orbis on the Internet and could search the catalog by title, journal, author, keyword, ranked keyword, subject, call number, and uniform title, and a “Search Help” was available to help users explore the online catalog. **Appendix 1009D** shows that the online catalog of the Yale University Library was in operation before the copy cataloging record for *Szeliski* was added to the online catalog on September 4, 2007.

D. University of Washington Library Records

72. **Appendix 1009E** is a true and correct copy of the bibliographic and MARC records for *Szeliski* that I obtained from the University of Washington Libraries. I personally located, identified, and obtained these records to further demonstrate the public availability of this work at libraries. They are the type of record experts in my field would reasonably rely upon when forming their opinions.

73. Pages 1 to 4 are the bibliographic record that shows *Szeliski* is available at the Engineering Library Stacks with a call number of “TA 1634 .F67 v.2.” The

record details on page 3 include the title, author, subjects, related title, language, format, description note, publisher, publication date, and ISBNs. These details match the information presented in **EX1009**, confirming this record represents *Szeliski*.

74. Pages 5 to 6 are the MARC record. The first six digits of Field 008 shows the MARC record was created on “070320” (*i.e.*, March 20, 2007). Subfield “a” of Field 040 shows “WAU” (*i.e.*, the University of Washington Libraries) created this record. Data from Field 008 and 040 inform my opinion that the MARC record for *Szeliski* was completed on March 20, 2007, making this work discoverable in the online catalog of the University of Washington Libraries from that date on.

75. Since the Yale University Library MARC record (**Appendix 1009C**) was based on the University of Washington MARC record (**Appendix 1009E**), the two records have many fields in common, including the ISBNs (Fields 020), author (Field 100), title (Field 245), publisher (Field 260), physical description (Field 300), and subject headings (Fields 650). Interested users would have been able to search for this work in the online catalog of the University of Washington Libraries by the author, title, ISBNs and series title. They would also have been able to conduct subject searches to locate this work.

76. As evidence that the University of Washington Libraries had an online catalog in operation in 2007 when the MARC record for *Szeliski* was completed on March 20, 2007, I searched Internet Archive for records of the library catalog.

Appendix 1009F is a true and correct copy of the online catalog archived by Internet Archive in 2006. I personally located, identified, and obtained this record. It is the type of record experts in my field would reasonably rely upon when forming their opinions.

77. Page 1 is a screen capture of a Wayback Machine calendar that shows the library online catalog was archived by Internet Archive on May 25, 2006, and available at <https://web.archive.org/web/20060525191432/http://catalog.lib.washington.edu/search/>. Page 2 is the PDF of the archived copy that shows that, as of May 25, 2006, users could search the library catalog by author, title, advanced keyword, call numbers, journal searches, Library of Congress Subjects, Medical Subjects, Genre/Form, and ISBN and other numbers. **Appendix 1009F** informs my opinion that, on May 25, 2006, the online catalog of the University of Washington Libraries was in operation and users would have been able to use the online catalog to discover *Szeliski* when the library record for this work was created on March 20, 2007.

E. Internet Archive Records

78. As evidence that *Szeliski* was published before the University of Washington Libraries and the Yale University Library created their cataloging records, I searched Internet Archive for records on *Szeliski*. **Appendix 1009G** is a true and correct copy of the webpage for *Foundations and Trends in Computer*

Graphics and Vision and the webpage for *Szeliski* archived by Internet Archive. I personally located, identified, and obtained these records. They are the type of record experts in my field would reasonably rely upon when forming their opinions.

79. Page 1 is a screen capture of a Wayback Machine calendar that shows the publisher's webpage for *Foundations and Trends* was archived on March 7, 2007. Pages 2 and 3 are the PDF of this archived copy that shows *Szeliski* is listed under "Just Published." This archived copy means that by March 7, 2007, users would have discovered that *Szeliski* was published and available for purchase.

80. Page 4 is a screen capture of a Wayback Machine calendar that shows the publisher's webpage for *Szeliski* was archived on March 3, 2007, by the Internet Archive. This archived copy shows the title, author, abstract, DOI, and series title and numbering of this work. The archived copy means that users would have discovered this webpage by March 3, 2007, and used it to obtain a copy from the publisher.

81. The archived copy of the publisher's webpage for the series and the publisher's webpage for *Szeliski* inform my opinion that the publisher listed *Szeliski* as a published work in March 2007, and users would have been able to discover it on the Internet by March 7, 2007. This date is consistent with the January 2007 publication date on the publisher's webpage (**Appendix 1009A**), the creation dates of the original MARC record by the University of Washington Libraries(**Appendix**

1009E), and the copy cataloging date of the Yale University Library (**Appendix 1009C**).

F. Usage Record

82. Actual usage of a publication is reflected by other publications that make reference to it. I used Google Scholar to review citations to *Szeliski* and compile a list of citations from 2007 to demonstrate usage. **Appendix 1009H** presents five 2007 citations, and shows the earliest citation appeared in June 2007, confirming my opinion that, in March 2007, *Szeliski* would have been publicly discoverable and accessible on the Internet and at the University of Washington Libraries.

G. Summary of My Opinion on *Szeliski*

83. The publisher copy of *Szeliski* (**EX1009**) is authentic because it contains no signs to raise suspicion about its authenticity, and the copy is in the custody of the publisher. The publisher webpage for this work (**Appendix 1009A**) shows a publication date of “02 January 2007.” The front matter of *Szeliski* from the Yale University Library copy (**Appendix 1009B**) is identical to the front matter in the publisher copy (**EX1009**) and the extract provided by the publisher (**Appendix 1009A**), confirming *Szeliski* has been publicly accessible at the Yale University Library. The Yale University Library’s MARC record (**Appendix 1009C**) shows it is a copy cataloging record that was added to their catalog on September 4, 2007,

making *Szeliski* discoverable in their online catalog from that date on. In addition, an archived copy of the library home and online catalog (**Appendix 1009D**) shows that by October 21, 2002, the online catalog was in operation. The University of Washington Library's MARC record (**Appendix 1009E**) shows the original record was created on March 20, 2007, making *Szeliski* discoverable in their online catalog from that date on. An archived record of the library's online catalog (**Appendix 1009F**) shows the online catalog was in operation on May 25, 2006. Archived copies of the publisher's webpages for the series and *Szeliski* (**Appendix 1009G**) show *Szeliski* would have been publicly discoverable and accessible by March 7, 2007. Usage records (**Appendix 1009H**) show at least five citations to *Szeliski* were published in 2007, and the earliest citation appeared in June 2007.

84. Based on the documents and records I have analyzed, it is my opinion that *Szeliski* (**EX1009**) was publicly discoverable and accessible by March 7, 2007 on the Internet. This work was cataloged by the University of Washington Libraries and became discoverable in their online catalog from March 20, 2007 on. The physical copy, after processing, was publicly accessible by March 27, 2007, at the University of Washington Libraries. If there was a delay in local processing, the physical copy would have been publicly accessible no later than April 20, 2007. The Yale University Library copy of *Szeliski* became publicly discoverable on September 4, 2007, when the record was added to the library catalog. The physical copy, after

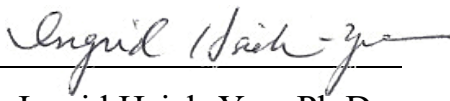
processing, was publicly accessible no later than September 11, 2007. If there is a delay in local processing, the physical copy would have been publicly accessible no later than October 4, 2007. Citation records show the earliest citation appeared in June 2007, confirming my opinion that *Szeliski* was publicly discoverable and accessible by March 7, 2007, on the Internet. Thus, *Szeliski* (**EX1009**) was published and publicly accessible as early as April 20, 2007 and no later than October 4, 2007 at libraries.

IV. Conclusion

85. In signing this Declaration, I recognize that the Declaration will be filed as evidence in a case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in the case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

86. I hereby declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with the knowledge that willful false statements and the like so made are made under penalty of perjury.

Date: 8-9-2024

Executed: 
Ingrid Hsieh-Yee, Ph.D.

APPENDIX A

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

Education

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

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

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

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

Work Experience

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

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

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

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

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

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

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

Areas of Teaching and Research Interests

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

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

Grants & Honors

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

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

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

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

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

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

ALISE Research Grant (2001).

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

Research Grant from ERIC (1999-2000).

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

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

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

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

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

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

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

Chinese-American Librarians Association Scholarship (1987).

Beta Phi Mu (1985).

Vilas Fellowship, University of Wisconsin-Madison. 1984

Publications

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- Hsieh-Yee, I. (2002). Cataloging and Metadata Education: Asserting a Central Role in Information Organization. *Cataloging & Classification Quarterly* 34(½): 203-222.
- Hsieh-Yee, I., and Smith, M. (2001). The CORC Experience: Survey of Founding Libraries, Part I. *OCLC Systems & Services*, 17: 133-140. (Received "The Most Outstanding Paper of OCLC Systems & Services in 2001" award.)
- Hsieh-Yee, I., and Smith, M. (2001). The CORC Experience: Survey of Founding Libraries, Part II, Automated Tools and Usage. *OCLC Systems & Services*, 17: 166-177. (Received "The Most Outstanding Paper of OCLC Systems & Services in 2001" award.)
- Hsieh-Yee, I. (2001). ERIC User Services: Changes and Evaluation for the Future. *Government Information Quarterly*, 18: 31-42.
- Hsieh-Yee, Ingrid. (2001). Research on Web Search Behavior. *Library and Information Science Research*, 23: 167-185.
- Logan, E., and Hsieh-Yee, I. (2001). Library and Information Science Education in the Nineties. *Annual Review of Information Science and Technology*, 35: 425-477.
- Hsieh-Yee, I. (Ed.) (2001). *Library and Information Science Research*, 23 (2). A special issue in honor of the retirement of Douglas L. Zweizig.
- Hsieh-Yee, I. (2000). *ERIC User Services: Evaluation in a Decentralized Environment*. Washington, D.C.: Dept. of Education.
- Hsieh-Yee, Ingrid. (2000). *Organizing Audiovisual and Electronic Resources for Access: A Cataloging Guide*. Littleton, CO: Libraries Unlimited.
- Hsieh-Yee, I. (2000). Organizing Internet Resources: Teaching Cataloging Standards and Beyond. *OCLC Systems & Services*, 16: 130-143. (Received "The Most Outstanding Paper of OCLC Systems & Services in 2000" award.)
- Hsieh-Yee, I. (1998). The Retrieval Power of Selected Search Engines: How Well Do They Address General Reference Questions and Subject Questions? *Reference Librarian*, 60: 27-47.
- Hsieh-Yee, I. (1998). Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study. *Reference Librarian*, 60: 61-85. (Received the 1997 Best ALISE Research Paper Award.)
- Hsieh-Yee, I. (1997). Access to OCLC and Internet Resources: LIS Educators' Views and Teaching Practices. *RQ*, 36: 569-86.

- Hsieh-Yee, I. (1997). Teaching Online and CD-ROM Resources: LIS Educators' Views and Practices. *Journal of Education for Library and Information Science*, 38: 14-34.
- Hsieh-Yee, I. (1996). The Cataloging Practices of Special Libraries and Their Relationship with OCLC. *Special Libraries*, 87: 10-20.
- Hsieh-Yee, I. (1996). Modifying Cataloging Practice and OCLC Infrastructure for Effective Organization of Internet Resources. In *Proceedings of the OCLC Internet Cataloging Colloquium*. [Online]. Available: <http://www.oclc.org/oclc/man/colloq/hsieh.htm>
- Hsieh-Yee, I. (1996). Student Use of Online Catalogs and Other Information Channels. *College & Research Libraries*, 57: 161-175.
- Hsieh-Yee, I. (1995). Ten entries in James S. C. Hu (Ed.), *Encyclopedia of Library & Information Science*, 913, 1028-29, 1036, 1037, 1145-46, 1514, 1575, 1763-64, 2216-27, 2378-79. Taipei, Taiwan: Sino-American Publishing. (Topics include "Advanced Technology/Libraries," "Information Ethics," "Instruction on Cataloging and Classification," "Instruction on Reference Services.")
- Hsieh-Yee, I. (1993). Effects of Search Experience and Subject Knowledge on Online Search Behavior: Measuring the Search Tactics of Novice and Experienced Searchers. *Journal of the American Society for Information Science*, 44: 161-174. (Received the 1993 Best JASIS Paper Award.)

Works in Progress

- Hsieh-Yee, I. Actionable lessons for debunking false information: A comparative analysis of literacy lessons in communication and library and information science
- Hsieh-Yee, I. Representing diverse voices and communities in cataloging and indexing: The evolution of controlled vocabularies
- Hsieh-Yee, I. Information Organization and Retrieval in Practice (a monograph scheduled for completion and publication in 2023)

Presentations

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

- Hsieh-Yee, I. and Fragan-Fly, J. (May 2018) Trends, Design & Strategies for Digital Scholarship Services. Presented at the 2018 Maryland/Delaware Library Association Conference, Cambridge, MD.
- Hsieh-Yee, I. (February, 2018) Research Data Management: What It Takes to Succeed. Presented at the 10th Bridging the Spectrum Symposium, Washington, D.C.
- Hsieh-Yee, I. (February, 2017) *Research Data Management: New Competencies and Opportunities for Information Professionals*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.
- Hsieh-Yee, I. and Lawton, P. (February, 2017) *Enhancing Catholic Portal Searches with User Terms and LCSH*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.
- Hsieh-Yee, I. (2016, October) *Visualizing Data for Information*. Presented at the 2016 Virginia Library Association Conference, Hot Springs, VA.
- Hsieh-Yee, I. (2016, August) *Religious Materials Toolbox for Archivists: Solutions to Problems Facing the Profession*. Presented at Archives * Records 2016, Atlanta, GA.
- Hsieh-Yee, I. and Lawton, P. (2016, March) *Enhancing Retrieval of Catholic Materials with LCSH Knowledge Structure*. Presented at the 2016 Catholic Library Association Conference, San Diego, CA.
- Fagan-Fry, J. and Hsieh-Yee, I. (2016, February) *Approaches to Digital Scholarship at Top Universities around the World: Scholarly Publishing in the Digital Age*. Presented at the 8th Bridging the Spectrum Symposium, Washington, D.C.
- Hsieh-Yee and Fagan-Fry, J. (2016, January) *Innovative Services for Digital Scholarship at Top 100 Research Libraries of the World*. Poster presented at the 2016 Annual Conference of the Association for Library and Information Science Education, Boston, Mass.
- Hsieh-Yee, I. and Lawton, P. (2015, June). *Crowdsourcing terms for CRRA portal themes*. Poster presented at the third CRRA symposium and annual meeting, Bringing the created toward the Creator: Liturgical art and design since Vatican II. Catholic Theological Union, Chicago, Illinois.
- Hsieh-Yee, I. and Lawton, P. (2015, February). *Crowdsourcing terms for thematic exploration in the Catholic Portal*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.
- Hsieh-Yee, I., James, R., and Fagan-Fry, J. (2015, February). *Support for digital scholarship at top university libraries of the world*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

- Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2015, February). *Thus said the end users: Summon experience and support for research workflows*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.
- Yontz, E., Hsieh-Yee, I., & Houston, S. (2015, February). *Healthy Heroes Summer Reading Club: Developing healthy youth at public libraries*. 11th Annual Jean Mills Health Symposium, Greenville, North Carolina.
- Yontz, E., Hsieh-Yee, I., and Houston, S. (2015, January). *Healthy youth and libraries: A pilot study*. Association for Library & Information Science Education (ALISE) Annual Conference, Chicago, Illinois.
- Hsieh-Yee, I. (2014, May). *Linking CRRRA resources to portal themes via authority files*. Presented at the Catholic Research Resources Alliance 2014 Membership Meeting, Marquette, WI.
- Hsieh-Yee, I. (2014, April). *Enhancing subject access to CRRRA resources*. Presented at the 2014 Catholic Library Association Conference, Pittsburgh, PA.
- Hsieh-Yee, I. (2014, January). *Health Information Technology Program: Educational entrepreneurship in action*. Presented at the 2014 annual Conference of the Association for Library and Information Science Education, Philadelphia, PA.
- Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2014, January). *Discovering information through Summon: An analysis of user search strategies and search success*. Paper presented at the 6th Bridging the Spectrum Symposium, Washington, D.C.
- Hsieh-Yee, I. (2012, December). *National Digital Stewardship Alliance and SLIS at CUA: An Educational Partnership*. Paper presented at Best Practices Exchange: Acquiring, Preserving, and Providing Access to Government Information in the Digital Era, Annapolis, MD.
- Choi, Y. and Hsieh-Yee, I. (2010, January). *Finding Images in an OPAC: Analysis of User Queries, Subject Headings, and Description Notes*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.
- Hsieh-Yee, I. and Coogan, J. (2010, January). *Google Scholar vs. Academic Search Premier: What Libraries and Searchers Need to Know*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.
- Hsieh-Yee, I. (2009, November). *Information Science Education: An LIS School's Perspective*. Paper presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada.

- Hsieh-Yee, I., Menard, E., Ya-Ning Chen, A., Shu-Jiun Chen, S., Kalfatovic, M. R., Wisser, K. M. (2009, November). *Information Organization in Libraries, Archives and Museums: Converging Practices and Collaboration Opportunities*. Presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada. (Organizer and moderator of this panel.)
- Hsieh-Yee, I. and Coogan, J. (2009, July). *Catching up to Google Scholar: The Retrieval Power of Academic Search Premier and Google Scholar*. Poster presented at American Library Association Conference, Chicago, Illinois.
- Hsieh-Yee, I., with the CUA Scholarly Communications Project Team. (2009, January). *Digital Scholarship@CUA: Developing an Institutional Repository for CUA*. Poster presented at 1st Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.
- Wise, M., Cylke, K., and Hsieh-Yee, I. (2009, January). *Digital Talking Books: Meeting the Needs of the Blind and the Handicapped*. Paper presented at the Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.
- Hsieh-Yee, I. (2009, January). *User Expectations of MERIC*. Presented at the Information Organization Competencies for the 21st Century Discussion Session of the 2009 Conference of the Association for Library and Information Science Education, Denver, Colorado.
- Choi, Y., and Hsieh-Yee, I. (2008, November). *Subject Access for Images in an OPAC*. Annual Meeting of the American Society for Information Science and Technology, Columbus, Ohio. (Also co-organized a panel on Retrieving and Using Visual Resources: Challenges and Opportunities for Research and Education.)
- Hsieh-Yee, I. (2008, June). *Educating Cataloging Professionals in a Changing Information Environment*. National Taiwan University, Taipei, Taiwan.
- Vellucci, S. L., Moen, W.E., Hsieh-Yee, I., Marson, B., and Wisser, K. (2008, January) *Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input*. A panel presented at the 2008 Conference of the Association for Library and Information Science Education, Philadelphia, Pennsylvania.
- Hsieh-Yee, I., Choi, Y. and Kules, B. (2007, October). *Searching for Books and Images in OPAC: Effects of LCSH, TOC and Subject Domains*. A poster presented at the American Society for Information Science and Technology Annual Meeting, Milwaukee, Wisconsin.
- Hsieh-Yee, I. and Coogan, J. (2007, August) *Google Scholar vs. Academic Search Premier: A Comparative Analysis*. Presented to the Faculty and Staff of the University of the District

of Columbia.

- Hsieh-Yee, I. and Coogan, J. (2007, June). *Google Scholar vs. Academic Search Premier: A Comparative Analysis*. Presented to the Washington Research Library Consortium Community, Catholic University of America, Washington, D.C.
- Hsieh-Yee, I., Choi, Y., and Kules, B.. (2007, June). *What Users Need for Subject Access: Table of Contents or Subject Headings?* A poster presented at the 2007 American Library Association Annual Conference, Washington, D.C., June 2007.
- Choi, Y., Hsieh-Yee, I., and Kules, B. (2007, June). *Retrieval Effectiveness of TOC and LCSH*. A paper presented at the Joint Conference on Digital Libraries 2007, Vancouver, Canada.
- Vellucci, S. L., Hsieh-Yee, I., and Moen, W.E. (2007, May). *If We Build It, Will They Come? Building a Community of Practice for Metadata Stakeholders*. A poster presented at the Rutgers University Research Day, Bridgeton, New Jersey.
- Hsieh-Yee, I. (2007, May). *Federated Searching: User Experience & Perceptions*. International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.
- Hsieh-Yee, I. (2007, May). *Search Performance of Google Scholar and Academic Search Premier*. International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.
- Hsieh-Yee, I. (2007, May) *MERIC: Building a Digital Commons for Metadata Education & Research*. International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.
- Hsieh-Yee, I., and Coogan, J. (2007, March/April). *A Comparative Analysis of Google Scholar and Academic Search Premier*. Poster presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland.
- Vellucci, S. L. and Hsieh-Yee, I. (2007, March/April) *They Didn't Teach Me That in Library School! Building a Digital Teaching Commons to Enhance Metadata Teaching, Learning and Research*. On-site presentation and Webcast by Elluminate. A contributed paper presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland. The acceptance rate for contributed paper was 20%. This paper was one of 10 conference papers chosen for live webcast during the conference.
- Moen, W., Hsieh-Yee, I. and Vellucci, S.L. (2007, January) *A DSpace Foundation for a Teaching & Research Commons: The Metadata Education and Research Information Commons*. A poster session presented at the Open Repositories Conference 2007, San Antonio, Texas.

- Tang, R., Hsieh-Yee, I., and Zhang, S. (2006, November) *User Perception of MetaLib Combined Search*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas, Nov. 2006.
- Hsieh-Yee, I. (2006, November). *Federated Searching: User Perceptions, System Design, and Library Instructions*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter).
- Hsieh-Yee, I. (2006, November). *Building a Digital Teaching Commons to Enhance Teaching and Learning: The MERIC Experience and Challenges*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter)
- Hsieh-Yee, I. (2006, September). *Search Performance of Google Scholar and Academic Search Premier*. Paper presented at the ERIC Publishers Meeting, Washington, D.C.
- Hsieh-Yee, I., Zhang, S., and Rong Tang, R. (2006, June). *User Perceptions of a Federated Search System*. Poster presented at Joint Conference on Digital Libraries, Chapel Hill, North Carolina.
- Hsieh-Yee, I. and Zhang, S. (2006, June). *Preparing Users for Federated Search: Implications of a MetaLib User Perceptions Study*. Paper presented at the 2006 Ex Libris User Groups of North America Conference, Knoxville, Tennessee.
- Hsieh-Yee, I. (2006, January). *MERIC Organizations and Navigation*. Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.
- Hsieh-Yee, I. (2006, January). *Metadata and Cataloging Education: Recommended Competencies*. Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.
- Hsieh-Yee, I. (2005, November). *Digital Library Evaluation: Progress & Next Steps*. Presentation at the Annual Meeting of the American Society for Information Science & Technology, Charlotte, North Carolina.
- Hsieh-Yee, I. (2005, August). *Providing Access to Digital Content: Issues for DL Managers*. Presentation at MDK12 Digital Library Steering Committee Meeting, Columbia, Maryland.
- Hsieh-Yee, I. (2005, April). *Enhancing Teaching and Learning: The Role of School Library Media Specialists*. Presentation at Meeting of the Baltimore County Public School System School Media Specialists, Baltimore, Maryland.

- Hsieh-Yee, I. (2005, January). *Subject Access and Users: Insights & Inspirations from Marcia J. Bates*. Paper presented at the Historical Perspectives SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.
- Hsieh-Yee, I. (2005, January). *Electronic Resource Management: Practice, Employer Expectations, & CE Interests*. Paper presented at Technical Services Education SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.
- Hsieh-Yee, I. (2004, October). *Library Professionals for the Digital Age: Competencies & Preparation*. Paper presented at Bibliographic Access Management Team meeting, Library of Congress, Washington, D.C.
- Hsieh-Yee, I. (2004, January). *Cataloging and metadata expertise for the digital era*. Presented at Preparing 21st Century Cataloging and Metadata Professionals: A Workshop for Educators and Trainers, San Diego and sponsored by ALCTS, ALISE, LC, and OCLC.
- Hsieh-Yee, I. (2004, January). *Educating catalogers for the digital era*. Paper presented at the Technical Services SIG, 2004 Conference of the Association for Library and Information Science Education, San Diego.
- Hsieh-Yee, I. (2003, July). *Cataloging Education for the 21st Century*. A presentation at the Library of Congress, Washington, D.C.
- Hsieh-Yee, I. (2002, January) *Metadata Education and Research Priorities: A Delphi Study of Metadata Experts*. Presentation at the 2002 Conference of the Association for Library and Information Science Education, New Orleans.
- Hsieh-Yee, I. (2001, November). *A Delphi Study of Metadata: Preliminary Findings*. Poster session at the 2001 Annual Meeting of the American Society for Information Science & Technology, Washington, D.C.
- Hsieh-Yee, I. (2001, June). *Resources on Asian American Children: Analysis of Retrieval by Search Engines and WorldCat*. Presentation at the National Conference on Asian Pacific American Librarians, San Francisco.
- Hsieh-Yee, I. (2001, January). *Delphi Study on Metadata: Project Design*. Presentation at Research Awards Session, Association for Library & Information Science Education, Washington, D.C.
- Hsieh-Yee, I. (2000, May). *Web Search Behavior Research: Progress and Implications*. Presentation at the Symposium on Evaluating Library and Information Science Research, University of Wisconsin-Madison, Madison, Wisconsin.

- Hsieh-Yee, I. (2000, March). *ERIC User Services: Evaluation in a Decentralized Environment*. Presentation at the National ERIC Joint Directors/Technical Meeting, Arlington, Virginia.
- Hsieh-Yee, I. (2000, January). *Enhancing Learning with Web Technology*. Presentation at Faculty Conversations, Catholic University of America, Washington, D.C.
- Hsieh-Yee, I. (2000, January). *From Surrogates to Objects: CUA's Approaches to Organizing Electronic Resources*. Paper presentation at the Annual Conference of the Association for Library and Information Science Education, San Antonio, Texas.
- Yee, P., and Hsieh-Yee, I. (1997, November). *Individual Differences in Search Behavior on the WWW*. A poster session presented at the 38th Annual Meeting of the Psychonomic Society, Philadelphia, Pennsylvania.
- Hsieh-Yee, I. (1997, April). *Research + Marketing + Preparation = Job!* Presented at the "Workshop on Resume and Interview Techniques," Special Libraries Association, Student Chapter, Catholic University of America, Washington, D.C.
- Hsieh-Yee, I. (1997, February). *Creating CyberCatalogers: Education and Training*. Presentation at ALA's Midwinter Meeting, Washington, D.C.
- Hsieh-Yee, I. (1997, February). *Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study*. Presented at the Conference of the Association for Library and Information Science Education, Washington, D.C.
- Hsieh-Yee, Ingrid. "Beginning Your Special Library/Information Center Career." Presented at SLA's "Career Day," Jan. 11, 1997, Catholic University of America.
- Hsieh-Yee, I. (1996, September). *The Roles of Library and Information Scientists in Managing Electronic Information*. Presentation at Hamilton College, Clinton, New York.
- Hsieh-Yee, I. (1996, May). *The Future of Cataloging as a Profession*. Presented at "The Cataloging Forum, Library of Congress, Washington, D.C.
- Hsieh-Yee, I. (1994, October). *The Impact of the Internet on OPACs*. Presented at the Third Workshop on User Interfaces for OPACs, Library of Congress, Washington, D.C.

Reports

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

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

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

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

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

Book Reviews

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

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

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

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

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

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

Service

Professional Associations and Societies

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

- 2012 Joint Conference on Digital Libraries. Program Planning Committee, Pre-Conference Proposals Review Committee, 2012
- Catholic Research Resources Alliance. Five-Year Strategic Plan Task Force, 2011-2012
- Institute of Museum and Library Services. Grant reviewer. 2004, 2005, 2010.
- Association for Library and Information Science Education.
 - * ALISE Bodan Wynar Research Paper Award Committee, 2015, 2016, 2017
 - * ALISE Eugene Garfield Dissertation Award Competition, Jury, 2013, 2014
 - * ALISE Research Grant Competition Committee. Chair, 2012
 - * Pratt-Severn Faculty Innovation Award. Chair, 2009, 2010
 - * ALISE Doctoral Poster Jury, 2012
 - * “Information Organization Competencies for the 21st Century” Discussion session leader. 2009 Conference of the Association for Library and Information Science Education.
 - * Assisted Technical Services SIG Convener in organizing a program, “Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input” for the 2008 ALISE conference.
 - * Association for Library Collections and Technical Services/Association for Library and Information Science Education (ALCTS/ALISE) Metadata Education and Research Information Center (MERIC) Advisory Board, Co-Chair (with Sherry Vellucci), 2005-2007. Chair, 2008-2009 (leading the effort to build MERIC, a repository and collaborative space for metadata educators, practitioners, and researchers)
 - * Technical Services SIG, Convener, 2004-2005. Organized a program on “Electronic Resources Management: Current Practices, Employer Expectations, and Teaching Strategies” for the 2005 conference in Boston, Massachusetts.
 - * Technical Services SIG, Convener, 2003-2004. Organized a program on “Organizing Information with Metadata: Desired Competencies and Teaching Innovations” for the 2004 conference.
 - * Technical Services SIG, Convener, 1999-2000. Organized a program on "Teaching the Organization of Electronic Resources" for the 2000 conference.
 - * Curriculum SIG, Co-convener (with Sibyl Moses), 1996-97. Organized a program on “Government Information Policy” for the 1997 conference.
- American Society for Information Science & Technology.
 - * Reviewer, Conference program panel submissions and poster submissions, 2005, 2006, 2007, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017
 - * Nomination Committee, 2009-2011
 - * Information Science Education Special Interest Group. American Society for Information Science and Technology. Chair-Elect, 2007-2008. Chair 2008-2009.
 - * Committee on Information Science Education. 1999-2006.
 - * Committee on Information Science Education. Organizing Committee for an orientation program for students at ASIS annual meetings, 1999-2001
 - * Committee on Information Science Education. Sub-committee on Student Welfare (focusing on issues related to master's education), 1998-2001

- * SIG ED. Organizing Committee for the "Seminar on Research and Career Development" for junior researchers. 1995-96 (chair), 1997-2001
- * ISI Doctoral Dissertation Proposal Scholarship Jury, 1997; 2001, 2002
- * Pratt-Severn Best Student Research Paper Award Jury. Chair. 1997
- * 1998 Midyear Meeting (referee of contributed papers), 1997
- * Organizer and moderator of the ASIS Doctoral Forum and the Doctoral Research Seminar 1994-1995
- * SIG Human Computer Interaction. Chair-Elect, Chair, 1993-1995
- * Doctoral Forum Award Jury, 1995
- * Best Student Paper Award Jury, 1995
- American Library Association.
 - * Committee on Accreditation, External Review Panelist, 2009- (site visiting team 2013-2014; site visiting team 2016-2017)
 - * Association for Library Collections and Technical Services Task Force on Competencies and Education for a Career in Cataloging, member, 2008-2009
 - * Facilitator for "What They Don't Teach in Library School: Competencies, Education and Employer Expectations for a Career in Cataloging," an Association for Library Collections and Technical Services Preconference, June 22, 2007 in Washington, D.C. Also a local liaison for bringing this program to the Catholic University of America.
 - * Facilitator for a discussion on "Effect of Electronic Resources on Technical Services" at ALA's Midwinter Meeting held in Feb. 1997 in Washington, D.C.
 - * International Relations Committee, Subcommittee Task Force for IFLA and China, 1994-1997
- Virginia Association of School Librarians. Scholarships and Awards Committee. 2010-2012
- Federal Knowledge Management Initiative, Knowledge Management Practices Action Group. Member. 2009 (leading the effort to build a knowledge management repository)
- Federal Knowledge Management Initiative, Knowledge Management Competencies & Learning Action Group. Member. 2009 (developing an action plan for helping government knowledge workers and government agencies to develop knowledge management competencies)
- National Center for Education Statistics. Technical Review Panel. 2008.
- External evaluator for a case of promotion to full professorship. University of Tennessee. 2008.
- National Information Standards Organization (NISO). Advisory Board, Revision of "IMLS Framework of Guidance for Building Good Digital Collections," 2004, 2007.
- Library of Congress, Bibliographic Control of Web Resources: A Library of Congress Action Plan. Principal Investigator of Action Item 5.1, focusing on cataloging and metadata education for students and new librarians, 2002-2003. (worked with the Association for Library Collections and Technical Services, Education Task Force)

- Chinese American Librarians Association
 - * Chinese American Librarians Association Outstanding Library Leadership Award in Memory of Dr. Margaret Chang Fung, Award Committee, 2016-2017
 - * Achievement Award Jury, 2000-2001
 - * CALA Goal 2000 Task Force, 1997
 - * Scholarship Committee, 1995, 1996-1997 (chair)
 - * Board of Directors, 1994-1997
 - * Publication Committee, 1993-1995
 - * International Relations Committee, 1993-1996
- SailorSM Assessment Advisory Group (An impact study of Sailor, Maryland's Public Information Network), 1995
- Editorial boards
 - Journal of Library & Information Science. Editorial Board, 2012-
 - Chinese American Librarians Association, *Occasional Papers Series*. Editorial Board, 2009-2016.
 - Library Quarterly*. Editorial Board, 2003-2008
 - Bulletin of the Medical Library Association*, 1994-97
 - Newsletter editor for the Chinese American Librarians Association, 1989-92
- Referee for the following journals
 - Information Processing and Management*
 - Journal of Digital Information*
 - Journal of Education for Library and Information Science*
 - Journal of Information Science*
 - Journal of Library & Information Science*
 - Journal of Library Metadata*
 - Journal of the American Society for Information Science & Technology*
 - Library and Information Science Research*
 - Library Quarterly*
- Expert reviewer, “Digital Library” course, Evaluation module, University of North Carolina, Chapel Hill, 2007-2008.
- Expert reviewer, “Information Organization” course, University of Michigan, Ann Arbor. 2007.

Catholic University of America

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

- Academic Senate representative (for School of Library & Information Science) 2003-2012
- Academic Senate Library Committee, Interim Chair (2007), Member, 2008-2012
- Academic Senate Committee on Computing, 1995-2003
- President's Administrative Council, 2010-2012
- Deans' Council, 2010-2012
- Academic Leadership Group, 2010-2012
- Graduate Board, 2010-2012
- School of Arts & Sciences, Committee on Appointments and Promotions, 2015-2019
- School of Arts & Sciences, Academic Council, 2015-2016.
- School of Arts & Sciences, Ordinary Professor Group, 2013-
- Doctoral Dissertation Defense Committee, Chair, Dept. of Psychology, 2016, 2017, 2018, 2019, 2020, 2021, 2022
- Doctoral Dissertation Defense Committee, Chair, Dept. of Education, 2014, 2015, 2017, 2018, 2019
- Doctoral Dissertation Defense Committee, Chair, National Catholic School of Social Services, 2019, 2020, 2021
- Doctoral Dissertation Defense Committee, Chair, School of Nursing, 2006, 2008
- CUA Scholarly Communication Project Team, Member (2007), Chair, 2008-2009
- Dean Search Committee, 1992-1994, 1998-1999, 2002-2003, 2006-2007
- Fulbright Review Panel, 2006
- CUA Service Learning Advisory Board, 2001-2002
- CUA Faculty Conversations on Enhancing Teaching and Learning through Technology, Planning Group, 1999-2001
- CUA Initiative on Technology and Teaching, 1998-2001

Dept. of Library and Information Science

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

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

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

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

APPENDIX B

[Library of Congress](#) >> [MARC](#) >> [Understanding MARC](#)

MARC 21 Reference Materials

[Part VII: A Summary of Commonly Used MARC 21 Fields](#)

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[Part IX: The Leader](#)

[Part X: Field 008 for Books](#)

Part VII:

A Summary of Commonly Used MARC 21 Fields

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

In the explanations on these pages:

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

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

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

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

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

010 Library of Congress Control Number -- (LCCN)

(NR, or Not Repeatable

Indicators undefined.

Subfield used most often:

\$a -- Library of Congress control number

Example: 010 ## \$a ###86000988#

020 International Standard Book Number -- (ISBN)

(R, or Repeatable)

Indicators undefined.

Subfields used most often:

\$a -- International Standard Book Number

\$c -- Terms of availability (often a price)

\$z -- Cancelled/invalid ISBN (R)

Example: 020 ## \$a 0877547637

040 Cataloging source -- (NR)

Indicators undefined.

Subfields used most often:

\$a -- Original cataloging agency

\$c -- Transcribing agency

\$d -- Modifying agency (R)

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

100 Main entry -- Personal name -- (primary author)

(NR; there can be only one main entry)

Indicator 1: Type of personal name entry element

0 -- Forename

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

3 -- Family name

Indicator 2 undefined.

Indicator 2 became obsolete in 1990. Older records may display 0 or 1

Subfields used most often:

\$a -- Personal name

\$b -- Numeration

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

\$q -- Fuller form of name

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

Example: 100 1# \$a Gregory, Ruth W.

<p>\$q (Ruth Wilhelme), \$d 1910-</p>

130 Main entry -- Uniform title -- (NR)*Indicator 1:* Nonfiling characters

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

Indicator 2 undefined.

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

Subfields used most often:

\$a -- Uniform title

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

\$l -- Language of a work

\$s -- Version

\$f -- Date of a work

<p><i>Example:</i> 130 0# \$a Bible. \$p O.T. \$p Psalms.</p>

240 Uniform title (NR)*Indicator 1:* Uniform title printed or displayed

0 -- Not printed or displayed

1 -- Printed or displayed (most common)

Indicator 2: Nonfiling characters

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

Subfields used most often:

\$a -- Uniform title

\$l -- Language of a work

\$f -- Date of a work

<p><i>Example:</i> 240 10 \$a Ile mystérieuse. \$l English. \$f 1978</p>
--

245 Title Statement (NR)*Indicator 1:* Title added entry

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

0 -- No title added entry

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

1 -- Title added entry

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

Indicator 2: Nonfiling characters

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

Subfields used most often:

\$a -- Title proper
\$h -- Medium (often used for non-book media)
\$p -- Name of part/section of a work (R)
\$b -- Reminder of title (subtitles, etc.)
\$c -- Remainder of title page transcription/Statement of responsibility

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

246 Varying form of title (R)

Indicator 1: Note/title added entry controller

1 -- Note, title added entry
 3 -- No note, title added entry

Indicator 2: Type of title

-- No information provided
 0 -- Portion of title
 1 -- Parallel title
 4 -- Cover title
 8 -- Spine title

Subfield used most often:

\$a -- Title proper

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

250 Edition statement (NR)

Indicators undefined.

Subfield used most often:

\$a -- Edition statement

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

260 Publication, distribution, etc. (Imprint) (R)

Indicator 1: Sequence of publishing statements

-- No information provided

Indicator 2: Undefined

Subfields used most often:

\$a -- Place of publication, distribution, etc. (R)

\$b -- Name of publisher, distributor, etc. (R)

\$c -- Date of publication, distribution, etc. (R)

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

300 Physical description (R)

Indicators undefined.

Subfields used most often:

\$a -- Extent (number of pages) (R)

\$b -- Other physical details (usually illustration information)

\$c -- Dimensions (cm.) (R)

\$e -- Accompanying material (for example, "teacher's guide" or "manual")

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

440 Series statement / Added entry--Title

This field was made obsolete in 2008 to simplify the series statement. See 490 and 830.

490 Series statement (No added entry is traced from field) (R)

Indicator 1: Specifies whether series is traced (whether an 8XX tag is also present)

0 -- Series not traced

1 -- Series traced (8XX is in record)

Indicator 2 undefined.

Subfield used most often:

\$a -- Series statement (R)

\$v -- Volume number (R)

Example: 490 1# \$a Colonial American craftsmen

500 General note (R)

Indicators undefined.

Subfield used most often:

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

Example: 500 ## \$a Includes index.

504 Bibliography, etc. note (R)

Indicators undefined.

Subfield used most often:

\$a -- Bibliography, etc. note

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

505 Formatted contents note (R)

Indicator 1: Type of contents note

0 -- Complete contents

1 -- Incomplete contents (used with multivolume set when some volumes are
not yet published)

2 -- Partial contents

Indicator 2: Level of content designation

-- Basic

Subfield used most often:

\$a -- Formatted contents note

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

520 Summary, etc. note (R)

Indicator 1: Display constant controller

-- Summary

1 -- Review

2 -- Scope and content

3 -- Abstract

Indicator 2 undefined

Subfields used most often

\$a -- Summary, abstract, or annotation

\$b -- Expansion of summary note

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

600 Subject added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

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

3 -- Family name

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

0 -- Library of Congress Subject Headings

1 -- LC subject headings for children's literature

2 -- Medical Subject Headings

3 -- National Agricultural Library subject authority file

4 -- Source not specified

5 -- Canadian Subject Headings

6 -- Répertoire de vedettes-matière

7 -- Source specified in subfield \$2

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

Subfields used most often:

\$a -- Personal name (surname and forename)

\$b -- Numeration

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

\$q -- Fuller form of name

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

\$t -- Title of a work

\$v -- Form subdivision (R)

\$x -- General subdivision (R)

\$y -- Chronological subdivision (R)

\$z -- Geographic subdivision (R)

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

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

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

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

610 Subject added entry -- Corporate name (R)

Indicator 1: Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

Indicator 2: Subject heading system/thesaurus.

See indicator 2 under 600

Subfields used most often:

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

\$b -- Subordinate unit (R)

\$v -- Form subdivision (R)

\$x -- General subdivision (R)

\$y -- Chronological subdivision (R)

\$z -- Geographic subdivision (R)

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

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

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

Indicator 1: Level of subject

-- No information provided

Indicator 2: Subject heading system/thesaurus

(identifies the specific list or file which was used)

0 -- Library of Congress Subject Headings

1 -- LC subject headings for children's literature

2 -- Medical Subject Headings

3 -- National Agricultural Library subject authority file

4 -- Source not specified

5 -- Canadian Subject Headings

6 -- Répertoire de vedettes-matière

7 -- Source specified in subfield \$2

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

Subfields used most often:

\$a -- Topical term

\$v -- Form subdivision (R)

\$x -- General subdivision (R)

\$y -- Chronological subdivision (R)

\$z -- Geographic subdivision (R)

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

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

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

651 Subject added entry -- Geographic name (R)

Indicator 1: undefined.

Indicator 2: Subject heading system/thesaurus.

See indicator 2 under 600

Subfields used most often:

\$a -- Geographic name

\$v -- Form subdivision (R)

\$x -- General subdivision (R)

\$y -- Chronological subdivision (R)

\$z -- Geographic subdivision (R)

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

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

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

700 Added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

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

3 -- Family name

Indicator 2: Type of added entry

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

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

Subfields used most often:

\$a -- Personal name

\$b -- Numeration

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

\$q -- Fuller form of name

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

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

\$4 -- Relator code (R)

Example: 700 1# \$a Baldrige, Letitia.

710 Added entry -- Corporate name (R)

Indicator 1: Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

Indicator 2: Type of added entry.

See Indicator 2 under 700

-- No information provided

2 -- Analytical entry

Subfields used most often:

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

\$b -- Subordinate unit (R)

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

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

Indicator 1: Nonfiling characters

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

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

-- No information provided

2 -- Analytical entry

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

Subfield used most often:

\$a -- Title

Example: 740 02 \$a Uncle Vanya.

800 Series added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

1 -- Surname

3 -- Family name

Indicator 2 undefined.

Subfields used most often:

\$a -- Personal name

\$b -- Numeration

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

\$q -- Fuller form of name

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

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

\$v -- Volume number

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

830 Series added entry -- Uniform title (R)

Indicator 1 undefined.

Indicator 2: Nonfiling characters

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

Subfield used most often:

\$a -- Uniform title

\$v -- Volume number

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

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Part VIII:

A List of Other Fields Often Seen in MARC Records

- 001 Control number
- 003 Control number identifier
- 005 Date and time of latest transaction
- 006 Fixed-length data elements -- additional material characteristics
- 007 Physical description fixed field
- 008 Fixed length data elements (See [Part X](#))
- 022 International Standard Serial Number (ISSN)
- 037 Source of acquisition
- 041 Language code
- 043 Geographic area code
- 050 Library of Congress call number
- 060 National Library of Medicine call number
- 082 Dewey Decimal classification number (the one recommended
by the Library of Congress; locally-assigned call numbers may
appear elsewhere)
- 110 Main entry -- Corporate name (less frequent under AACR2
rules)
- 256 Computer file characteristics
- 263 Projected publication date
(indicates a CIP -- Cataloging in Publication -- record)

- 306 Playing time
- 508 Creation/production credits note
- 510 Citation/references note (review sources)
- 511 Participant or performer note
- 521 Target audience note (first indicator: 0 = reading grade level, 1 = interest age level, 2 = interest grade level, 3 = special audience characteristics, 4 = motivation interest level)
- 530 Additional physical form available note
- 538 System details note
- 586 Awards note
- 656 Index term -- Occupation
- 730 Added entry -- Uniform title
- 852 Location
- 856 Electronic location and access
- 9XX Reserved for local use. (They are used by vendors, systems, or individual libraries to exchange additional data)

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Part IX:

The Leader

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

- 00-04 Record length (calculated by the computer for each record)
- 05 Record status
 - a = increase in encoding level
 - c = corrected or revised
 - d = deleted
 - n = new
 - p = increase in encoding from prepublication (previous CIP)
- 06 Type of record
 - a = language material
 - c = printed music
 - d = manuscript music
 - e = cartographic material
 - f = manuscript cartographic material
 - g = projected medium
 - i = nonmusical sound recording
 - j = musical sound recording
 - k = 2-dimensional nonprojectable graphic
 - m = computer file
 - o = kit
 - p = mixed materials
 - r = 3-dimensional artifact or naturally occurring object
 - t = manuscript language material
- 07 Bibliographic level
 - a = monographic component part
 - b = serial component part

- c = collection
- d = subunit
- i = integrating resource
- m = monograph/item
- s = serial
- 08 **Type of control**
 - # = no specified type
 - a = archival
- 09 **Character coding scheme**
 - # = MARC-8
 - a = UCS/Unicode
- 10 **Indicator count** (always "2")
- 11 **Subfield code count** (always "2")
- 12-16 **Base address of data** (calculated by the computer for each record)
- 17 **Encoding level**
 - # = full level
 - 1 = full level, material not examined
 - 2 = less-than-full level, material not examined
 - 3 = abbreviated level
 - 4 = core level
 - 5 = partial (preliminary) level
 - 7 = minimal level
 - 8 = prepublication level (CIP)
 - u = unknown
 - z = not applicable
- 18 **Descriptive cataloging form**
 - # = non-ISBD
 - a = AACR2
 - i = ISBD
 - u = unknown
- 19 **Multipart resource record level**
 - # = Not specified or not applicable
 - a = Set
 - b = Part with independent title
 - c = Part with dependent title
- 20 **Length of the length-of-field portion** (always "4")
- 21 **Length of the starting-character-position portion** (always "5")
- 22 **Length of the implementation-defined portion** (always "0")
- 23 **Undefined** (always "0")

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Part X:

Field 008 for Books

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

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

Note that field 008 has no indicators or subfield codes.

- 00-05 Date entered on file (YYMMDD),
 where Y=year, M=month, and D=day
- 06 Type of date/publication status:
 b = no dates given; B.C. date involved
 e = detailed date
 s = single known date/probable date
 m = multiple dates
 r = reprint/reissue date (Date 1) and original date (Date 2)
 n = dates unknown
 q = questionable date
 t = publication date and copyright date
 | = no attempt to code
- 07-10 Date 1/beginning date of publication
- 11-14 Date 2/ending date of publication

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

- 15-17 Place of publication, production, or execution
 For example:
 pk# = Pakistan
 cau = California (US)

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

- 18-21 Illustrations (up to 4 codes):
 # = no illustrations
 a = illustrations
 b = maps
 c = portraits
 d = charts
 e = plans
 f = plates
 g = music
 h = facsimiles
 i = coats of arms
 j = genealogical tables
 k = forms
 l = samples
 m = phonodisc, phonowire, etc.
 o = photographs
 p = illuminations
 | = no attempt to code
- 22 Target audience:
 # = unknown or not specified
 a = preschool

- b = primary
 - c = pre-adolescent
 - d = adolescent
 - e = adult
 - f = specialized
 - g = general
 - j = juvenile
 - | = no attempt to code
- 23 **Form of item:**
- # = none of the following
 - a = microfilm
 - b = microfiche
 - c = microopaque
 - d = large print
 - f = braille
 - r = regular print reproduction
 - s = electronic
 - | = no attempt to code
- 24-27 **Nature of contents (up to 4):**
- # = no specified nature of contents
 - a = abstracts/summaries
 - b = bibliographies (is one or contains one)
 - c = catalogs
 - d = dictionaries
 - e = encyclopedias
 - f = handbooks
 - g = legal articles
 - i = indexes
 - j = patent document
 - k = discographies
 - l = legislation
 - m = theses
 - n = surveys of literature
 - o = reviews
 - p = programmed texts
 - q = filmographies
 - r = directories
 - s = statistics
 - t = technical reports
 - u = standards/specifications
 - v = legal cases and notes
 - w = law reports and digests
 - z = treaties
 - | = no attempt to code
- 28 **Government publication:**
- # = not a government publication
 - i = international intergovernmental
 - f = federal/national
 - a = autonomous or semi-autonomous component
 - s = state, provincial, territorial, dependent, etc.
 - m = multistate
 - c = multilocal

- 1 = local
- z = other type of government publication
- o = government publication -- level undetermined
- u = unknown if item is government publication
- | = no attempt to code
- 29 **Conference publication:**
 - 0 = not a conference publication
 - 1 = conference publication
 - | = no attempt to code
- 30 **Festschrift:**
 - 0 = not a festschrift
 - 1 = festschrift
 - | = no attempt to code
- 31 **Index:**
 - 0 = no index
 - 1 = index present
 - | = no attempt to code
- 32 **Undefined (since 1990)** (Earlier records may contain the values 0 or 1)
 - # = Undefined
 - | = no attempt to code
- 33 **Literary form:**
 - 0 = not fiction (not further specified)
 - 1 = fiction (not further specified)
 - c = comic strips
 - d = dramas
 - e = essays
 - f = novels
 - h = humor, satires, etc.
 - i = letters
 - j = short stories
 - m = mixed forms
 - p = poetry
 - s = speeches
 - u = unknown
 - | = no attempt to code
- 34 **Biography:**
 - # = no biographical material
 - a = autobiography
 - b = individual biography
 - c = collective biography
 - d = contains biographical information
 - | = no attempt to code
- 35-37 **Language:**

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

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

- 38 **Modified record:**
 - # = not modified
 - x = missing characters (because of characters unavailable in MARC character set)
 - s = shortened
 - d = "dashed-on" information omitted

- r = completely romanized/printed cards in script
- o = completely romanized/printed cards romanized
- | = no attempt to code

39 **Cataloging source:**

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

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APPENDIX 1008A

Robust Generalized Total Least Squares Iterative Closest Point Registration

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Abstract. This paper investigates the use of a total least squares approach in a generalization of the iterative closest point (ICP) algorithm for shape registration. A new Generalized Total Least Squares (GTLS) formulation of the minimization process is presented opposed to the traditional Least Squares (LS) technique. Accounting for uncertainty both in the target and in the source models will lead to a more robust estimation of the transformation. Robustness against outliers is guaranteed by an iterative scheme to update the noise covariances. Experimental results show that this generalization is superior to the least squares counterpart.

1 Introduction

The iterative closest point (ICP) algorithm [1] has been extensively used as optimization technique for rigid model based registration based on features extracted from medical datasets. ICP is an iterative descent procedure which seeks to minimize the sum of the squared distances between all points in a source and their closest points in a target model. As stated by Besl and McKay [2], ICP cannot deal with outliers and unequal uncertainty among points.

When there is a known correspondence between the points in the source and the target, the rigid transformation between those sets can be solved in a least squares sense with a closed form solution [2]. From a statistical point of view, least squares methods assume that the points are observed with isotropic, identical and independent Gaussian noise. A more general approach would be to assume that both the source and the target have noise that can be neither isotropic nor identical. This kind of model leads to a Generalized Total Least Squares (GTLS) problem. Kanatani et al. [3] have introduced a total least squares solution to the problem of rotations of correspondent points.

This paper introduces a novel total least squares generalization of ICP. This generalization will allow us to consider anisotropic noise both in the target shape and the source shape. Moreover, an iterative technique is presented that allows us to estimate the optimal set of covariance matrices so the effect of outlier points is minimized. An evaluation study is carried out to show the superiority of the proposed method compared to the standard ICP.

1.1 Iterative Closest Points

Let $\mathcal{P}$ be the data shape (source shape) and $\mathcal{X}$ the model shape (target shape) to be registered with. The data shape is decomposed in point set form, if not already available in that form. The model shape could originally be given in any representation but for our purpose we will assume that is also decomposed in a point set. Thus, let N_P, N_X be the number of points in the shapes. P and X are respectively defined by the N_P -tuple $\mathcal{P} = \{\mathbf{p}_1, \mathbf{p}_2, \dots, \mathbf{p}_{N_P}\}$ and the N_X -tuple $\mathcal{X} = \{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_{N_X}\}$. There is not a preestablished correspondence between the points $\mathbf{p}_j$ and $\mathbf{x}_j$.

ICP finds the rigid body transformation^[1], rotation $\mathbf{R}$ and translation $\mathbf{t}$ that aligns the source with the target by minimizing the distance metric

$$J(\mathbf{R}, \mathbf{t}) = \sum_{i=1}^{N_P} \|\mathbf{y}_i - \mathbf{R}\mathbf{p}_i - \mathbf{t}\|^2, \quad \text{where } \mathbf{y}_i = \mathcal{C}(\mathbf{R}\mathbf{p}_i + \mathbf{t}, \mathcal{X}) \quad (1)$$

is a point on the surface of the target model $\mathcal{X}$ that corresponds to the point $\mathbf{p}_i$. Given that *a priori* correspondence between source points and target points does not exist, an iterative search is needed in order to solve the problem. At each iteration, a correspondence is established by means of the *correspondence operator* $\mathcal{C}$. Then, the transformation that minimizes a mean square metric is computed. The data points are transformed using the computed transformation and the process is repeated until a minimum error threshold is achieved or a maximum number of iterations is reached. The correspondence operator is typically the *closest point* operator: $\mathcal{C}_{cp}(\mathbf{a}, \mathcal{X}) = \arg \min_{\mathbf{x} \in \mathcal{X}} \|\mathbf{x} - \mathbf{a}\|$.

One of the main drawbacks of ICP is that unequal uncertainty among points is not considered in the process. Several authors have tried to *partially* take into account unequal uncertainty by using a weighted least squares minimization [4, 5, 6]. This approach, although effective and intuitively correct, is not optimal due to isotropic assumptions.

2 Method

Real problems present data with noise both in the source and in the target. Moreover, the noise is typically anisotropic, i.e. certain directions are prone to being more inaccurate than others. These facts lead us to introduce a generalized total least squares approach to the aforementioned registration problem.

2.1 GTLS Registration of Corresponding 3-D Point Sets

Let us assume that the target points and the source points are corrupted with additive noise: $\mathbf{x}_i = \bar{\mathbf{x}}_i + \Delta\mathbf{x}_i$ and $\mathbf{p}_i = \bar{\mathbf{p}}_i + \Delta\mathbf{p}_i$, where $\Delta\mathbf{x}_i$ and $\Delta\mathbf{p}_i$ are independent random variables with zero mean and known covariance matrices

¹ The method can also handle affine transformations by looking for the solution in a linear affine subspace

$V[\mathbf{x}_i] = E[\Delta\mathbf{x}_i\Delta\mathbf{x}_i^T]$ and $V[\mathbf{p}_i] = E[\Delta\mathbf{p}_i\Delta\mathbf{p}_i^T]$. The relation between the free noise data is given by the rigid transformation model

$$\bar{\mathbf{x}}_i = \mathbf{R}\bar{\mathbf{p}}_i + \mathbf{t}, \quad i = 1, \dots, N_P. \quad (2)$$

Our problem is to find an estimator of the rotation matrix, $\hat{\mathbf{R}}$, and the translation term, $\hat{\mathbf{t}}$ from the noisy data $\{\mathbf{x}_i\}$ and $\{\mathbf{p}_i\}$.

The Gauss-Markov theorem states that the linear minimum variance unbiased estimator when the noise is correlated is given by the minimization of the *Mahalanobis* distance

$$J(\mathbf{R}, \mathbf{t}) = \sum_{i=1}^{N_P} (\mathbf{p}_i - \bar{\mathbf{p}}_i)^T V[\mathbf{p}_i]^{-1} (\mathbf{p}_i - \bar{\mathbf{p}}_i) + \sum_{i=1}^N (\mathbf{x}_i - \bar{\mathbf{x}}_i)^T V[\mathbf{x}_i]^{-1} (\mathbf{x}_i - \bar{\mathbf{x}}_i), \quad (3)$$

subject to the model constraint (2). This problem can be seen as a Generalized Total Least Squares problem [7] from the matrix algebra point of view. The main difficulty of this problem is that we are looking for the solution in the group of rotations $SO(3)$. To find a feasible implementation, we have decoupled the problem over the minimization variable. Thus, we will independently minimize the rotation variable and the translation variable. An iterative approach will seek the optimal solution in both spaces.

Rotation term. Let us restrict our data model to be

$$\bar{\mathbf{x}}_i = \mathbf{R}\bar{\mathbf{p}}_i, \quad i = 1, \dots, N_P. \quad (4)$$

The minimization of the functional J in eq. (3) subject to (4) has been previously addressed by Ohta and Kanatani [3]. The authors show that the values of $\hat{\mathbf{x}}_i$ and $\hat{\mathbf{p}}_i$ that minimize (3) can be solved analytically using Lagrange multipliers and considering $\mathbf{R}$ fixed. From this solution, the resulting minimum is minimized with respect to $\mathbf{R}$. The problem reduces to

$$J_R(\mathbf{R}) = \sum_{i=1}^{N_P} (\mathbf{x}_i - \mathbf{R}\mathbf{p}_i)^T \mathbf{W}_i^{\mathbf{R}} (\mathbf{x}_i - \mathbf{R}\mathbf{p}_i) \quad \hat{\mathbf{R}} = \arg \min_{\mathbf{R} \in SO(3)} J_R, \quad (5)$$

where $\mathbf{W}_i^{\mathbf{R}} = (\mathbf{R}V[\mathbf{p}_i]\mathbf{R}^T + V[\mathbf{x}_i])^{-1}$. The same authors proposed an optimization scheme based on quaternions using the renormalization technique of Kanatani [8]. The implementation of this optimization method has been proven to be robust and stable.

Translation term. In this case, the data model is merely

$$\bar{\mathbf{x}}_i = \bar{\mathbf{p}}_i + \mathbf{t}, \quad i = 1, \dots, N_P. \quad (6)$$

Following the same approach as in [3], we have solved the values of $\hat{\mathbf{x}}_i$ and $\hat{\mathbf{p}}_i$ that minimize (3) considering $\mathbf{t}$ fixed. Again, minimizing that result with respect

to $\mathbf{t}$, we can write

$$J_t(\mathbf{t}) = \sum_{i=1}^{N_P} (\mathbf{x}_i - \mathbf{p}_i - \mathbf{t})^T \mathbf{W}_i^t (\mathbf{x}_i - \mathbf{p}_i - \mathbf{t}), \quad \hat{\mathbf{t}} = \arg \min_{\mathbf{t} \in \mathbb{R}^3} J_t \quad (7)$$

where $\mathbf{W}_i^t = (V[\mathbf{p}_i] + V[\mathbf{x}_i])^{-1}$. $\hat{\mathbf{t}}$ can be analytically obtained by equating the gradient to zero and solving for $\mathbf{t}$. The solution is given by

$$\hat{\mathbf{t}} = \left(\sum_{i=1}^{N_P} \mathbf{W}_i^t \right)^{-1} \sum_{i=1}^{N_P} \mathbf{W}_i^t (\mathbf{x}_i - \mathbf{p}_i). \quad (8)$$

Note that setting the covariance matrices to the identity, the solutions $\hat{\mathbf{R}}$ and $\hat{\mathbf{t}}$ reduce to the least squares ones.

Robustness. A total least squares approach has the flexibility of encoding the uncertainty information of the observed data points in the covariance matrices. In point correspondence problems we can identify two sources of noise: extrinsic noise due to sensor errors and intrinsic noise due to incorrect matches. The extrinsic noise is problem dependent and we try to model it by means of the covariance matrices. The intrinsic noise has paramount importance as recognized by Haralick et al. [9]. Outliers make ordinary LS estimators the estimator of least virtue. We have enforced the robustness of the correspondence problem by an iterative algorithm that looks for the optimal set of covariance matrices. At the same time, the iterative approach will allow us to look for the solution in both parameter spaces, rotation and translation.

Our aim is to make the outlier points having a noise covariance higher than initially expected by adding an isotropic part. The covariance matrix can be written as the sum of two terms

$$V[\mathbf{x}_i] = V_{ex}[\mathbf{x}_i] + \sigma_{x_i}^2 \mathbf{I}_3 \quad V[\mathbf{p}_i] = V_{ex}[\mathbf{p}_i] + \sigma_{p_i}^2 \mathbf{I}_3. \quad (9)$$

An iterative scheme will look for the optimal set of $\sigma_{x_i}^2$ and $\sigma_{p_i}^2$ such that the outliers are identified.

The robust corresponding points algorithm can be summarized as follows:

1. Set initial variable: $\hat{\mathbf{t}} = [0, 0, 0]^T$, $V[\mathbf{x}_i] = V_{ex}[\mathbf{x}_i] + \mathbf{I}$, $V[\mathbf{p}_i] = V_{ex}[\mathbf{p}_i] + \mathbf{I}$.
2. Estimate $\hat{\mathbf{R}}$ as described in [3] using $\{\mathbf{x}'_i = \mathbf{x}_i - \hat{\mathbf{t}}\}$ and $\{\mathbf{p}_i\}$.
3. Rotate source points with estimated $\hat{\mathbf{R}}$: $\{\mathbf{p}'_i = \hat{\mathbf{R}}\mathbf{p}_i\}$.
4. Estimate $\hat{\mathbf{t}}$ using eq. (8) with points $\{\mathbf{x}_i\}$ and $\{\mathbf{p}'_i\}$.
5. Update covariance matrix before next iteration
 - a) $\{\mathbf{p}'_i = \hat{\mathbf{R}}\mathbf{p}_i + \hat{\mathbf{t}}\}$.
 - b) Transform source covariance matrix: $V_{ex}[\mathbf{p}_i] = \hat{\mathbf{R}}V_{ex}[\mathbf{p}_i]\hat{\mathbf{R}}^T$.
 - c) $\sigma_{x_i}^2 = \begin{cases} \|\mathbf{p}'_i - \mathbf{x}_i\|^2/2 & \text{if } \text{Tr}[V_{ex}[\mathbf{x}_i]] < 3\|\mathbf{p}'_i - \mathbf{x}_i\|^2/2, \\ 0 & \text{otherwise,} \end{cases}$
 - $\sigma_{p_i}^2 = \begin{cases} \|\mathbf{p}'_i - \mathbf{x}_i\|^2/2 & \text{if } \text{Tr}[V_{ex}[\mathbf{p}_i]] < 3\|\mathbf{p}'_i - \mathbf{x}_i\|^2/2, \\ 0 & \text{otherwise.} \end{cases}$
6. Check for convergence, if not go to step 2.

2.2 Generalized Total Least Squares ICP: GTLS-ICP

The iterative closest points problem defined in section 1.1 can be solved using the minimization method presented in the previous section. In this case, the correspondence between the data points, $\{\mathbf{p}_i\}$, and the model points, $\{\mathbf{x}_i\}$, is not known. For each point, we know the covariance matrix of the noise, $V_{ex}[\mathbf{p}_i]$ and $V_{ex}[\mathbf{x}_i]$ respectively. The functional (10) can be rewritten as

$$J(\mathbf{R}, \mathbf{t}) = \sum_{i=1}^{N_P} (\mathbf{p}_i - \bar{\mathbf{p}}_i)^T V[\mathbf{p}_i]^{-1} (\mathbf{p}_i - \bar{\mathbf{p}}_i) + \sum_{i=1}^{N_X} (\mathbf{y}_i - \bar{\mathbf{y}}_i)^T V[\mathbf{y}_i]^{-1} (\mathbf{y}_i - \bar{\mathbf{y}}_i). \quad (10)$$

where $\mathbf{y}_i$ is the result of the closest point operator. An iterative closest point approach will start by assuming a matching between data and model points. From this matching, the transformation that minimizes the function (10) will be solved by using the previous algorithm. In the initial iterations, it is dangerous to minimize J using the initial covariances, V_{ex} , since the dominant noise will be due to the uncertainty of the matching. Sharp et al. [10] have shown that the noise due to the closest point correspondence operator can be modeled as an isotropic Gaussian noise with variance equal to the distance between the data point and the closest point in the model. This noise model can be introduced to update the covariance matrices globally for each iteration. Thus, the algorithm will initially look for the solution in the least squares sense and the closer the data points and model points get, the more the algorithm will rely on the provided noise covariances, V_{ex} .

The *GTLS-ICP* algorithm can be summarized as follows:

1. Set the initial transformation: $\hat{\mathbf{R}} = \mathbf{I}_3$, $\hat{\mathbf{t}} = [0, 0, 0]^T$.
2. Transform data points: $\{\mathbf{p}'_i = \hat{\mathbf{R}}\mathbf{p}_i + \hat{\mathbf{t}}\}$.
3. Find closest points: $\{\mathbf{y}_i = \mathcal{C}_{cp}(\mathbf{p}'_i, \mathcal{X})\}$.
4. Noise level estimation due to $\mathcal{C}_{cp}$: $\sigma^2 = \frac{1}{N_P} \sum_{i=1}^{N_P} \|\mathbf{y}_i - \mathbf{p}'_i\|^2$.
5. Update model covariance matrices: $V[\mathbf{y}_i] = V_{ex}[\mathbf{y}_i] + \sigma^2 \mathbf{I}_3$.
6. Solve corresponding points registration between $\{\mathbf{y}_i\}$ and $\{\mathbf{p}_i\} \rightarrow \hat{\mathbf{R}}$ and $\hat{\mathbf{t}}$.
7. Check for convergence, if not go to step 2.

3 Experiments

3.1 Methodology

The reliability of our algorithm has been tested by random noise simulations. A hip model has been used as the model shape. Points have been randomly sampled from that mesh and transformed with a known rotation matrix $\mathbf{R}$, and translation vector $\mathbf{t}$ (see Fig. 1).

Noise has been independently added to the mesh and the transformed points. The noise between points is independent but not identically distributed with a known covariance matrix. Noise has been generated according to two distributions: Normal and Tukey's *slash* distribution. The slash distribution can be

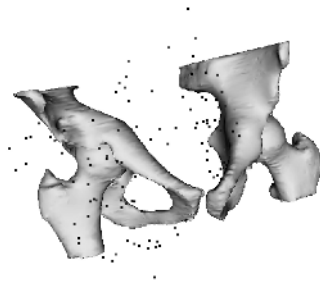


Fig. 1. Hip and random sampled points after transformation used for the evaluation of the algorithm.

Table 1. Eigenvalues of noise covariance matrices for each class. The degree of anisotropy decreases with the the number of the class

Cov. class	λ_1	λ_2	λ_3	Cov. class	λ_1	λ_2	λ_3	Cov. class	λ_1	λ_2	λ_3
1	1.00	0.00	0.00	6	0.67	0.17	0.17	11	0.44	0.33	0.22
2	0.80	0.20	0.00	7	0.57	0.29	0.14	12	0.40	0.40	0.20
3	0.67	0.33	0.00	8	0.50	0.38	0.12	13	0.40	0.30	0.30
4	0.57	0.43	0.00	9	0.44	0.44	0.11	14	0.36	0.36	0.27
5	0.50	0.50	0.00	10	0.50	0.25	0.25	15	0.33	0.33	0.33

obtained as a Gaussian random variable with zero mean and a given covariance divided by a uniform random variable over the interval $[0, 1]$. The slash distribution has been used to model outliers due to its broad tails. 15 different classes of noise have been simulated depending on the covariance. Table 1 shows the eigenvalues of the different noise covariance matrices. The first five classes correspond to the case of noise confined onto a plane.

A distance metric on rotation matrices can be defined as the minimal angle of rotation needed, around some axis, to transform one rotation into another. This can be calculated using quaternions of the relative rotation error $\mathbf{R}_e = \hat{\mathbf{R}}\mathbf{R}^T$. The quaternion representation of $\mathbf{R}_e$ is $\mathbf{q}_e = [q_0, q_1, q_2, q_3]^T$. The error vector is defined as $\Delta\Omega = \Delta\Omega\mathbf{l}_r$, where $\Delta\Omega = \arccos(2q_0)$ is the angle of the rotation error $\mathbf{R}_e$ and $\mathbf{l}_r = [q_1, q_2, q_3]^T / \sin(\frac{\Delta\Omega}{2})$ is the axis of rotation. The variance of the error is given by $V[\Delta\Omega] = E\{\Delta\Omega\Delta\Omega^T\}$.

The two statistics that we have used to assess the rotation error have been the mean rotation error E_Ω and the standard deviation S_Ω defined as

$$E_\Omega = \|E\{\Delta\Omega\}\|, \quad S_\Omega = \sqrt{\text{Tr}[V[\Delta\Omega]]}. \tag{11}$$

Regarding the translation, we have used the mean translation error E_t and the standard deviation S_t defined as

$$E_t = \|E\{\mathbf{t} - \hat{\mathbf{t}}\}\|, \quad S_t = \sqrt{\text{Tr}[E\{(\mathbf{t} - \hat{\mathbf{t}})(\mathbf{t} - \hat{\mathbf{t}})^T\}]}. \tag{12}$$

To estimate the error statistics, 100 independent realizations have been carried out for each anisotropic noise class and variance. We have compared our method

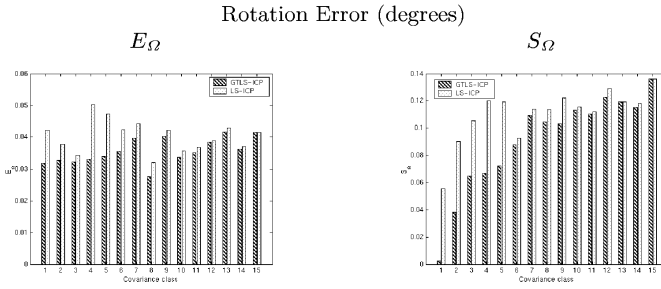


Fig. 2. Evaluation of the rotation error and translation error for different covariance matrices and Gaussian noise. Dark bar: GTLS-ICP. Light bar: LS-ICP

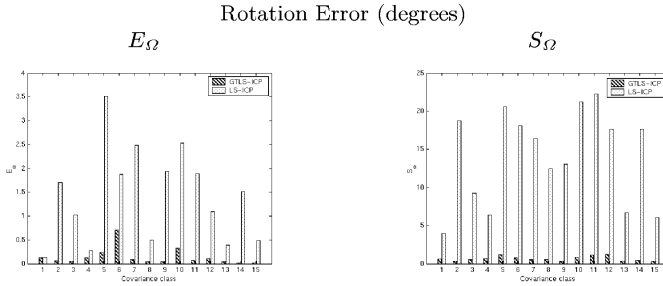


Fig. 3. Evaluation of the rotation error and translation error for different covariance matrices and slash noise. Dark bar: GTLS-ICP. Light bar: LS-ICP.

(GTLS-ICP) with the standard least squares ICP (LS-ICP) using Horn method [2] to minimize the functional at each iteration.

3.2 Results

The GTLS-ICP algorithm has been tested by randomly sampling 150 points from the mesh. A rotation of 30° around the axis $[1, 1, 1]^T$ and a translation $[1, 1, 1]^T$ have been applied. Noise has been added to the mesh and to the sampled points after the transformation.

Figure 2 shows the rotation error statistics for Gaussian noise. From these results we can see that, as long as rotations are involved, the mean error is similar for both methods; however the standard deviation of our solution is significantly smaller for anisotropic noise classes. The more isotropic the noise becomes, our solution tends to the standard least squares as expected. The translation error follows a similar tendency, our method shows a lower S_t when the noise distributes in an anisotropic way.

Figure 3 shows the error statistics for slash noise. Slash noise has been only added to the sampled points, while the mesh has been corrupted with Gaussian noise. The results clearly shows the stability and robustness of our method. It is fair to say that a preprocessing for outliers rejection may improve the results for

LS-ICP. However, our method seamlessly incorporates the rejection of outliers by setting up the covariance matrices adequately.

4 Conclusions

A generalization of the iterative closest points algorithm has been presented using a generalized total least squares framework. The main contributions of this work are: 1) noise is modeled both in the target shape and the source shape (total least squares), 2) anisotropic noise can be taken into account in the estimation of the transformation (generalized total least squares) and 3) outlier rejection is intrinsically handled by iterative estimation of the optimal isotropic noise variance of the covariance matrices. We believe that registration techniques that use ICP, or some of its variants, as optimization process will directly benefit of the generalized approach introduced in this paper, yielding a more robust estimation.

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References

1. Paul J. Besl and Neil D. McKay. A method for registration of 3-D shapes. *IEEE Transaction on Pattern Analysis and Machine Intelligence*, 14(2):239–256, 1992.
2. B. K. P. Horn. Closed-form solution of absolute orientation using unit quaternions. *Journal of the Optical Society of America*, 4(4):629–642, 1987.
3. N. Ohta and K. Kanatani. Optimal estimation of three-dimensional rotation and reliability evaluation. *IEEE Transactions on Information and Systems*, E81-D(11):1247–1252, 1998.
4. Zhengyou Y. Zhang. Iterative point matching for registration of free-form curves and surfaces. *International Journal of Computer Vision*, 13(2):119–152, Oct 1994.
5. Calvin R. Maurer, Georges B. Aboutanos, Benoit M. Dawant, Robert J. Maciunas, and J. Michael Fitzpatrick. Registration of 3-D images using weighted geometrical features. *IEEE Transaction on Medical Imaging*, 15(6):836 – 849, Dec 1996.
6. Chitra Dorai, John Weng, and Anil K. Jain. Optimal registration of objects view using range data. *IEEE Transaction on Pattern Analysis and Machine Intelligence*, 19(10):1131 – 1138, Dec 1997.
7. S. van Huffel and J. Vandewalle. Analysis and properties of the generalized total least squares problem $AX \approx B$, when some or all columns are subject to error. *SIAM Journal on Matrix Analysis and Applications*, 10(3):294 – 315, 1989.
8. K. Kanatani. *Statistical Optimization for Geometric Computation: Theory and Practice*. Elsevier, 1996.
9. Robert M. Haralick, Hyonam Joo, Chung-Nan Lee, Xinhua Zhuang, Vinay G. Vaidya, and Man Bae Kim. Pose estimation from corresponding point data. *IEEE Transactions on Systems, Man, and Cybernetics*, 19(6):1426 – 1446, Nov 1989.
10. Gregory C. Sharp, Sang W. Lee, and David K. Wehe. ICP registration using invariant features. *IEEE Transaction on Pattern Analysis and Machine Intelligence*, 24(1):90–102, Jan 2002.

APPENDIX 1008B

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Robust Generalized Total Least Squares Iterative Closest Point Registration

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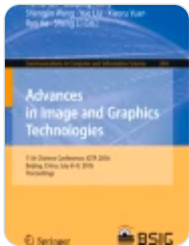
Abstract

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closest point (ICP) algorithm for shape registration. A new Generalized Total Least Squares (GTLS) formulation of the minimization process is presented opposed to the traditional Least Squares (LS) technique. Accounting for uncertainty both in the target and in the source models will lead to a more robust estimation of the transformation. Robustness against outliers is guaranteed by an iterative scheme to update the noise covariances. Experimental results show that this generalization is superior to the least squares counterpart.

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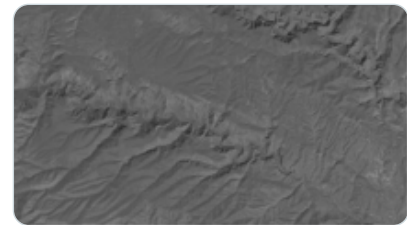
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Keywords

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[Generalize Total](#)

[Iterative Close Point](#)

[Target Shape](#)

[Rotation Error](#)

These keywords were added by machine and not by the authors. This process is experimental and the keywords may be updated as the learning algorithm improves.

References

1. Besl, P.J., McKay, N.D.: A method for registration of 3-D shapes. *IEEE Transaction on Pattern Analysis and Machine Intelligence* 14(2), 239–256 (1992)
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2. Horn, B.K.P.: Closed-form solution of absolute orientation using unit quaternions. *Journal of the Optical Society of America* 4(4), 629–642 (1987)
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3. Ohta, N., Kanatani, K.: Optimal estimation of three-dimensional rotation and reliability evaluation. *IEEE Transactions on Information and Systems* E81- D(11), 1247–1252 (1998)
[Google Scholar](#)
4. Zhang, Z.Y.: Iterative point matching for registration of free-form curves and surfaces. *International Journal of Computer Vision* 13(2), 119–152 (1994)
[Article](#) [Google Scholar](#)
5. Maurer, C.R., Aboutanos, G.B., Dawant, B.M., Maciunas, R.J., Michael Fitzpatrick, J.: Registration of 3-D images using weighted geometrical features. *IEEE Transaction on Medical Imaging* 15(6), 836–849 (1996)
[Article](#) [Google Scholar](#)
6. Dorai, C., Weng, J., Jain, A.K.: Optimal registration of objects view using range data. *IEEE Transaction on Pattern Analysis and Machine Intelligence* 19(10), 1131–1138 (1997)
[Article](#) [Google Scholar](#)
7. van Huffel, S., Vandewalle, J.: Analysis and properties of the generalized total least squares problem

$AX \approx B$, when some or all columns are subject to error. SIAM Journal on Matrix Analysis and Applications 10(3), 294–315 (1989)

[Article](#) [MATH](#) [MathSciNet](#) [Google Scholar](#)

8. Kanatani, K.: Statistical Optimization for Geometric Computation: Theory and Practice. Elsevier, Amsterdam (1996)

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9. Haralick, R.M., Joo, H., Lee, C.-N., Zhuang, X., Vaidya, V.G., Kim, M.B.: Pose estimation from corresponding point data. IEEE Transactions on Systems, Man, and Cybernetics 19(6), 1426–1446 (1989)

[Article](#) [Google Scholar](#)

10. Sharp, G.C., Lee, S.W., Wehe, D.K.: ICP registration using invariant features. IEEE Transaction on Pattern Analysis and Machine Intelligence 24(1), 90–102 (2002)

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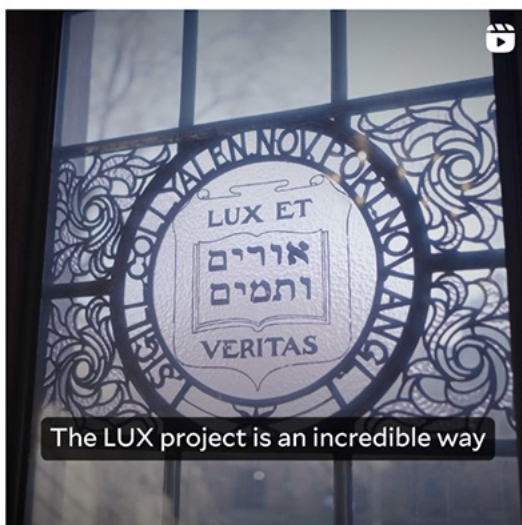
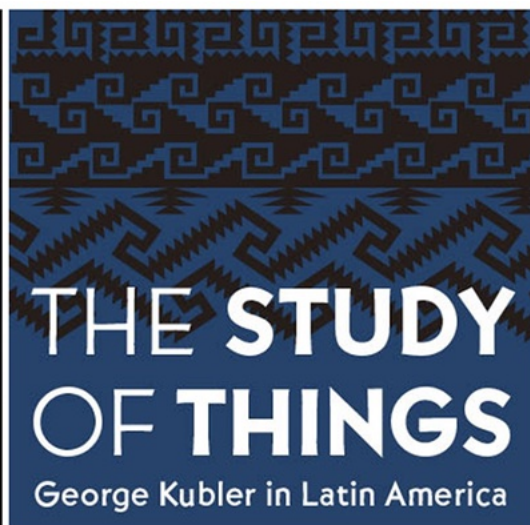
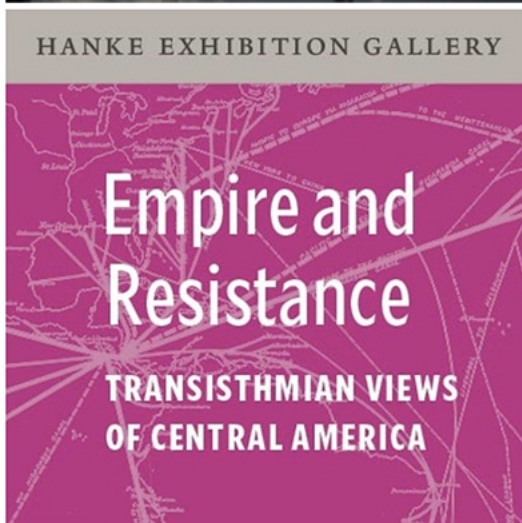
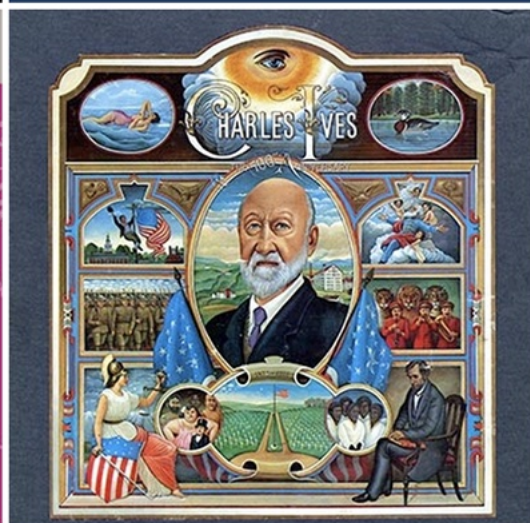
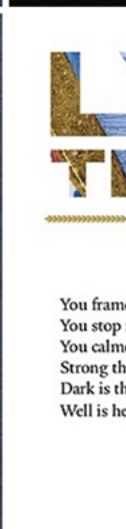
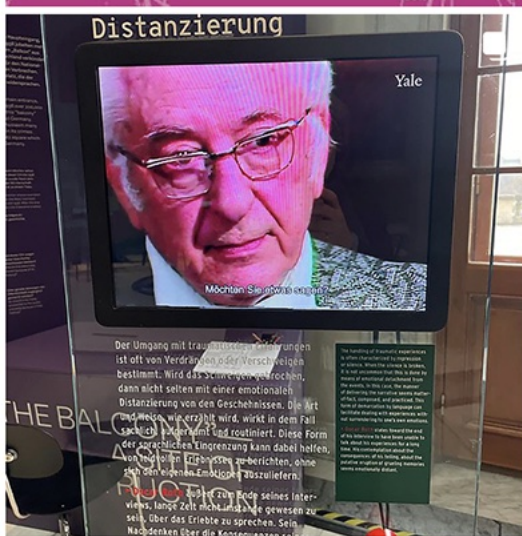
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Yeung, S. K. (2005, June). *Stochastic framework for inverse consistent registration* (Doctoral dissertation).

Yeung, S. K., & Shi, P. (2006, August). Stochastic framework for symmetric affine matching between point sets. In *18th International Conference on Pattern Recognition (ICPR'06)* (Vol. 3, pp. 790-793). IEEE.

Wilson, K., Guiraudon, G., Jones, D., & Peters, T. M. (2006, October). 4D shape registration for dynamic electrophysiological cardiac mapping. In *International Conference on Medical Image Computing and Computer-Assisted Intervention* (pp. 520-527). Berlin, Heidelberg: Springer Berlin Heidelberg.

Sofka, M., Yang, G., & Stewart, C. V. (2007, June). Simultaneous covariance driven correspondence (cdc) and transformation estimation in the expectation maximization framework. In *2007 IEEE Conference on Computer Vision and Pattern Recognition* (pp. 1-8). IEEE.

Kashani, A. H., Owen, W. S., Lawrence, P. D., & Hall, R. A. (2007, August). Real-time robot joint variable extraction from a laser scanner. In *2007 IEEE International Conference on Automation and Logistics* (pp. 2994-2999). IEEE.

Fontanelli, D., Ricciato, L., & Soatto, S. (2007, September). A fast ransac-based registration algorithm for accurate localization in unknown environments using lidar measurements. In *2007 IEEE International Conference on Automation Science and Engineering* (pp. 597-602). IEEE.

APPENDIX 1009A

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Image Alignment and Stitching: A Tutorial

By **Richard Szeliski**, Microsoft Research, USA, szeliski@microsoft.com 

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- 3. Direct (pixel-based) Alignment
- 4. Feature-Based Registration
- 5. Global Registration
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- 7. Extensions and Open Issues
- References

Abstract

This tutorial reviews image alignment and image stitching algorithms. Image alignment algorithms can discover the correspondence relationships among images with varying degrees of overlap. They are ideally suited for applications such as video stabilization, summarization, and the creation of panoramic mosaics. Image stitching algorithms take the alignment estimates produced by such registration algorithms and blend the images in a seamless manner, taking care to deal with potential problems such as blurring or ghosting caused by parallax and scene movement as well as varying image exposures. This tutorial reviews the basic motion models underlying alignment and stitching algorithms, describes effective direct (pixel-based) and feature-based alignment algorithms, and describes blending algorithms used to produce seamless mosaics. It ends with a discussion of open research problems in the area.

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Image Alignment and Stitching

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Image Alignment and Stitching: A Tutorial is an invaluable resource for anyone planning or conducting research in this particular area, or computer vision generally. The essentials of the topic are presented in a tutorial style and an extensive bibliography guides towards further reading.

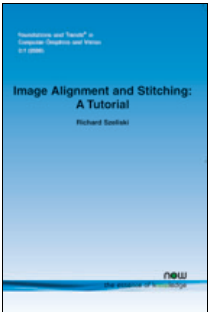


Image Alignment and Stitching: A Tutorial

Image Alignment and Stitching: A Tutorial

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Image Alignment and Stitching: A Tutorial

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Abstract

This tutorial reviews image alignment and image stitching algorithms. Image alignment algorithms can discover the correspondence relationships among images with varying degrees of overlap. They are ideally suited for applications such as video stabilization, summarization, and the creation of panoramic mosaics. Image stitching algorithms take the alignment estimates produced by such registration algorithms and blend the images in a seamless manner, taking care to deal with potential problems such as blurring or ghosting caused by parallax and scene movement as well as varying image exposures. This tutorial reviews the basic motion models underlying alignment and stitching algorithms, describes effective direct (pixel-based) and feature-based alignment algorithms, and describes blending algorithms used to produce seamless mosaics. It ends with a discussion of open research problems in the area.

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1

Introduction

Algorithms for aligning images and stitching them into seamless photo-mosaics are among the oldest and most widely used in computer vision. Frame-rate image alignment is used in every camcorder that has an “image stabilization” feature. Image stitching algorithms create the high-resolution photo-mosaics used to produce today’s digital maps and satellite photos. They also come bundled with most digital cameras currently being sold, and can be used to create beautiful ultra wide-angle panoramas.

An early example of a widely used image registration algorithm is the patch-based translational alignment (optical flow) technique developed by Lucas and Kanade [123]. Variants of this algorithm are used in almost all motion-compensated video compression schemes such as MPEG and H.263 [113]. Similar parametric motion estimation algorithms have found a wide variety of applications, including video summarization [20,203,111,93], video stabilization [81], and video compression [95,114]. More sophisticated image registration algorithms have also been developed for medical imaging and remote sensing – see [29,226,71] for some previous surveys of image registration techniques.

2 Introduction

In the photogrammetry community, more manually intensive methods based on surveyed *ground control points* or manually registered *tie points* have long been used to register aerial photos into large-scale photo-mosaics [181]. One of the key advances in this community was the development of *bundle adjustment* algorithms that could simultaneously solve for the locations of all of the camera positions, thus yielding globally consistent solutions [207]. One of the recurring problems in creating photo-mosaics is the elimination of visible seams, for which a variety of techniques have been developed over the years [135, 136, 148, 50, 1].

In film photography, special cameras were developed at the turn of the century to take ultra wide-angle panoramas, often by exposing the film through a vertical slit as the camera rotated on its axis [131]. In the mid-1990s, image alignment techniques were started being applied to the construction of wide-angle seamless panoramas from regular hand-held cameras [124, 193, 43, 194]. More recent work in this area has addressed the need to compute globally consistent alignments [199, 167, 178], the removal of “ghosts” due to parallax and object movement [50, 178, 210, 1], and dealing with varying exposures [124, 210, 116, 1]. (A collection of some of these papers can be found in [19].) These techniques have spawned a large number of commercial stitching products [43, 168], for which reviews and comparison can be found on the Web.

While most of the above techniques work by directly minimizing pixel-to-pixel dissimilarities, a different class of algorithms works by extracting a sparse set of *features* and then matching these to each other [227, 35, 38, 7, 129, 30]. Feature-based approaches have the advantage of being more robust against scene movement and are potentially faster, if implemented the right way. Their biggest advantage, however, is the ability to “recognize panoramas,” i.e., to automatically discover the adjacency (overlap) relationships among an unordered set of images, which makes them ideally suited for fully automated stitching of panoramas taken by casual users [30].

What, then, are the essential problems in image alignment and stitching? For image alignment, we must first determine the appropriate mathematical model relating pixel coordinates in one image to pixel coordinates in another. Section 2 reviews these basic *motion*

models. Next, we must somehow estimate the correct alignments relating various pairs (or collections) of images. Section 3 discusses how *direct* pixel-to-pixel comparisons combined with gradient descent (and other optimization techniques) can be used to estimate these parameters. Section 4 discusses how distinctive *features* can be found in each image and then efficiently matched to rapidly establish correspondences between pairs of images. When multiple images exist in a panorama, techniques must be developed to compute a globally consistent set of alignments and to efficiently discover which images overlap one another. These issues are discussed in Section 5.

For image stitching, we must first choose a final compositing surface onto which to warp and place all of the aligned images (Section 6). We also need to develop algorithms to seamlessly blend overlapping images, even in the presence of parallax, lens distortion, scene motion, and exposure differences (Section 6). In the last section of this survey, additional applications of image stitching and open research problems were discussed.

References

- [1] A. Agarwala *et al.*, “Interactive digital photomontage,” *ACM Transactions on Graphics*, vol. 23, no. 3, pp. 292–300, August 2004.
- [2] A. Agarwala *et al.*, “Panoramic video textures,” *ACM Transactions on Graphics*, vol. 24, no. 3, pp. 821–827, August 2005.
- [3] P. Anandan, “A computational framework and an algorithm for the measurement of visual motion,” *International Journal of Computer Vision*, vol. 2, no. 3, pp. 283–310, January 1989.
- [4] V. Argyriou and T. Vlachos, “Estimation of sub-pixel motion using gradient cross-correlation,” *Electronic Letters*, vol. 39, no. 13, pp. 980–982, June 2003.
- [5] N. Ayache, *Vision Stéréoscopique et Perception Multisensorielle*. Paris: InterEditions, 1989.
- [6] A. Bab Hadiashar and D. Suter, “Robust total least squares based optic flow computation,” in *Asian Conference on Computer Vision (ACCV’98)*, (Hong Kong), pp. 566–573, ACM, January 1998.
- [7] F. Badra, A. Qumsieh, and G. Dudek, “Rotation and zooming in image mosaicing,” in *IEEE Workshop on Applications of Computer Vision (WACV’98)*, (Princeton), pp. 50–55, October 1998. IEEE Computer Society.
- [8] S. Baker and T. Kanade, “Limits on super-resolution and how to break them,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 24, no. 9, pp. 1167–1183, September 2002.
- [9] S. Baker and I. Matthews, “Lucas-Kanade 20 years on: A unifying framework: Part 1: The quantity approximated, the warp update rule, and the gradient descent approximation,” *International Journal of Computer Vision*, vol. 56, no. 3, pp. 221–255, March 2004.

96 *References*

- [10] S. Baker *et al.*, “Lucas-kanade 20 years on: A unifying framework: Part 4,” The Robotics Institute, Carnegie Mellon University, February 2004. Technical Report CMU-RI-TR-04-14.
- [11] S. Baker *et al.*, “Lucas-kanade 20 years on: A unifying framework: Part 2,” The Robotics Institute, Carnegie Mellon University, February 2003. Technical Report CMU-RI-TR-03-01.
- [12] S. Baker *et al.*, “Lucas-kanade 20 years on: A unifying framework: Part 3,” The Robotics Institute, Carnegie Mellon University, November 2003. Technical Report CMU-RI-TR-03-35.
- [13] J. P. Barreto and K. Daniilidis, “Fundamental matrix for cameras with radial distortion,” in *Tenth International Conference on Computer Vision (ICCV 2005)*, (Beijing, China), vol. 1, pp. 625–632, October 2005.
- [14] A. Bartoli, M. Coquelles, and P. Sturm, “A framework for pencil-of-points structure-from-motion,” in *Eighth European Conference on Computer Vision (ECCV 2004)*, (Prague), vol. II, pp. 28–40, Springer-Verlag, May 2004.
- [15] P. Baudisch *et al.*, “Panoramic viewfinder: Providing a real-time preview to help users avoid flaws in panoramic pictures,” in *OZCHI 2005*, (Canberra, Australia), November 2005.
- [16] A. Baumberg, “Reliable feature matching across widely separated views,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’2000)*, (Hilton Head Island), vol. 1, pp. 774–781, June 2000.
- [17] H. Bay, T. Tuytelaars, and L. V. Gool, “Surf: Speeded up robust features,” in *Computer Vision – ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3951, pp. 404–417, of *Lecture Notes in Computer Science*, Springer, 2006.
- [18] J. S. Beis and D. G. Lowe, “Shape indexing using approximate nearest-neighbour search in high-dimensional spaces,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’97)*, (San Juan, Puerto Rico), pp. 1000–1006, June 1997.
- [19] R. Benosman and S. B. Kang, eds., *Panoramic Vision: Sensors, Theory, and Applications*. New York: Springer, 2001.
- [20] J. R. Bergen, P. Anandan, K. J. Hanna, and R. Hingorani, “Hierarchical model-based motion estimation,” in *Second European Conference on Computer Vision (ECCV’92)*, (Santa Margherita Ligure, Italy), pp. 237–252, Springer-Verlag, May 1992.
- [21] J. R. Bergen, P. J. Burt, R. Hingorani, and S. Peleg, “A three-frame algorithm for estimating two-component image motion,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 14, no. 9, pp. 886–896, September 1992.
- [22] M. J. Black and P. Anandan, “The robust estimation of multiple motions: Parametric and piecewise-smooth flow fields,” *Computer Vision and Image Understanding*, vol. 63, no. 1, pp. 75–104, 1996.
- [23] M. J. Black and A. D. Jepson, “EigenTracking: Robust matching and tracking of articulated objects using a view-based representation,” *International Journal of Computer Vision*, vol. 26, no. 1, pp. 63–84, January 1998.

- [24] M. J. Black and A. Rangarajan, "On the unification of line processes, outlier rejection, and robust statistics with applications in early vision," *International Journal of Computer Vision*, vol. 19, no. 1, pp. 57–91, 1996.
- [25] J. F. Blinn, "Jim Blinn's corner: Compositing, part 1: Theory," *IEEE Computer Graphics and Applications*, vol. 14, no. 5, pp. 83–87, September 1994.
- [26] G. Borgefors, "Distance transformations in digital images," *Computer Vision, Graphics and Image Processing*, vol. 34, no. 3, pp. 227–248, June 1986.
- [27] Y. Boykov, O. Veksler, and R. Zabih, "Fast approximate energy minimization via graph cuts," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 23, no. 11, pp. 1222–1239, November 2001.
- [28] D. C. Brown, "Close-range camera calibration," *Photogrammetric Engineering*, vol. 37, no. 8, pp. 855–866, 1971.
- [29] L. G. Brown, "A survey of image registration techniques," *Computing Surveys*, vol. 24, no. 4, pp. 325–376, December 1992.
- [30] M. Brown and D. Lowe, "Recognizing panoramas," in *Ninth International Conference on Computer Vision (ICCV'03)*, (Nice, France), pp. 1218–1225, October 2003.
- [31] M. Brown, R. Szeliski, and S. Winder, "Multi-image matching using multi-scale oriented patches," Technical Report MSR-TR-2004-133, Microsoft Research, December 2004.
- [32] M. Brown, R. Szeliski, and S. Winder, "Multi-image matching using multi-scale oriented patches," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2005)*, (San Diego, CA), vol. I, pp. 510–517, June 2005.
- [33] L. M. Bugayevskiy and J. P. Snyder, *Map Projections: A Reference Manual*. CRC Press, 1995.
- [34] P. J. Burt and E. H. Adelson, "A multiresolution spline with applications to image mosaics," *ACM Transactions on Graphics*, vol. 2, no. 4, pp. 217–236, October 1983.
- [35] D. Capel and A. Zisserman, "Automated mosaicing with super-resolution zoom," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'98)*, (Santa Barbara), pp. 885–891, June 1998.
- [36] D. Capel and A. Zisserman, "Super-resolution enhancement of text image sequences," in *Fifteenth International Conference on Pattern Recognition (ICPR'2000)*, (Barcelona, Spain), vol. I, pp. 600–605, IEEE Computer Society Press, September 2000.
- [37] G. Carneiro and A. Jepson, "The distinctiveness, detectability, and robustness of local image features," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2005)*, (San Diego, CA), vol. II, pp. 296–301, June 2005.
- [38] T. J. Cham and R. Cipolla, "A statistical framework for long-range feature matching in uncalibrated image mosaicing," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'98)*, (Santa Barbara), pp. 442–447, June 1998.
- [39] G. Champleboux *et al.*, "Accurate calibration of cameras and range imaging sensors, the NPBS method," in *IEEE International Conference on Robotics*

98 *References*

- and Automation*, (Nice, France), pp. 1552–1558, IEEE Computer Society Press, May 1992.
- [40] S. Chaudhuri, *Super-Resolution Imaging*. Springer, 2001.
- [41] P. Cheeseman, B. Kanefsky, R. Hanson, and J. Stutz, “Super-resolved surface reconstruction from multiple images,” Technical Report FIA-93-02, NASA Ames Research Center, Artificial Intelligence Branch, January 1993.
- [42] C.-Y. Chen and R. Klette, “Image stitching – comparisons and new techniques,” in *Computer Analysis of Images and Patterns (CAIP’99)*, (Ljubljana), pp. 615–622, Springer-Verlag, September 1999.
- [43] S. E. Chen, “QuickTime VR – an image-based approach to virtual environment navigation,” *Computer Graphics (SIGGRAPH’95)*, pp. 29–38, August 1995.
- [44] O. Chum and J. Matas, “Matching with prosac – progressive sample consensus,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’2005)*, (San Diego, CA), vol. I, pp. 220–226, June 2005.
- [45] D. Claus and A. Fitzgibbon, “A rational function lens distortion model for general cameras,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’2005)*, (San Diego, CA), vol. I, pp. 213–219, June 2005.
- [46] S. Coorg and S. Teller, “Spherical mosaics with quaternions and dense correlation,” *International Journal of Computer Vision*, vol. 37, no. 3, pp. 259–273, June 2000.
- [47] J. Corso and G. Hager, “Coherent regions for concise and stable image description,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’2005)*, (San Diego, CA), vol. II, pp. 184–190, June 2005.
- [48] I. J. Cox, S. Roy, and S. L. Hingorani, “Dynamic histogram warping of image pairs for constant image brightness,” in *IEEE International Conference on Image Processing (ICIP’95)*, vol. 2, pp. 366–369, IEEE Computer Society, 1995.
- [49] P. E. Danielsson, “Euclidean distance mapping,” *Computer Graphics and Image Processing*, vol. 14, no. 3, pp. 227–248, November 1980.
- [50] J. Davis, “Mosaics of scenes with moving objects,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’98)*, (Santa Barbara), pp. 354–360, June 1998.
- [51] E. De Castro and C. Morandi, “Registration of translated and rotated images using finite fourier transforms,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. PAMI-9, no. 5, pp. 700–703, September 1987.
- [52] P. E. Debevec and J. Malik, “Recovering high dynamic range radiance maps from photographs,” in *Proceedings of SIGGRAPH 97*, Los Angeles, California, pp. 369–378, August 1997. ISBN 0-89791-896-7.
- [53] F. Dellaert and R. Collins, “Fast image-based tracking by selective pixel integration,” in *ICCV Workshop on Frame-Rate Vision*, pp. 1–22, 1999.
- [54] F. Durand and J. Dorsey, “Fast bilateral filtering for the display of high-dynamic-range images,” *ACM Transactions on Graphics (TOG)*, vol. 21, no. 3, pp. 257–266, 2002.

- [55] A. Eden, M. Uyttendaele, and R. Szeliski, "Seamless image stitching of scenes with large motions and exposure differences," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2006)*, (New York, NY), vol. 3, pp. 2498–2505, June 2006.
- [56] A. A. Efros and W. T. Freeman, "Image quilting for texture synthesis and transfer," in *SIGGRAPH 2001, Computer Graphics Proceedings*, (E. Fiume, ed.), pp. 341–346, ACM Press/ACM SIGGRAPH, 2001.
- [57] M. El Melegly and A. Farag, "Nonmetric lens distortion calibration: Closed-form solutions, robust estimation and model selection," in *Ninth International Conference on Computer Vision (ICCV 2003)*, (Nice, France), pp. 554–559, October 2003.
- [58] J. H. Elder and R. M. Goldberg, "Image editing in the contour domain," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 23, no. 3, pp. 291–296, March 2001.
- [59] R. Fattal, D. Lischinski, and M. Werman, "Gradient domain high dynamic range compression," *ACM Transactions on Graphics (TOG)*, vol. 21, no. 3, pp. 249–256, 2002.
- [60] M. A. Fischler and R. C. Bolles, "Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography," *Communications of the ACM*, vol. 24, no. 6, pp. 381–395, June 1981.
- [61] D. Fleet and A. Jepson, "Computation of component image velocity from local phase information," *International Journal of Computer Vision*, vol. 5, no. 1, pp. 77–104, January 1990.
- [62] W. Förstner, "A feature-based correspondence algorithm for image matching," *International Archives on Photogrammetry and Remote Sensing*, vol. 26, no. 3, pp. 150–166, 1986.
- [63] W. Förstner, "A framework for low level feature extraction," in *Third European Conference on Computer Vision (ECCV'94)*, (Stockholm, Sweden), pp. 383–394, Springer-Verlag, May 1994.
- [64] W. T. Freeman and E. H. Adelson, "The design and use of steerable filters," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 13, no. 9, pp. 891–906, September 1991.
- [65] W. T. Freeman, T. R. Jones, and E. C. Pasztor, "Example-based super-resolution," *IEEE Computer Graphics and Applications*, vol. 22, no. 2, pp. 56–65, March–April 2002.
- [66] C.-S. Fuh and P. Maragos, "Motion displacement estimation using an affine model for image matching," *Optical Engineering*, vol. 30, no. 7, pp. 881–887, July 1991.
- [67] S. Geman and D. Geman, "Stochastic relaxation, Gibbs distribution, and the Bayesian restoration of images," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. PAMI-6, no. 6, pp. 721–741, November 1984.
- [68] M. A. Gennert, "Brightness-based stereo matching," in *Second International Conference on Computer Vision (ICCV'88)*, (Tampa), pp. 139–143, IEEE Computer Society Press, December 1988.
- [69] G. Golub and C. F. Van Loan, *Matrix Computation*. Baltimore and London: The John Hopkins University Press, Third Edition, 1996.

100 *References*

- [70] A. Goshtasby, "Correction of image deformation from lens distortion using bezier patches," *Computer Vision, Graphics, and Image Processing*, vol. 47, no. 4, pp. 385–394, November 1989.
- [71] A. Goshtasby, *2-D and 3-D Image Registration*. New York: Wiley, 2005.
- [72] V. M. Govindu, "Revisiting the brightness constraint: Probabilistic formulation and algorithms," in *Computer Vision – ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3953, pp. 177–188, of *Lecture Notes in Computer Science*, Springer, 2006.
- [73] N. Greene, "Environment mapping and other applications of world projections," *IEEE Computer Graphics and Applications*, vol. 6, no. 11, pp. 21–29, November 1986.
- [74] N. Greene and P. Heckbert, "Creating raster Omnimax images from multiple perspective views using the elliptical weighted average filter," *IEEE Computer Graphics and Applications*, vol. 6, no. 6, pp. 21–27, June 1986.
- [75] K. D. Gremban, C. E. Thorpe, and T. Kanade, "Geometric camera calibration using systems of linear equations," in *IEEE International Conference on Robotics and Automation*, (Philadelphia), pp. 562–567, IEEE Computer Society Press, April 1988.
- [76] M. D. Grossberg and S. K. Nayar, "A general imaging model and a method for finding its parameters," in *Eighth International Conference on Computer Vision (ICCV 2001)*, (Vancouver, Canada), vol. II, pp. 108–115, July 2001.
- [77] G. D. Hager and P. N. Belhumeur, "Efficient region tracking with parametric models of geometry and illumination," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 20, no. 10, pp. 1025–1039, October 1998.
- [78] F. R. Hampel *et al.*, *Robust Statistics: The Approach Based on Influence Functions*. New York: Wiley, 1986.
- [79] M. J. Hannah, *Computer Matching of Areas in Stereo Images*. PhD thesis, Stanford University, 1974.
- [80] M. J. Hannah, "Test results from SRI's stereo system," in *Image Understanding Workshop*, (Cambridge, Massachusetts), pp. 740–744, Morgan Kaufmann Publishers, April 1988.
- [81] M. Hansen, P. Anandan, K. Dana, G. van der Wal, and P. Burt, "Real-time scene stabilization and mosaic construction," in *IEEE Workshop on Applications of Computer Vision (WACV'94)*, (Sarasota), pp. 54–62, December 1994. IEEE Computer Society.
- [82] C. Harris and M. J. Stephens, "A combined corner and edge detector," in *Alvey Vision Conference*, pp. 147–152, 1988.
- [83] R. I. Hartley, "Self-calibration from multiple views of a rotating camera," in *Third European Conference on Computer Vision (ECCV'94)*, (Stockholm, Sweden), vol. 1, pp. 471–478, Springer-Verlag, May 1994.
- [84] R. I. Hartley and S. B. Kang, "Parameter-free radial distortion correction with centre of distortion estimation," in *Tenth International Conference on Computer Vision (ICCV 2005)*, (Beijing, China), vol. 2, pp. 1834–1841, October 2005.
- [85] R. I. Hartley and A. Zisserman, *Multiple View Geometry*. Cambridge, UK: Cambridge University Press, September 2000.

- [86] R. I. Hartley and A. Zisserman, *Multiple View Geometry*. Cambridge, UK: Cambridge University Press, March 2004.
- [87] C. Herley, "Automatic occlusion removal from minimum number of images," in *International Conference on Image Processing (ICIP 2005)*, (Genova), vol. II, pp. 1046–1049–16, September 2005.
- [88] B. K. P. Horn, "Determining lightness from an image," *Computer Graphics and Image Processing*, vol. 3, no. 1, pp. 277–299, December 1974.
- [89] B. K. P. Horn, *Robot Vision*. Cambridge, Massachusetts: MIT Press, 1986.
- [90] B. K. P. Horn and M. J. Brooks, *Shape from Shading*. Cambridge, Massachusetts: MIT Press, 1989.
- [91] B. K. P. Horn and B. G. Schunck, "Determining optical flow," *Artificial Intelligence*, vol. 17, pp. 185–203, 1981.
- [92] P. J. Huber, *Robust Statistics*. New York: John Wiley & Sons, 1981.
- [93] M. Irani and P. Anandan, "Video indexing based on mosaic representations," *Proceedings of the IEEE*, vol. 86, no. 5, pp. 905–921, May 1998.
- [94] M. Irani and P. Anandan, "About direct methods," in *International Workshop on Vision Algorithms*, (Kerkyra, Greece), pp. 267–277, Springer, September 1999.
- [95] M. Irani, S. Hsu, and P. Anandan, "Video compression using mosaic representations," *Signal Processing: Image Communication*, vol. 7, pp. 529–552, 1995.
- [96] M. Irani and S. Peleg, "Improving resolution by image registration," *Graphical Models and Image Processing*, vol. 53, no. 3, pp. 231–239, May 1991.
- [97] J. Jia and C.-K. Tang, "Image registration with global and local luminance alignment," in *Ninth International Conference on Computer Vision (ICCV 2003)*, (Nice, France), pp. 156–163, October 2003.
- [98] F. Jurie and M. Dhome, "Hyperplane approximation for template matching," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 24, no. 7, pp. 996–1000, July 2002.
- [99] T. Kadir and M. Brady, "Saliency, scale and image description," *International Journal of Computer Vision*, vol. 45, no. 2, pp. 83–105, November 2001.
- [100] T. Kadir, A. Zisserman, and M. Brady, "An affine invariant salient region detector," in *Eighth European Conference on Computer Vision (ECCV 2004)*, (Prague), vol. I, pp. 228–241, Springer-Verlag, May 2004.
- [101] S. B. Kang, "Radial distortion snakes," *IEICE Transactions on Information and Systems*, vol. E84-D, no. 12, pp. 1603–1611, December 2001.
- [102] S. B. Kang, R. Szeliski, and M. Uyttendaele, "Seamless stitching using multi-perspective plane sweep," Technical Report MSR-TR-2004-48, Microsoft Research, June 2004.
- [103] S. B. Kang and R. Weiss, "Characterization of errors in compositing panoramic images," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'97)*, (San Juan, Puerto Rico), pp. 103–109, June 1997.
- [104] S. B. Kang *et al.*, "High dynamic range video," *ACM Transactions on Graphics*, vol. 22, no. 3, pp. 319–325, July 2003.

102 *References*

- [105] Y. Ke and R. Sukthankar, "PCA-SIFT: A more distinctive representation for local image descriptors," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2004)*, (Washington, DC), vol. II, pp. 506–513, June 2004.
- [106] C. Kenney, M. Zuliani, and B. Manjunath, "An axiomatic approach to corner detection," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2005)*, (San Diego, CA), vol. I, pp. 191–197, June 2005.
- [107] D. Keren, S. Peleg, and R. Brada, "Image sequence enhancement using sub-pixel displacements," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'88)*, (Ann Arbor, Michigan), pp. 742–746, IEEE Computer Society Press, June 1988.
- [108] J. Kim, V. Kolmogorov, and R. Zabih, "Visual correspondence using energy minimization and mutual information," in *Ninth International Conference on Computer Vision (ICCV 2003)*, (Nice, France), pp. 1033–1040, October 2003.
- [109] C. D. Kuglin and D. C. Hines, "The phase correlation image alignment method," in *IEEE 1975 Conference on Cybernetics and Society*, (New York), pp. 163–165, September 1975.
- [110] R. Kumar, P. Anandan, and K. Hanna, "Direct recovery of shape from multiple views: A parallax based approach," in *Twelfth International Conference on Pattern Recognition (ICPR'94)*, (Jerusalem, Israel), vol. A, pp. 685–688, IEEE Computer Society Press, October 1994.
- [111] R. Kumar, P. Anandan, M. Irani, J. Bergen, and K. Hanna, "Representation of scenes from collections of images," in *IEEE Workshop on Representations of Visual Scenes*, (Cambridge, Massachusetts), pp. 10–17, June 1995.
- [112] V. Kwatra *et al.*, "Graphcut textures: Image and video synthesis using graph cuts," *ACM Transactions on Graphics*, vol. 22, no. 3, pp. 277–286, July 2003.
- [113] D. Le Gall, "MPEG: A video compression standard for multimedia applications," *Communications of the ACM*, vol. 34, no. 4, pp. 44–58, April 1991.
- [114] M.-C. Lee *et al.*, "A layered video object coding system using sprite and affine motion model," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 7, no. 1, pp. 130–145, February 1997.
- [115] A. Levin, A. Zomet, and Y. Weiss, "Separating reflections from a single image using local features," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2004)*, (Washington, DC), vol. I, pp. 306–313, June 2004.
- [116] A. Levin, A. Zomet, S. Peleg, and Y. Weiss, "Seamless image stitching in the gradient domain," in *Eighth European Conference on Computer Vision (ECCV 2004)*, (Prague), vol. IV, pp. 377–389, Springer-Verlag, May 2004.
- [117] Y. Li *et al.*, "Lazy snapping," *ACM Transactions on Graphics*, vol. 23, no. 3, pp. 303–308, August 2004.
- [118] Y. Li *et al.*, "Stereo reconstruction from multiperspective panoramas," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 26, no. 1, pp. 44–62, January 2004.

- [119] T. Lindeberg, "Scale-space for discrete signals," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 12, no. 3, pp. 234–254, March 1990.
- [120] D. Lischinski, Z. Farbman, M. Uytendaele, and R. Szeliski, "Interactive local adjustment of tonal values," *ACM Transactions on Graphics*, vol. 25, no. 3, pp. 646–653, August 2006.
- [121] C. Loop and Z. Zhang, "Computing rectifying homographies for stereo vision," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'99)*, (Fort Collins), vol. I, pp. 125–131, June 1999.
- [122] D. G. Lowe, "Distinctive image features from scale-invariant keypoints," *International Journal of Computer Vision*, vol. 60, no. 2, pp. 91–110, November 2004.
- [123] B. D. Lucas and T. Kanade, "An iterative image registration technique with an application in stereo vision," in *Seventh International Joint Conference on Artificial Intelligence (IJCAI-81)*, (Vancouver), pp. 674–679, 1981.
- [124] S. Mann and R. W. Picard, "Virtual bellows: Constructing high-quality images from video," in *First IEEE International Conference on Image Processing (ICIP-94)*, (Austin), vol. I, pp. 363–367, November 1994.
- [125] S. Mann and R. W. Picard, "On being 'undigital' with digital cameras: Extending dynamic range by combining differently exposed pictures," in *IS&T's 48th Annual Conference*, (Washington, D. C.), pp. 422–428, Society for Imaging Science and Technology, May 1995.
- [126] M. Massey and W. Bender, "Salient stills: Process and practice," *IBM Systems Journal*, vol. 35, nos. 3&4, pp. 557–573, 1996.
- [127] J. Matas *et al.*, "Robust wide baseline stereo from maximally stable extremal regions," *Image and Vision Computing*, vol. 22, no. 10, pp. 761–767, September 2004.
- [128] L. H. Matthies, R. Szeliski, and T. Kanade, "Kalman filter-based algorithms for estimating depth from image sequences," *International Journal of Computer Vision*, vol. 3, pp. 209–236, 1989.
- [129] P. F. McLauchlan and A. Jaenicke, "Image mosaicing using sequential bundle adjustment," *Image and Vision Computing*, vol. 20, nos. 9–10, pp. 751–759, August 2002.
- [130] L. McMillan and G. Bishop, "Plenoptic modeling: An image-based rendering system," *Computer Graphics (SIGGRAPH'95)*, pp. 39–46, August 1995.
- [131] J. Meehan, *Panoramic Photography*. Watson-Guptill, 1990.
- [132] K. Mikolajczyk and C. Schmid, "Scale & affine invariant interest point detectors," *International Journal of Computer Vision*, vol. 60, no. 1, pp. 63–86, October 2004.
- [133] K. Mikolajczyk and C. Schmid, "A performance evaluation of local descriptors," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 27, no. 10, pp. 1615–1630, October 2005.
- [134] K. Mikolajczyk *et al.*, "A comparison of affine region detectors," *International Journal of Computer Vision*, vol. 65, nos. 1–2, pp. 43–72, November 2005.
- [135] D. L. Milgram, "Computer methods for creating photomosaics," *IEEE Transactions on Computers*, vol. C-24, no. 11, pp. 1113–1119, November 1975.

104 *References*

- [136] D. L. Milgram, "Adaptive techniques for photomosaicking," *IEEE Transactions on Computers*, vol. C-26, no. 11, pp. 1175–1180, November 1977.
- [137] T. Mitsunaga and S. K. Nayar, "Radiometric self calibration," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'99)*, (Fort Collins), vol. 1, pp. 374–380, June 1999.
- [138] H. Moravec, "The stanford cart and the cmu rover," in *Proceedings of the IEEE*, vol. 71, no. 7, pp. 872–884, July 1983.
- [139] M. Mühlich and R. Mester, "The role of total least squares in motion analysis," in *Fifth European Conference on Computer Vision (ECCV'98)*, (Freiburg, Germany), vol. II, pp. 305–321, Springer-Verlag, June 1998.
- [140] S. K. Nayar and T. Mitsunaga, "High dynamic range imaging: Spatially varying pixel exposures," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2000)*, (Hilton Head, Island), vol. 1, pp. 472–479, June 2000.
- [141] S. Nene and S. K. Nayar, "A simple algorithm for nearest neighbor search in high dimensions," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 19, no. 9, pp. 989–1003, September 1997.
- [142] G. M. Nielson, "Scattered data modeling," *IEEE Computer Graphics and Applications*, vol. 13, no. 1, pp. 60–70, January 1993.
- [143] D. Nister and H. Stewenius, "Scalable recognition with a vocabulary tree," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2006)*, (New York City, NY), vol. 3, pp. 2161–2168, June 2006.
- [144] M. Okutomi and T. Kanade, "A multiple baseline stereo," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 15, no. 4, pp. 353–363, April 1993.
- [145] OpenGL-ARB, *OpenGL Reference Manual: The Official Reference Document to OpenGL, Version 1.1.*, Second Edition, Addison-Wesley, Reading, MA, 1997.
- [146] A. V. Oppenheim, R. W. Schaffer, and J. R. Buck, *Discrete-Time Signal Processing*, Second Edition, Pearson Education, 1999.
- [147] R. Peleg, M. Ben-Ezra, and Y. Pritch, "Omnistereo: Panoramic stereo imaging," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 23, no. 3, pp. 279–290, March 2001.
- [148] S. Peleg, "Elimination of seams from photomosaics," *Computer Vision, Graphics, and Image Processing*, vol. 16, pp. 1206–1210, 1981.
- [149] S. Peleg and A. Rav Acha, "Lucas-Kanade without iterative warping," in *International Conference on Image Processing (ICIP-2006)*, (Atlanta), pp. 1097–1100, October 2006.
- [150] S. Peleg *et al.*, "Mosaicing on adaptive manifolds," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 22, no. 10, pp. 1144–1154, October 2000.
- [151] P. Pérez, M. Gangnet, and A. Blake, "Poisson image editing," *ACM Transactions on Graphics*, vol. 22, no. 3, pp. 313–318, July 2003.
- [152] B. Platel, E. Balmachnova, L. M. J. Florack, and B. M. ter Haar Romeny, "Top-points as interest points for image matching," in *Computer Vision –*

- ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3951, pp. 418–429, of *Lecture Notes in Computer Science*, Springer, 2006.
- [153] T. Porter and T. Duff, “Compositing digital images,” *Computer Graphics (SIGGRAPH’84)*, vol. 18, no. 3, pp. 253–259, July 1984.
 - [154] L. H. Quam, “Hierarchical warp stereo,” in *Image Understanding Workshop*, (New Orleans), pp. 149–155, Science Applications International Corporation, December 1984.
 - [155] P. Rademacher and G. Bishop, “Multiple-center-of-projection images,” in *Computer Graphics Proceedings, Annual Conference Series*, pp. 199–206, Proc. SIGGRAPH’98 (Orlando), ACM SIGGRAPH, July 1998.
 - [156] A. Rav Acha, Y. Pritch, D. Lischinski, and S. Peleg, “Dynamosaics: Video mosaics with non-chronological time,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’2005)*, (San Diego, CA), vol. I, pp. 58–65, June 2005.
 - [157] J. Rehag and A. Witkin, “Visual tracking with deformation models,” in *IEEE International Conference on Robotics and Automation*, (Sacramento), pp. 844–850, IEEE Computer Society Press, April 1991.
 - [158] E. Reinhard, G. Ward, S. Pattanaik, and P. Debevec, *High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting*. Morgan Kaufmann, 2005.
 - [159] E. Reinhard *et al.*, “Photographic tone reproduction for digital images,” *ACM Transactions on Graphics (TOG)*, vol. 21, no. 3, pp. 267–276, 2002.
 - [160] E. Rosten and T. Drummond, “Machine learning for high-speed corner detection,” in *Computer Vision – ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3951, pp. 430–443, of *Lecture Notes in Computer Science*, Springer, 2006.
 - [161] C. Rother, V. Kolmogorov, and A. Blake, ““GrabCut” – interactive foreground extraction using iterated graph cuts,” *ACM Transactions on Graphics*, vol. 23, no. 3, pp. 309–314, August 2004.
 - [162] P. J. Rousseeuw, “Least median of squares regression,” *Journal of the American Statistical Association*, vol. 79, pp. 871–880, 1984.
 - [163] P. J. Rousseeuw and A. M. Leroy, *Robust Regression and Outlier Detection*. New York: Wiley, 1987.
 - [164] H. Samet, *The Design and Analysis of Spatial Data Structures*. Reading, Massachusetts: Addison-Wesley, 1989.
 - [165] H. S. Sawhney, “3D geometry from planar parallax,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’94)*, (Seattle), pp. 929–934, IEEE Computer Society, June 1994.
 - [166] H. S. Sawhney and S. Ayer, “Compact representation of videos through dominant multiple motion estimation,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 18, no. 8, pp. 814–830, August 1996.
 - [167] H. S. Sawhney and R. Kumar, “True multi-image alignment and its application to mosaicing and lens distortion correction,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 21, no. 3, pp. 235–243, March 1999.

106 *References*

- [168] H. S. Sawhney *et al.*, “Videobrush: Experiences with consumer video mosaicing,” in *IEEE Workshop on Applications of Computer Vision (WACV’98)*, (Princeton), pp. 56–62, IEEE Computer Society, October 1998.
- [169] F. Schaffalitzky and A. Zisserman, “Multi-view matching for unordered image sets, or “How do I organize my holiday snaps?”,” in *Seventh European Conference on Computer Vision (ECCV 2002)*, (Copenhagen), vol. I, pp. 414–431, Springer-Verlag, May 2002.
- [170] D. Scharstein and R. Szeliski, “A taxonomy and evaluation of dense two-frame stereo correspondence algorithms,” *International Journal of Computer Vision*, vol. 47, no. 1, pp. 7–42, May 2002.
- [171] C. Schmid, R. Mohr, and C. Bauckhage, “Evaluation of interest point detectors,” *International Journal of Computer Vision*, vol. 37, no. 2, pp. 151–172, June 2000.
- [172] G. Shakhnarovich, P. Viola, and T. Darrell, “Fast pose estimation with parameter sensitive hashing,” in *Ninth International Conference on Computer Vision (ICCV 2003)*, (Nice, France), vol. 2, pp. 750–757, October 2003.
- [173] J. Shi and C. Tomasi, “Good features to track,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’94)*, (Seattle), pp. 593–600, IEEE Computer Society, June 1994.
- [174] K. Shoemake, “Animating rotation with quaternion curves,” *Computer Graphics (SIGGRAPH’85)*, vol. 19, no. 3, pp. 245–254, July 1985.
- [175] H.-Y. Shum and L.-W. He, “Rendering with concentric mosaics,” in *SIGGRAPH’99*, (Los Angeles), pp. 299–306, ACM SIGGRAPH, August 1999.
- [176] H.-Y. Shum and R. Szeliski, “Panoramic image mosaicing,” Technical Report MSR-TR-97-23, Microsoft Research, September 1997.
- [177] H.-Y. Shum and R. Szeliski, “Stereo reconstruction from multiperspective panoramas,” in *Seventh International Conference on Computer Vision (ICCV’99)*, (Kerkyra, Greece), pp. 14–21, September 1999.
- [178] H.-Y. Shum and R. Szeliski, “Construction of panoramic mosaics with global and local alignment,” *International Journal of Computer Vision*, vol. 36, no. 2, pp. 101–130, February 2000, Erratum published July 2002, vol. 48, no. 2, pp. 151–152, 2000.
- [179] H.-Y. Shum *et al.*, “Omnivergenet stereo,” in *Seventh International Conference on Computer Vision (ICCV’99)*, (Greece), pp. 22–29, September 1999.
- [180] E. P. Simoncelli, E. H. Adelson, and D. J. Heeger, “Probability distributions of optic flow,” in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’91)*, (Maui, Hawaii), pp. 310–315, IEEE Computer Society Press, June 1991.
- [181] C. C. Slama, ed., *Manual of Photogrammetry*. Fourth Edition, Falls Church, Virginia, 1980. American Society of Photogrammetry.
- [182] P. Soille, “Morphological image compositing,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 28, no. 5, pp. 673–683, May 2006.
- [183] D. Steedly *et al.*, “Efficiently registering video into panoramic mosaics,” in *Tenth International Conference on Computer Vision (ICCV 2005)*, (Beijing, China), pp. 1300–1307, October 2005.

- [184] R. Steele and C. Jaynes, "Feature uncertainty arising from covariant image noise," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2005)*, (San Diego, CA), vol. I, pp. 1063–1070, June 2005.
- [185] R. M. Steele and C. Jaynes, "Overconstrained linear estimation of radial distortion and multi-view geometry," in *Computer Vision – ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3951, pp. 253–264, of *Lecture Notes in Computer Science*, Springer, 2006.
- [186] G. Stein, "Accurate internal camera calibration using rotation, with analysis of sources of error," in *Fifth International Conference on Computer Vision (ICCV'95)*, (Cambridge, Massachusetts), pp. 230–236, June 1995.
- [187] G. Stein, "Lens distortion calibration using point correspondences," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'97)*, (San Juan, Puerto Rico), pp. 602–608, June 1997.
- [188] C. V. Stewart, "Robust parameter estimation in computer vision," *SIAM Reviews*, vol. 41, no. 3, pp. 513–537, September 1999.
- [189] P. Sturm, "Multi-view geometry for general camera models," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2005)*, (San Diego, CA), vol. I, pp. 206–212, June 2005.
- [190] J. Sun, N. Zheng, and H. Shum, "Stereo matching using belief propagation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 25, no. 7, pp. 787–800, July 2003.
- [191] R. Szeliski, *Bayesian Modeling of Uncertainty in Low-Level Vision*. Boston: Kluwer Academic Publishers, 1989.
- [192] R. Szeliski, "Fast surface interpolation using hierarchical basis functions," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 12, no. 6, pp. 513–528, June 1990.
- [193] R. Szeliski, "Image mosaicing for tele-reality applications," in *IEEE Workshop on Applications of Computer Vision (WACV'94)*, (Sarasota), pp. 44–53, IEEE Computer Society, December 1994.
- [194] R. Szeliski, "Video mosaics for virtual environments," *IEEE Computer Graphics and Applications*, vol. 16, no. 2, pp. 22–30, March 1996.
- [195] R. Szeliski, "Locally adapted hierarchical basis preconditioning," *ACM Transactions on Graphics*, vol. 25, no. 3, pp. 1135–1143, August 2006.
- [196] R. Szeliski and J. Coughlan, "Hierarchical spline-based image registration," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'94)*, (Seattle), pp. 194–201, IEEE Computer Society, June 1994.
- [197] R. Szeliski and S. B. Kang, "Recovering 3D shape and motion from image streams using nonlinear least squares," *Journal of Visual Communication and Image Representation*, vol. 5, no. 1, pp. 10–28, March 1994.
- [198] R. Szeliski and S. B. Kang, "Direct methods for visual scene reconstruction," in *IEEE Workshop on Representations of Visual Scenes*, (Cambridge, Massachusetts), pp. 26–33, June 1995.
- [199] R. Szeliski and H.-Y. Shum, "Creating full view panoramic image mosaics and texture-mapped models," in *Computer Graphics (SIGGRAPH'97 Proceedings)*, pp. 251–258, August 1997.

108 *References*

- [200] M. F. Tappen and W. T. Freeman, "Comparison of graph cuts with belief propagation for stereo, using identical MRF parameters," in *Ninth International Conference on Computer Vision (ICCV 2003)*, (Nice, France), pp. 900–907, October 2003.
- [201] J.-P. Tardif, P. Sturm, and S. Roy, "Self-calibration of a general radially symmetric distortion model," in *Computer Vision – ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3954, pp. 186–199, of *Lecture Notes in Computer Science*, Springer, 2006.
- [202] J.-P. Tardif *et al.*, "Self-calibration of a general radially symmetric distortion model," in *Seventh European Conference on Computer Vision (ECCV 2002)*, (Graz), vol. 4, pp. 186–199, Springer-Verlag, May 2006.
- [203] L. Teodosio and W. Bender, "Salient video stills: Content and context preserved," in *ACM Multimedia 93*, (Anaheim, California), pp. 39–46, August 1993.
- [204] S. Thirithala and M. Pollefeys, "The radial trifocal tensor: A tool for calibrating the radial distortion of wide-angle cameras," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2005)*, (San Diego, CA), vol. I, pp. 321–328, June 2005.
- [205] Q. Tian and M. N. Huhns, "Algorithms for subpixel registration," *Computer Vision, Graphics, and Image Processing*, vol. 35, pp. 220–233, 1986.
- [206] B. Triggs, "Detecting keypoints with stable position, orientation, and scale under illumination changes," in *Eighth European Conference on Computer Vision (ECCV 2004)*, (Prague), vol. IV, pp. 100–113, Springer-Verlag, May 2004.
- [207] B. Triggs *et al.*, "International Workshop on Vision Algorithms," in *Bundle adjustment – a modern synthesis*, (Kerkyra, Greece), pp. 298–372, Springer, September 1999.
- [208] J. Tumblin, A. Agrawal, and R. Raskar, "Why i want a gradient camera," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2005)*, (San Diego, CA), vol. I, pp. 103–110, June 2005.
- [209] T. Tuytelaars and L. Van Gool, "Matching widely separated views based on affine invariant regions," *International Journal of Computer Vision*, vol. 59, no. 1, pp. 61–85, August 2004.
- [210] M. Uyttendaele, A. Eden, and R. Szeliski, "Eliminating ghosting and exposure artifacts in image mosaics," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2001)*, (Kauai, Hawaii), vol. II, pp. 509–516, December 2001.
- [211] M. Uyttendaele *et al.*, "Image-based interactive exploration of real-world environments," *IEEE Computer Graphics and Applications*, vol. 24, no. 3, May/June 2004.
- [212] S. v. Huffel and J. Vandewalle, "The Total Least Squares Problem: Computational Aspects and Analysis," in *Society for Industrial and Applied Mathematics*, (Philadelphia), 1991.
- [213] J. van de Weijer and C. Schmid, "Coloring local feature extraction," in *Computer Vision – ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3952, pp. 334–348, of *Lecture Notes in Computer Science*, Springer, 2006.

- [214] P. Viola and W. Wells III, "Alignment by maximization of mutual information," in *Fifth International Conference on Computer Vision (ICCV'95)*, (Cambridge, Massachusetts), pp. 16–23, June 1995.
- [215] L. Wang, S. B. Kang, R. Szeliski, and H.-Y. Shum, "Optimal texture map reconstruction from multiple views," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2001)*, (Kauai, Hawaii), vol. I, pp. 347–354, December 2001.
- [216] A. Watt, *3D Computer Graphics*. Addison-Wesley, Third Edition, 1995.
- [217] J. Weber and J. Malik, "Robust computation of optical flow in a multi-scale differential framework," *International Journal of Computer Vision*, vol. 14, no. 1, pp. 67–81, January 1995.
- [218] Y. Weiss, "Deriving intrinsic images from image sequences," in *Eighth International Conference on Computer Vision (ICCV 2001)*, (Vancouver, Canada), vol. II, pp. 7–14, July 2001.
- [219] L. Williams, "Pyramidal parametrics," *Computer Graphics*, vol. 17, no. 3, pp. 1–11, July 1983.
- [220] D. N. Wood *et al.*, "Multiperspective panoramas for cell animation," in *Computer Graphics Proceedings, Annual Conference Series*, (Los Angeles), pp. 243–250, Proc. SIGGRAPH'97, ACM SIGGRAPH, August 1997.
- [221] R. J. Woodham, "Analysing images of curved surfaces," *Artificial Intelligence*, vol. 17, pp. 117–140, 1981.
- [222] Y. Xiong and K. Turkowski, "Creating image-based VR using a self-calibrating fisheye lens," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'97)*, (San Juan, Puerto Rico), pp. 237–243, June 1997.
- [223] Y. Xiong and K. Turkowski, "Registration, calibration and blending in creating high quality panoramas," in *IEEE Workshop on Applications of Computer Vision (WACV'98)*, (Princeton), pp. 69–74, IEEE Computer Society, October 1998.
- [224] D. Yang *et al.*, "A 640x512 CMOS image sensor with ultra-wide dynamic range floating-point pixel level ADC," *IEEE Journal of Solid State Circuits*, vol. 34, no. 12, pp. 1821–1834, December 1999.
- [225] R. Zabih and J. Woodfill, "Non-parametric local transforms for computing visual correspondence," in *Third European Conference on Computer Vision (ECCV'94)*, (Stockholm, Sweden), vol. II, pp. 151–158, Springer-Verlag, May 1994.
- [226] B. Zitov'aa and J. Flusser, "Image registration methods: A survey," *Image and Vision Computing*, vol. 21, pp. 997–1000, October 2003.
- [227] I. Zoghlami, O. Faugeras, and R. Deriche, "Using geometric corners to build a 2D mosaic from a set of images," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'97)*, (San Juan, Puerto Rico), pp. 420–425, June 1997.

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Image Alignment and Stitching: A Tutorial

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Abstract

This tutorial reviews image alignment and image stitching algorithms. Image alignment algorithms can discover the correspondence relationships among images with varying degrees of overlap. They are ideally suited for applications such as video stabilization, summarization, and the creation of panoramic mosaics. Image stitching algorithms take the alignment estimates produced by such registration algorithms and blend the images in a seamless manner, taking care to deal with potential problems such as blurring or ghosting caused by parallax and scene movement as well as varying image exposures. This tutorial reviews the basic motion models underlying alignment and stitching algorithms, describes effective direct (pixel-based) and feature-based alignment algorithms, and describes blending algorithms used to produce seamless mosaics. It ends with a discussion of open research problems in the area.

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1

Introduction

Algorithms for aligning images and stitching them into seamless photo-mosaics are among the oldest and most widely used in computer vision. Frame-rate image alignment is used in every camcorder that has an “image stabilization” feature. Image stitching algorithms create the high-resolution photo-mosaics used to produce today’s digital maps and satellite photos. They also come bundled with most digital cameras currently being sold, and can be used to create beautiful ultra wide-angle panoramas.

An early example of a widely used image registration algorithm is the patch-based translational alignment (optical flow) technique developed by Lucas and Kanade [123]. Variants of this algorithm are used in almost all motion-compensated video compression schemes such as MPEG and H.263 [113]. Similar parametric motion estimation algorithms have found a wide variety of applications, including video summarization [20,93,111,203], video stabilization [81], and video compression [95,114]. More sophisticated image registration algorithms have also been developed for medical imaging and remote sensing – see [29,71,226] for some previous surveys of image registration techniques.

2 Introduction

In the photogrammetry community, more manually intensive methods based on surveyed *ground control points* or manually registered *tie points* have long been used to register aerial photos into large-scale photo-mosaics [181]. One of the key advances in this community was the development of *bundle adjustment* algorithms that could simultaneously solve for the locations of all of the camera positions, thus yielding globally consistent solutions [207]. One of the recurring problems in creating photo-mosaics is the elimination of visible seams, for which a variety of techniques have been developed over the years [1, 50, 135, 136, 148].

In film photography, special cameras were developed at the turn of the century to take ultra wide-angle panoramas, often by exposing the film through a vertical slit as the camera rotated on its axis [131]. In the mid-1990s, image alignment techniques were started being applied to the construction of wide-angle seamless panoramas from regular hand-held cameras [43, 124, 193, 194]. More recent work in this area has addressed the need to compute globally consistent alignments [167, 178, 199], the removal of “ghosts” due to parallax and object movement [1, 50, 178, 210], and dealing with varying exposures [1, 116, 124, 210]. (A collection of some of these papers can be found in [19].) These techniques have spawned a large number of commercial stitching products [43, 168], for which reviews and comparison can be found on the Web.

While most of the above techniques work by directly minimizing pixel-to-pixel dissimilarities, a different class of algorithms works by extracting a sparse set of *features* and then matching these to each other [7, 30, 35, 38, 129, 227]. Feature-based approaches have the advantage of being more robust against scene movement and are potentially faster, if implemented the right way. Their biggest advantage, however, is the ability to “recognize panoramas,” i.e., to automatically discover the adjacency (overlap) relationships among an unordered set of images, which makes them ideally suited for fully automated stitching of panoramas taken by casual users [30].

What, then, are the essential problems in image alignment and stitching? For image alignment, we must first determine the appropriate mathematical model relating pixel coordinates in one image to pixel coordinates in another. Section 2 reviews these basic *motion*

models. Next, we must somehow estimate the correct alignments relating various pairs (or collections) of images. Section 3 discusses how *direct* pixel-to-pixel comparisons combined with gradient descent (and other optimization techniques) can be used to estimate these parameters. Section 4 discusses how distinctive *features* can be found in each image and then efficiently matched to rapidly establish correspondences between pairs of images. When multiple images exist in a panorama, techniques must be developed to compute a globally consistent set of alignments and to efficiently discover which images overlap one another. These issues are discussed in Section 5.

For image stitching, we must first choose a final compositing surface onto which to warp and place all of the aligned images (Section 6). We also need to develop algorithms to seamlessly blend overlapping images, even in the presence of parallax, lens distortion, scene motion, and exposure differences (Section 6). In the last section of this survey, additional applications of image stitching and open research problems were discussed.

References

- [1] A. Agarwala *et al.*, "Interactive digital photomontage," *ACM Transactions on Graphics*, vol. 23, no. 3, pp. 292–300, August 2004.
- [2] A. Agarwala *et al.*, "Panoramic video textures," *ACM Transactions on Graphics*, vol. 24, no. 3, pp. 821–827, August 2005.
- [3] P. Anandan, "A computational framework and an algorithm for the measurement of visual motion," *International Journal of Computer Vision*, vol. 2, no. 3, pp. 283–310, January 1989.
- [4] V. Argyriou and T. Vlachos, "Estimation of sub-pixel motion using gradient cross-correlation," *Electronic Letters*, vol. 39, no. 13, pp. 980–982, June 2003.
- [5] N. Ayache, *Vision Stéréoscopique et Perception Multisensorielle*. Paris: InterEditions, 1989.
- [6] A. Bab Hadiashar and D. Suter, "Robust total least squares based optic flow computation," in *Asian Conference on Computer Vision (ACCV'98)*, (Hong Kong), pp. 566–573, ACM, January 1998.
- [7] F. Badra, A. Qumsieh, and G. Dudek, "Rotation and zooming in image mosaicing," in *IEEE Workshop on Applications of Computer Vision (WACV'98)*, (Princeton), pp. 50–55, October 1998. IEEE Computer Society.
- [8] S. Baker and T. Kanade, "Limits on super-resolution and how to break them," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 24, no. 9, pp. 1167–1183, September 2002.
- [9] S. Baker and I. Matthews, "Lucas-Kanade 20 years on: A unifying framework: Part 1: The quantity approximated, the warp update rule, and the gradient descent approximation," *International Journal of Computer Vision*, vol. 56, no. 3, pp. 221–255, March 2004.

- [10] S. Baker *et al.*, "Lucas-kanade 20 years on: A unifying framework: Part 4," The Robotics Institute, Carnegie Mellon University, February 2004. Technical Report CMU-RI-TR-04-14.
- [11] S. Baker *et al.*, "Lucas-kanade 20 years on: A unifying framework: Part 2," The Robotics Institute, Carnegie Mellon University, February 2003. Technical Report CMU-RI-TR-03-01.
- [12] S. Baker *et al.*, "Lucas-kanade 20 years on: A unifying framework: Part 3," The Robotics Institute, Carnegie Mellon University, November 2003. Technical Report CMU-RI-TR-03-35.
- [13] J. P. Barreto and K. Daniilidis, "Fundamental matrix for cameras with radial distortion," in *Tenth International Conference on Computer Vision (ICCV 2005)*, (Beijing, China), vol. 1, pp. 625–632, October 2005.
- [14] A. Bartoli, M. Coquerelle, and P. Sturm, "A framework for pencil-of-points structure-from-motion," in *Eighth European Conference on Computer Vision (ECCV 2004)*, (Prague), vol. II, pp. 28–40, Springer-Verlag, May 2004.
- [15] P. Baudisch *et al.*, "Panoramic viewfinder: Providing a real-time preview to help users avoid flaws in panoramic pictures," in *OZCHI 2005*, (Canberra, Australia), November 2005.
- [16] A. Baumberg, "Reliable feature matching across widely separated views," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2000)*, (Hilton Head Island), vol. 1, pp. 774–781, June 2000.
- [17] H. Bay, T. Tuytelaars, and L. V. Gool, "Surf: Speeded up robust features," in *Computer Vision – ECCV 2006*, (A. Leonardis, H. Bischof, and A. Pinz, eds.), vol. 3951, pp. 404–417, of *Lecture Notes in Computer Science*, Springer, 2006.
- [18] J. S. Beis and D. G. Lowe, "Shape indexing using approximate nearest-neighbour search in high-dimensional spaces," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'97)*, (San Juan, Puerto Rico), pp. 1000–1006, June 1997.
- [19] R. Benosman and S. B. Kang, eds., *Panoramic Vision: Sensors, Theory, and Applications*. New York: Springer, 2001.
- [20] J. R. Bergen, P. Anandan, K. J. Hanna, and R. Hingorani, "Hierarchical model-based motion estimation," in *Second European Conference on Computer Vision (ECCV'92)*, (Santa Margherita Ligure, Italy), pp. 237–252, Springer-Verlag, May 1992.
- [21] J. R. Bergen, P. J. Burt, R. Hingorani, and S. Peleg, "A three-frame algorithm for estimating two-component image motion," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 14, no. 9, pp. 886–896, September 1992.
- [22] M. J. Black and P. Anandan, "The robust estimation of multiple motions: Parametric and piecewise-smooth flow fields," *Computer Vision and Image Understanding*, vol. 63, no. 1, pp. 75–104, 1996.
- [23] M. J. Black and A. D. Jepson, "EigenTracking: Robust matching and tracking of articulated objects using a view-based representation," *International Journal of Computer Vision*, vol. 26, no. 1, pp. 63–84, January 1998.

- [214] P. Viola and W. Wells III, "Alignment by maximization of mutual information," in *Fifth International Conference on Computer Vision (ICCV'95)*, (Cambridge, Massachusetts), pp. 16–23, June 1995.
- [215] L. Wang, S. B. Kang, R. Szeliski, and H.-Y. Shum, "Optimal texture map reconstruction from multiple views," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'2001)*, (Kauai, Hawaii), vol. I, pp. 347–354, December 2001.
- [216] A. Watt, *3D Computer Graphics*. Addison-Wesley, Third Edition, 1995.
- [217] J. Weber and J. Malik, "Robust computation of optical flow in a multi-scale differential framework," *International Journal of Computer Vision*, vol. 14, no. 1, pp. 67–81, January 1995.
- [218] Y. Weiss, "Deriving intrinsic images from image sequences," in *Eighth International Conference on Computer Vision (ICCV 2001)*, (Vancouver, Canada), vol. II, pp. 7–14, July 2001.
- [219] L. Williams, "Pyramidal parametrics," *Computer Graphics*, vol. 17, no. 3, pp. 1–11, July 1983.
- [220] D. N. Wood *et al.*, "Multiperspective panoramas for cell animation," in *Computer Graphics Proceedings, Annual Conference Series*, (Los Angeles), pp. 243–250, Proc. SIGGRAPH'97, ACM SIGGRAPH, August 1997.
- [221] R. J. Woodham, "Analysing images of curved surfaces," *Artificial Intelligence*, vol. 17, pp. 117–140, 1981.
- [222] Y. Xiong and K. Turkowski, "Creating image-based VR using a self-calibrating fisheye lens," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'97)*, (San Juan, Puerto Rico), pp. 237–243, June 1997.
- [223] Y. Xiong and K. Turkowski, "Registration, calibration and blending in creating high quality panoramas," in *IEEE Workshop on Applications of Computer Vision (WACV'98)*, (Princeton), pp. 69–74, IEEE Computer Society, October 1998.
- [224] D. Yang *et al.*, "A 640x512 CMOS image sensor with ultra-wide dynamic range floating-point pixel level ADC," *IEEE Journal of Solid State Circuits*, vol. 34, no. 12, pp. 1821–1834, December 1999.
- [225] R. Zabih and J. Woodfill, "Non-parametric local transforms for computing visual correspondence," in *Third European Conference on Computer Vision (ECCV'94)*, (Stockholm, Sweden), vol. II, pp. 151–158, Springer-Verlag, May 1994.
- [226] B. Zitov'aa and J. Flusser, "Image registration methods: A survey," *Image and Vision Computing*, vol. 21, pp. 997–1000, October 2003.
- [227] I. Zoghlami, O. Faugeras, and R. Deriche, "Using geometric corners to build a 2D mosaic from a set of images," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'97)*, (San Juan, Puerto Rico), pp. 420–425, June 1997.

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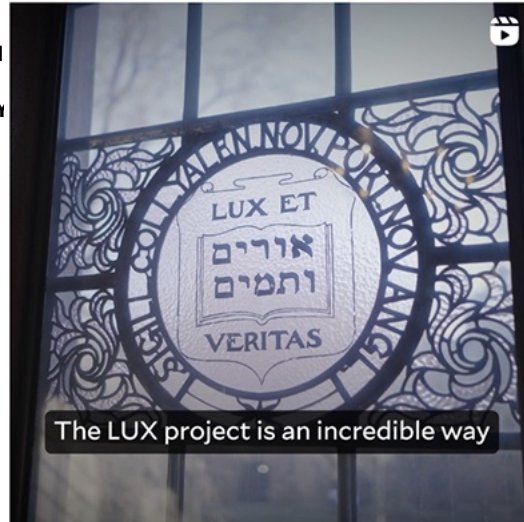
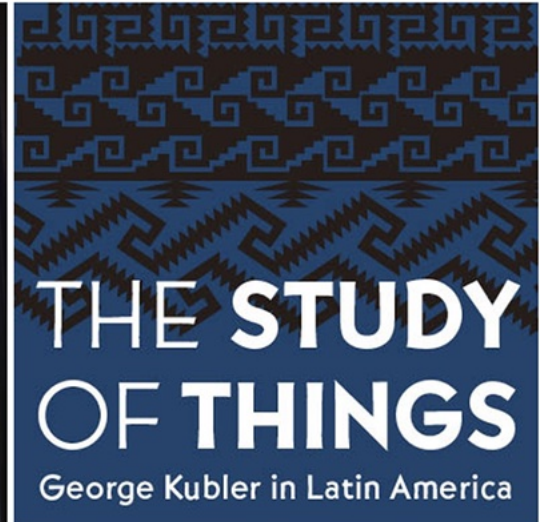
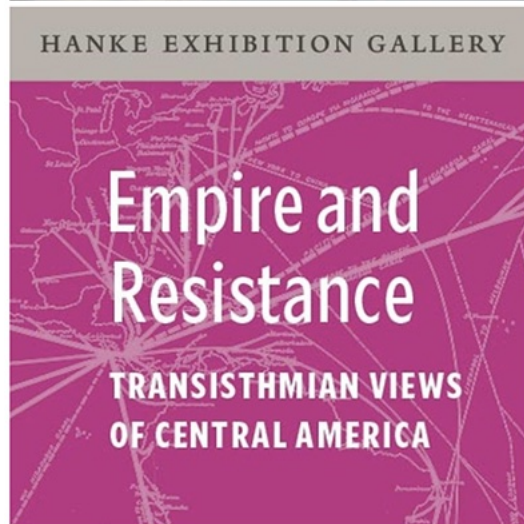
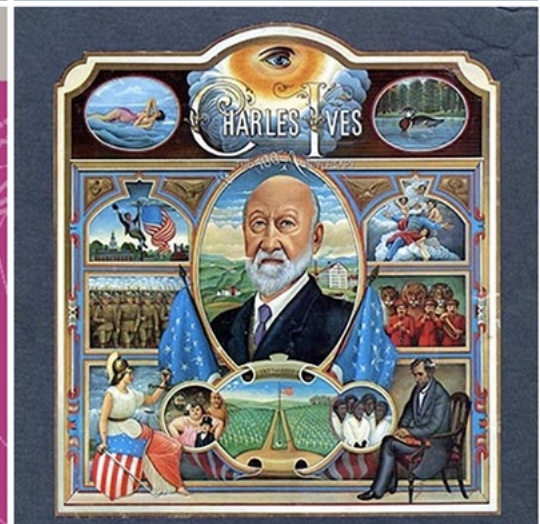
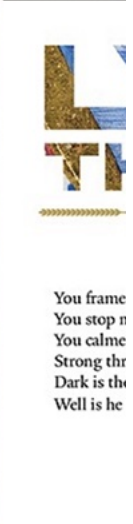
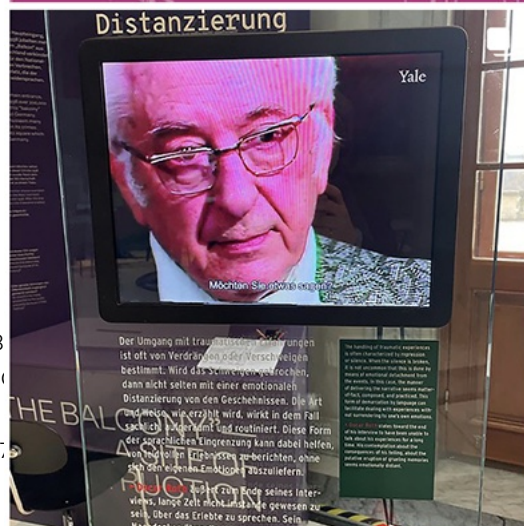
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Foundations and Trends® in
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Volume 2 Issue 1

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Image Alignment and Stitching: A Tutorial

Abstract

This tutorial reviews image alignment and image stitching algorithms. Image alignment algorithms can discover the correspondence relationships among images with varying degrees of overlap. They are ideally suited for applications such as video stabilization, summarization, and the creation of panoramic mosaics. Image stitching algorithms take the alignment estimates produced by such registration algorithms and blend the images in a seamless manner, taking care to deal with potential problems such as blurring or ghosting caused by parallax and scene movement as well as varying image exposures. This tutorial reviews the basic motion models underlying alignment and stitching algorithms, describes effective direct (pixel-based) and feature-based alignment algorithms, and describes blending algorithms used to produce seamless mosaics. It ends with a discussion of open research problems in the area.

Abstract

1 Introduction

2 Motion Models

3 Direct (pixel-based)

Alignment

4 Feature-Based

Registration

5 Global Registration

6 Compositing

7 Extensions and Open

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APPENDIX 1009H

Appendix 1009H

Citations to Szeliski

Source Document

Szeliski, R. (2007). Image alignment and stitching: A tutorial. in *Foundations and Trends in Computer Graphics and Vision*, vol. 2, issue 1, pp. 1-104.

Citations: 2007 (in chronological order)

Zheng, K. C., Kang, S. B., Cohen, M. F., & Szeliski, R. (2007, June). Layered depth panoramas. In *2007 IEEE Conference on Computer Vision and Pattern Recognition* (pp. 1-8). IEEE.

Bielski, C., Grazzini, J., & Soille, P. (2007, July). Automated morphological image composition for mosaicing large image data sets. In *2007 IEEE International Geoscience and Remote Sensing Symposium* (pp. 4068-4071). IEEE.

Kopf, J., Uyttendaele, M., Deussen, O., & Cohen, M. F. (2007, July). Capturing and viewing gigapixel images. *ACM Transactions on Graphics (TOG)*, 26(3), 93-es.

Zelnik-Manor, L., & Perona, P. (2007, August). Automating joiners. In *Proceedings of the 5th international symposium on Non-photorealistic animation and rendering* (pp. 121-131).

Yuan, L., Sun, J., Quan, L., & Shum, H. Y. (2007, October). Blurred/non-blurred image alignment using sparseness prior. In *2007 IEEE 11th International Conference on Computer Vision* (pp. 1-8). IEEE.