

DECLARATION OF JUNE ANN MUNFORD

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.
2. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as Appendix CV.
3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog

search performance and creating lending agreements between libraries during my time as a Library Director.

4. In the process of studying Library and Information Science for my Master's degree, I was instructed in the usage and writing of various standardized data formats including but not limited to MARC (Machine Readable Cataloging), RDA (Resource Description and Access) and Dublin Core.
5. I am familiar with the Dublin Core archival record process. In the process of indexing an item using the Dublin Core format, catalogers will denote information describing the item in question – including bibliographic data such as author, title, publisher, language, licensing rights and format among others. As such, Dublin Core records can be valuable to libraries, museums and other institutions as rigorous and detailed descriptions of materials owned by those institutions.
6. Attached hereto as Appendix DC01 is a screen capture of a page entitled “Creating Metadata” hosted on the DublinCore website at https://dublincore.org/resources/userguide/creating_metadata/. This page describes guidelines followed by catalogers to write and interpret DublinCore data fields. To use an example, consider the ‘Title’ heading

which begins on page 4 of this appendix. This section on assigning a title field contains use cases for materials with single titles, multiple titles and titles containing abbreviations. Depending on the version of DublinCore implemented at the time of the record's creation, the title field of a DublinCore record could be represented as 'DC:title', 'dc.title' or 'dcterms:title'. In each use case, the title field would be indexed using the same set of syntax rules presented in Appendix DC01.

7. I have reviewed Exhibit APPLE-1004, a thesis submitted to the University of Arizona entitled *Development of a Remote Pulse Oximeter* by Joseph Sankman, Brian Bailey, Scott Galvin, Jack Grantham, Scott Little, Erica Morey and Christopher Stemple.
8. Attached hereto as Appendix BAILEY01 are screen captures of the metadata record for *Development of a Remote Pulse Oximeter* from the University of Arizona. I secured these screen captures myself from <https://repository.arizona.edu/handle/10150/146648?show=full> and <https://repository.arizona.edu/handle/10150/146648>.
9. Attached hereto as Appendix BAILEY02 is a copy of a file named 'azu_etd_mr20100136_sip1_m.pdf' containing *Development of a Remote*

Pulse Oximeter. I secured this file from

https://repository.arizona.edu/bitstream/handle/10150/146648/azu_etd_mr20100136_sip1_m.pdf?sequence=1&isAllowed=y.

10. In comparing Appendix BAILEY02 to Exhibit APPLE-1004, it is my determination that Exhibit APPLE-1004 is a true and correct copy of *Development of a Remote Pulse Oximeter*.

11. Considering the record found in Appendix BAILEY01 offers a direct link to ‘azu_etd_mr20100136_sip1_m.pdf’, the metadata record is describing *Development of a Remote Pulse Oximeter*. The DublinCore rules presented on page 29 of Appendix DC01 indicates the ‘Date Available’ should be interpreted as “This property refers to a description of the date a resource did become or will become available. A resource becomes available only once, every other availability belongs to another resource that has to be described on its own.” The dc.date.available field visible on page 1 of Appendix BAILEY01 indicates *Development of a Remote Pulse Oximeter* was first made available to the public as of October 24, 2011.

12. I am familiar with the Internet Archive, a digital library formally certified by the State of California as a public library. Among other services that the

Internet Archive makes available to the general public is the Wayback Machine, an online archive. The Internet Archive's Wayback Machine service archives webpages as of a certain capture date to track changes in the web over time. The Internet Archive has been in operation as a nonprofit library since 1996 and has hosted the Wayback Machine service since its inception in 2001. During my time as a librarian, I frequently used the Internet Archive's Wayback Machine for research and instruction purposes. This includes teaching instructional classes on using the Wayback Machine to library patrons and using the Wayback Machine to research reference inquiries that require hard-to-find online resources. I consider the Internet Archive's recordskeeping to be as rigorous and detailed as other formal library recordskeeping practices such as MARC records, OCLC records and Dublin Core.

13. Appendix BAILEY02 is a copy of *Development of a Remote Pulse Oximeter* downloaded from the University of Arizona's thesis repository. Appendix BAILEY01 is a metadata record describing University of Arizona thesis repository's copy of *Development of a Remote Pulse Oximeter*.

14. Attached hereto as Appendix IA01 is a screen capture of the Internet Archive Wayback Machine entry for

<http://www.library.arizona.edu/help/tutorials/dissertations/index.html>. I

secured these screen captures myself from

<https://web.archive.org/web/20120209080543/http://www.library.arizona.edu/help/tutorials/dissertations/index.html>.

15. Contained within Appendix IA01 is webpage entitled “Dissertations and Theses in the UA Libraries” hosted on the University of Arizona webpage as of February 9, 2012. This page, authored by the University of Arizona library, describes the various holdings and distribution processes involved with the University of Arizona’s thesis repository. This page references several resources that make the university’s theses available: a collection held at academic database service ProQuest, the University of Arizona open-access campus repository and the University of Arizona library’s online catalog. This same page indicates on page 3 that the University of Arizona’s library catalog allows users to search by author, title, keyword or subject.

16. Attached hereto as Appendix IA02 is a screen capture of the Internet

Archive Wayback Machine entry for

<http://www.library.arizona.edu/help/how/keywordsearch.html>. I secured

these screen captures myself from

<https://web.archive.org/web/20091023104154/http://www.library.arizona.edu/help/how/keywordsearch.html>.

17. Contained within Appendix IA02 is a webpage entitled “Library Catalog – Advanced Keyword Search Tips” hosted on the University of Arizona’s website as of October 23, 2009. This page is a detailed description of the University of Arizona library catalog’s search features. Page 3 of Appendix IA02 indicates that users may search the library catalog using keyword searches, boolean language such as ‘and or or’ as well as proximity operators such as ‘after, before, near, within # (number of words)’. Page 4 of Appendix IA02 indicates the library catalog can be search-limited by the following fields: author, title, subject and note. Page 5 indicates that users may further limit search results by format, holding location, language and years of publication.

18. Considering Appendix BAILEY01 indicates that *Development of a Remote Pulse Oximeter* was first made available by the University of Arizona as of October 24, 2011, Appendix IA01 indicates the University’s theses are available from multiple university resources including the library catalog and Appendix IA02 indicates the library catalog can be searched using complex language strings, it is my determination that *Development of a Remote Pulse Oximeter* was first made available to the public by the University of Arizona as of October 24, 2011 and has been sufficiently

indexed in such a way that a person of ordinary skill could discover the University of Arizona's holdings for *Development of a Remote Pulse Oximeter*.

19. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in Machine Readable Catalog (herein referred to as "MARC") code and contain information such as a physical description of the material, metadata from the material's publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access, it is my experience that an item's MARC record indicates the date of an item's public availability.

20. Typically, in creating a MARC record, a librarian would gather various bits of metadata such as book title, publisher and subject headings among others and assign each value to a relevant numerical field. For example, a book's physical description is tracked in field 300 while title/attribution is tracked in field 245. Fields 650 and 655 are frequently used to index library materials by subject. The 008 field of the MARC record is reserved for denoting the

creation of the library record itself. As this is the only date reflecting the inclusion of said materials within the library's collection, it is my experience that an item's 008 field accurately indicates the date of an item's public availability.

21.I have reviewed Exhibit APPLE-1011, "A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring" by Y. Mendelson, R.J. Duckworth and G. Comtois as published in *Proceedings of the 28th IEEE EMBS Annual International Conference*, 2006.

22.I have reviewed Exhibit APPLE-1007, "A Sensor Network to iPhone Interface Separating Continuous and Sporadic Processes in Mobile Telemedicine" by Lorenzo T. D'Angelo, Michael Schneider, Paul Neugubauer and Tim C. Lueth as published in *Proceedings of the 33rd IEEE EMBS Annual International Conference*, 2011.

23.Attached hereto as Appendix OSU01 is a true and correct copy of the MARC record for *Proceedings of the IEEE EMBS Annual International Conference* as held by the Ohio State University library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix OSU01 accurately describes the title, author,

publisher, and ISSN number of *Proceedings of the IEEE EMBS Annual International Conference*. Due to the record's inclusion in the library catalog, these proceedings have been indexed by subject and made searchable by keyword- and subject-level searching. I spoke with staff at the Ohio State University library who confirmed that their collection of *Proceedings of the IEEE EMBS Annual International Conference* contains the proceedings of the 28th conference containing "A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring" (APPLE-1011) and the 33rd conference containing "A Sensor Network to iPhone Interface Separating Continuous and Sporadic Processes in Mobile Telemedicine" (APPLE-1007).

24. Attached hereto as Appendix SU01 is a true and correct copy of the MARC record for *Proceedings of the IEEE EMBS Annual International Conference* as held by the Syracuse University library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix SU01 accurately describes the title, author, publisher, and ISSN number of *Proceedings of the IEEE EMBS Annual International Conference*. Due to the record's inclusion in the library catalog, these proceedings have been indexed by subject and made searchable by keyword- and subject-level searching. I spoke with staff at the Syracuse University library who

confirmed that their collection of *Proceedings of the IEEE EMBS Annual International Conference* contains the proceedings of the 28th conference containing “A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring” (APPLE-1011) and the 33rd conference containing “A Sensor Network to iPhone Interface Separating Continuous and Sporadic Processes in Mobile Telemedicine” (APPLE-1007).

25. Attached hereto as Appendix UOFM01 is a true and correct copy of the MARC record for *Proceedings of the IEEE EMBS Annual International Conference* as held by the University of Michigan library. I secured this record myself from the library’s public catalog. The MARC record contained within Appendix UOFM01 accurately describes the title, author, publisher, and ISSN number of *Proceedings of the IEEE EMBS Annual International Conference*. Due to the record’s inclusion in the library catalog, these proceedings have been indexed by subject and made searchable by keyword- and subject-level searching. I spoke with staff at the University of Michigan library who confirmed that their collection of *Proceedings of the IEEE EMBS Annual International Conference* contains the proceedings of the 28th conference containing “A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring” (APPLE-1011) and the 33rd conference containing “A Sensor Network to iPhone Interface

Separating Continuous and Sporadic Processes in Mobile Telemedicine”
(APPLE-1007).

26. Attached hereto as Appendix MENDELSON01 is a true and correct copy of
“A Wearable Reflectance Pulse Oximeter for Remote Physiological
Monitoring” as published in *Proceedings of the 28th IEEE EMBS Annual
International Conference* as held by the Ohio State University library. I
secured this file myself from the library’s collection. In comparing Exhibit
APPLE-1011 to Appendix MENDELSON01, it is my determination that
Exhibit APPLE-1011 is a true and correct copy of “A Wearable Reflectance
Pulse Oximeter for Remote Physiological Monitoring” as published in
Proceedings of the 28th IEEE EMBS Annual International Conference by Y.
Mendelson, R.J. Duckworth and G. Comtois.

27. Attached hereto as Appendix DANGELO01 is a true and correct copy of “A
Sensor Network to iPhone Interface Separating Continuous and Sporadic
Processes in Mobile Telemedicine” as published in *Proceedings of the 33rd
IEEE EMBS Annual International Conference* as held by the Ohio State
University library. I secured this file myself from the library’s collection. In
comparing Exhibit APPLE-1007 to Appendix DANGELO01, it is my
determination that Exhibit APPLE-1007 is a true and correct copy of “A

Sensor Network to iPhone Interface Separating Continuous and Sporadic Processes in Mobile Telemedicine” as published in *Proceedings of the 33rd IEEE EMBS Annual International Conference* by Lorenzo T. D’Angelo, Michael Schneider, Paul Neugubauer and Tim C. Lueth.

28. I am familiar with the Internet Archive, a digital library formally certified by the State of California as a public library. Among other services that the Internet Archive makes available to the general public is the Wayback Machine, an online archive. The Internet Archive’s Wayback Machine service archives webpages as of a certain capture date to track changes in the web over time. The Internet Archive has been in operation as a nonprofit library since 1996 and has hosted the Wayback Machine service since its inception in 2001. During my time as a librarian, I frequently used the Internet Archive’s Wayback Machine for research and instruction purposes. This includes teaching instructional classes on using the Wayback Machine to library patrons and using the Wayback Machine to research reference inquiries that require hard-to-find online resources. I consider the Internet Archive’s recordskeeping to be as rigorous and detailed as other formal library recordskeeping practices such as MARC records, OCLC records and Dublin Core.

29. Attached hereto as Appendix MENDELSON02 is a screen capture of the Internet Archive Wayback Machine entry for <http://embs.gsbme.unsw.edu.au/confs.html>. I secured these screen captures myself from https://web.archive.org/web/20060515000000*/http://embs.gsbme.unsw.edu.au/confs.html. This particular record is dated as May 15, 2006.
30. Appendix MENDELSON02 is a screen capture of a webpage entitled “IEEE EMBSH Sponsorship of Conferences” hosted by the IEEE Engineering in Medicine and Biology Society. As visible on page 3 of this Appendix, the 2006 IEEE EMBC Conference where “A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring” was presented is being advertised to take place from August 30 – September 3, 2006. As the capture date of this record is May 15, 2006, this web page also indicates that the IEEE EMBS was advertising this conference months before it took place.
31. Attached hereto as Appendix DANGELO02 is a screen capture of the Internet Archive Wayback Machine entry for <http://www.embs.org/conferences/index.html>. I secured these screen captures myself from

<https://web.archive.org/web/20110718005649/http://www.embs.org/conferences/index.html>. This particular record is dated as July 18, 2011.

32. Appendix DANGELO02 is a screen capture of a webpage entitled “IEEE EMBSH Sponsorship of Conferences” hosted by the IEEE Engineering in Medicine and Biology Society. As visible on page 2 of this Appendix, the 2011 IEEE EMBC Conference where “A Sensor Network to iPhone Interface Separating Continuous and Sporadic Processes in Mobile Telemedicine” was presented is being advertised to take place from August 30 – September 3, 2011. As the capture date of this record is July 18, this web page also indicates that the IEEE EMBS was advertising this conference a month before it took place.

33. The 008 field of the MARC record in Appendix OSU01 indicates the date of record creation. The 008 field of Appendix OSU01 indicates the Ohio State University library first acquired these proceedings as of March 11, 2005 and continued to acquire new editions in perpetuity.

34. The 008 field of the MARC record in Appendix SU01 indicates the date of record creation. The 008 field of Appendix SU01 indicates the Syracuse

University library first acquired these proceedings as of March 11, 2005 and continued to acquire new editions in perpetuity.

35. The 008 field of the MARC record in Appendix UOFM01 indicates the date of record creation. The 008 field of Appendix UOFM01 indicates the University of Michigan library first acquired these proceedings as of July 22, 2005 and continued to acquire new editions in perpetuity.

36. “A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring” was published in the 28th edition of *Proceedings of the IEEE EMBS Annual International Conference*. This paper was presented at the 2006 edition of the IEEE EMBS Annual International Conference and Appendix MENDELSON02 indicates this conference held from August 30, 2006 – September 3 2006. As multiple universities were collecting new editions of *Proceedings of the IEEE EMBS Annual International Conference* as of September 2006, it is my determination that “A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring” was first made available to the public at the 2006 IEEE EMBS Annual International Conference and was shortly after made available to the public from the Ohio State University, Syracuse University and University of Michigan among others.

37. “A Sensor Network to iPhone Interface Separating Continuous and Sporadic Processes in Mobile Telemedicine” was published in the 33rd edition of *Proceedings of the IEEE EMBS Annual International Conference*. This paper was presented at the 2011 edition of the IEEE EMBS Annual International Conference and Appendix DANGELO02 indicates this conference held from August 30, 2011 – September 3 2011. As multiple universities were collecting new editions of *Proceedings of the IEEE EMBS Annual International Conference* as of September 2011, it is my determination that “A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring” was first made available to the public at the 2011 IEEE EMBS Annual International Conference and was shortly after made available to the public from the Ohio State University, Syracuse University and University of Michigan among others via the conference proceedings.
38. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am being compensated for my services in this matter at the rate of \$200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

39. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of 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 punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 12/11/2023

A handwritten signature in cursive script, appearing to read "June Ann Munford".

June Ann Munford

APPENDIX CV

June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.
- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.
- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in

Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over \$400,000 and total assets of approximately \$1,300,000.

- Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.
- Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.
- Led the organization and digitization of the library's archival records.
- Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.
- Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013

Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

- Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.
- Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.
- Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013

Library Assistant, Hart Area Public Library
Hart, MI

- Responsible for verifying imported MARC records and original MARC

cataloging for the local-level collection as well as the Michigan Electronic Library.

- Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter

- Treasurer, 2012

Library Of Michigan

- Level VII Certification, 2008
- Level II Certification, 2013

Michigan Library Association Annual Conference 2014

- New Directors Conference Panel Member

Southwest Michigan Library Cooperative

- Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008

Petoskey, MI

- Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011

Nashville, TN

- Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012

Fairbanks, AK

- Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Civil Action No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Cases IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (IPR2021-01182)

2023 ● Fish & Richardson

Neuroderm Ltd. v. Abbvie, Inc (Case No. PGR2022-00040)

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (IPR2022-00735)

Limited Case History & Potential Conflicts

Alston & Bird

- Ericsson
 - v. Collision Communications (IPR2022-01233)
- Nokia
 - v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)

Arnold & Porter

- Ivantis
 - v. Glaukos (Case No. 8:18-cv-00620)
- Samsung
 - v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis
 - v. Cathx (Case No. 5:21-cv-00077-RWS)

Erise I.P.

- Apple
 - v. Ericsson Inc. (IPR2022-00715)
 - v. Future Link Systems (IPRs 6317804, 6622108, 6807505, and 7917680)
 - v. INVT (Case No. 20-1881)
 - v. Navblazer LLC (IPR2020-01253)
 - v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)
 - v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)
 - v. Telefonaktiebolaget LM Ericsson (IPR2022-00275)

- Fanduel
 - v. CGT (Case No. 19-1393)
- Garmin
 - v. Phillips North America LLC (Case No. 2:19-cv-6301-AB-KS)
- Netscout
 - v. Longhorn HD LLC (Case No. 2:20-cv-00349)
 - v. Implicit, LLC (Civil Action No. 2:18-cv-53-JRG)
- Sony Interactive Entertainment LLC
 - v. Bot M8 LLC (IPR2020-01288)
 - v. Infernal Technology LLC (Case No. 2:19-CV-00248-JRG)
- Unified Patents
 - v. GE Video Compression (Civil Action No. 2:19-cv-248)

Fish & Richardson

- Apple
 - v. AliveCor (3:21-cv-03958)
 - v. LBS Innovations (Case No. 2:19-cv-00119-JRG-RSP)
 - v. Koss Corporation (IPR2021-00305)
 - v. Masimo (IPR 50095-0012IP1, 50095-0012IP2, 50095-0013IP1, 50095-0013IP2, 50095-0006IP1)
 - v. Neonode (Case No. 21-cv-08872-EMC)
 - v. Qualcomm (IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)
- Dell
 - v. Neo Wireless (IPR2022-00616)

- Dish Network
 - v. Realtime Adaptive Streaming (Case No. 1:17-CV-02097-RBJ)
 - v. TQ Delta LLC (Case No. 18-1798)
- Evapco Dry Cooling
 - v. SPG Dry Cooling (IPR2021-00688)
- Genetec
 - v. Sensormatic Electronics (Case No. 1:20-CV-00760)
- Huawei
 - v. Bell Northern Research LLC (IPR2019-01174)
- Kianxis
 - v. Blue Yonder (Case No. 3:20-cv-03636)
- LG Electronics
 - v. Bell Northern Research LLC (Case No. 3:18-cv-2864-CAB-BLM)
- Metaswitch
 - v. Sonus Networks (IPR2018-01719)
- Microsoft
 - v. Throughputer Inc (IPR2022-00757)
- MLC Intellectual Property
 - v. MicronTech (Case No. 3:14-cv-03657-SI)
- Nearmap Inc
 - v. EagleView Technologies (IPR2022-01009)
- Neuroderm Ltd.
 - v. Abbvie, Inc (Case No. PGR2022-00040)
- Realtek Semiconductor
 - v. Future Link (IPR2021-01182)

- Quectel
 - v. Koninklijke Philips (Case No. 1:20-cv-01710)
- Samsung
 - v. Aire Technology (IPR2022-00877)
 - v. Bell Northern Research (Case No. 2:19-cv-00286-JRG)
 - v. Communication Technologies Inc (IPR2022-01221)
 - v. Jawbone Innovations (IPR2022-00865)
 - v. MemoryWeb LLC (IPR2022-00885)
 - v. Telefonaktiebolaget LM Ericsson (IPR2021-00615)
- Texas Instruments
 - v. Vantage Micro LLC (IPR2020-01261)
- Xilinx
 - v. Sentient Sensors LCC (Case No. 1:22-cv-00173)

Irell & Manella

- Curium

O'Melveny & Myers

- Apple
 - v. Maxell (Case No. 5:19-cv-00036-RWS)

Perkins-Coie

- Heru Industries
 - v. The UAB Research Foundation (IPR2022-01148)
- Realtek Semiconductor
 - v. Future Link (IPR2021-01182)

- Twitter Inc
 - v. VOIP-Pal.com (Case No. 3:20-cv-02397-JD)
- TCL Industries
 - v. Koninklijke Philips NV (IPR2021-00495, IPR2021-00496 and IPR2021-00497)

Pillsbury Winthrop Shaw Pittman

- Intel
 - v. FG SRC LLC (Case No. 6:20-cv-00315)
- Gravel Rating Systems
 - v. Costco (Case No. 4:21-cv-149)
 - v. Lowe's Home Centers (Case No. 4:21-cv-150)
 - v. T-Mobile USA (Case No. 4:21-cv-152)
 - v. Kohl's Inc. (Case No. 4:21-cv-258)
 - v. Under Armor (Case No. 4:21-cv-356)

APPENDIX BAILEY01



Login

Home / UA Graduate and Undergraduate Research / UA Theses and Dissertations / Honors Theses / View Item

Browse

All of UA Campus Repository

- Communities
- Title
- Authors
- Issue Date
- Submit Date
- Subjects
- Publisher
- Journal

This Collection

- Title
- Authors
- Issue Date
- Submit Date
- Subjects
- Publisher
- Journal

My Account

- Login
- Register

About

- About
- UA Faculty Publications
- UA Dissertations
- UA Master's Theses
- UA Honors Theses
- UA Press
- UA Yearbooks
- UA Catalogs
- UA Libraries

Statistics

- Most Popular Items
- Statistics by Country
- Most Popular Authors

Search



Show simple item record

Development of a Remote Pulse Oximeter

Export

dc.contributor.author	Sankman, Joseph	
dc.contributor.author	Bailey, Brian	
dc.contributor.author	Ebel, Brian	
dc.contributor.author	Galvin, Scott	
dc.contributor.author	Grantham, Jack	
dc.contributor.author	Little, Scott	
dc.contributor.author	Morey, Erica	
dc.contributor.author	Stemple, Christopher	
dc.creator	Sankman, Joseph	en_US
dc.creator	Bailey, Brian	en_US
dc.creator	Ebel, Brian	en_US
dc.creator	Galvin, Scott	en_US
dc.creator	Grantham, Jack	en_US
dc.creator	Little, Scott	en_US
dc.creator	Morey, Erica	en_US
dc.creator	Stemple, Christopher	en_US
dc.date.accessioned	2011-10-24T18:51:55Z	
dc.date.available	2011-10-24T18:51:55Z	
dc.date.issued	2010-05	
dc.identifier.citation	Sankman, Joseph, Bailey, Brian, Ebel, Brian, Galvin, Scott, Grantham, Jack, Little, Scott, Morey, Erica, & Stemple, Christopher. (2010). Development of a Remote Pulse Oximeter (Bachelor's thesis, University of Arizona, Tucson, USA).	
dc.identifier.uri	http://hdl.handle.net/10150/146648	
dc.description.abstract	Pulse oximetry is widely maintained as the standard method for measuring a person's blood oxygen saturation. Monitoring such a vital sign allows for detecting the onset and progression of various diseases and conditions that could result in tissue and organ damage or death due to lack of required oxygen delivery. The goal of this project was to design a pulse oximeter geared toward consumer use that could wirelessly transmit data to a portable device, such as a smartphone, for convenient, remote monitoring of oxygen saturation. This report describes the design process for developing a working prototype of the pulse oximeter. Texas Instruments sponsored this project for the Interdisciplinary Engineering Design Program at the University of Arizona. Their goal in funding this project was to develop an intimate knowledge base of the considerations, components, and overall design of a pulse oximeter in order to better assist their customers. The creation of the pulse oximeter reference design was inspired by thorough research on the scientific principles underlying pulse oximetry as well as existing pulse oximeter technologies. From the information collected, the team developed three potential designs for the device. Analysis of each design was conducted to distinguish the one design that would be further developed and fabricated into the working reference design required by the project sponsor. Results obtained by testing the final prototype, discussion of future directions for the reference design, and conclusions drawn from the completion of the project are also presented in this report.	
dc.language.iso	en	en_US
dc.publisher	The University of Arizona.	en_US
dc.rights	Copyright © is held by the author. Digital access to this material is made possible by the	en_US

University Libraries, University of Arizona. Further transmission, reproduction or presentation (such as public display or performance) of protected items is prohibited except with permission of the author.		
dc.rights.uri	http://rightsstatements.org/vocab/InC/1.0/	
dc.title	Development of a Remote Pulse Oximeter	en_US
dc.type	text	en_US
dc.type	Electronic Thesis	en_US
thesis.degree.grantor	University of Arizona	en_US
thesis.degree.level	bachelors	en_US
thesis.degree.discipline	Honors College	en_US
thesis.degree.discipline	Electrical Engineering	en_US
thesis.degree.name	B.S.	en_US
refterms.dateFOA	2018-08-15T22:34:07Z	
html.description.abstract	Pulse oximetry is widely maintained as the standard method for measuring a person's blood oxygen saturation. Monitoring such a vital sign allows for detecting the onset and progression of various diseases and conditions that could result in tissue and organ damage or death due to lack of required oxygen delivery. The goal of this project was to design a pulse oximeter geared toward consumer use that could wirelessly transmit data to a portable device, such as a smartphone, for convenient, remote monitoring of oxygen saturation. This report describes the design process for developing a working prototype of the pulse oximeter. Texas Instruments sponsored this project for the Interdisciplinary Engineering Design Program at the University of Arizona. Their goal in funding this project was to develop an intimate knowledge base of the considerations, components, and overall design of a pulse oximeter in order to better assist their customers. The creation of the pulse oximeter reference design was inspired by thorough research on the scientific principles underlying pulse oximetry as well as existing pulse oximeter technologies. From the information collected, the team developed three potential designs for the device. Analysis of each design was conducted to distinguish the one design that would be further developed and fabricated into the working reference design required by the project sponsor. Results obtained by testing the final prototype, discussion of future directions for the reference design, and conclusions drawn from the completion of the project are also presented in this report.	

Files in this item



Name:
azu_etd_mr20100136_sip1_m.pdf

Size:
4.330Mb

Format:
PDF

[Download](#)

This item appears in the following Collection(s)

- [Honors Theses](#)
- [Show simple item record](#)

[Show Statistical Information](#)



Login

Home / UA Graduate and Undergraduate Research / UA Theses and Dissertations / Honors Theses / View Item

Browse

All of UA Campus Repository

- Communities
- Title
- Authors
- Issue Date
- Submit Date
- Subjects
- Publisher
- Journal

This Collection

- Title
- Authors
- Issue Date
- Submit Date
- Subjects
- Publisher
- Journal

My Account

- Login
- Register

About

- About
- UA Faculty Publications
- UA Dissertations
- UA Master's Theses
- UA Honors Theses
- UA Press
- UA Yearbooks
- UA Catalogs
- UA Libraries

Statistics

- Most Popular Items
- Statistics by Country
- Most Popular Authors

Search



Development of a Remote Pulse Oximeter

Export



Name:
azu_etd_mr20100136_sip1_m.pdf
Size:
4.330Mb
Format:
PDF

Download

Author
Sankman, Joseph
Bailey, Brian
Ebel, Brian
Galvin, Scott
Grantham, Jack
Little, Scott
Morey, Erica
Stemple, Christopher

Issue Date
2010-05

Metadata
[Show full item record](#)

Publisher
The University of Arizona.

Rights
Copyright © is held by the author. Digital access to this material is made possible by the University Libraries, University of Arizona. Further transmission, reproduction or presentation (such as public display or performance) of protected items is prohibited except with permission of the author.

Abstract
Pulse oximetry is widely maintained as the standard method for measuring a person's blood oxygen saturation. Monitoring such a vital sign allows for detecting the onset and progression of various diseases and conditions that could result in tissue and organ damage or death due to lack of required oxygen delivery. The goal of this project was to design a pulse oximeter geared toward consumer use that could wirelessly transmit data to a portable device, such as a smartphone, for convenient, remote monitoring of oxygen saturation. This report describes the design process for developing a working prototype of the pulse oximeter. Texas Instruments sponsored this project for the Interdisciplinary Engineering Design Program at the University of Arizona. Their goal in funding this project was to develop an intimate knowledge base of the considerations, components, and overall design of a pulse oximeter in order to better assist their customers. The creation of the pulse oximeter reference design was inspired by thorough research on the scientific principles underlying pulse oximetry as well as existing pulse oximeter technologies. From the information collected, the team developed three potential designs for the device. Analysis of each design was conducted to distinguish the one design that would be further developed and fabricated into the working reference design required by the project sponsor. Results obtained by testing the final prototype, discussion of future directions for the reference design, and conclusions drawn from the completion of the project are also presented in this report.

Type
text
Electronic Thesis

Degree Name
B.S.

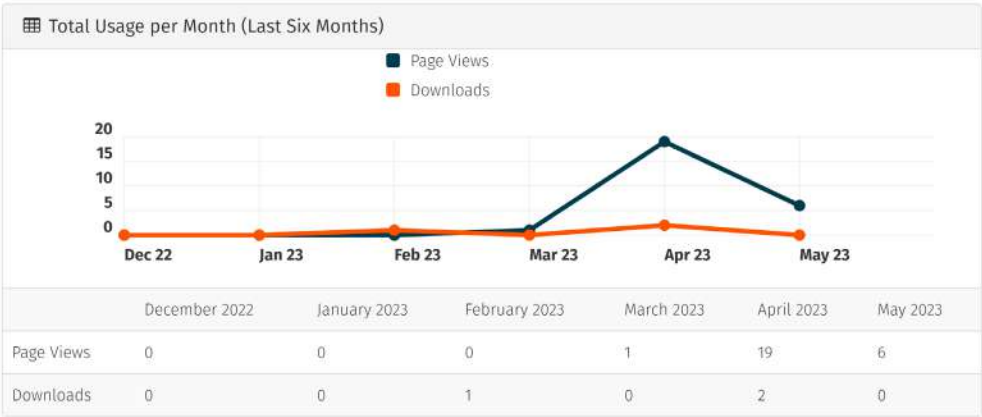
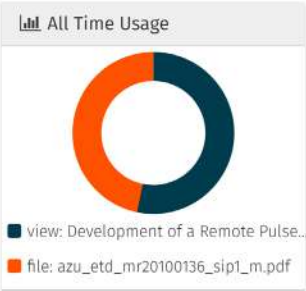
Degree Level
bachelors

Degree Program
Honors College
Electrical Engineering

Degree Grantor
University of Arizona

Collections
[Honors Theses](#)

Hide Statistical Information



Top Country Visits (All Time)

United States
235
China
149
Russia
84
United Kingdom
34
France
30
Netherlands
30
Germany
22
South Korea
15
Ukraine
14
Ireland
14

Top City Visits (All Time)

Beijing
113
Tucson
24
Sayreville
18
Ennis
14
Woodbridge
14
Seattle
9
Shanghai
8
Tianjin
6
Pittsburgh
6
Chongqing
6





The University of Arizona Libraries | 1510 E. University Blvd. | Tucson, AZ 85721-0055
Tel 520-621-6442 | repository@u.library.arizona.edu
DSpace software copyright © 2002-2017 DuraSpace
[Quick Guide](#) | [Contact Us](#) | [Send Feedback](#)

Open Repository is a service
operated by

The ATMIRE logo consists of a stylized blue and white triangle to the left of the word "ATMIRE" in a bold, sans-serif font.

APPENDIX BAILEY02



Development of a Remote Pulse Oximeter

Item Type	text; Electronic Thesis
Authors	Sankman, Joseph; Bailey, Brian; Ebel, Brian; Galvin, Scott; Grantham, Jack; Little, Scott; Morey, Erica; Stemple, Christopher
Citation	Sankman, Joseph, Bailey, Brian, Ebel, Brian, Galvin, Scott, Grantham, Jack, Little, Scott, Morey, Erica, & Stemple, Christopher. (2010). Development of a Remote Pulse Oximeter (Bachelor's thesis, University of Arizona, Tucson, USA).
Publisher	The University of Arizona.
Rights	Copyright © is held by the author. Digital access to this material is made possible by the University Libraries, University of Arizona. Further transmission, reproduction or presentation (such as public display or performance) of protected items is prohibited except with permission of the author.
Download date	16/06/2023 14:52:41
Item License	http://rightsstatements.org/vocab/InC/1.0/
Link to Item	http://hdl.handle.net/10150/146648

DEVELOPMENT OF A
REMOTE PULSE OXIMETER

By

BRIAN BAILEY
BRIAN EBEL
SCOTT GALVIN
JACK GRANTHAM
SCOTT LITTLE
ERICA MOREY
JOSEPH SANKMAN
CHRISTOPHER STEMPLE

A Thesis Submitted to The Honors College
In Partial Fulfillment of the Bachelors degree

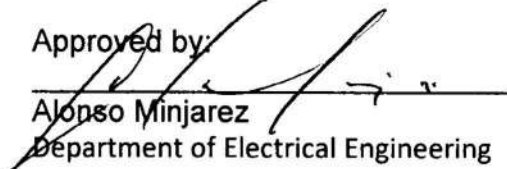
With Honors in

Electrical Engineering

THE UNIVERSITY OF ARIZONA

May 2010

Approved by:



Alonso Minjarez

Department of Electrical Engineering

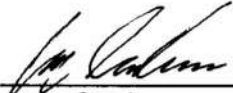
The University of Arizona Electronic Theses and Dissertations Reproduction and Distribution Rights Form

Name (Last, First, Middle) Sankman, Joseph, A	
Degree title (eg BA, BS, BSE, BSB, BFA): BS Engineering	
Honors area (eg Molecular and Cellular Biology, English, Studio Art): Electrical Engineering	
Date thesis submitted to Honors College: 5-5-10	
Title of Honors thesis: Development of Remote Pulse Oximeter	
:The University of Arizona Library Release	I hereby grant to the University of Arizona Library the nonexclusive worldwide right to reproduce and distribute my dissertation or thesis and abstract (herein, the "licensed materials"), in whole or in part, in any and all media of distribution and in any format in existence now or developed in the future. I represent and warrant to the University of Arizona that the licensed materials are my original work, that I am the sole owner of all rights in and to the licensed materials, and that none of the licensed materials infringe or violate the rights of others. I further represent that I have obtained all necessary rights to permit the University of Arizona Library to reproduce and distribute any nonpublic third party software necessary to access, display, run or print my dissertation or thesis. I acknowledge that University of Arizona Library may elect not to distribute my dissertation or thesis in digital format if, in its reasonable judgment, it believes all such rights have not been secured. Signed: <u><i>J. Sankman</i></u> Date: <u>5-5-10</u>

Last updated: Nov 15, 2009

Statement of Responsibilities:

Brian Bailey:	Microcontroller coding and wireless design
Brian Ebel:	LED driver design
Scott Galvin:	Optical design and photodiode research
Jack Grantham:	User interface design and coding
Scott Little:	LED driver design
Erica Morey:	Housing design, research on pulse oximetry
Joseph Sankman:	Transimpedance amplifier design
Christopher Stemple:	Team lead and manager and amplifier design



Joey Sankman

Date: 5-5-10

Development of a Remote Pulse Oximeter

Submitted by Team 4171:

Brian Bailey
Brian Ebel
Scott Galvin
Jack Grantham
Scott Little
Erica Morey
Joseph Sankman
Christopher Stemple

Submitted to:

Fred Highton (Mentor)
Matthew Hann (Sponsor)

Submitted on:

May 1, 2010

**Interdisciplinary Engineering Design Program
University of Arizona**

FRONTISPIECE



The team members comprising the Remote Pulse Oximeter design group. Members on bottom row starting at left: Brian Ebel, Erica Morey, Joey Sankman, and Brian Bailey. Members on top row starting at left: Scott Galvin, Jack Grantham, Christopher Stemple, and Scott Little.

ABSTRACT

Pulse oximetry is widely maintained as the standard method for measuring a person's blood oxygen saturation. Monitoring such a vital sign allows for detecting the onset and progression of various diseases and conditions that could result in tissue and organ damage or death due to lack of required oxygen delivery. The goal of this project was to design a pulse oximeter geared toward consumer use that could wirelessly transmit data to a portable device, such as a smartphone, for convenient, remote monitoring of oxygen saturation. This report describes the design process for developing a working prototype of the pulse oximeter. Texas Instruments sponsored this project for the Interdisciplinary Engineering Design Program at the University of Arizona. Their goal in funding this project was to develop an intimate knowledge base of the considerations, components, and overall design of a pulse oximeter in order to better assist their customers. The creation of the pulse oximeter reference design was inspired by thorough research on the scientific principles underlying pulse oximetry as well as existing pulse oximeter technologies. From the information collected, the team developed three potential designs for the device. Analysis of each design was conducted to distinguish the one design that would be further developed and fabricated into the working reference design required by the project sponsor. Results obtained by testing the final prototype, discussion of future directions for the reference design, and conclusions drawn from the completion of the project are also presented in this report.

TABLE OF CONTENTS

1	Introduction	8
2	Theory	9
2.1	Background & Assumptions	9
2.2	Principles of Pulse Oximetry	10
3	System Requirements	13
3.1	Accuracy	13
3.2	Battery Life	13
3.3	Perceptible Alert Signal	14
3.4	Data Logging	14
3.5	Transmission Distance	14
3.6	Shock Resistance	14
3.7	Water Resistance	15
4	Design Concepts & Analysis	15
4.1	Design 1	16
4.2	Design 2	17
4.3	Design 3	18
4.4	Concept Analysis	20
5	Final Design Breakdown	22
5.1	Theory of Operation	22
5.2	Subsystems	22
5.2.1	Housing	24
5.2.2	Source/Detector	27
5.2.3	LED Driver	29
5.2.4	Transimpedance Amplifier	34
5.2.5	Digital Interface	45
5.2.6	User Interface	47
6	System Build	51
6.1	Subsystem Testing	51
6.2	Subsystem Integration	53
7	System Testing	54
7.1	Housing Testing	55

7.2	LED Driver Testing	58
7.3	Transimpedance Amplifier Testing	59
7.4	Microcontroller Testing	61
7.5	User Interface Testing	62
8	Conclusions & Recommendations	63
9	Acknowledgements.....	65
10	References	66
11	Appendix A: Main Component List	67
12	Appendix B: Bill of Materials.....	68
13	Appendix C: Project Budget/Expenses.....	70
14	Appendix D: Housing Material Properties	71
15	Appendix E: Microcontroller Source Code.....	77

LIST OF TABLES

Table 1: System requirements specified by sponsor for final pulse oximeter design	13
Table 2: Pugh study for three design concepts.....	21
Table 3: Bits 1 and 0 of the pointing register which determine where the next read/write will occur	46
Table 4: Both bytes of the configuration register to be written to	46
Table 5: Subsystem testing procedures and results	52
Table 6: Testing equipment	53
Table 7: Overall system testing procedure and results	55

LIST OF FIGURES

Figure 1: Typical pulse oximeter configuration [4]	10
Figure 2: Attenuation of oxyhemoglobin and deoxyhemoglobin with wavelength [5]	11
Figure 3: Representation of light absorption with time [8]	12
Figure 4: Design 1 - (Left) LED driver circuit. (Right) Driver current output	16
Figure 5: Design 2 - (Left) LED driver circuit. (Right) Driver current output	18
Figure 6: Design 3 - (Left) LED driver design. (Right) Driver current output.....	19
Figure 7: Block diagram showing final design by subsections	23
Figure 8: Sensor housing: (Left) Trimetric view, (Right) Cross-sectional view.....	25
Figure 9: Exploded view of sensor housing: (Left) Top/front housing arm. (Right) Bottom/back housing arm	25
Figure 10: Main housing: (Left) Exterior of housing, (Right) Exploded view showing components.....	26
Figure 11: Photo of completed prototype and iPod Touch used for interface.....	26
Figure 12: Infrared LED, red LED, and photodiode selected (left to right). Relative sizes are accurate....	27
Figure 13: Attenuation curve showing location of red and infrared wavelengths	28
Figure 14: LED driver block diagram	29
Figure 15: LED driver configuration	30
Figure 16: TINA LED driver circuit diagram	31
Figure 17: TINA simulation results: (Left) Voltage versus current. (Right) Pulse voltage versus current..	31
Figure 18: LED current for variable input voltage	32
Figure 19: LED current for a pulsed signal	32

Figure 20: LED driver circuit with compensation: (Left) Circuit diagram. (Right) LED current for a pulsed signal	33
Figure 21: LED driver circuit with temperature sensor.....	34
Figure 22: Block diagram of analog frontend and adjoining components	35
Figure 23: (Left) Simple transimpedance amplifier. (Right) Compensated transimpedance amplifier.....	36
Figure 24: Gain curves for A_{OL} and $1/\beta$	36
Figure 25: (Left) Transimpedance amplifier. (Right) Small signal transimpedance amplifier.....	37
Figure 26: Resistive tee network.....	40
Figure 27: Bootstrapping configuration.....	41
Figure 28: TINA circuit layout of the transimpedance amplifier.....	43
Figure 29: (Left) Frequency response of transimpedance amplifier. (Right) Transient response to 10nA, 500 μ s pulse	43
Figure 30: Noise analysis of transimpedance amplifier	44
Figure 31: Design template for user interface featuring 2 main screens	48
Figure 32: Final user interface GUI implemented on iPod Touch.....	48
Figure 33: User interface program flow.....	49
Figure 34: Full system flowchart	53
Figure 35: PCB layout for main housing board	54
Figure 36: SolidWorks FEA analysis performed on main housing unit	56
Figure 37: SolidWorks FEA analysis performed on LED arm of sensor housing	56
Figure 38: SolidWorks FEA analysis performed on photodiode arm of sensor housing.....	57
Figure 39: SolidWorks FEA analysis performed on photodiode cover.....	57
Figure 40: SolidWorks FEA analysis performed on cover for LEDs	57
Figure 41: Voltage across the LED driver drain resistor - used for current sensing.....	58
Figure 42: Red and infrared LEDs switching capability	59
Figure 43: Voltage output from transimpedance amplifier.....	60
Figure 44: AC ripple representing pulse rate	61
Figure 45: Final iPhone interface	62

1 Introduction

This report details the design, development, and construction of a remotely monitored pulse oximeter, a device that measures blood oxygen saturation. The project was offered as part of the Interdisciplinary Engineering Design Program at the University of Arizona. In this program, undergraduate seniors are grouped into design teams that are responsible for the completion of a project sponsored by one of several companies from industry. The teams have 30 weeks to develop and construct the device specified by the project sponsor. Texas Instruments (TI) was the sponsor of this project with Matthew Hann, an HPA Linear Applications Engineer for TI, as the company representative in charge of guiding the project and working with the student team during its development.

Texas Instruments designed this project such that the design team would assist them in an area where they lack technical expertise. TI is a world leader in the design and manufacture of analog, digital signal processing, radio frequency (RF), and digital light processing (DLP) technologies that other companies utilize in the development of electronic devices and equipment. Recently, they have had numerous customers interested in designing pulse oximeters and seeking expertise regarding component selection and design architecture. Since TI does not develop pulse oximeters themselves, they lack the technical knowledge in demand.

The project entailed the design of a pulse oximeter intended primarily for consumer use. This requirement meant that the device needed to be user-friendly and as small and unobtrusive as possible. Pulse oximeters for consumer use have been on the market for a number of years now; however, the novelty of this project was mostly in the remote monitoring capability of the oxygen saturation data. TI wanted a device that could incorporate and demonstrate some of the wireless technology it has developed, so the decision was made to have a pulse oximeter with the ability to communicate data to a smartphone or other portable device. This potentially made the device smaller by not needing to incorporate a display and user interface on the oximeter itself. It also lent itself to situations such as remote monitoring of an infant's oxygen levels during sleep to warn of dangerously low oxygen conditions that may be associated with Sudden Infant Death Syndrome (SIDS) or suffocation. However, the ultimate goal of the project was to develop a working oximeter prototype so TI could use it as a reference design. TI could then use the design and the knowledge accumulated throughout its development to better address the needs of their customers.

This report discusses the functional requirements specified by Texas Instruments for the design of the oximeter. It then outlines the three design concepts developed and considered, with emphasis on the development and analysis of the final design that was chosen for further scrutiny and construction. The details of each subsystem and the testing performed on each are discussed, as well as the integration of the components and the overall system testing. Testing results are shown and related to system functionality and the original functional requirements laid out for the project. Finally, discussion of results and concluding remarks about the project are made along with any recommendations for further development.

2 Theory

The science of pulse oximetry has been around since the mid 1970s. It was developed in response to a need for a real time, non-invasive method for measuring a person's blood oxygen saturation. The purpose of acquiring this data is to ensure that the wearer's ability to transport oxygen to the cells in his or her body has not been compromised. It is important for tissues and organs to receive substantial oxygen, because without it, they do not function properly and damage results. Lack of substantial oxygen delivery to any part of the body, called hypoxia, can be a primary symptom of many diseases or conditions, but it can also result any number of secondary symptoms depending on where it is occurring. Therefore, pulse oximetry is helpful for assessing a more direct cause of many symptoms in medical diagnostics. The specific low oxygen condition detected by pulse oximeters is called hypoxemia, which is characterized by hemoglobin oxygen saturation at or below 90%. Invasive oximeters (the first type to be developed) rely on taking an arterial blood sample from the patient and submitting it to the oximeter for analysis of blood gas levels. This process provides extremely accurate data; however, it is also time consuming, invasive, and only offers a snapshot of a person's blood gas levels, which can change very quickly. Pulse oximetry addressed these concerns by allowing for real time, non-invasive, continuous monitoring of oxygen saturation albeit with slightly lower accuracy and use limitations when compared with traditional, invasive blood gas analysis.

2.1 Background & Assumptions

Hemoglobin is a main component contributing to the composition of a person's blood. It is a molecule responsible for binding with the oxygen inhaled through the lungs and then transporting that oxygen through the blood stream to the body's tissues and organs. Hemoglobin that is bonded to oxygen is

called oxyhemoglobin (HbO_2) while hemoglobin that is not is termed deoxyhemoglobin (Hb). When the heart contracts, it pumps a fresh supply of oxyhemoglobin through the blood stream where the oxygen then diffuses down its concentration gradient into the cells of the body. Each pump results in a high concentration of oxyhemoglobin in the arteries. Each time the heart relaxes, the pressure in the arteries decreases along with the concentration of oxyhemoglobin. However, as one may suspect, this is a highly simplified overview of the processes occurring in the body.

In addition to the hemoglobin, called functional hemoglobin, which is able to bind with oxygen, it can also bind with other substances to form non-functional hemoglobin. These substances include most notably carbon monoxide, forming carboxyhemoglobin (HbCO) and methane, forming methemoglobin (METHb), for which the pulse oximeter does not account. When the heart contracts, all forms of hemoglobin present are being forced through the arteries, not just deoxy- and oxyhemoglobin. Pulse oximetry has an important limitation in that it makes the critical assumption that in normal functioning of the body there are very low levels of HbCO and METHb, which allows for a relatively simple percentage calculation involving only HbO_2 and Hb for measuring oxygen saturation levels. It assumes that the concentration of all hemoglobin types except deoxy- and oxyhemoglobin at any point in the body is constant and negligible as blood is pumped through the arteries with each relaxation and contraction of the heart. This most often reasonable assumption allows for a less complicated way of measuring blood oxygen saturation [4].

2.2 Principles of Pulse Oximetry

Typical pulse oximeters utilize two light emitting diodes (LEDs), one red and one infrared, to measure relative levels of HbO_2 and Hb as blood is pumped through the body. The LEDs are positioned on one side of an extremity of the body, usually a finger, ear or toe, and a photodiode is placed on the opposite side, as in Figure 1.

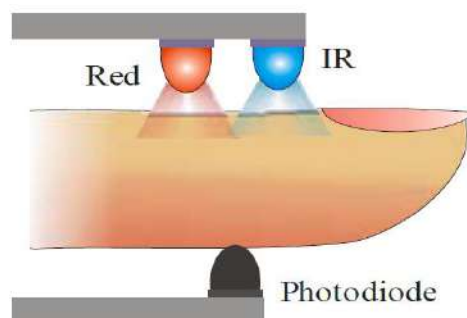


Figure 1: Typical pulse oximeter configuration [4]

In operation the LEDs are pulsed alternately, with one off while the other is on, allowing the photodetector to measure the transmitted light intensity at each wavelength separately. The transmitted light intensity differs greatly at each wavelength and can be attributed to the attenuation as it travels through the body, which results from a combination of reflection, scattering, and absorption by tissue and bone, venous blood, and arterial blood in the region. These values are then also related to the absorption of light by the oxyhemoglobin and deoxyhemoglobin molecules. Figure 2 shows the absorption of each molecule and its dependence on wavelength.

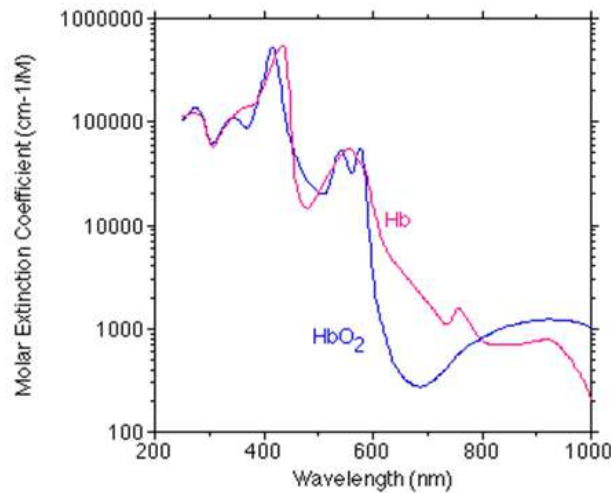


Figure 2: Attenuation of oxyhemoglobin and deoxyhemoglobin with wavelength [5]

The idea is that at the red wavelength (normally around 660 nm), the absorption by oxyhemoglobin (HbO_2) is significantly less than for deoxyhemoglobin (Hb). Conversely, at the infrared wavelength (usually around 910 nm), the relationship switches, with HbO_2 absorbing more than Hb. This means that measuring the light output at these two wavelengths will differ greatly due to the concentrations and absorbance properties of each hemoglobin type. As stated before, as the heart contracts and relaxes, the concentration of HbO_2 fluctuates respectively, which causes the amount of light absorbed as it travels through the sample to change. This results in a cyclic relationship between absorption and time that takes the form shown in Figure 3, with the peaks and troughs corresponding to the beating of the heart as well as high and low oxyhemoglobin concentrations respectively.

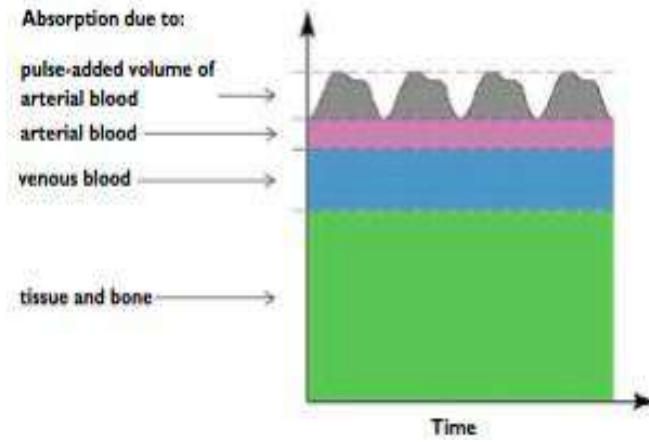


Figure 3: Representation of light absorption with time [8]

The corresponding transmitted light measured by the pulse oximeter at each wavelength will follow a similar pattern to the absorbance in Figure 3, but inverted. This is due to the inverse relationship between optical power and absorbance. The direct current (DC) component of the pulse oximeter signal is attributed to the aforementioned scattering, reflection, and absorption as the light passes through the sample, which is assumed constant. As such, the AC component is attributed solely to the changes in Hb and HbO₂ concentrations. By taking a ratio of the difference in the AC and DC components at each wavelength, the blood oxygen saturation can be estimated. The ratio (R) can be expressed by the relationship in Equation 1, where I refers to the current output by the photodetector [3].

$$R = \frac{\log_{10}(I_{DC+AC}/I_{DC})_{\lambda 1}}{\log_{10}(I_{DC+AC}/I_{DC})_{\lambda 2}} \quad (1)$$

Through calibration of the pulse oximeter, this ratio can then be related to actual blood oxygen saturation. Pulse oximeters are typically calibrated by comparing readings at specific times with data gathered from a blood gas analysis done at the same times and then mathematically relating the ratios to actual blood oxygen levels.

3 System Requirements

The project sponsor specified several requirements the final pulse oximeter design would need to meet. Table 1 shows a summary of those requirements along with several other characteristics relating to each condition. The importance of each requirement to the sponsor is shown on a scale of 1 to 5, with 5 signifying the most important. In addition, the metrics and target values used to objectively quantify the requirements are shown.

Table 1: System requirements specified by sponsor for final pulse oximeter design

Functional Requirement	Customer Importance	CTQ (metric)	Target Value
Accuracy	5	Percentage (%)	Accurate to within $\pm 2\%$ of actual blood oxygen concentration
Battery Life	5	Hour	Minimum of 12 hour battery life on a single charge
Perceptible Alert Signal	5	Decibels (dB)	80 dB
Data Logging	4	Week	1 weeks worth of data from continuous monitoring
Transmission Distance	4	Meter (m)	25 m wireless data transmission
Shock Resistance	2	Meter (m)	Survive at least 2 m fall
Water Resistance	2	Meter (m)	Water resistant to depth of 3 m

3.1 Accuracy

One of the most important aspects of any medical device is its accuracy. Inaccurate devices can generate false positives, potentially leading to medical action taken when it may not be required. Even worse, they may fail to detect or report a condition that could lead to serious health risks or even death. Therefore, the final pulse oximeter design was required to be accurate to within $\pm 2\%$ of the actual blood oxygen concentration of the user. This metric is comparable to the accuracy of many other pulse oximeters that are currently available and used in medical environments.

3.2 Battery Life

The pulse oximeter was developed for consumer use, and thus would require the potential to be worn throughout the night while the user slept. Consequently, the device needed to last a minimum of 12 hours on a single charge such that it would continue to function without need for attention while the user rested.

3.3 Perceptible Alert Signal

One of the novel aspects of the remote pulse oximeter design was the implementation of an alarm in the event that the blood oxygen level of the user fell below a safe level. The alarm needed to be loud enough to be heard throughout a typical household, but not so loud that it would damage human hearing. A target metric of 80 dB was chosen for the pulse oximeter alarm due to it being a nice balance between normal human conversation (60-65 dB) and the human pain threshold (125 dB).

3.4 Data Logging

In order to monitor trends in the blood oxygen saturation of the user, a means to record and store data was integrated into the final pulse oximeter design. A metric of one week's worth of continuous oxygen saturation data being able to be stored and accessed was chosen in order to give the user ample time to back up the data to an external source, such as a hard drive or home computer. It was proposed that the device would output a file that was easily accessible and readable using common software, such as Microsoft Excel, so that both the user and medical personnel alike could easily read and analyze the recorded blood oxygen levels over long periods of time.

3.5 Transmission Distance

A wired design limits how a pulse oximeter can be used and where it can be located on the body. To alleviate these constraints, the design of the remote pulse oximeter included a unique feature, the ability to transmit information wirelessly to a portable device such as an iPod or iPhone. The average American home is approximately 2300 square feet in size [10]. By assuming the average house is three times longer than it is wide, this corresponds to a length of 83 feet or 25 meters. This led to the chosen transmission distance metric of 25 meters for the design.

3.6 Shock Resistance

The physical construction of the pulse oximeter needed to be durable enough to handle the daily rigors of being worn by an adult or child. Therefore, it was desired that the final product have a measurable level of shock resistance. Since the device was intended to be worn by a person, and it was reasonably assumed the device would suffer only normal abuse, the shock it would need to withstand was that of a fall from the height of a typical person. Thus, the conservative target metric of maintaining functionality after a two meter fall was chosen.

3.7 Water Resistance

The two most realistic concerns in relation to water resistance were that the device may end up either in a bathtub of water, or experience some sort of wet environment from human sweat or saliva from an infant. In consideration of these conditions, and given that it is the common metric for a wristwatch, a target metric of water resistance to a depth of 3 meters was imposed on the pulse oximeter design.

4 Design Concepts & Analysis

Accompanying the functional requirements specified by the sponsor, there were several important considerations that went into the development of the possible pulse oximeter designs. One consideration, which was also a functional requirement, was that the oximeter needed to operate solely on battery power for at least 12 hours. This meant the electronic design and components selected needed to result in low power consumption in order to meet the requirement. Another point to consider was the oximeter being developed for consumer use. This required that the device be relatively small and as unobtrusive as possible, while also being comfortable and convenient for the user to wear throughout prolonged periods of use. The last major consideration was the accuracy requirement for the device. This meant the location used to measure the oxygen saturation needed to be carefully selected, and the design of the electronic components needed to be stable enough to ensure the device would meet the specified accuracy of $\pm 2\%$.

In each of the following system designs there are four parts: the source/detector, the LED driver, the signal amplifier, and the digital/user interface. The source is a combination of two LEDs, one red and one infrared, which are pulsed at alternate times. The detector consists of a photodiode located opposite the two LEDs, which detects the amount of light passing through the tissue. The LED driver is a circuit coupled with a temperature sensor and is used to manipulate the brightness and on/off state of each LED. The signal amplifier circuit amplifies the small currents generated by light incident on the photodiode to a usable signal. The digital interface is the circuit brain – it includes the microcontroller and its programming, which directs the functionality of the entire circuit. The digital interface also includes the wireless transmitter that sends data to the user interface. The user interface is the means by which the user can monitor his heart rate and oxygen saturation levels. The three system designs initially considered are summarized in the following sections.

4.1 Design 1

The first design the team developed consisted of an oximeter that would be placed on the finger of the wearer. Two LEDs would be used for the source, one red and one infrared, and an avalanche photodiode (APD) utilized as the detector. An APD can be thought of as a photodetector that provides a built-in first stage of gain through avalanche multiplication, which is regarded as the semiconductor analog to photomultiplier tubes. The trade-off to obtain this gain is that a large reverse-bias voltage must be present across the APD. Furthermore, a Fresnel lens would be placed above the APD to collect as much of the light as possible that was transmitted through the finger.

The LED driver circuit for this design is shown in Figure 4. This design places the LEDs on the collector of the NPN transistor shown. This implementation uses a small number of components and offers low power consumption and low current drift. The feedback loop around the operational amplifier provides stability by reducing the current drift on the output. A downside to the design is that there is an overshoot present on the output current (see Figure 4 at right). This overshoot will make the max current of 100mA difficult to get exactly because if the input voltage is slightly under or slightly over, the current will be below the 100mA. This also presents a possibility that the transistor could become too hot since it would be driving all the current.

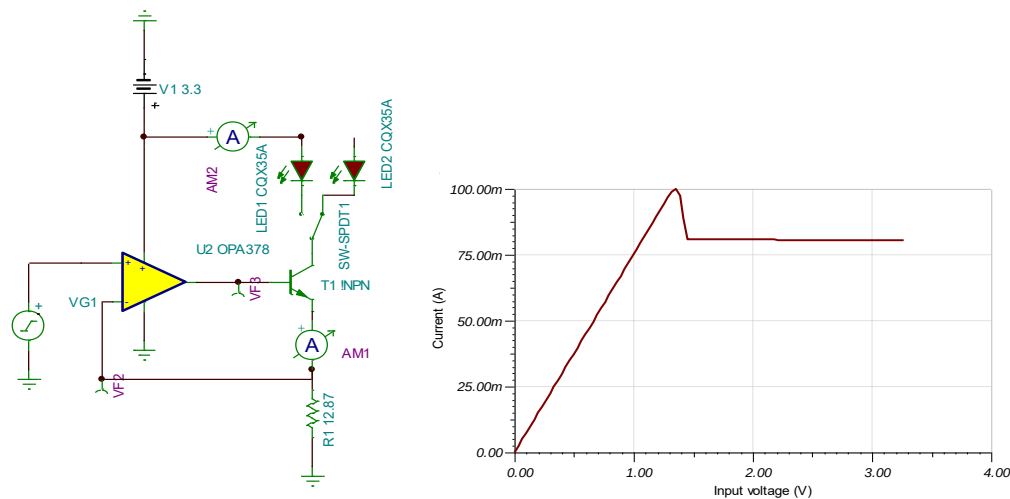


Figure 4: Design 1 - (Left) LED driver circuit. (Right) Driver current output

The signal amplifier would rely on a standard operational amplifier (op-amp) design with a voltage to voltage amplification structure using a photoconductive operation. A photodiode in photoconductive mode is operated in reverse-biased conditions, reducing the junction capacitance. This would be a low power design offering high speed and sensitivity. However, the voltage generated by the photodiode would be extremely small and extremely difficult to resolve with a high level of precision. In addition, the increased sensitivity would lead to higher noise. Due to the very small voltage levels and high sensitivity, this design would result in higher noise and lower signal strength, thus making it less accurate than other designs.

The interface design of the system would consist of the pulse oximeter transmitting via WiFi to the Internet where it would then be accessible to any web-capable device. This design offers the flexibility that any web-capable device could access it; however, it would also be complex to implement and consume a large amount of power.

4.2 Design 2

The second design that the team developed was also for use as a finger-mounted pulse oximeter. The source design was the same, consisting of two LEDs, one red and one infrared. A phototransistor was selected for the detector, as it would provide internal gain. To increase the light collection capability, a reflective light collector made of either glass or plastic would be placed on top of the detector. This design would increase the light collection efficiency, thereby decreasing the power consumption of the system, but unfortunately it would be fairly large and bulky due to the size of the light collector.

The LED driver circuit for this design is shown in Figure 5. This design places the LEDs on the output of an AB power output stage. This allows the current to go both directions depending on the input voltage. If the input voltage is high or positive then the top NPN transistor will be on, pushing the current out and turning LED 1 on. If the input voltage is low or negative then the bottom PNP transistor will be on, pulling the current and turning LED 2 on. The feedback enables this transition to not have what is called a dead zone, or a small region in the middle in which both transistors are off at the same time. This circuit is advantageous because it enables a very stable linear output current, it does not need a switch, and it allows the two transistors to have all of the current so one does not heat up. Some of the main problems are that this circuit will draw more power than the previous design, and it is a larger overall circuit. Another issue is that this circuit needs $\pm 5V$ power supply, but only a 3V battery was specified for use.

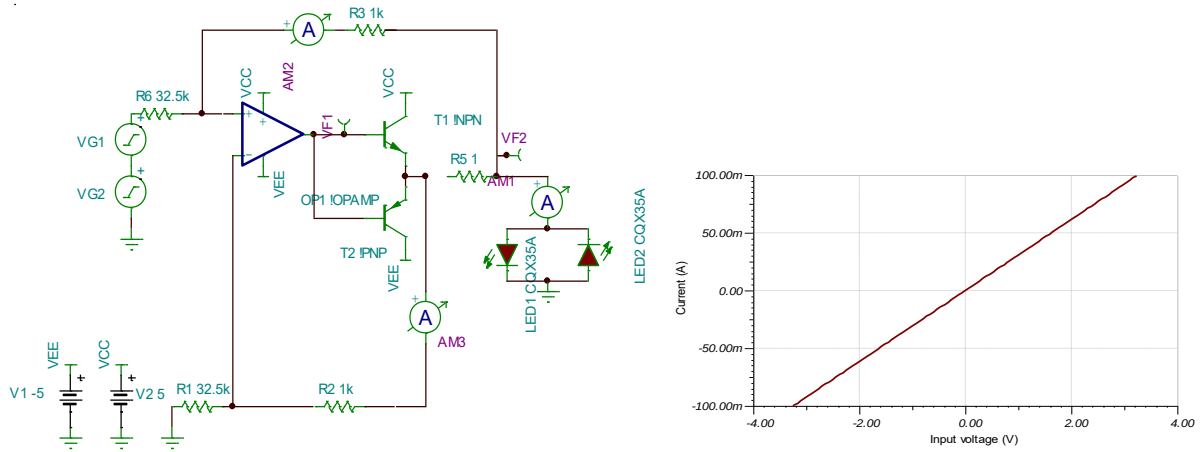


Figure 5: Design 2 - (Left) LED driver circuit. (Right) Driver current output

The signal amplifier would rely on current to current amplification structure using a photovoltaic operation. Photovoltaic operation has no reverse-bias on the photodiode. This would be a low noise, low power design that would also offer direct amplification of the signal from the photodetector. However, the current output from the amplifier would then need to be converted to a voltage for the analog-to-digital converter. If dissipated through a resistor to produce a voltage, this would constitute an unreasonable waste of power to create a voltage signal. If a small resistor is used to dissipate the current to save power, and a voltage amplifier is used to condition the signal for analog-to-digital converter, the purpose of a current to current amplifier would be defeated. Thusly, a current to current amplifier would be an inefficient option.

The method of wireless transmission chosen for this design was Bluetooth. Transmission of the data to a portable device using Bluetooth would be the simplest to implement and allow for a direct connection to the device. The downside would be that only Bluetooth compatible devices could receive the signal, and that Bluetooth also consumes a large amount of power.

4.3 Design 3

The third design considered, and the one ultimately chosen to proceed with development, consisted of a pulse oximeter sensor fastened to the ear of the wearer. This offered an advantage over the proposed finger oximeters because a person generally moves their ears much less than their fingers. This would reduce motion artifact within the signal, which would increase the accuracy of the oxygen saturation read out from the pulse oximeter. The downside to this design was that the housing was more complex in order to make it more comfortable for the wearer.

Due to the small size requirements of the ear-oximeter housing, the source and detector design was restricted to being relatively simple. Again, two LEDs would be used for this design, one red and one infrared. However, for the detector a PIN photodiode would be used for its relatively high responsiveness and low dark current. Furthermore, the photodiode would not need to be reverse-biased to operate which would result in a lower power design. No optics could be feasibly used due to the size restrictions on the housing.

The LED driver circuit for this design is shown in Figure 6. This circuit is similar to that in Design 1; however, it uses a PNP transistor with positive feedback instead of the negative feedback method used in Design 1. The positive feedback helps stabilize the current drift of the LED driver, but the PNP transistor allows a larger voltage drop across the LEDs because the output from the operational amplifier can be about 700mV below the 3V rail. Also, the collector of the PNP will allow the voltage to be above the base, thus the voltage above the LEDs can be close to 2.8V. This provides a larger voltage swing for the LEDs, whereas the NPN transistor would only allow about 2.1V. This promotes a higher accuracy of the output current since it allows for a larger input voltage swing and because there is no overshoot on the current. This allows any voltage above the maximum to achieve a maximum current of 100mA. This circuit still introduces the concern that only one transistor is being used to drive all of the current, leading to the possibility of it becoming too hot. Also, this design requires a switch to alternate between each LED. Overall the smaller size and power consumption makes it better than Design 2, as well as not needing a $\pm 5V$ power supply. It also offers a desirable linear output current, similar to that of Design 2.

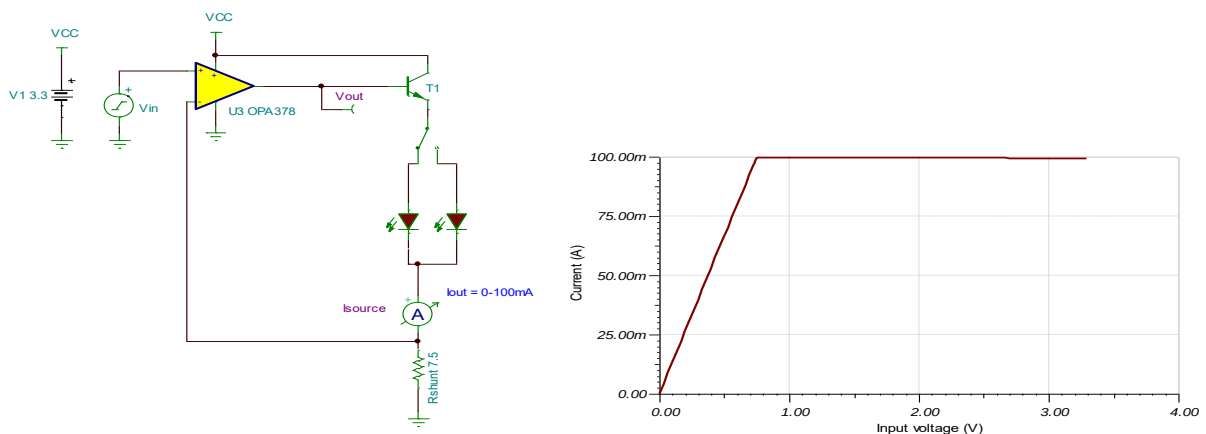


Figure 6: Design 3 - (Left) LED driver design. (Right) Driver current output

The signal amplifier design was based on a current to voltage amplification structure using a photovoltaic operation of the photodiode. This design allowed for direct amplification of the photodiode current while producing a voltage output for the analog-to-digital converter. This was a major advantage over Design 2 in that it eliminated the need for a second stage or the need for significant dissipation of power through a resistor. By amplifying the current through the photodiode instead of the voltage across it, a significant improvement in the signal-to-noise ratio was achieved in comparison with Design 1. Low noise and low power consumption are also benefits of this type of design, but the trade-off is the speed and sensitivity of the device.

The interface for the design was similar to that proposed for Design 1. The pulse oximeter would transmit data wirelessly via radio frequency (RF) to a base station and then the base station would transmit via WiFi directly to a portable device such as an iPod or iPhone. This design would benefit from low power consumption and easier implementation than the other designs.

4.4 Concept Analysis

After the three potential design concepts had been developed, it was necessary to devise a way of comparing the three designs in order to select the most promising design with which to move forward. This requirement led the team to conduct extensive research into the individual components and technologies outlined in the descriptions of each design concept. By researching the pros and cons of each design through trade studies, component specification comparisons, and computer modeling of component performance, the Pugh chart shown in Table 2 was developed.

The Pugh chart outlines the major characteristics of each design component that were considered and compared during the analysis. Each characteristic of each design was assigned a score from 1 to 5, with 5 meaning the design most desirably satisfied the requirement and 1 meaning the design least desirably met the requirement. Furthermore, each characteristic was weighted by importance also using a value between 1 and 5, with 1 representing low importance and 5 representing high importance. In order to compare the three designs overall, a weighted total of all characteristics for all three designs was calculated and is shown at the bottom of the chart.

Table 2: Pugh study for three design concepts

DESIGN PARAMETER	CHARACTERISTIC	IMPORTANCE (1-5)	DESIGN 1	DESIGN 2	DESIGN 3
<i>Oximeter Location on Body</i>	Design Simplicity	3	4	4	2
	Accuracy	5	3	3	5
	Cost	2	3	3	3
	Form Factor	1	4	4	2
<i>Source/Detector</i>	Design Simplicity	3	3	1	5
	Cost	2	1	3	5
	Power Consumption	4	2	3	4
	Sensitivity	3	5	4	3
<i>LED Driver</i>	Design Simplicity	3	4	2	4
	Cost	2	5	3	5
	Accuracy	5	3	5	5
	Sensitivity	3	2	4	4
	Power Consumption	4	4	3	4
<i>Amplifier</i>	Design Simplicity	3	4	3	5
	Cost	2	5	5	5
	Noise	5	3	4	5
	Accuracy	5	3	3	5
	Sensitivity	3	5	4	4
	Power Consumption	4	5	2	5
<i>Interface</i>	Design Simplicity	3	3	4	5
	Cost	2	3	3	4
	Transmission Distance	3	3	2	5
	Reliability	3	4	4	4
	Power Consumption	4	3	3	5

Weighted Total

265

253

341

By analyzing the results of the Pugh study, Design 3 proved to be the most desirable design option based on the requirements outlined for the project. It received a final weighted score of 341, which was 76 points above the second strongest design concept. This confirmed the team's suspicion that Design 3 would be the most viable design with which to move forward. Hence, it was decided that Design 3, the ear-mounted pulse oximeter, would be the design that was further developed into a working prototype. The following section of this report describes in detail how the individual subsystems of this design were developed and implemented.

5 Final Design Breakdown

As stated previously, the final design selected for further development and construction was an ear-mounted pulse oximeter. This design allowed for the oximeter to be placed in an unobtrusive location, conveniently allowing the wearer to use his or her hands and conduct him or herself normally. The placement also helped reduce the signal noise due to motion artifact, thereby increasing the detection accuracy. Despite these advantages, the details of the pulse oximeter prototype design needed careful consideration due to the very small size requirement, making it more challenging to meet the functional requirements of the project. The details of final design are discussed in the sections that follow.

5.1 Theory of Operation

The operation of the ear oximeter was to closely follow that of standard pulse oximeters currently on the market. Therefore, it would consist of a red and an infrared LED placed on one side of the ear and opposite a photodiode. The LEDs would be pulsed, with one being on while the other is off and continually alternating in that fashion, at a combined rate of 100 Hz. Light would reach the photodiode, causing it to output a signal, which would then be amplified, processed, and the ratio of the two signals would be mathematically related to the actual oxygen saturation of the user. Afterward, the device would transmit the oxygen saturation as well as the pulsatile signal to an iPhone or iPod Touch and be displayed on a user interface that would allow the data to be monitored and stored.

5.2 Subsystems

The design of the pulse oximeter can be broken down into several subsystems. The subsystems and their interactions are visualized in the block diagram depicted in Figure 7. Within the housing of the ear-oximeter there are three main systems: the LED driver control, analog signal processing, and digital signal processing systems. The user interface is located outside the housing on a portable device and receives data wirelessly from the pulse oximeter.

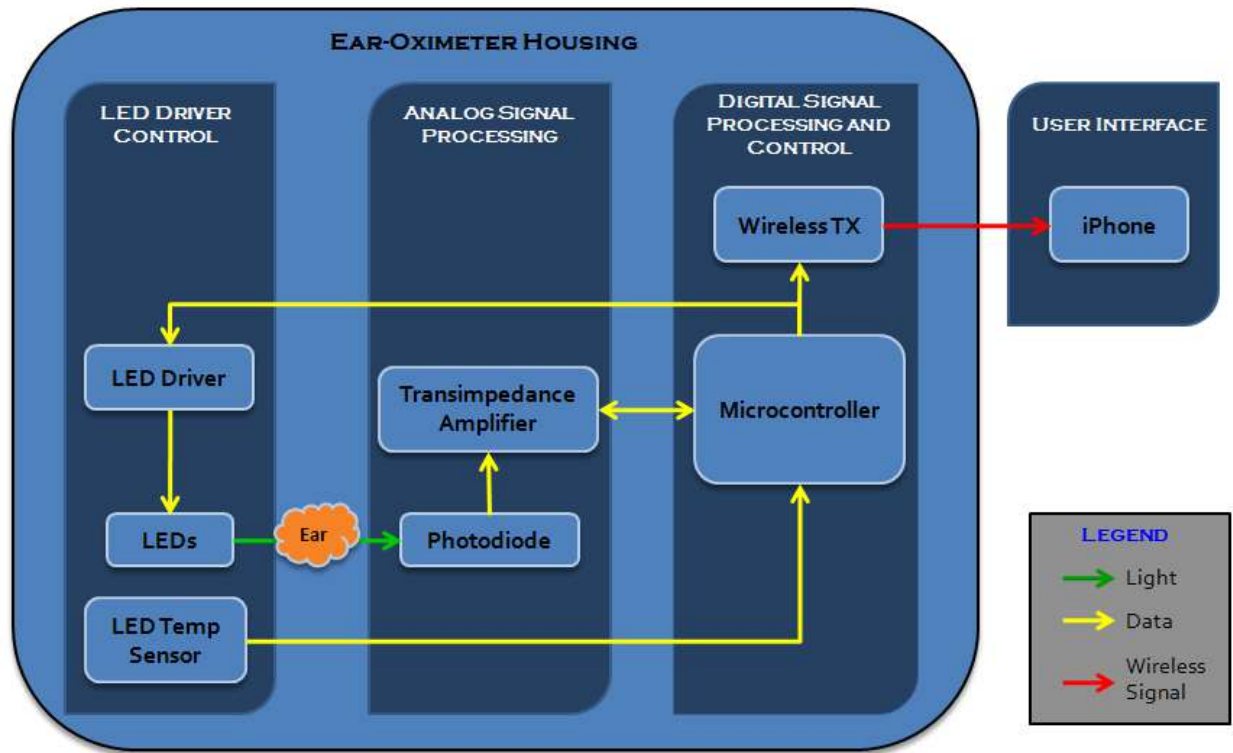


Figure 7: Block diagram showing final design by subsections

The microcontroller is the central unit controlling the functionality of most of the other systems. It sends signals to the LED driver, which adjusts the current going through the LEDs to produce a consistent and accurate light output. The photodiode senses the optical power (light) present on the other side of the sample (the ear in this case) and proportionally produces a current. This signal, in the form of an electrical current, is then sent to the transimpedance amplifier where it is converted into a voltage and amplified. The amplified signal is sent to the microcontroller where the signal data is processed and then sent to the wireless transmitter. The transmitter wirelessly communicates with the application on the iPhone to send and display the data on the user interface. There is also an LED temperature sensor in the housing that monitors the temperature of the LEDs and communicates with the microcontroller to adjust the current to the LEDs if the temperature near the skin rises to dangerous levels.

5.2.1 Housing

The pulse oximeter housing was divided into two main parts: the main circuitry housing and the sensor housing. The main housing contained the LED driver circuit, temperature sensor, microcontroller circuit, antenna, and battery, while the sensor housing contained the LEDs, photodiode, and signal amplifier circuit. Two separate modules were needed for several reasons. First, during design integration of the circuitry for the oximeter, it was discovered that the printed circuit board (PCB), in order to accommodate all of the circuitry, required the housing to be larger than originally anticipated. As a result, an ear-mounted housing would have been uncomfortably large. Furthermore, the team was initially planning to create an ear sensor as well as a finger sensor as interchangeable attachments, and this modular design would have allowed for the main housing to be used with each sensor without redesign. Given the cost of just one sensor housing and the unforeseen expenses incurred with regard to the PCBs, only the ear sensor was constructed.

Both housings were originally to be made of engineering plastic such as acrylonitrile butadiene styrene (ABS) or polycarbonate (PC). However, given the tight timeline and budget for this project, the team decided to use thermoplastic materials that mimic engineering plastic properties, supplied and suggested by 360 Prototyping, a rapid prototyping company located in Round Rock, Texas. Two different materials were required for the housings, a hard plastic for the shell of each housing and a rubbery material for the sensor housing where it would make contact with the ear. The rubbery pieces were fabricated using a material called TangoPlus – FullCure®930. The shell of the two housings was made using solid-state stereolithography (SLA) and a material called Accura®25, which has the look and feel of polypropylene (PP). The pertinent properties of both materials are given in Appendix D: Housing Material Properties. All parts of the housing needed to be dyed black to prevent ambient light from polluting the photodiode signal.

As stated previously, the sensor housing was designed to mount comfortably on the ear and contain the LEDs, photodiode, and amplifier circuitry. A 3-D model of the sensor housing design and cross-sectional view is shown in Figure 8.



Figure 8: Sensor housing: (Left) Trimetric view, (Right) Cross-sectional view

The sensor housing is made of two arms connected by a pin and spring. The pin allows the two arms of the housing to rotate, and the spring adds the perfect amount of tension, allowing for adjustment of the opening between the arms for application to and removal from the ear of the wearer (similar to the operation of a hair clip). The top/front arm of the sensor housing contains the PCB with the two LEDs mounted to it. The bottom/back arm of the housing contains the PCB with the transimpedance amplifier and the photodiode. An exploded SolidWorks model view, displaying housing arms, the pin and the PCBs, is shown in Figure 9. The PCBs are shown in green and the two rubbery pieces that contact the ear are depicted in black between the two PCBs.

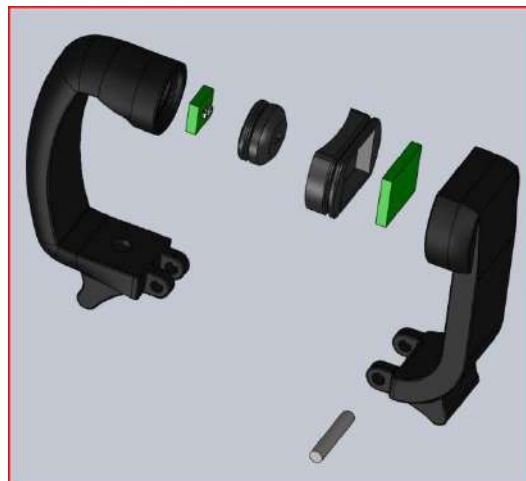


Figure 9: Exploded view of sensor housing: (Left) Top/front housing arm. (Right) Bottom/back housing arm

The main housing, accounting for its size, was mounted on the upper arm similarly to a portable music player. Figure 10 shows a 3-D model of the main housing. In the image at left, two bars are visible that run the length of the housing but are offset from the main unit. These bars will allow for an adjustable armband to be threaded through them in order to mount the device comfortably. The exploded view shows the lower compartment where the battery is housed and a view of the front compartment containing the main PCB, which consists of the temperature sensor, LED driver, microcontroller, and wireless transmitter.

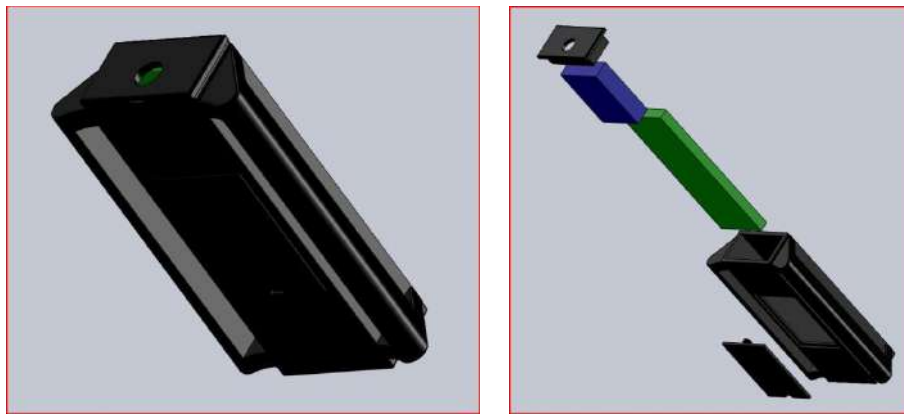


Figure 10: Main housing: (Left) Exterior of housing, (Right) Exploded view showing components

To connect the two housings, a 26 gauge wire was inserted into the sensor housing and soldered to the PCBs, while the free end of the wire terminated in a male flexible printed circuit (FPC) connector. This connector was plugged into a corresponding female FPC connector embedded in the main housing and connected to the PCB contained within. A photo depicting both prototyped housings and the wire connecting them is shown in Figure 11.



Figure 11: Photo of completed prototype and iPod Touch used for interface

5.2.2 Source/Detector

The source and detector design chosen for the ear oximeter is commonly used in standard pulse oximeters on the market today. Since the ear was to be used to measure oxygen saturation, the device needed to be as small and as lightweight as possible. This meant that the LEDs and photodetector selected needed to be as small as possible. This constraint also made it nearly impossible to include any sort of light collection optics to enhance the power output of the photodetector. However, due to the fact that the thickness of the ear in the site chosen is so small when compared to a finger or toe, the additional collecting optics were not necessary because plenty light would be incident on the photodetector without their use.

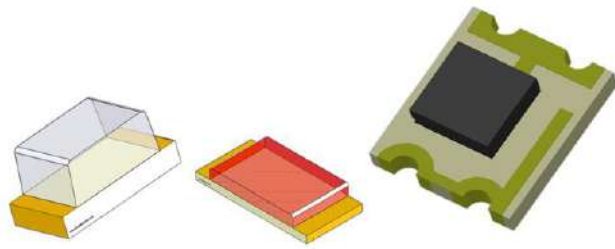


Figure 12: Infrared LED, red LED, and photodiode selected (left to right). Relative sizes are accurate.

With the aforementioned in mind, the LEDs chosen for the oximeter were a red LED with a peak wavelength of 650 nm and an infrared LED with a peak wavelength of 940 nm (see Figure 12). The red wavelength is located where the difference between the attenuation of oxyhemoglobin and deoxyhemoglobin is large, but not too large, otherwise not enough light would be incident on the photodetector (depicted in Figure 13). Likewise, the infrared wavelength was also chosen to have a large difference between the two attenuations but with the opposite sign. Choosing the wavelengths in this fashion would allow for a larger difference between the output signals at each wavelength, resulting in a more accurate calculation of the ratio of the two signals and thus the oxygen saturation level.

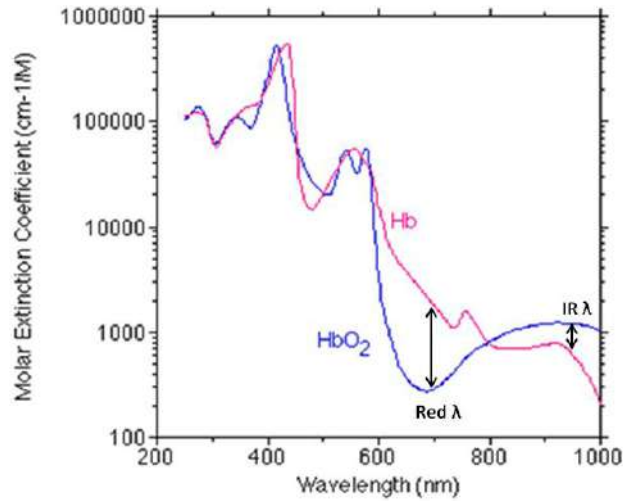


Figure 13: Attenuation curve showing location of red and infrared wavelengths

The LEDs were chosen for their high luminous intensities to allow as much light to be transmitted through the ear as possible, resulting in a higher signal output before amplification. They were also fabricated with a small footprint (approximately 1.5 mm by 0.8 mm) and low voltage and current requirements in an attempt to reduce the overall power consumption of the device. The LEDs were mounted in the housing next to each other on one side of the ear and directly opposite the photodetector.

As previously stated, the photodetector used was a silicon PIN photodiode. This was selected due to its high responsivity to both visible and near infrared wavelengths and its photovoltaic operation, again allowing the device to operate with lower power consumption. As with the LEDs, the footprint of the photodiode was also very important. However, this requirement also needed to be balanced with an active area that was as large as possible in order to collect the maximum amount of light possible. With these constraints in mind, the photodiode chosen has a small footprint of approximately 3.2 mm by 2.7 mm while maintaining a fairly large active area of 2.37 mm². The relative sizes between the photodiode and LEDs is shown in Figure 12. The manufacturers and part numbers for all components are available in Appendix A: Main Component List.

5.2.3 LED Driver

The main purpose of the LED driver was to produce a stable current to the two LEDs at separate times for a linear input voltage from the microcontroller. A typical LED driver block diagram is shown in Figure 14. TI specified that the LED driver needed to not only produce a stable current, but also have this current be variable from 0 to 100mA in order to decrease or increase the LED brightness as needed. Furthermore, the device was constrained to operating by means of a 3V Li-Ion battery which needed to be considered during design of the circuitry. If time permitted, TI also wanted a temperature sensor to be integrated with the LED driver to the possibility of burning a user as well as to keep the LEDs stable as high temperatures would cause the peak wavelength output to drift, affecting the oxygen saturation measurement.

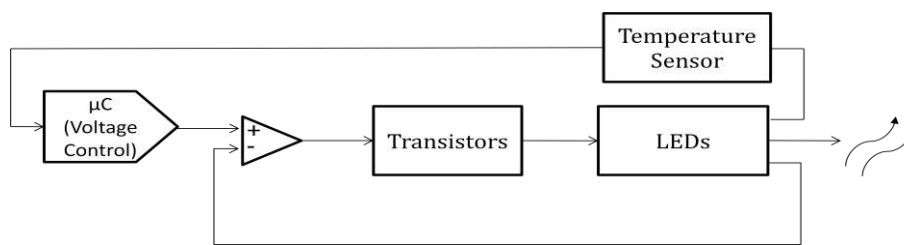


Figure 14: LED driver block diagram

The LED driver design depicted in Figure 15 shows the general circuit that was designed and used in the final prototype. The digital to analog converter (DAC) is controlled by the microcontroller to give different input voltages to the driver. The amount of current flowing through the LEDs is determined by this input voltage in a linear fashion, so as the input voltage increases so does the LED current. The feedback design of the LED driver along with the low voltage, zero drift operational amplifier being used (TI part OPA333) eliminates any current drift that would normally arise in the circuit.

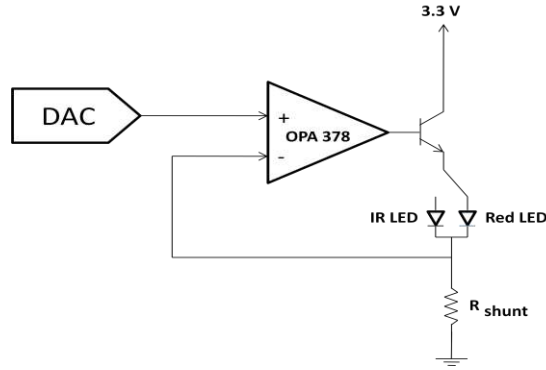


Figure 15: LED driver configuration

By nature of the operation amplifier, there is almost zero current in the feedback loop allowing the current through the LEDs to be determined by using the formula in Eq. 2.

$$I = \frac{V}{R} \quad (2)$$

The capability of the LED driver to deliver a variable current is very important for several reasons. For example, the LED brightness would need to be adjusted depending on the amount of fatty tissue present, the skin pigmentation, the bone density, as well as to reduce current to the LEDs if the temperature sensor reads that the LEDs are becoming too hot. Thus, it was crucial that the LED driver be able to produce a linear output current as the design in Figure 15 does.

To predict the operation of the LED driver circuit before a prototype was created, a circuit simulation program called TINA and provided by Texas Instruments was used. Figure 16 shows a circuit diagram of the LED driver as created with the TINA simulation software. The label V_{cc} present in the figure represents the constant voltage from the battery while V_{in} is the variable input voltage from the microcontroller and R_{shunt} is the resistor. The value of R_{shunt} dictates the amount of current that flows through the LEDs.

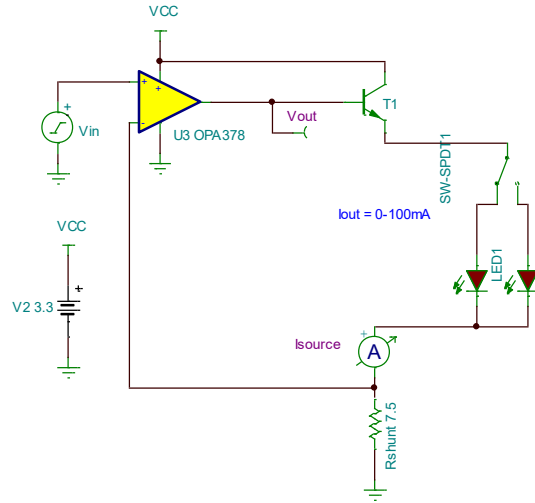


Figure 16: TINA LED driver circuit diagram

Figure 17 shows the TINA simulation results. The plot on the left depicts the current that passes through the LEDs as the voltage input from the microcontroller is varied. The plot on the right shows that with a pulse present on the input, there is a rise time and a fall time for the current through the LEDs, but it is very small. The simulation showed that the circuit operated as was expected, with a variable output current from 0 to 100mA and the ability for the red and infrared LEDs to pulse at separate times.

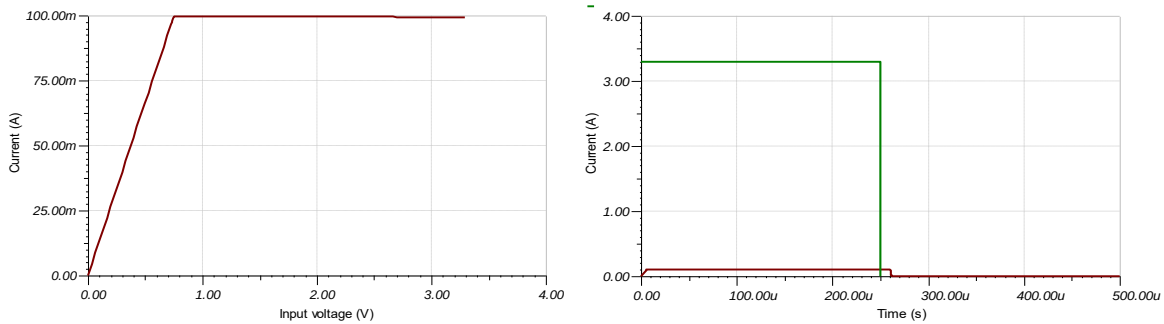


Figure 17: TINA simulation results: (Left) Voltage versus current. (Right) Pulse voltage versus current

The next step was to breadboard the circuit and see if similar results could be obtained to those predicted by the simulation. Figure 18 shows the results of the breadboarded circuit. The output current was linear as was predicted and desired. As the plot shows, the current did not go to 100mA due to the fact that the LEDs were not pulsed during this particular test. Therefore, the maximum current shown is near 25mA because this is the maximum current that the LED can run on at a constant voltage.

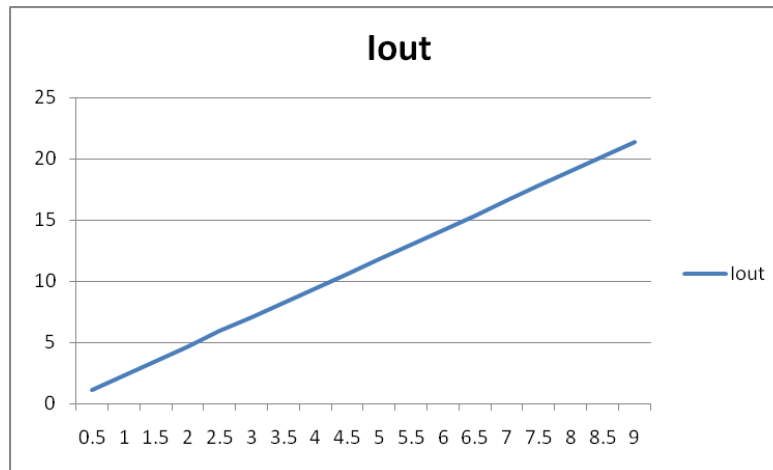


Figure 18: LED current for variable input voltage

The major discrepancy between the simulated results and those obtained while breadboarding the circuit arose when the LEDs were pulsed. Figure 19 shows that there were oscillations in the LED current (blue line) with a pulsed signal (orange line). The signal should have been a straight line instead of a saw-tooth curve. This test showed that the LED driver was not stable as was expected from the simulation. The oscillations showed the design was only marginally stable, and would need to be compensated.

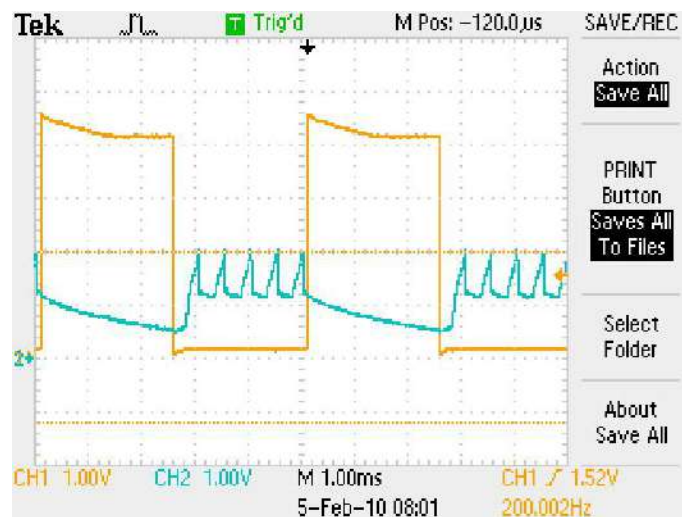


Figure 19: LED current for a pulsed signal

The circuit shown in Figure 20 (on left) shows the compensation that was added to the circuit to handle the oscillation in the output current. The circuit also has the LEDs in a back-to-back configuration to allow testing with a commercial Nellcor finger sensor. Adding the back-to-back configuration added an extra switch into the circuit. To accomplish the switching needed for this design, a quad switch TS3A44159 was used from Texas Instruments. The circuit was then assembled and tested on a prototype board. When tested, the oscillations in the LED current were no longer visible (refer to Figure 20 on right), only a clean output current was present. The circuit does have a small rise and fall time, but that was expected and should not affect the overall performance of the pulse oximeter.

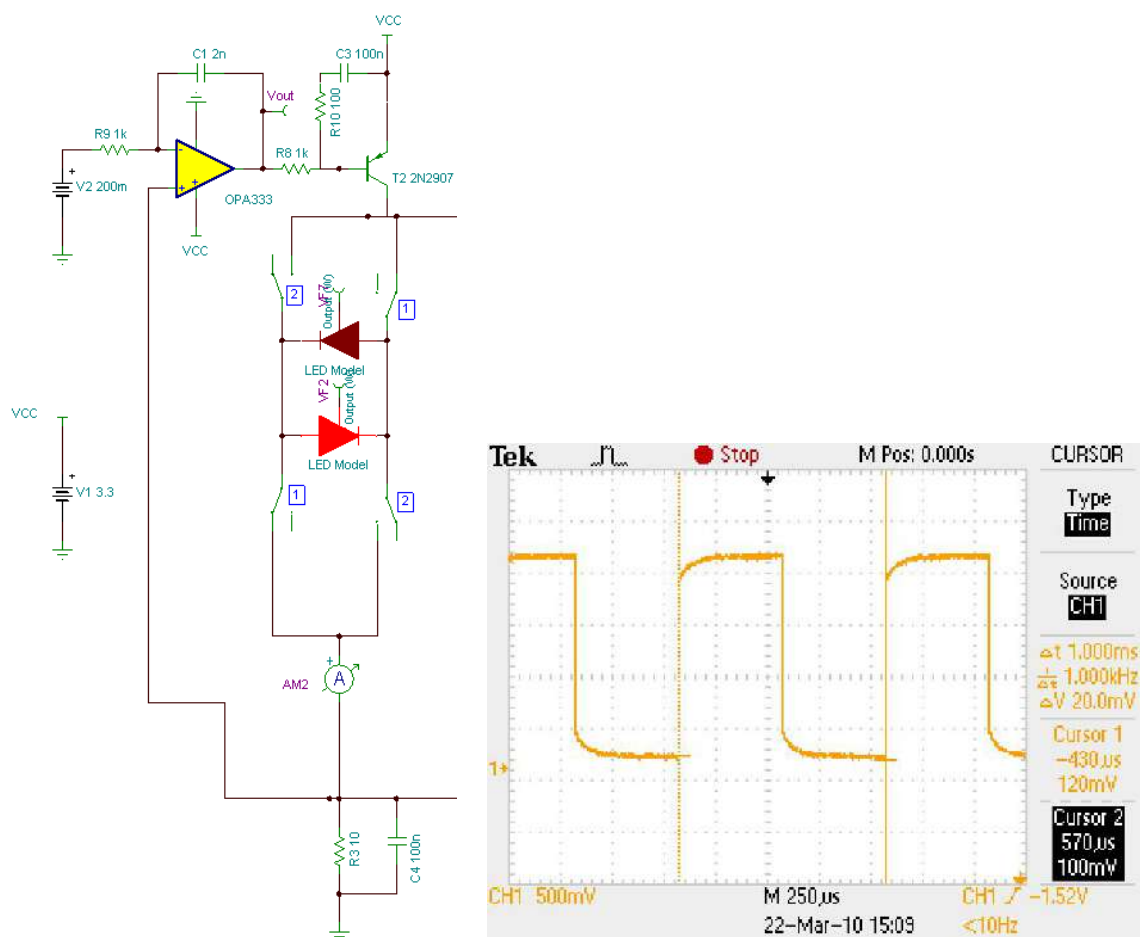


Figure 20: LED driver circuit with compensation: (Left) Circuit diagram. (Right) LED current for a pulsed signal

The last step in the LED driver design was to incorporate the temperature sensor with the driver circuitry. Figure 21 shows the resulting design of the circuit. The temperature sensor chosen was the TMP411. It works by sending a small current across the LED and measuring the voltage drop across it.

[illegible]

5.2.4 Transimpedance Amplifier

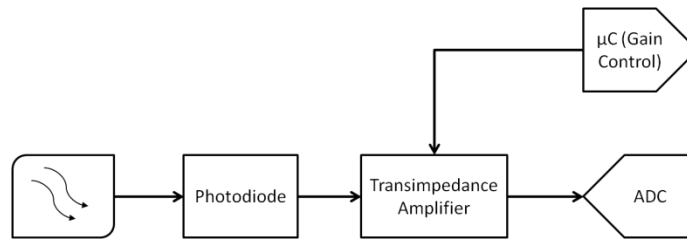


Figure 22: Block diagram of analog frontend and adjoining components

There are four methods of electrical signal amplification, each with advantages and disadvantages.

- Voltage-to-voltage: Easy to implement, but the voltage obtained from photodiode signal would be very small and thus difficult to accurately amplify.
- Current-to-current: Would directly amplify the photodiode current, but the analog frontend would connect to an analog to digital converter (ADC), which measures voltage not current. To translate the signal into a voltage, the current would need to flow through a passive or active element which would increase power consumption.
- Voltage-to-current: Combines the shortcomings of both prior methods.
- Current-to-voltage: Makes use of the current output by the photodiode and amplifies it as a voltage that an ADC could read.

The optimal choice was a current-to-voltage amplifier, also called a ‘transimpedance amplifier’. In its simplest form, the transimpedance amplifier consists of an op-amp core and a resistive feedback loop (see Figure 23). The voltage at the output of the amplifier is the product of the photodiode current, I_{ph} , and the feedback resistor, R_{fb} . However, to properly model the amplifier, the capacitance of the photodiode, C_{ph} , needed to be taken into account. The photodiode capacitance introduced a pole into the feedback factor that de-stabilized the amplifier without a compensation capacitor, C_{fb} . The compensated amplifier design can be seen in Figure 23 as well.

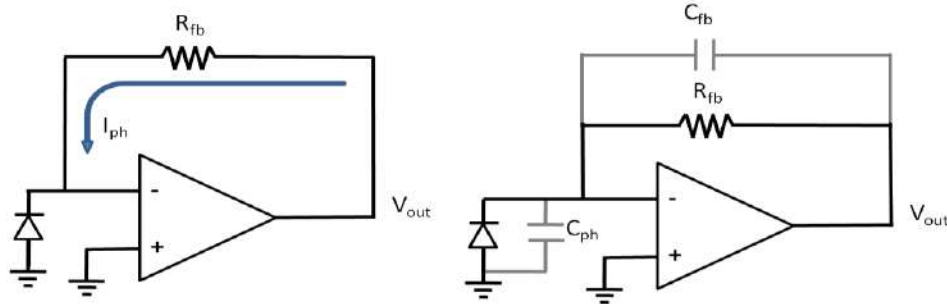


Figure 23: (Left) Simple transimpedance amplifier. (Right) Compensated transimpedance amplifier

The stability analysis was performed by analyzing the open-loop gain (A_{OL}) of the op-amp and the gain response of the feedback network (feedback factor or β). To ensure stability, the product of the open-loop gain and the closed-loop gain ($A_{OL}\beta$) could undergo an 180° phase shift by the time unity gain was reached. This was illustrated by using a log-graph of A_{OL} and $1/\beta$ (see Figure 24). The point at which the two lines intersect is unity gain. To preserve stability, the 'rate of closure', or rate of $A_{OL}\beta$ change at the intersection, cannot be greater than or equal to -40 dB/decade. This is because -40 dB/decade implies a 180° phase shift (under the assumption that the poles are at least a decade apart).

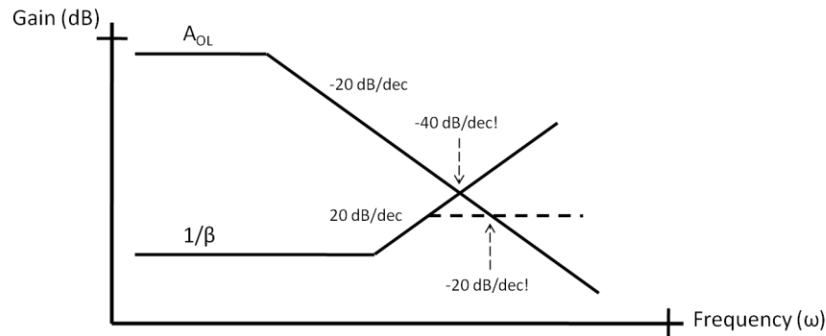


Figure 24: Gain curves for A_{OL} and $1/\beta$

To mitigate the instability, a compensation capacitor C_{fb} , was added to the feedback network (see Figure 25). This capacitor inserted a zero into β to roll-off the gain before the intersection with the A_{OL} curve, thus reducing the rate of closure to -20 dB/decade. This can be seen in Figure 24 as the dashed line. The precise location of the roll-off affected the phase margin and bandwidth of the system. To ensure that there was no ringing in the system, C_{fb} was chosen to give at least a 60° phase margin. To reduce high frequency noise, an RC low-pass filter with a cut-off frequency equal to $A_{OL}\beta$ unity gain was also added to the amplifier.

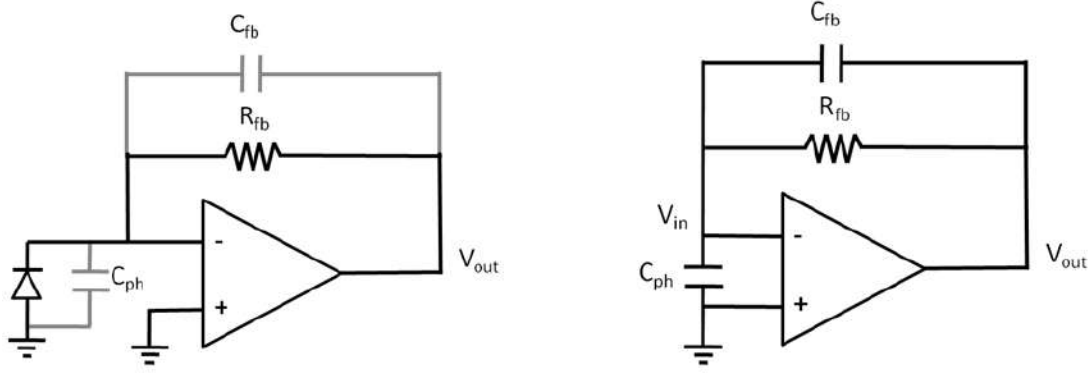


Figure 25: (Left) Transimpedance amplifier. (Right) Small signal transimpedance amplifier

Equations 3-6 show the method to solve for the feedback factor, β , which is equal to V_{in}/V_{out} .

$$\frac{V_{out} - V_{in}}{\left(\frac{R_{fb}}{1 + sR_{fb}C_{fb}} \right)} = \frac{V_{in}}{1/sC_{ph}} \quad (3)$$

$$\frac{V_{out}}{\left(\frac{R_{fb}}{1 + sR_{fb}C_{fb}} \right)} = \frac{V_{in}}{1/sC_{ph}} + \frac{V_{in}}{\left(\frac{R_{fb}}{1 + sR_{fb}C_{fb}} \right)} \quad (4)$$

$$\frac{V_{out}}{V_{in}} = \frac{sC_{ph}R_{fb}}{1 + sR_{fb}C_{fb}} + 1 \quad (5)$$

$$\frac{V_{in}}{V_{out}} = \frac{sR_{fb}C_{fb}}{1 + sR_{fb}(C_{fb} + C_{ph})} \quad (6)$$

After analyzing the β equation (Eq. 6), it was evident that the sum of the photodiode and feedback capacitance created a pole in the feedback loop. The feedback capacitor created a zero which was used to roll-off the feedback gain and ensure stability.

Meeting the requirement of $\pm 2\%$ accuracy of SpO_2 saturation was of paramount, as a person could die because as the result of an inaccurate reading. To ensure an accurate measurement, noise had to be taken into account and the transimpedance amplifier had to be designed to restrict noise. A 100% oxygen saturation level corresponds to a 0.5 ratio of IR to Red light intensity and an 82% level corresponds to a 1.0 ratio. Assuming linearity, a 2% change is equivalent to a 0.056 change in the ratio of

light intensities. In the worst case, the noise on each light signal is 180° out of phase. Equations 7-10 below outline the method used to find the maximum SNR needed to maintain an accurate measurement.

$$0.5 + 0.056 = \frac{v_{signal} + v_{noise}}{2v_{signal} - v_{noise}} \quad (7)$$

$$(2v_{signal} - v_{noise})0.556 = (v_{signal} + v_{noise}) \quad (8)$$

$$0.112v_{signal} = 1.556v_{noise} \quad (9)$$

$$\frac{v_{signal}}{v_{noise}} = SNR \cong 13.89 \quad (10)$$

As seen by Eq. 10, the maximum calculated SNR that could still result in a $\pm 2\%$ accuracy was 13.89. Taking into account the quantization noise of the DAC, we then calculated the minimum number of required bits to achieve the maximum allowable SNR,

$$SNR = 13.89 \cong 22.85dB \quad (11)$$

$$SNR = 6N + 1.76dB \quad (12)$$

$$22.85dB = 6N + 1.76dB \quad (13)$$

$$N \cong 3.52 \quad (14)$$

$$\text{Min. Bits Required} = 2^N \cong 11.44 \quad (15)$$

Rounding to the closest integer,

$$\text{Min. Bits Required} = 12 \quad (16)$$

In terms of transimpedance core op-amp selection, noise, capacitance, open-loop bandwidth, power, and output swing were considered. The op-amp used in the transimpedance core needed to have low voltage and current noise. In addition, the input capacitance of the amplifier had to be small (on the order of 1 pF or smaller) as the input capacitance reduced the bandwidth of the transimpedance amplifier. This was due to the input capacitance being added to the capacitance of the photodiode. A

large open-loop bandwidth was preferable, but since large bandwidth amplifiers tend to use more power, the power dissipation of the amplifier had to be carefully considered. The higher the bandwidth, the more accurate the amplified signal. That is, if a square pulse were the input, a high bandwidth op-amp would accurately output an amplified square pulse. A low bandwidth amplifier may have output a signal closer to a saw tooth shape. Because the amplifier was required to operate between 3.3 V and 0 V, an op-amp capable of rail-to-rail operation was desirable. Finally, the input current of the op-amp was required to be small. Even a small input current would induce a significant DC offset on the output. Only the AC component of the photodiode was of interest, but large DC offsets could push the signal to the rails. To mitigate this risk, an FET-based op-amp was selected.

There were three main candidates for the transimpedance amplifier stage: the OPA363, OPA381, and OPA376. Ultimately, we selected the OPA376 because of its superior noise and input current characteristics. The OPA376 uses 150 μ A more quiescent current than the OPA363, but it was deemed an acceptable trade-off due to the better performance.

Initially, a LED pulse width of 50 μ s was chosen. It was also desired that the pulse settle over a period of 12 time constants. The number of time constants chosen affects the required bandwidth, required gain, and maximum number of bits of resolution (more time constants corresponds to more resolution).

The required open-loop bandwidth was calculated as follows,

$$f_{clBW} = \frac{\left(0.35 + \frac{\tau_{num}}{2\pi}\right)}{t_{sample}} = \frac{2.26}{50\mu s} \cong 45.2kHz \quad (17)$$

$$f_{clBW_{max}} = 1.25 f_{clBW} \quad (18)$$

$$f_{opBW} = 10 f_{clBW_{max}} \cong 565kHz \quad (19)$$

The OPA376 met the bandwidth requirement calculated in Eq. 19.

In order to limit the noise, several RC low-pass filters were implemented to roll-off the noise gain from the feedback loop. To decrease the effect of noise in the system, the closed-loop bandwidth was limited. Because of this, the LED pulse width had to be increased to 500 μ s. The new closed-loop bandwidth calculation is shown in Eq. 20.

$$f_{clBW} = \frac{\left(0.35 + \frac{\tau_{num}}{2\pi}\right)}{t_{sample}} = \frac{2.26}{500\mu s} \cong 4.52kHz \quad (20)$$

To limit the noise in the system, low-pass filters at twice the closed-loop bandwidth, 10kHz, were placed in different paths in the amplifier. The 3dB cutoff frequencies for the low-pass filters were placed at twice the closed-loop bandwidth to avoid shrinking the closed-loop bandwidth unnecessarily. As can be seen in Figure 28, low-pass filters were placed at the output of each amplifier stage as well as inside the feedback loop of each stage to limit the noise gain. The resistor values at the outputs of the amplifiers had to be at least 5-10 times greater than the output impedance of the amplifiers at 10kHz. Thusly, a 1kΩ resistor was chosen for the low-pass filter at the output of the OPA376 and a 10kΩ resistor was used for the low-pass filter at the output of the OPA333.

The feedback capacitor and resistor needed to be low noise. To ensure low voltage noise from the capacitor, a low Equivalent Series Resistance (ESR) capacitor was chosen. To reduce the noise from the feedback resistor, a high power, 0805 metal-film resistor was chosen (larger area resistors have lower noise). In order to mitigate the large resistance and small capacitance requirements of the feedback network, a ‘tee’ network was considered, as in Figure 26. A tee network significantly increases equivalent resistance or decreases equivalent capacitance values so that more reasonably-valued components can be used. However, the consequence of a tee network was increased noise, which ultimately rendered it impractical.

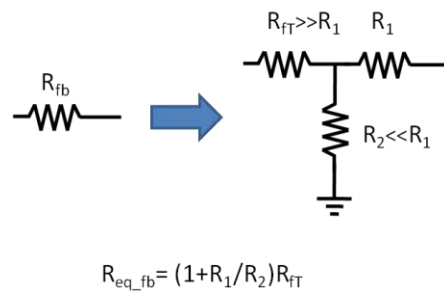


Figure 26: Resistive tee network

To increase the bandwidth of the amplifier, the photodiode could be operated in photoconductive mode. That is, a large voltage is dropped across the photodiode to place it in reverse bias. This increases the width of the diode depletion region, thus decreasing the capacitance. The reduction in capacitance pushes the pole in the feedback factor to a higher frequency, which increases the bandwidth. In addition, the reverse bias increases the sensitivity of the photodiode. However, this increase in sensitivity increases noise, and a DC current, known as 'dark current', will continually flow. The alternative was photovoltaic operation of the photodiode. In this mode, no voltage is dropped across the photodiode. The capacitance of the photodiode is greater, but it does not suffer from the noise and dark current present in photoconductive operation. Using a technique known as 'bootstrapping', the effective capacitance of the photodiode can be reduced by several orders of magnitude while remaining in photovoltaic mode. Bootstrapping requires a voltage buffer to be placed around the photodiode. This buffer has similar requirements to the transimpedance core op-amp, it must have low noise, negligible input current, and small input capacitance. The bootstrapping configuration is shown in Figure 27.

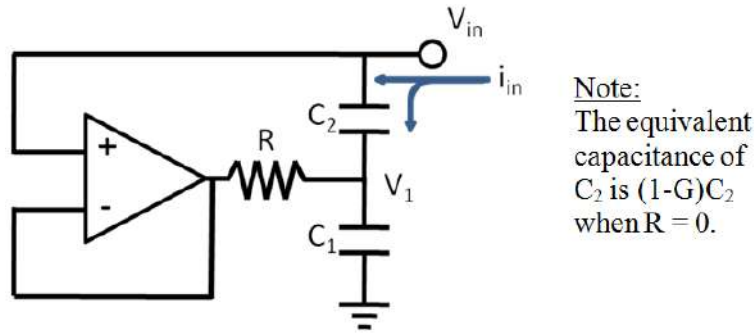


Figure 27: Bootstrapping configuration

The current into V_{in} is given by Eq. 21. Performing KCL at the node V_1 , we get Eq. 22,

$$i_{in} = \frac{V_{in} - V_1}{1/sC_1} \quad (21)$$

$$\frac{V_1}{1/sC_1} = \frac{V_{in} - V_1}{1/sC_1} + \frac{GV_{in} - V_1}{R} \quad (22)$$

Where G is the buffer gain ($G \approx 1$). Solving for V_1 from Eq. 22,

$$sC_1V_1 + sC_2V_1 + \frac{V_1}{R} = sC_2V_{in} + \frac{G}{R}V_{in} \quad (23)$$

$$V_1 = \frac{V_{in} \left[sC_2 + \frac{G}{R} \right]}{sC_1 + sC_2 + \frac{1}{R}} = \frac{V_{in} [sRC_2 + G]}{sR(C_1 + C_2) + 1} \quad (24)$$

Solving for the equivalent impedance of C_2 (photodiode), V_{in}/i_{in} ,

$$i_{in} = \frac{V_{in} \left[1 - \frac{sRC_2 + G}{sR(C_1 + C_2) + 1} \right]}{1/sC_2} \quad (25)$$

$$i_{in} = V_{in} \left[sC_2 - \frac{s^2RC_2^2 + sGC_2}{sR(C_1 + C_2) + 1} \right] \quad (26)$$

$$\frac{V_{in}}{i_{in}} = \left[\frac{s^2RC_2(C_1 + C_2) + sC_2 - s^2RC_2^2 + sGC_2}{sR(C_1 + C_2) + 1} \right]^{-1} \quad (27)$$

$$\frac{V_{in}}{i_{in}} = \left[\frac{sR(C_1 + C_2) + 1}{s^2RC_1C_2 + sC_2 - sGC_2} \right] \quad (28)$$

Eq. 28 is the equivalent impedance looking into node V_{in} . For a small R , large C_1 , and a buffer gain close to unity gain, the equivalent capacitance of C_2 becomes very small.

Ultimately, photovoltaic operation was chosen due to the lower noise and lower power dissipation of the photodiode. Bootstrapping was also not used as the capacitance of the chosen photodiode was approximately 20pF. At such a low capacitance value, the closed-loop bandwidth was not limited by the photodiode and bootstrapping was unnecessary. The final transimpedance amplifier design used is shown in Figure 28.

There are several adjustable features of the transimpedance amplifier. Firstly, to mitigate a high DC offset on the signal, the microcontroller DAC can apply a voltage to the V_{off} terminal, seen in Figure 28. Increasing values of V_{off} will shift the DC level of the signal towards ground. There are two feedback

loops in the gain stage (the amplifier on the right in Figure 28); the microcontroller controls which of the two feedback paths are used. One has a gain of 2, the other a gain of 10, and both have 3dB points at 10kHz.

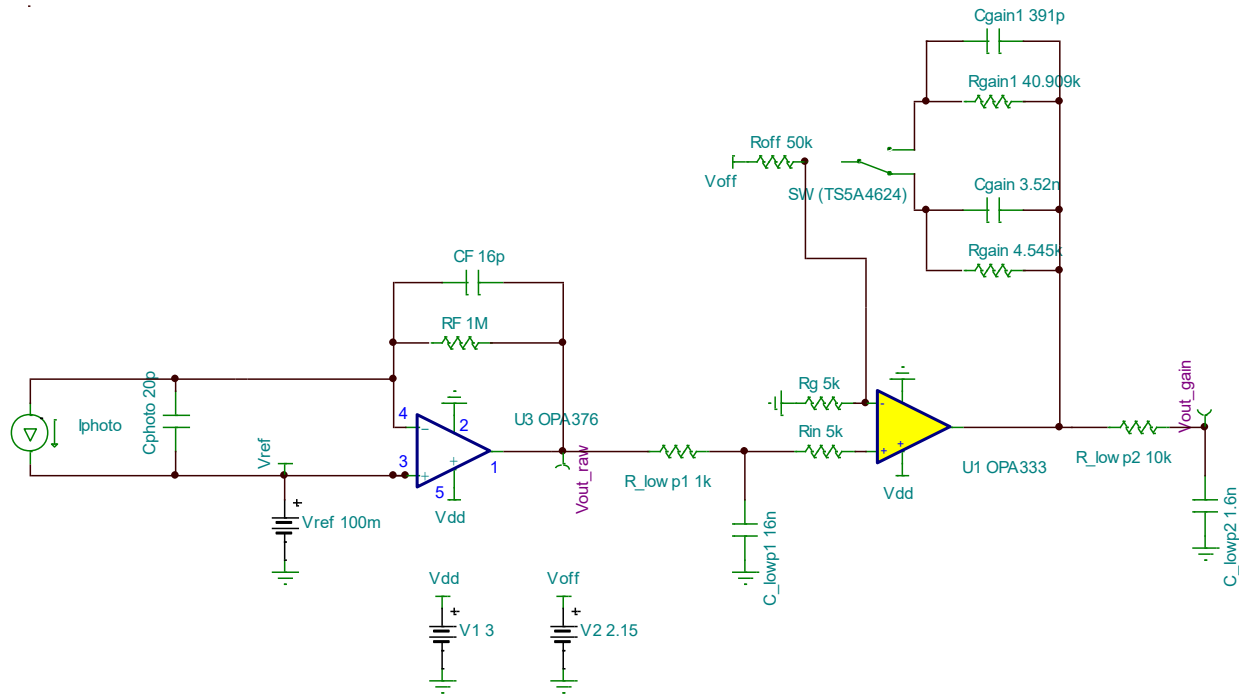


Figure 28: TINA circuit layout of the transimpedance amplifier

TINA simulations were performed on the transimpedance amplifier circuit to ensure its operation before breadboarding. The circuit was modeled using a 20 pF capacitor and current source as a photodiode. There was a 100 mV DC bias applied to the transimpedance core op-amp to avoid dipping below the minimum input voltage of the OPA376.

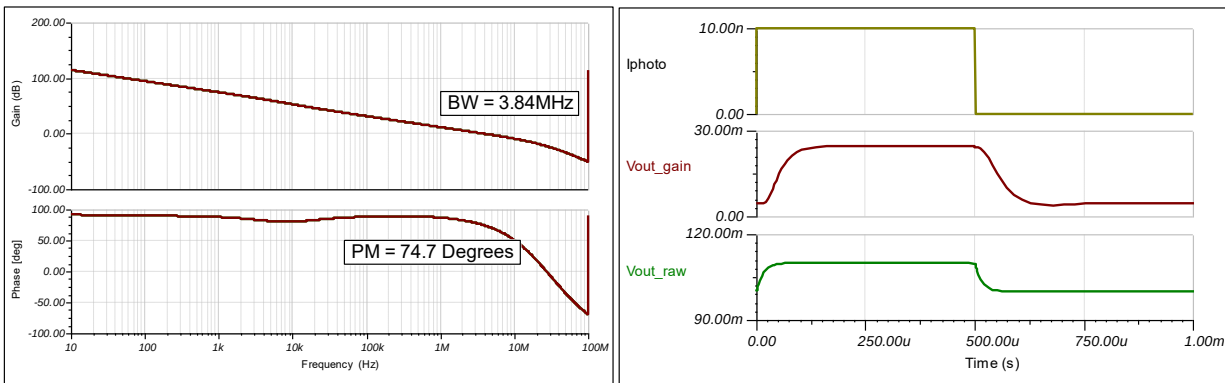


Figure 29: (Left) Frequency response of transimpedance amplifier. (Right) Transient response to 10nA, 500μs pulse

From Figure 29, the phase margin of the amplifier was 74.7° with a bandwidth of approximately 3.84 MHz. The DC gain was approximately 125 dB. The output voltage of the amplifier, in response to a current pulse, is shown in the figure (at right). The output had no overshoot, as was expected, with a phase margin larger than 60° .

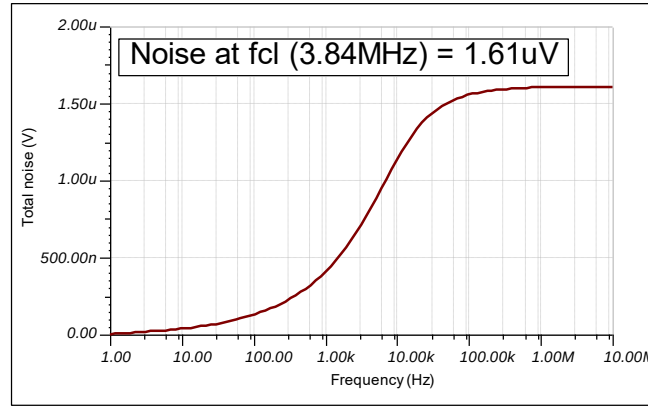


Figure 30: Noise analysis of transimpedance amplifier

Figure 30 shows a noise analysis performed on the transimpedance amplifier using the TINA software. Based on the noise at the open-loop bandwidth, the SNR of the transimpedance amplifier was calculated as follow,

$$v_{signal} = 10nA \cdot 1M\Omega \cdot 2 \frac{V}{V} = 0.02V \quad (29)$$

$$SNR = \frac{v_{signal}}{v_{noise}} = \frac{0.02V}{1.61\mu V} \cong 12422 \quad (30)$$

Thus, the maximum number of bits for the resolution of the transimpedance amplifier was,

$$n = \frac{\log(1 + V_{DD} \cdot SNR)}{\log(2)} \cong 15.19 \quad (31)$$

Rounding to the lowest integer,

$$n = 15 \quad (32)$$

This result satisfied the requirements necessary for achieving $\pm 2\%$ oxygen saturation accuracy.

5.2.5 Digital Interface

The purpose of the digital interface is to control all of the analog circuitry. This is done by collecting and transmitting the data from the analog circuitry to the user interface. The digital interface consists of two MSP430 microcontrollers, an analog to digital converter, two wireless transceivers, and a USB interface device. A microcontroller unit (MCU) was needed that would be capable of communicating with all of the peripherals including the ADC and temperature sensor, which both use an I²C interface, and the RF transceiver which uses the SPI protocol. The controller also needed several timers to regulate the pulses for the LED driver, as well as two onboard DACs to set the brightness of the LED driver and to regulate the gain of the gain stage. To accommodate all of these requirements the MSP430FG477 MCU was chosen as it had all of the necessary components and its size was small enough to fit well with the other components.

The first digital to analog converter (DAC0) was used to control the brightness level of the red and infrared LEDs. This brightness varied depending on the voltage coming out of the analog frontend. In order to get both LEDs to flash alternately, a timer was set on the microcontroller to interrupt every 10ms, giving a period of 100Hz. Each time this event was triggered a pin connected to the switch portion of the LED driver toggled. A second interrupt would then occur 50us after the first interrupt toggled the pin, creating a total pulse width of 50us. During this time, DAC0 would send out a voltage dependent on which LED was being toggled. In order to sample the voltage coming out of the transimpedance amplifier, a read of the 12-bit ADC would also happen during this 50us pulse. The second digital to analog converter (DAC1) was used to set the gain for the gain stage. There were two bias voltages needed for this stage in order to output a stable signal.

The analog to digital converter that was chosen was the ADS1015 12-bit ADC. This was chosen both because it came highly recommended by our sponsor and it was easy to communicate with. In order to configure the ADC, correct commands must be sent via I²C. The ADS1015 needs an address command (0x48 for the chip used) followed by a write to the pointer register, which selects the register that needs to be configured (see Table 3). Once this occurs, the next two bytes are used to set the configuration setting (see Table 4).

Table 3: Bits 1 and 0 of the pointing register which determine where the next read/write will occur

BIT 1	BIT 0	REGISTER
0	0	Conversion register
0	1	Config register
1	0	Lo_thresh register
1	1	Hi_thresh register

Table 4: Both bytes of the configuration register to be written to

BIT	15	14	13	12	11	10	9	8
NAME	OS	MUX2	MUX1	MUX0	PGA2	PGA1	PGA0	MODE
BIT	7	6	5	4	3	2	1	0
NAME	DR2	DR1	DR0	COMP_MODE	COMP_POL	COMP_LAT	COMP_QUE1	COMP_QUE0

For the purposes of this project, the following registers were written to in order to correctly configure the unit for conversions.

1. Pointer Register 0x01: Selects the configuration register.
2. Configuration Register 0x42: Selects continuous mode, FSR voltage of +/- 4.096V, and selects AIN0 as AINp and ground as AINn.
3. Configuration Register 0x83: Selects 1600 samples per second and disables the comparator.
4. Pointer Register 0x00: Selects the conversion register.

From here, a simple read command, which consisted of sending the address with the read bit set, followed by two bytes of clock signal was used to read the data from the conversion register. This data was then entered into Eq. 33 to get the voltage level.

$$V_{ADC} = \frac{ADC_{code} * 4.096}{4096} \quad (33)$$

The MCU also controlled the temperature sensor using the I²C interface with the same method described for the ADC. Data was written to the temperature sensor to set the temperature coefficients of the two LEDs, which were subsequently read. This occurred once every three seconds to minimize power consumption. In the case that the LEDs reached a threshold, DAC0 then limited their brightness until they reached a safe temperature.

The EZ430-RF2500 RF module was chosen for the wireless interface. This selection was made because the protocol was already written and because of its convenient compact size. The code was easily transferred from the MSP430F2272 to the MSP430FG477 and implemented on the board that we prototyped. The actual RF transceiver implemented was TI's CC2500, which uses a serial peripheral interface (SPI) protocol to communicate with the microcontroller. Combining this with TI's SimpliciTI wireless communication protocol allowed successful transmissions of data from the microcontroller to the EZ430-RF2500 USB stick. The only data that was actually sent from the digital interface to the user interface was the voltage level and its corresponding LED, which was sent over in a 2-bit array of data.

5.2.6 User Interface

The purpose of the user interface was to display the recorded data from the microcontroller via wireless interface. It also needed to be able to sound an alarm when a low oxygen level was reached. These two functional requirements had to be met for a successful design of the user interface. The alert signal was constrained by an audible level around 80dB so that it could be easily heard and responded to but not as loud as to damage a person's hearing.

TI also had a separate requirement that the user interface be implemented for an iPhone. This was attainable because Apple makes a software development kit (SDK) available for the public to develop software for the iPhone OS. The iPhone OS is the operating system that the iPhone and iPod Touch use for operation. Since an iPhone was more expensive than an iPod Touch and had features that the project did not require, the final device was used with the pulse oximeter prototype was an iPod Touch. The iPod Touch had Bluetooth and WiFi capabilities that could be used for wireless communication. The Bluetooth was limited by the SDK to peer-to-peer communication so we had to use the WiFi to connect to the intermediary pass-through device. It also had a speaker to accommodate the alert signal, a file system allow the saving of files, an LCD to display the GUI, and a development framework allowing access to these features.

The SDK used Objective C as its primary language along with C, Java, and some C++ being able to be used as well. The SDK provided several tools to help in the application development process. These tools were Xcode, Interface Builder, and Instruments. Xcode is an integrated development environment (IDE) for writing code for Apple's products. Interface Builder is a tool allowing the GUI to be created graphically rather than programmatically (writing code). Instruments is a utility that gave a plethora of

vitals on the application in the debug process which included a leak detector and memory usage. Apple provided these tools to developers to streamline the process of creating software for their products.

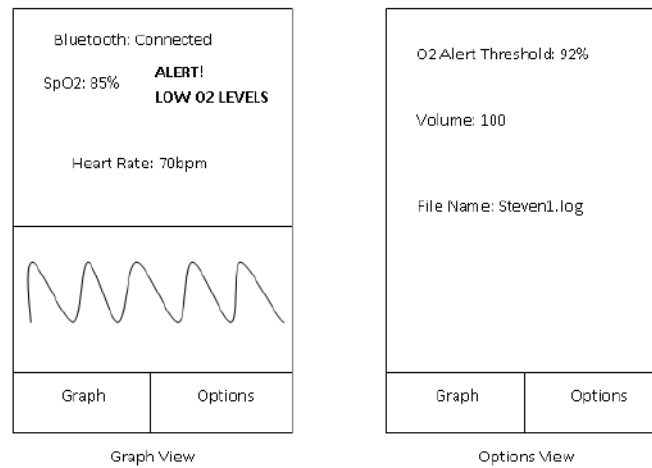


Figure 31: Design template for user interface featuring 2 main screens

Figure 31 shows a preliminary layout of the GUI that was used as a design template. Figure 32 shows the completed GUI for the user interface with test data visible.



Figure 32: Final user interface GUI implemented on iPod Touch

The underlying program flow for the user interface is shown below in Figure 33. The program flow shows how the user interface operates. It manages the WiFi connection, listens for data, verifies the data, updates the GUI, and manages the alert sound.

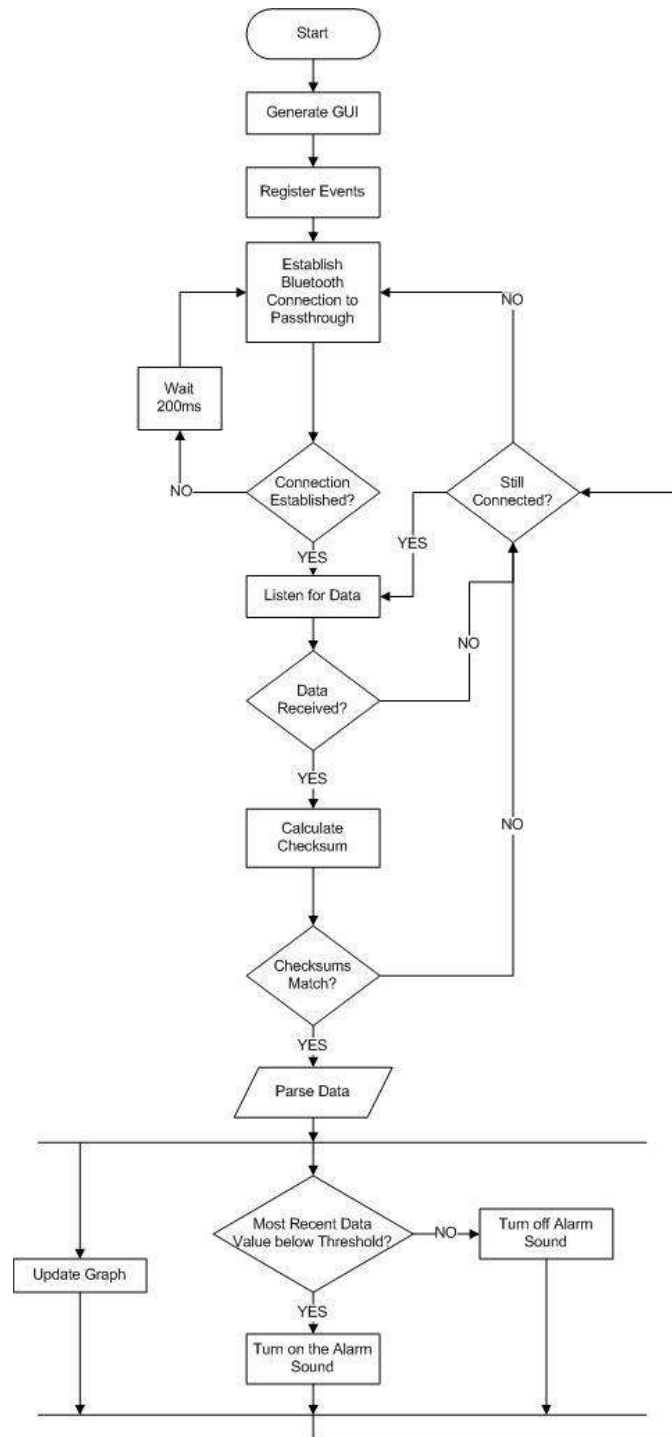


Figure 33: User interface program flow

The user interface used a few examples GUIs to help with development. The first was sample code from Apple that was used to develop the WiFi and FTP functionality. Specifically, the sample code named *SimpleNetworkStreams* [7] was used for the WiFi and *SimpleFTPSample* [6] was used for the FTP connection. They allowed for functioning connections that could then be modified to what was needed for the user interface. The plotting software used was from an open source plotting framework called *Core Plot* [2]. *Core Plot* simplified the graphing function of the user interface. It was able to periodically update the graph to the new data from the WiFi. This allowed the data to be viewed in real time.

For the calculations of oxygen saturation and heart rate, a peak detection algorithm was used in the time domain to find the peaks and troughs. This algorithm is based on Matlab code from Eli Billauer on his website [1]. This allowed the minimum and maximum of each pulse and time between pulses to be used in several calculations. The heart rate was found to be sixty divided by the time between the last two pulses. This was then compared to the last calculated heart rate to see if it was a possible value since the peaks and troughs found contained the data from the dicrotic notch and noise, which would give incorrect saturation and heart rate data. Since the peak of the pulsatile wave and dicrotic notch could be used to calculate the heart rate, it would report a substantially higher heart rate than the actual heart rate. To eliminate this issue, the program rejects the last peak or trough and keeps the last heart rate if the calculated heart rate is incorrect. Then the oxygen saturation is calculated using the data where the dicrotic notch data points were removed. This method allowed for the most accurate readings.

A fast Fourier transform (FFT) was going to be used to calculate the AC and DC components of the pulsatile waveform and the heart rate but it would have caused several problems. First, a sample size of 2048 data points at a sampling rate of 34Hz was required to achieve a heart rate resolution of 1 beat per minute. This would have caused the iPod Touch to become sluggish from the calculations since the FFT algorithm is $O(n \cdot \log_2(n))$ or that it would have taken $256 \cdot \log_2(2048) = 2816$ loop iterations to obtain the information that was needed. Second, a sample size of 2048 data points would have obscured the actual changes in heart rate. Lastly, the FFT algorithm could not handle transients correctly. For example, if a person had a rising saturation, the pulsatile waveform would look like the steady state waveform that had been rotated toward in an increasing manner. These transient conditions caused the FFT to produce incorrect values. Overall, the FFT could not handle transient conditions in heart rate or saturation. These problems could be resolved with a smaller sample size such as 64 points but then the heart rate would be incorrect by more than 15 beats per minute which was unacceptable. In the peak detection scheme,

the heart rate was extremely accurate and the oxygen saturation calculations could be corrected using linear interpolation [8]. The FFT was not used because of these problems.

6 System Build

The completion of the design process led to the development of a robust testing procedure designed to ensure that the final pulse oximeter operated correctly and met the functional requirements laid out by the project sponsor. The testing process was implemented in two stages: the first stage was designed to test the individual subsystems of the pulse oximeter, while the second tested the final, assembled pulse oximeter as a whole.

6.1 Subsystem Testing

Prior to any integration of the individual subsystems, each was tested independently as a stand-alone system in order to validate basic functionality, as well as eliminate as many potential compatibility issues as possible. The subsystem testing was divided into two primary stages: breadboard testing and PCB testing. The breadboard testing phase was the initial mockup for each of the electronic circuits using discrete components, in order to establish baseline values for the electrical parameters of interest. The shortcomings of breadboard testing lie in the large amount of capacitance inherent to breadboard designs. This capacitance has the potential to induce additional noise into the measured signals, which was particularly prevalent in the small signals seen at the transimpedance amplifier input.

Once basic functionality had been established through breadboard testing, a prototype PCB was created that encompassed the transimpedance amplifier, microcontroller, and LED driver circuits. Further testing revealed that the PCB circuits were much less prone to noise saturation than their breadboard counterparts, making for more accurate signal acquisition. The information in Table 5 outlines the tests performed on the individual subsystems and defines the required condition, testing procedure, metric, and expected as well as final results of the testing. Table 6 details the equipment used throughout the testing process.

Table 5: Subsystem testing procedures and results

Subsystem	Requirement	Measurement Procedure	Metric	Expected Result	Actual Result	Pass/Fail
LED Driver	Provide a linear variable output current	Measure the output current as input voltage changes	Amps	0-30mA linear current	0-29.6mA linear current	✓
	Provide a square wave output current at 1kHz	Measure output current with an oscilloscope while switch is in circuit	Amps	Square wave with rise/fall times of the current level at 1kHz	More of a triangle wave at current level at 1kHz (Usable signal)	✓
	Have correct LED function with known Nellcor oximeter sensor	Verify that both Red and IR LEDs pulse at proper rate and sequence	Visual Pulse	Both LEDs pulsed opposite each other at 1kHz	LEDs pulse alternately, similar to commercially available units	✓
LED Driver & Temp Sensor	Circuit produces desired voltage across LEDs	Measure the V_{be} across the LED with multimeter	Volts	Voltage across LEDs between 0-1.1V	1.9V voltage drop across both LEDs	✓
User Interface	Transmit data via WiFi	Transmit text from computer to iPod Touch	Visual	Correct message displays on screen	Correct message displayed on screen	✓
	Plays sound	Run code to produce sound	Aural	Sound clip is heard	Sound played correctly	✓
	Parse and graph data	Observe the graph	Visual	Data graphed correctly	Data graphed correctly	✓
	Data translated	Input data to RF and receive output on WiFi	Visual	Data received correctly	Data received correctly	✓
	GUI functions correctly	Use the program on iPod Touch to find faults/bugs	Visual	No faults/bugs	No faults/bugs found	✓
	Live data streaming	Observe the graph	Visual	Graph updates correctly	Graph updates in real time	✓
	Alert threshold functions correctly	Observe when levels go below threshold	Aural/Visual	Alert sounds when level falls below threshold	Alert sounds at low levels	✓
	Data logging	Inspect datalog generated from data received	Visual	Data is present and well formed	Data is present and well formed	✓
Digital Hardware	Communicate between microcontroller and ADC	Verify I2C signal lines	Volts	9 cycle clock and data	Stable clock	✓
Transimpedance Amplifier	Amplifier stable with photodiode on input	Apply step input and observe stability of output	Volts	Saturated or unsaturated output	Stable output for photodiode with large junction capacitance	✓
	Amplify 10nA to 1uA photodiode signal	Use OxSim and Nellcor sensor to inject current	Volts	Amplified square wave voltage with DC offset	Square wave output with high frequency noise; heart beat detected	✓
	Output square wave settles fast enough for ADC to sample peak signal	Measure settling time	Time	Settles quickly (should not see much overshoot with PM=80°)	With 50µs pulses, output wave settles in a sufficient amount of time	✓

Table 6: Testing equipment

Description	Manufacturer	Part Number
Oscilloscope	Tektronics	TDS2014B
Function Generator	Hewlett-Packard	33120A
Triple DC Power Supply	Agilent	E3631A
Current Source	Yokogawa	GS610
Digital Multimeter	Agilent	34401A
Voltage Source	Data Precision	8200

6.2 Subsystem Integration

Following the independent subsystem testing, the next step was to combine the subsystems into a single, functioning pulse oximeter. The initial input is taken at the photodiode; the output current from the photodiode is proportional to the amount of light absorbed from the LEDs after passing through the user's earlobe or fingertip. The LED driver circuit is responsible for receiving commands from the microcontroller in order to pulse light appropriately. The photodiode output current is received by the transimpedance amplifier, converted to a voltage, and sent to the microcontroller. The microcontroller in turn transmits the signals via WiFi to the user interface, where the data is sorted and expressed as a percentage of oxygen concentration.

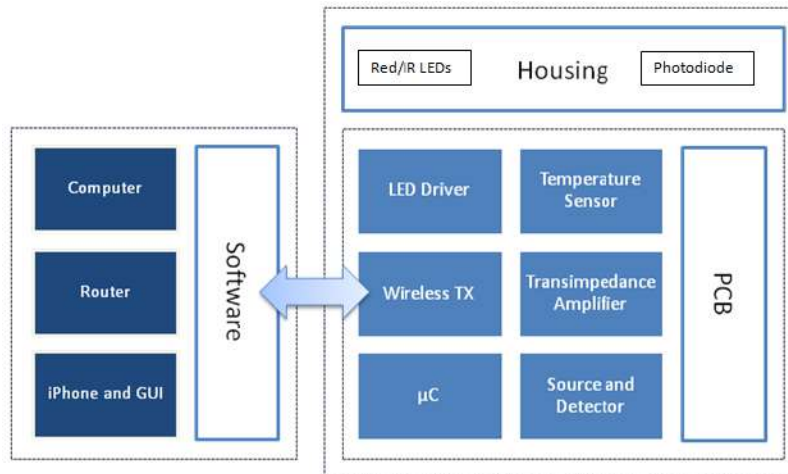


Figure 34: Full system flowchart

Physically, the subsystems are integrated in three major parts: the components contained within the physical housing, the components contained within the sensor housing, and the components of the user interface. The flowchart presented in Figure 34 indicates how the various subsystems interface with one

another. The microcontroller, LED driver, and wireless transmitter circuits are located on a single PCB, located within the main housing, which mounts to the arm of the wearer. The LEDs, photodiode, and transimpedance amplifier are located in the sensor housing, which clamps around the ear of the wearer. The sensor housing and main housing are connected via a wire and an FPC connector that is accepted by the main housing. The remaining portions of the pulse oximeter are implemented in the user interface itself, within the GUI application that is displayed on the iPod. The user interface is where data transmitted over WiFi from the microcontroller is received and displayed. The PCB layout for the main board containing the microcontroller, LED driver, and wireless transmitter is shown in Figure 35. The dimensions of the final board were 2.969" by 0.881".

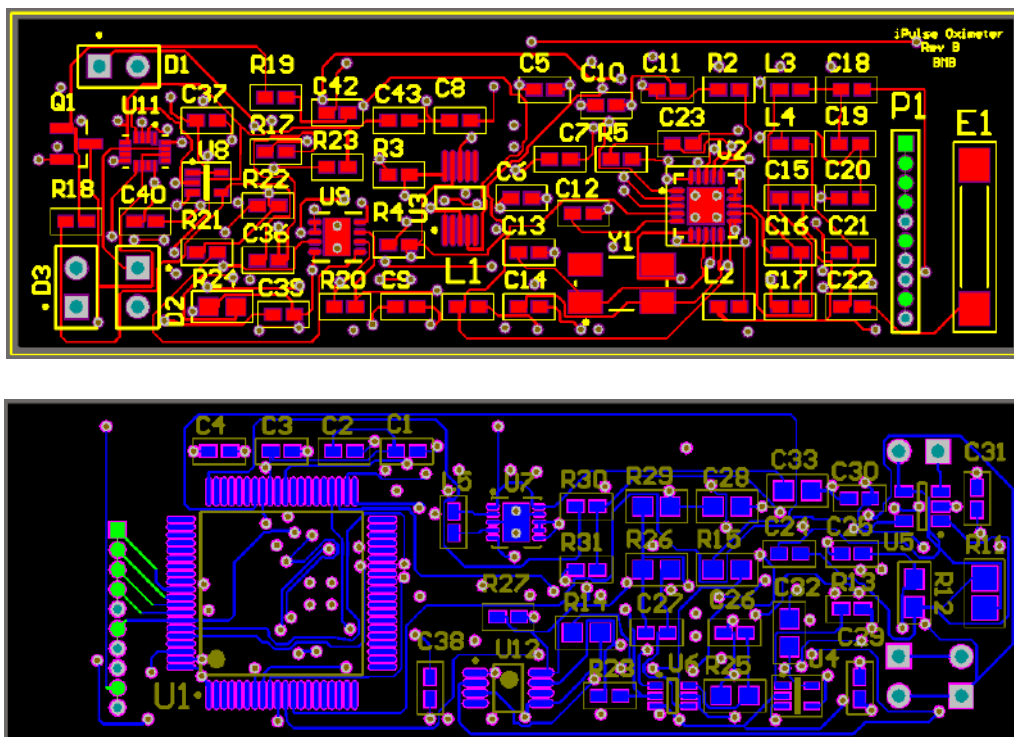


Figure 35: PCB layout for main housing board

7 System Testing

Upon completion of the subsystem interfacing, the final step in the testing procedure was to verify that the completed pulse oximeter met all of the specified functional requirements. Table 7 outlines the tests performed on the pulse oximeter in order to verify full system functionality and more details on the individual testing procedures and results are presented in the following sections.

Table 7: Overall system testing procedure and results

Requirement	Measurement Procedure	Metric	Expected Result	Actual Result	Pass/Fail
Accuracy – accurate to within $\pm 2\%$ of actual blood oxygen concentration	Compare O_2 concentration values from remote pulse oximeter with those of Massimo oximeter	Oxygen saturation (%)	$\pm 2\%$ difference from Massimo oximeter readings		?
Perceptible Alert Signal - audible alert during low oxygen conditions	Generate a simulated low oxygen signal in order to trigger alert	Decibels	80dB alert signal triggered at adjustable low oxygen level	65dB at 1m ~80dB at ~0.5m	✓
Battery Life - remain functional for desired time on battery power	Run oximeter continuously until electronic components shut off due to insufficient power from battery	Time (Hours)	Oximeter will be able to run continuously for 12 hours or longer	~2 hours continuous use	✓
Transmission Distance - wirelessly send data over the required distance	Gradually separate oximeter from user interface until data is no longer transferred	Distance (m)	Transmit data no less than 25m	~35m	✓
Data Logging – ability to continuously monitor data for specified time period	Run oximeter over course of one night, observe file size, multiply by seven	Time (Weeks)	At least 1 week worth of data logged from continuous monitoring	~11MB/week (iPhone has 8GB of capacity)	✓
Shock Resistance – system must remain functional after 2m fall	Model housing and components in SolidWorks and conduct FEA analysis to predict performance	Stress (N/m^2)	Oximeter will maintain full functionality after fall	SolidWorks verification of maximum stress of $\sim 400kN/m^2$	✓
Water Resistance – resistant to a depth of 3m	Submerge in water for period of 30 seconds	Distance (m)	Oximeter will maintain full functionality after water submersion	Not performed due to time constraints	✗

7.1 Housing Testing

The testing that was done for the housing was a force analysis using simulation tools in SolidWorks called Simulation Xpress. The main limitation of using this program was that the specific materials used for the housing were not available. Therefore, the properties of medium-high impact Acrylic, a predefined SolidWorks material, were used for the rigid Accura25 parts and the properties of Rubber, another predefined SolidWorks material, were used for the TangoPlus FullCure930 pieces. The following force distribution images were obtained from the simulation. The fixed face and the force-applied face were chosen conservatively, such that the worse-case scenario was analyzed. The force used ($F=0.3924$ N) was based on the product of gravitational acceleration ($a=9.81$ m/s²) and the mass of the total housing ($m=40$ g) using the kinematic equation shown in Eq. 33.

$$F = ma \quad (33)$$

The calculated force was a conservative estimate for the actual force that the prototype may experience. In the series of images presented in Figure 36 through Figure 40, the results of the finite element analysis are depicted. The blue areas are those exhibiting the lowest stresses and have the least danger of failure while the red areas are those experiencing the great stresses and are of concern.

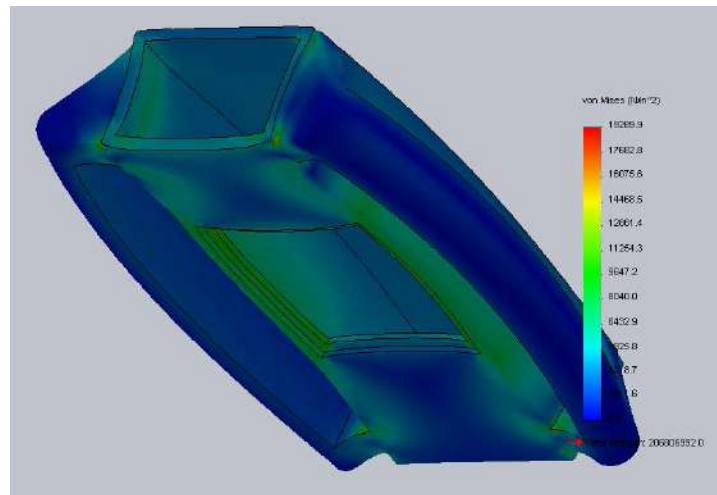


Figure 36: SolidWorks FEA analysis performed on main housing unit

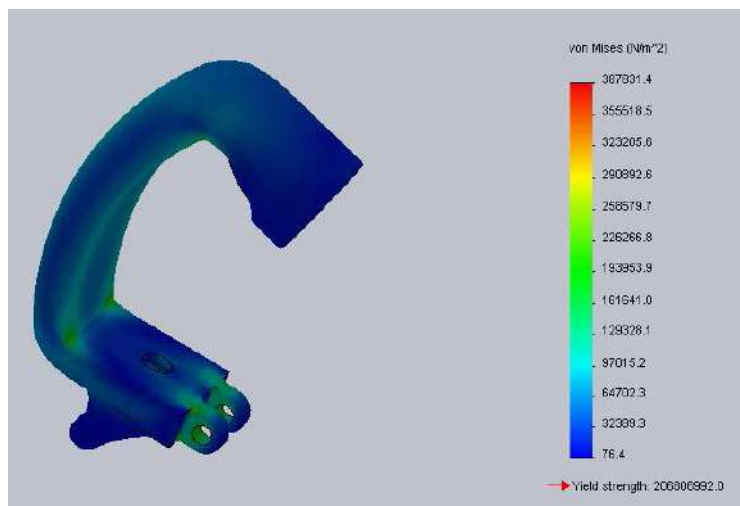


Figure 37: SolidWorks FEA analysis performed on LED arm of sensor housing

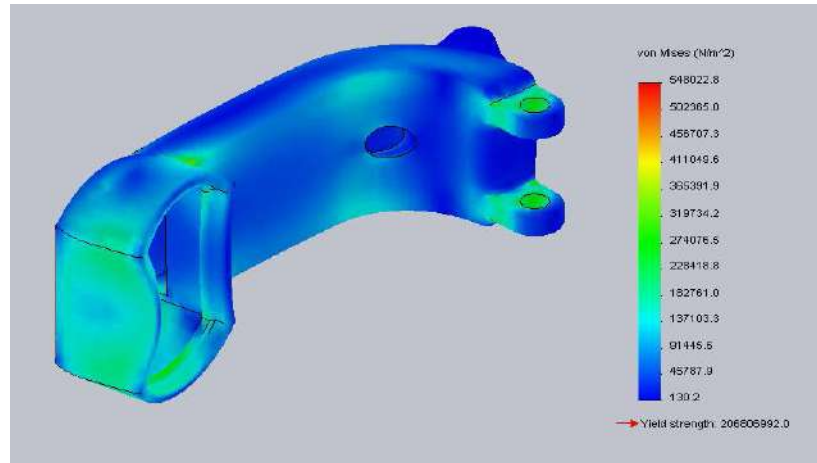


Figure 38: SolidWorks FEA analysis performed on photodiode arm of sensor housing

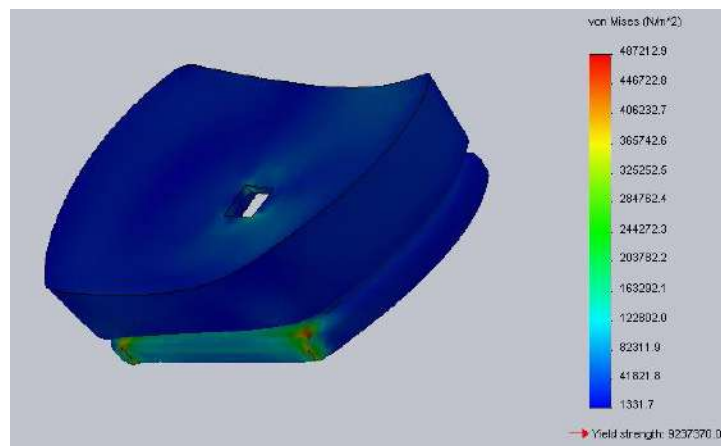


Figure 39: SolidWorks FEA analysis performed on photodiode cover

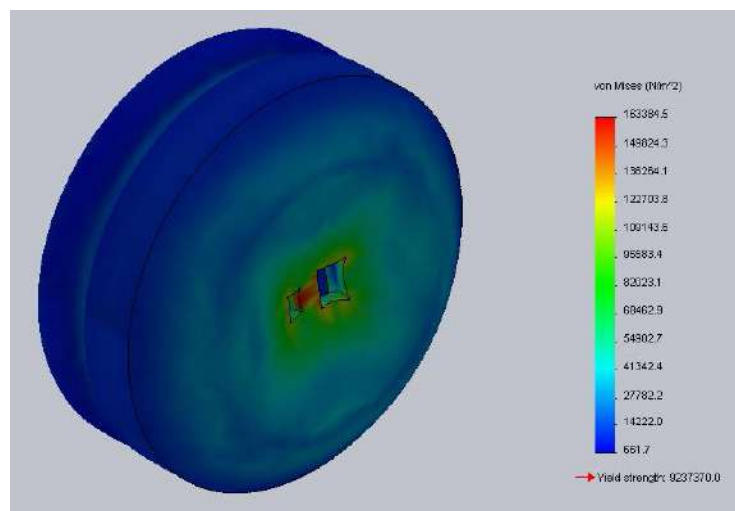


Figure 40: SolidWorks FEA analysis performed on cover for LEDs

Since the housing, in total, was incredibly light and was constructed out a very strong material in regards to the application, housing breakage was not of much concern as long as it stayed within a reasonable temperature range (temperatures usually experienced by the human body – 0 to 120°F). Please refer to the data sheets in Appendix D: Housing Material Properties for more information on the housing materials.

There was no reasonable way to test the water resistance of the housing as there was only time to develop one prototype before the completion of the project. If the time and budget was available to create multiple prototypes, then a submersion test could have been carried out to test the water resistance of the oximeter. In order not to damage the one prototype available to us, this functional requirement was not tested.

7.2 LED Driver Testing

The required functions of the LED driver were: to have a variable output current through the LEDs (ranging from 0-100mA), to have a stable output current independent of temperature, and to switch between a red and an infrared LED.

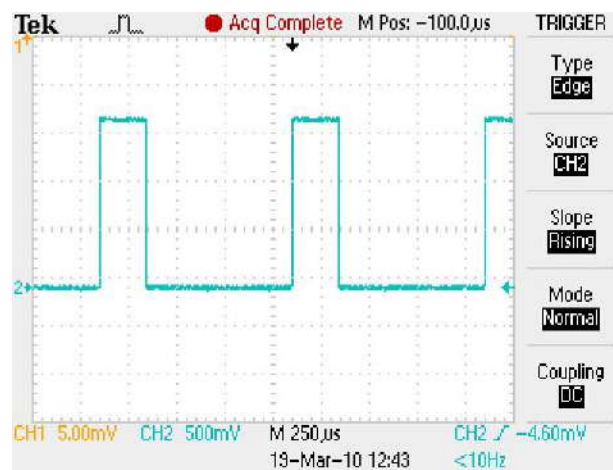


Figure 41: Voltage across the LED driver drain resistor - used for current sensing

Figure 41 illustrates the LED driver operating at 100mA. The LED driver is stable at both current levels. The LED driver was tested through the entire range of current values from 0mA to 100mA. Up to approximately 85mA, the input voltage from the microcontroller versus the LED current (V_{in}/I_{LED}) was linear. Between 85mA to 100mA, V_{in}/I_{LED} began to slowly decrease. This decrease was not significant enough to have a major effect on the linearity of V_{in}/I_{LED} and the overall functionality of the LED driver.

The transconductance of the LED driver was experimentally determined as 0.05A/V. This value illustrates the relationship between the change in output current for a given change in the input voltage. Or put simply, a 20mV change of input voltage corresponded to a 1mA change in the output current.

We have operated the LED driver continuously for extended periods of time and have observed no significant deviations in the output current. The OPA333 was chosen for the LED driver as it is a zero-drift operational amplifier whose performance has been verified by Texas Instruments. Our results were consistent with the performance claimed by TI.

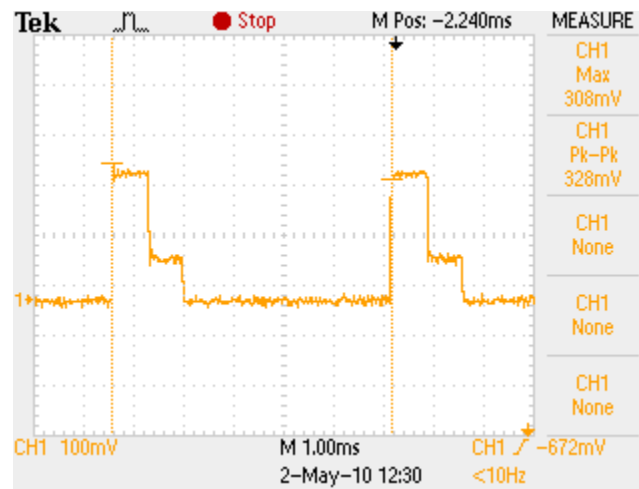


Figure 42: Red and infrared LEDs switching capability

We have tested and verified the switching capability of the LED driver between an IR and a red LED, as shown in Figure 42. The switching speed was tested up to 1kHz to ensure that its operational characteristics would be sufficient at 100Hz. The output at 1kHz, switching between the LEDs, was almost a perfect square wave, as the rise time was approximately 9ns. Thusly, the rise and fall times were negligible with regard to the signal waveform. It was possible to have small rise and fall times due to the final design including a Texas Instruments TS3A44159RSVR switch.

7.3 Transimpedance Amplifier Testing

The required functions of the transimpedance amplifier were: to precisely amplify the photodiode current to a usable voltage for the ADC (with low noise), to have a variable DC offset, and to have adjustable gain.

During breadboard testing, very high levels of noise were observed. A Yokogawa GS610 high precision current source was used to simulate the current from a photodiode. However, the current source had

an offset of $1.53\mu\text{A}$, which was on the order of the expected signal. As such, the accuracy of the test was suspect. Significant noise injection from this current source and noise from the high capacitance breadboard contributed approximately 200mV_{pp} of noise. These noise levels necessitated testing on a PCB with an actual photodiode. During testing with the final PCB and photodiode, the design and simulation in TINA-SPICE was verified by the extremely low noise levels on the output voltage signal. The detected noise was on the level of the noise floor for the oscilloscope (TDS2002B): approximately 20mV_{pp} . The output voltage range was 100mV to 3.3V . Below approximately 100mV , the OPA376 and OPA333 are not guaranteed to function properly. Thusly, the smallest possible output was 100mV . In Figure 43, the pulses come in pairs. For a given pair, the first pulse was due to the red LED and the second pulse was due to the IR LED. As can be seen, they were in the range of $0.8\text{--}1.22\text{ V}$.

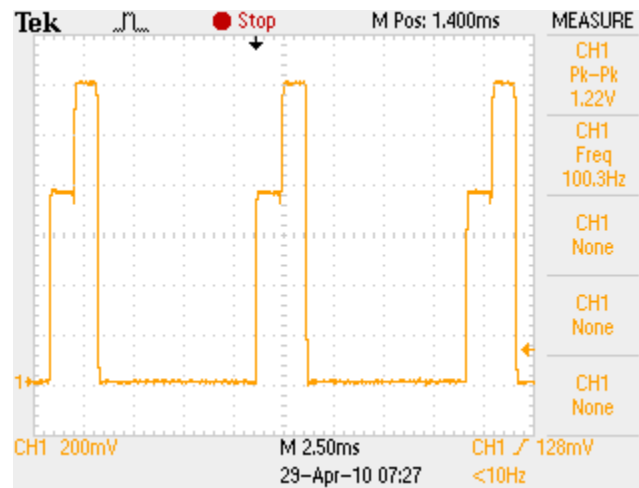


Figure 43: Voltage output from transimpedance amplifier

The variable DC offset is controlled by a microcontroller DAC. Different DC levels were applied by the DAC and the DC offset on the output was observed to change by the same level, thus confirming the correct functionality of the variable DC offset.

To test the two gain loops (gains of 2 and 10), the output voltage was observed with the stage of gain 2 enabled, followed by observation of the stage of gain 10. No input was applied; thus, the output was equal to the product of the 100mV offset on the OPA376 and the gain. Voltages of approximately 200mV and 1V were measured on the output of the transimpedance amplifier with gains 2 and 10 respectively.

It is important to note that the AC signal, representing the pulse rate of the oximeter user, is on the order of 1% of the detected DC signal [10]. Thusly, the AC signal was expected to be on the order of 1-10mV, which was below the noise floor. As can be seen in Figure 44, the AC ripple was found to be approximately 20mV. Measuring the period between peaks, the heart rate of Scott Little was calculated to be 1.398Hz or 83.84 beats/min. To verify his heart rate, Scott counted his heart beats over 15 seconds. His manually measured heart rate was 84 beats/min.

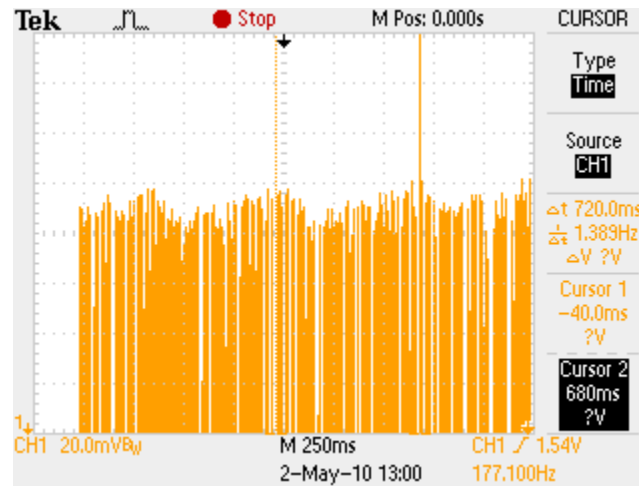


Figure 44: AC ripple representing pulse rate

7.4 Microcontroller Testing

The required functions of the microcontroller were: control the LED driver, acquire data from the transimpedance amplifier, and send data to the user interface.

The microcontroller controlled a DAC that is a voltage input to the LED driver, which controlled the output current (therefore the intensity) of the LEDs. This was verified by measuring the output voltages for the DAC and also from the LED driver testing. In addition, the microcontroller controlled the switching of the LEDs. This was verified by measuring the voltage applied on the switch using an oscilloscope (TDS2002B).

The transimpedance amplifier outputted a voltage to the ADC, which was read by the microcontroller. The microcontroller also sent a control signal to the gain stage to adjust the gain and ensure the signal fell within the desired range. In addition, the microcontroller applied a DC offset to the signal. Both the gain control and DC offset control were verified in the testing of the transimpedance amplifier.

The data was sent to the user interface from the microcontroller. To ensure proper functionality of the data transmission, the TDS2002B oscilloscope was used to analyze the logic signals being sent from the microcontroller. Upon verification of the logic signals, a known set of data was sent from the pulse oximeter microcontroller to the USB receiver connected to a personal computer. The received data was viewed in HyperTerminal to verify that the data was correctly received. Data transmission to the iPhone was verified during user interface testing.

7.5 User Interface Testing

The required functions of the user interface were: to display the SpO_2 and heart rate, to sound an alert for low SpO_2 levels, and to perform data logging.



Figure 45: Final iPhone interface

To verify that the SpO_2 display functioned properly, SpO_2 data was sent to the iPhone and the reading on the display was observed to change accordingly. Figure 45 shows the final interface design being utilized by a user.

To test the alert signal, data corresponding to a low SpO_2 was sent to the iPhone. Following SpO_2 calculations, the alert signal was triggered as expected.

To verify the data logging functionality, data was sent to the iPhone from the USB wireless receiver and saved to a temporary file. The file was then uploaded to an FTP server which was read by a personal laptop.

8 Conclusions & Recommendations

The remote pulse oximeter project has resulted in a functional design that fulfilled all of the major functional requirements, as well as Texas Instruments' request for a reference design for future customers in the medical device field. The unit is powered from a readily available 2032 battery, which is already widely implemented in several other medical devices. The form factor of the housing is such that it mitigates ambient light noise, protects the vital circuitry from damage in day-to-day use, and the novel ear-clip design is compatible with a wide range of potential users. In terms of functionality, the oximeter was able to output the user's SpO_2 level, with an accuracy comparable with commercial-grade sensors, in addition to dynamically calculating and displaying the user's heart rate. The oximeter hardware was able to transmit data wirelessly, and can do so through any existing WiFi network. Lastly, the novel iPhone OS-based user interface proved to be a simple means of acquiring and displaying data, and due to the growing popularity of Apple's iPhone and iPod touch, is currently available to over 70 million consumers.

Despite the success of this first-generation project, there is room for improvement in a number of areas of this project. The use of smaller electronics packages could result in a smaller PCB, and hence, a smaller overall housing. With enough design iterations, all of the electrical components could potentially be integrated into the ear-clip portion of the housing, significantly reducing the overall form factor of the device. The use of a higher supply voltage, thus necessitating a larger battery or voltage regulator, would improve the quality of the output signal by making the AC signal easier to measure. Modifying the analog circuitry to perform sample and hold functions would allow the separation of the vital signals into separate channels; AC and DC could be separated, as well as the red and IR signals. The use of multiple channels could result in higher resolution of the individual signals, ultimately increasing the overall accuracy of the device.

Even without the aforementioned improvements, this pulse oximeter design has demonstrated that not only is it fully functional as a stand-alone device, but also that it could potentially be commercialized by Texas Instruments. The most expensive portions of this prototype, being the rapid-prototyped housing and PCB fabrication and population, would be significantly reduced if ordered in large numbers. Further, nearly all of the analog components are produced by Texas Instruments, further reducing cost. Expanding the user interface to include both PCs, Macs, as well as other smart-phone operating systems, such as Google Android, Palm WebOS, and Blackberry devices would account for a much larger

percentage of the target consumer audience, reducing design costs associated with creating a proprietary user interface system.

9 Acknowledgements

Project Sponsor:

Texas Instruments

Matthew Hann

HPA Linear Applications Engineer

ENGR498 Mentor:

Fred Highton

Departmental Advisors:

Michael Descour

College of Optical Sciences

Charles Higgins

Neuroscience

Ali Akoglu

Electrical/Computer Engineering

Jeong –Yeol Yoon

Agriculture/Biosystems Engineering

Companies Providing Components/Services:

Texas Instruments

Develops analog, digital signal processing, RF, and DLP

Kingbright

LED manufacturer

Advanced Photonix

Opto-Electronics manufacturer

Fairchild

Semiconductor manufacturer

Sierra Proto Express

Printed circuit board manufacturer

360 Prototyping

Supplier of rapid- prototyped components

10 References

1. Billauer, Eli. "Peakdet: Peak Detection Using MATLAB." *Eli Billauer's Home Page*. Web. <<http://www.billauer.co.il/peakdet.html>>.
2. "Core-Plot." *Google Code*. Web. <<http://code.google.com/p/core-plot/>>.
3. Kyriacou, P. A. "Pulse Oximetry in the Oesophagus." *Physiological Measurement* 27.1 (2006). Web.
4. Li, Yun-Thai. "Pulse Oximetry." Web. <<http://personal.ph.surrey.ac.uk/~phs3ps/surj/v2/li.pdf>>.
5. Prahl, Scott. "Optical Absorption of Hemoglobin." *Laser Photomedicine and Biomedical Optics at the Oregon Medical Laser Center*. Web. <<http://omlc.ogi.edu/spectra/hemoglobin/index.html>>.
6. "SimpleFTPSample." *Apple Developer*. Web. <<http://developer.apple.com/iphone/library/samplecode/SimpleFTPSample/Introduction/Intro.html>>.
7. "SimpleNetworkStreams." *Apple Developer*. Web. <<http://developer.apple.com/iphone/library/samplecode/SimpleNetworkStreams/>>.
8. "Understanding Pulse Oximetry SpO2 Concepts." *Philips Medical Systems*. Web. <http://incenter.medical.philips.com/doclib/enc/fetch/586262/586457/Understanding_Pulse_Oximetry.pdf%3Fnodeid=586458&vernum=2>.
9. "U.S. Home Size — Infoplease.com." *Infoplease: Encyclopedia, Almanac, Atlas, Biographies, Dictionary, Thesaurus. Free Online Reference, Research & Homework Help. — Infoplease.com*. Web. <<http://www.infoplease.com/askeds/us-home-size.html>>.
10. Webster, John G. *Design of Pulse Oximeters*. Bristol: Institute of Physics Pub., 1997. Print.

11 Appendix A: Main Component List

	Name/Description	Manufacturer	Part #
Housing	Black ABS/Black Rubber	360 Prototyping	N/A
Source/Detector	Surface Mount PIN Photodiode	Advanced Photonix	PDB-C154SM
	Red Surface Mount LED	Kingbright	APG1608SURKC/T
	IR Surface Mount LED	Kingbright	APT1608F3C
LED Driver/ Temp Sensor	Remote Temperature Sensor	Texas Instruments	TMP411
	CMOS Low Voltage Op Amp	Texas Instruments	OPA333
	Quad SPDT Analog Switch	Texas Instruments	TS3A44159
	PNP Transistor	Fairchild	PN2907
Transimpedance Amplifier	Low Noise Op Amp	Texas Instruments	OPA376
	CMOS Low Voltage Op Amp	Texas Instruments	OPA333
Microcontroller	Surface Mount MCU	Texas Instruments	MSP430FG477
	RF Transceiver	Texas Instruments	CC2500
	Analog to Digital Converter	Texas Instruments	ADS1015
User Interface	iPod Touch	Apple	N/A

12 Appendix B: Bill of Materials

Subassembly	Part No.	Description	Manufacturer	Qty	Price Each	Subtotal
Housing	PROTO	Ear Back Housing	360 Prototyping	1	\$25.00	\$25.00
	PDB-C154SM	Ear Front Housing	360 Prototyping	1	\$26.00	\$26.00
	N/A	Main Battery Cover	360 Prototyping	1	\$23.00	\$23.00
	N/A	Main Cap	360 Prototyping	1	\$12.00	\$12.00
	N/A	Main House	360 Prototyping	1	\$185.00	\$185.00
	N/A	Silicone Insert Convex Detect	360 Prototyping	1	\$132.00	\$132.00
	N/A	Silicone Insert Convex LED's	360 Prototyping	1	\$75.00	\$75.00
Source/ Detector	APG1608SURKC/T	Red Surface Mount LED	Kingbright	1	\$0.30	\$0.30
	APT1608F3C	IR Surface Mount LED	Kingbright	1	\$0.26	\$0.26
	PDB-C154SM	Photodiode	Advanced Photonix Inc	1	\$2.34	\$2.34
LED Driver	OPA2333AIDRBT	CMOS Low Voltage Op Amp	Texas Instruments	1	\$2.00	\$2.00
	TS3A44159RSVR	Switch	Texas Instruments	1	\$0.52	\$0.52
	TMP411ADGKR	Temperature Sensor	Texas Instruments	1	\$1.40	\$1.40
	MMBT2907A-TP	PNP Transistor	Micro Commercial Co	1	\$0.32	\$0.32
	RP1005S-100-F	Resistor 10Ω	Susumu	10	\$0.50	\$5.00
	ERJ-2RKF1000X	Resistor 100Ω	Panasonic - ECG	10	\$0.10	\$1.00
	ERJ-2RKF1001X	Resistor 1kΩ	Panasonic - ECG	10	\$0.10	\$0.98
	ERJ-2RKF1002X	Resistor 10kΩ	Panasonic - ECG	10	\$0.10	\$1.00
	ERJ-2RKF1003X	Resistor 100kΩ	Panasonic - ECG	10	\$0.10	\$1.00
	ERJ-2RKF1243X	Resistor 125kΩ	Panasonic - ECG	10	\$0.10	\$1.00
	GRM1885C1H202JA01D	Capacitor 2nF	Murata Electronics	1	\$0.08	\$0.08
	C0402C104K8PACTU	Capacitor 100nF	C0402C104K8PACTU	7	\$0.02	\$0.14
Interface	MB528LL/A	iPod Touch (8GB)	Apple	1	\$189.00	\$189.00
	APPDEVSDK	iPhone Software Developer Kit	Apple	1	\$99.00	\$99.00
	MSP430FG477	MSP430 Microcontroller	Texas Instruments	1	\$5.55	\$5.55
	ADC1015	A2D Converter	Texas Instruments	1	\$5.54	\$5.54
	CC2500	RF Sensor	Texas Instruments	1	\$3.83	\$3.83
	PGA204	Programmable Gain Amp	Texas Instruments	1	\$16.58	\$16.58
	TPS60120	Power Mgmt IC	Texas Instruments	1	\$3.60	\$3.60
	PCBEXPRESSQ4	Printed Circuit Board	Sierra Circuits	1	\$107.00	\$107.00
	PCBPOP	PCB Population	Sierra Circuits	1	\$50.00	\$50.00

Subassembly	Part No.	Description	Manufacturer	Qty	Price Each	Subtotal
Amplifier	OPA376AIDBVT	OP Amp /OPA376	Texas Instruments	1	\$1.50	\$1.50
	OPA333AIDCKT	OP Amp /OPA333	Texas Instruments	1	\$1.94	\$1.94
	OPA344	Capacitor Bootstrapping	Texas Instruments	1	\$1.55	\$1.55
	NSWC	Low ESR capacitor	NIC Components	10	\$1.25	\$12.50
	PTF56	Metal Film Resistor	Vishay	50	\$0.40	\$20.00
	TS5A4624DCKR	Switch	Texas Instruments	1	\$0.20	\$0.20
	ERA-3AEB102V	Resistor 1kΩ	Panasonic - ECG	1	\$0.20	\$0.20
	ERA-3AEB472V	Resistor 4.7kΩ	Panasonic - ECG	1	\$0.20	\$0.20
	ERA-3AEB512V	Resistor 5.1kΩ	Panasonic - ECG	2	\$0.20	\$0.40
	ERA-3AEB103V	Resistor 10kΩ	Panasonic - ECG	1	\$0.20	\$0.20
	ERA-3AEB393V	Resistor 39kΩ	Panasonic - ECG	1	\$0.20	\$0.20
	ERA-3AEB513V	Resistor 51kΩ	Panasonic - ECG	1	\$0.20	\$0.20
	ERA-6AEB105V	Resistor 1MΩ	Panasonic - ECG	1	\$0.20	\$0.20
	C1005C0G1H160J	Capacitor 15pF	TDK Corporation	1	\$0.02	\$0.02
	04025C391JAT2A	Capacitor 390pF	AVX Corporation	1	\$0.42	\$0.42
	GRM1885C1H162JA01D	Capacitor 1.6nF	Murata Electronics	1	\$0.08	\$0.08
	LMK105SD332JV-F	Capacitor 3.3nF	Taiyo Yuden	1	\$0.43	\$0.43
	0402YC153KAT2A	Capacitor 15nF	ManufacturerAVX	1	\$0.11	\$0.11
	C0402C104K8PACTU	Capacitor 100nF	Kemet	3	\$0.02	\$0.07
Microcontroller	ADS1015IRUGT	ADC	Texas Instruments	1	\$2.68	\$2.68
	CC2500RTKR	RF Transceiver	Texas Instruments	1	\$2.26	\$2.26
	MSP430F1612IRTD	MSP430	Texas Instruments	1	\$13.33	\$13.33
	TPS63001	Regulator	Texas Instruments	1	\$2.00	\$2.00
	7488910245	Antenna	Würth Electronics Inc	1	\$4.80	\$4.80
	ABM3B-26.000MHZ-10-1-U-T	Crystal	Abrakon Corporation	1	\$2.63	\$2.63
	ERJ-2RKF5602X	Resistor 56kΩ	Panasonic - ECG	1	\$0.10	\$0.10
	ERJ-2RKF1002X	Resistor 10kΩ	Panasonic - ECG	3	\$0.10	\$0.29
	ERJ-2RKF4702X	Resistor 47kΩ	Panasonic - ECG	1	\$0.10	\$0.10
	ERJ-2GEJ114X	Resistor 110kΩ	Panasonic - ECG	1	\$0.08	\$0.08
	C0402C104K8PACTU	Capacitor 100nF	Kemet	12	\$0.02	\$0.29
	GRM1555C1H270JZ01D	Capacitor 27pF	Murata Electronics	2	\$0.02	\$0.04
	GRM1555C1H101JZ01D	Capacitor 100pF	Murata Electronics	5	\$0.02	\$0.08
	ECJ-0EC1H010C	Capacitor 1pF	Panasonic - ECG	2	\$0.08	\$0.16
	ECD-G0ER508	Capacitor .47pF	Panasonic - ECG	2	\$0.42	\$0.84
	ECJ-1VB0J106M	Capacitor 10μF	Panasonic - ECG	2	\$0.45	\$0.90
	ELJ-RF4N7DFB	Inductor 4.7nH	Panasonic - ECG	3	\$0.08	\$0.24
	MLF1005A1R0KT	Inductor 1μH	TDK Corporation	1	\$0.60	\$0.60
	MLF1005A2R2KT	Inductor 2.2μH	TDK Corporation	1	\$0.60	\$0.60
					Total	\$1,047.88

13 Appendix C: Project Budget/Expenses

Category	Description	Funding Source	Amount Budgeted	Amount Spent	Remainder
Components	LED Driver	ENGR 498A	\$ 25.00	\$ 17.34	\$ 7.66
	Transimpedance Amplifier		\$ 50.00	\$ 40.42	\$ 9.58
	Wireless Transmission		\$ 100.00	\$ 67.12	\$ 32.88
	User Interface		\$ 220.00	\$ 199.00	\$ 21.00
	Housing		\$ 800.00	\$ 478.00	\$ 322.00
	PCB Fabrication		\$ 600.00	\$ 725.00	\$ (125.00)
Equipment	Precision Voltage Source	Sponsor	\$ -	\$ -	\$ -
	Precision DMM				
	Oscilloscope				
	Function Generator				
	Logic Analyzer				
	USB Microcontroller				
	A/D Converter Evaluation Module				
Software	iPhone Application Development Software	ENGR 498A	\$ 110.00	\$ 106.52	\$ 3.48
Shipping	Shipping Expenses	ENGR 498A	\$ 200.00	\$ 212.60	\$ (12.60)
Presentation	Design Day Poster	ENGR 498A	\$ 150.00	\$ 128.52	\$ 21.48
Miscellaneous	Contingency Funds	ENGR 498A	\$ 745.00	\$ -	\$ 745.00

Total Budgeted \$ 3,000.00

Total Spent \$ 1,974.52

Total Remaining \$ 1,025.48

14 Appendix D: Housing Material Properties



Accura[®] 25 plastic

for use with solid-state stereolithography (SLA[®]) systems

Simulate the properties and aesthetics of polypropylene with this accurate and flexible material.



APPLICATIONS

- Functional components for assemblies and mock-ups for:
 - Automotive styling parts — trim, fascia, and other components
 - Consumer electronic components
 - Toys
 - Snap fit assemblies
- Master patterns for RTV/silicone molding
- Replace CNC machining of polypropylene to produce short-run plastic parts
- Simulate injection molded parts
- Concept and marketing models

FEATURES

- Look and feel of molded polypropylene
- High flexibility with excellent shape retention
- Outstanding feature resolution and accuracy
- High production speed
- Fully developed and tested build styles

BENEFITS

- Increased market opportunities for models
- Reliable and robust functional prototypes
- Suitable for master patterns
- More parts and better system utilization
- Maximize reliability with no user R&D

3D SYSTEMS CORPORATION

TRANSFORM YOUR PRODUCTS

Accura® 25 plastic

For use with all solid-state stereolithography (SLA®) systems

"After providing some models in Accura 25 to a couple of our regular customers, they have decided to make it their default SL material for all future orders. To date they have already ordered hundreds of parts. They get a material that looks like a final article molded part having a great balance of durability and flexibility. I get a material that is very easy to clean and finish, but most importantly is extremely reliable in the machine. This has been a real win-win for us."

— Steve Grundahl — Owner, Midwest Prototyping LLC

TECHNICAL DATA

Liquid Material

MEASUREMENT	METHOD/CONDITION	VALUE
Appearance		White
Liquid Density	@ 25 °C (77 °F)	1.13 g/cm ³
Solid Density	@ 25 °C (77 °F)	1.19 g/cm ³
Viscosity	@ 30 °C (86 °F)	250 cps
Penetration Depth (Dp) *		4.2 mils
Critical Exposure (Ec) *		10.5 mJ/cm ²
Tested Build Styles		FAST™, EXACT™, Exact HR

Post-Cured Material

MEASUREMENT	METHOD/CONDITION	METRIC	U.S.
Tensile Strength	ASTM D 638	38 MPa	5,450 - 5,570 PSI
Tensile Modulus	ASTM D 638	1,590 - 1,660 MPa	230 - 240 KSI
Elongation at Break (%)	ASTM D 638	13 - 20 %	
Flexural Strength	ASTM D 790	55 - 58 MPa	7,960 - 8,410 PSI
Flexural Modulus	ASTM D 790	1,380 - 1,660 MPa	200 - 240 KSI
Impact Strength (Notched Izod)	ASTM D 256	19-24 J/m	0.4 ft-lb/in
Heat Deflection Temperature	ASTM D 648 @ 66 PSI @ 264 PSI	58 - 63 °C 51 - 55 °C	136 - 145 °F 124 - 131 °F
Hardness, Shore D		80	
Co-efficient of Thermal Expansion	ASTM E 831-93 TMA (T<Tg, 0 - 20 °C) TMA (T>Tg, 90 - 150 °C)	107 x 10 ⁻⁶ m/m °C 151 x 10 ⁻⁶ m/m °C	
Glass Transition (Tg)	DMA, E''	60 °C	140 °F

* Dp/Ec values are the same on all systems.



3D Systems Corporation
333 Three D Systems Circle
Rock Hill, SC 29730 U.S.A.

Tel: 803.326.4080
Toll-free: 800.889.2964
Fax: 803.324.8810

moreinfo@3dsystems.com
www.3dsystems.com
NASDAQ: TDSC

Warranty/Disclaimer: The performance characteristics of these products may vary according to product application, operating conditions, material combined with, or with end use. 3D Systems makes no warranties of any type, express or implied, including, but not limited to, the warranties of merchantability or fitness for a particular use.

© 2007 by 3D Systems, Inc. All rights reserved. Specifications subject to change without notice. The 3D logo, Accura and SLA are registered trademarks of 3D Systems, Inc.

PN 70668 Issue Date - 06 Sep 07



FullCure Materials

Support Your Application

- Elongation at break of 20% and 44% for rigid models enables fit and function
- Elongation at break of 47% and 218% for rubber-like materials
- Models ready to use, no extra finishing required
- Models can be handled right off the tray
- Paint readily adheres to model surfaces
- Easy to remove gel-like support material ensures no hard grid edges
- Single support material for all materials
- High accuracy models



Support your Applications

The FullCure® line of photopolymer resins open up a whole world of possibilities for users of 3-dimensional printings.

Based on Objet's unique ultra-thin-layer PolyJet™ technology, FullCure® resins are used to create accurate, highly detailed three-dimensional models for a wide range of applications. Unlike models created by other technologies, Objet-made parts are fully cured during the build process and can be handled immediately after build.

The FullCure® line includes several types of flexible and rigid model materials. The FullCure® support material enables users to produce any geometry, including overhangs and undercuts.

The FullCure® line currently includes the following materials, with more to come in the near future:

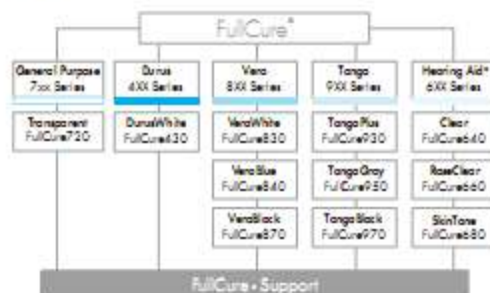
FullCure®720 - General-purpose resin, offers excellent technical properties in a transparent color.

Vero materials - Feature opaque colors and improved mechanical properties, offering users excellent detail visualization and even wider range of applications.

Tango materials - offer users highly flexible materials with different levels of elasticity, enabling a close "touch and feel" match for any design.

Key Advantages

- Elongation at break of 20% for rigid models enables fit and function.
- Elongation at break of 47% and 218% for rubber-like materials.
- Models ready to use, no extra finishing required.
- Models can be handled right off the tray.
- Paint readily adheres to model surfaces.
- Easy to remove gel-like support materials ensures no hard grid edges.
- Single support material for all materials.
- High accuracy models.



* See Objet Hearing Aid brochure

Tango

TangoPlus - FullCure930

Property	ASTM	Metric		Imperial	
Tensile Strength at Break	D-412	MPa	1.455	psi	211
Tensile Modulus at 20% Strain	D-413	MPa	0.146	psi	21
Tensile Modulus at 30% Strain	D-414	MPa	0.185	psi	27
Tensile Modulus at 50% Strain	D-415	MPa	0.263	psi	38
Elongation at Break	D-412	%	21.8	%	218.0
Compressive Set, 22 Hr, 75°C	D-395	%	4.4	%	4.4
Shore A Hardness	D-2240	Scale A	27	Scale A	27
Ross Flex	D-1052		Above 150,000		Above 150,000
Tensile Tear Resistance	D-624	Kg/cm	3.47	lb/in	20
Tg	DSC (-80°C+100°C)	°C	-9.6	°F	15



TangoGray - FullCure950

Property	ASTM	Metric		Imperial	
Tensile Strength	D-412	MPa	4.36	psi	632
Elongation at Break	D-412	%	47	%	47.0
Compressive Set	D-395	%	1	%	1
Shore A Hardness	D-2240	Scale A	75	Scale A	75
Tensile Tear Resistance	D-624	Kg/cm	9.5	lb/in	54
Tg	DSC (-80°C+100°C)	°C	2.6	°F	37



TangoBlack - FullCure970

Property	ASTM	Metric		Imperial	
Tensile Strength	D-412	MPa	2	psi	290
Elongation at Break	D-412	%	47.7	%	47.7
Compressive Set	D-395	%	0.8	%	1
Shore A Hardness	D-2240	Scale A	61	Scale A	61
Tensile Tear Resistance	D-624	Kg/cm	3.8	lb/in	21
Tg	DSC (-80°C+100°C)	°C	10.7	°F	13





Vero

VeroWhite - FullCure830

Property	ASTM	Metric		Imperial	
Tensile Strength	D-638-03	MPa	49.8	psi	7221
Modulus of Elasticity	D-638-04	MPa	2495	psi	361775
Elongation at Break	D-638-05	%	20	%	20
Flexural Strength	D-790-03	MPa	74.6	psi	10817
Flexural Modulus	D-790-04	MPa	2137	psi	309865
Izod Notched Impact	D-256-06	J/m	24.1	ft lb/in	0.45
Shore Hardness	Scale D	Scale D	83	Scale D	83
Rockwell Hardness	Scale M	Scale M	81	Scale M	81
HDT at 0.45 MPa	D-648-06	C°	43	F°	109
HDT at 1.82 MPa	D-648-07	C°	40	F°	104
Tg	DMA, E°	C°	58	F°	136
Ash Content	NA	%	<0.4	%	<0.4
Water Absorption	D570-98 24 Hr	%	1.15	%	1.15



VeroBlue - FullCure840

Property	ASTM	Metric		Imperial	
Tensile Strength	D-638-03	MPa	55.1	psi	7990
Modulus of Elasticity	D-638-04	MPa	2740	psi	397300
Elongation at Break	D-638-05	%	20	%	20
Flexural Strength	D-790-03	MPa	83.6	psi	12122
Flexural Modulus	D-790-04	MPa	1983	psi	287335
Compressive Strength	D-695-02	MPa	79.3	psi	11499
Izod Notched Impact	D-256-06	J/m	23.6	ft lb/in	0.44
Shore Hardness	Scale D	Scale D	83	Scale D	83
Rockwell Hardness	Scale M	Scale M	81	Scale M	81
HDT at 0.45 MPa	D-648-06	C°	48.8	F°	120
HDT at 1.82 MPa	D-648-07	C°	44.8	F°	113
Tg	DMA, E°	C°	48.7	F°	120
Ash Content	NA	%	<0.3	%	<0.3
Water Absorption	D570-98 24 Hr	%	1.54	%	1.54



VeroBlack - FullCure870

Property	ASTM	Metric		Imperial	
Tensile Strength	D-638-03	MPa	50.7	psi	7352
Modulus of Elasticity	D-638-04	MPa	2192	psi	317840
Elongation at Break	D-638-05	%	17.7	%	18
Flexural Strength	D-790-03	MPa	79.6	psi	11542
Flexural Modulus	D-790-04	MPa	2276	psi	330020
Izod Notched Impact	D-256-06	J/m	23.9	ft lb/in	0.45
Shore Hardness	Scale D	Scale D	83	Scale D	83
Rockwell Hardness	Scale M	Scale M	81	Scale M	81
HDT at 0.45 MPa	D-648-06	C°	47	F°	117
HDT at 1.82 MPa	D-648-07	C°	42.9	F°	109
Tg	DMA, E°	C°	62.7	F°	145
Water Absorption	D570-98 24 Hr	%	1.01	%	1.01



General Purpose

FullCure720

Property	ASTM	Metric		Imperial	
Tensile Strength	D638-03	MPa	60.3	psi	8744
Modulus of Elasticity	D638-04	MPa	2870	psi	416150
Elongation at Break	D638-05	%	20	%	20
Flexural Strength	D790-03	MPa	75.8	psi	10991
Flexural Modulus	D790-04	MPa	1718	psi	249110
Compressive Strength	D695-02	MPa	84.3	psi	12224
Izod Notched Impact	D256-06	J/m	23.6	ft lb/in	0.44
Shore Hardness	Scale D	Scale D	83	Scale D	83
Rockwell Hardness	Scale M	Scale M	81	Scale M	81
HDT at 0.45 MPa	D648-06	C°	48.4	F°	119
HDT at 1.82 MPa	D648-07	C°	44.4	F°	112
Tg	DMA, E°	C°	48.7	F°	120
Ash Content	NA	%	<0.01	%	<0.01
Water Absorption	D57098 24 Hr	%	1.53	%	1.53



Durus

DurusWhite - FullCure430

Property	ASTM	Metric		Imperial	
Tensile Strength	D-638-03	MPa	21.3	psi	3089
Modulus of Elasticity	D-638-04	MPa	1135.8	psi	164691
Elongation at Break	D-638-05	%	44.2	%	44
Flexural Strength	D-790-03	MPa	33.2	psi	4814
Flexural Modulus	D-790-04	MPa	1026.1	psi	148785
Compressive Strength	D-695-02	MPa	30.7	psi	4452
Izod Notched Impact	D-25606	J/m	44.22	ft lb/in	0.83
Shore Hardness	D-2240-03	Scale D	76	Scale D	76
Rockwell Hardness	D-785-03	Scale M	97	Scale M	97
HDT at 0.45 MPa	D-648-06	C°	36.3	F°	98
HDT at 1.82 MPa	D-648-07	C°	32.6	F°	91
Tg	DMA, E°	C°	35.9	F°	97
Water Absorption	D57098 24 Hr	%	1.69	%	1.69



Objet Geometries Ltd.
Headquarters
2 Holzman St.,
Science Park,
P.O. Box 2496,
Rehovot 76124, Israel
T: +972-8-931-4314
F: +972-8-931-4315

Objet Geometries Inc.
North America
5 Fortune Drive
Billerica,
MA 01821
USA
T: +1-877-489-9449
F: +1-866-676-1533

Objet Geometries
GMBH
Im Leuschnerpark 4,
64347 Griesheim
Germany
T: +49-6155-605-346
F: +49-6155-605-344

Objet Geometries AP
Asia Pacific
13th Floor, Unit 52A,
HITEC
1 Trademart Drive
Kowloon Bay, Hong Kong
T: +852-217-40111
F: +852-217-40555

Objet Geometries AP
Limited China Rep Office
Rm1220, CIMIC Tower,
1090 Century Blvd,
Pudong Shanghai
2000120 P. R. China
T: +86-21-5836-2468
F: +86-21-5836-2469

Info@objet.com www.objet.com

© 2008 Objet, Quadra, QuadeTempo, PolyJet, FullCure 3HR, Eden, Eden250, Eden260, Eden330, Eden350, Eden350V, Eden500V, Jet Manager, Objet Studio, Connex, Connex500, PolyJet, TongeBlack, TongeGray, TongePlus, VerdBlue, VerdWhite, VerdBlack, Digital Materials and PolyJet Materials are trademarks of Objet Geometries Ltd. and may be registered in certain jurisdictions. All other trademarks belong to their respective owners.



15 Appendix E: Microcontroller Source Code

```

//*****
// THIS PROGRAM IS PROVIDED "AS IS". TI MAKES NO WARRANTIES OR
// REPRESENTATIONS, EITHER EXPRESS, IMPLIED OR STATUTORY,
// INCLUDING ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS
// FOR A PARTICULAR PURPOSE, LACK OF VIRUSES, ACCURACY OR
// COMPLETENESS OF RESPONSES, RESULTS AND LACK OF NEGLIGENCE.
// TI DISCLAIMS ANY WARRANTY OF TITLE, QUIET ENJOYMENT, QUIET
// POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY
// INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO THE PROGRAM OR
// YOUR USE OF THE PROGRAM.
//
// IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, INCIDENTAL,
// CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY
// THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED
// OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT
// OF THIS AGREEMENT, THE PROGRAM, OR YOUR USE OF THE PROGRAM.
// EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF
// REMOVAL OR REINSTALLATION, COMPUTER TIME, LABOR COSTS, LOSS
// OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, OR LOSS OF
// USE OR INTERRUPTION OF BUSINESS. IN NO EVENT WILL TI'S
// AGGREGATE LIABILITY UNDER THIS AGREEMENT OR ARISING OUT OF
// YOUR USE OF THE PROGRAM EXCEED FIVE HUNDRED DOLLARS
// (U.S.$500).
//
// Unless otherwise stated, the Program written and copyrighted
// by Texas Instruments is distributed as "freeware". You may,
// only under TI's copyright in the Program, use and modify the
// Program without any charge or restriction. You may
// distribute to third parties, provided that you transfer a
// copy of this license to the third party and the third party
// agrees to these terms by its first use of the Program. You
// must reproduce the copyright notice and any other legend of
// ownership on each copy or partial copy, of the Program.
//
// You acknowledge and agree that the Program contains
// copyrighted material, trade secrets and other TI proprietary
// information and is protected by copyright laws,
// international copyright treaties, and trade secret laws, as
// well as other intellectual property laws. To protect TI's
// rights in the Program, you agree not to decompile, reverse
// engineer, disassemble or otherwise translate any object code
// versions of the Program to a human-readable form. You agree
// that in no event will you alter, remove or destroy any
// copyright notice included in the Program. TI reserves all
// rights not specifically granted under this license. Except

```

```

// as specifically provided herein, nothing in this agreement
// shall be construed as conferring by implication, estoppel,
// or otherwise, upon you, any license or other right under any
// TI patents, copyrights or trade secrets.
//
// You may not use the Program in non-TI devices.
//
//*****
// eZ430-RF2500 Temperature Sensor End Device
//
// Description: This is the End Device software for the eZ430-2500RF
//             Temperature Sensing demo
//
//
// L. Westlund
// Version 1.02
// Texas Instruments, Inc
// November 2007
// Built with IAR Embedded Workbench Version: 4.09A
//*****
//Change Log:
//*****
//Version: 1.02
//Comments: Changed Port toggling to abstract method
//         Fixed comment typos
//Version: 1.01
//Comments: Added support for SimpliciTI 1.0.3
//         Added Flash storage/check of Random address
//         Moved LED toggle to HAL
//Version: 1.00
//Comments: Initial Release Version
//*****

#include "bsp.h"
#include "mrfi.h"
#include "nwk_types.h"
#include "nwk_api.h"
#include "bsp_leds.h"
#include "bsp_buttons.h"
#include "vlo_rand.h"
#include "mrfi_board_defs.h"
#include "msp430xG47x.h"

volatile unsigned int i;
float ADC;
int RxData;
unsigned int results;

```

```

#define NUM_BYTES_TX 1           // How many bytes?

int RXByteCtr, RPT_Flag = 0;     // enables repeated start when 1
volatile unsigned char RxBuffer[12]; // Allocate 128 byte of RAM
unsigned char *PTxData;          // Pointer to TX data
unsigned char TXByteCtr;
unsigned char MSData = 0x01;

void Setup_TX(void);
void Transmit(void);
void Receive(void);

void linkTo(void);
void MCU_Init(void);

__no_init volatile int tempOffset @ 0x10F4; // Temperature offset set at production
__no_init volatile char Flash_Addr[4] @ 0x10F0; // Flash address set randomly

void createRandomAddress();
void i2cconfig3();
void i2creceive();
void spiconfig();
unsigned char *PRxData;          // Pointer to RX data
unsigned char RXByteCtr;
unsigned int RxData;
unsigned char RxBuffer[18];      // Allocate 2 byte of RAM
unsigned char *PTxData;          // Pointer to TX data
unsigned char TXByteCtr;
char j = 1;
int k;
unsigned int ADC, ADCtest;
//unsigned char tst[5];
const unsigned char TxData[] =    // Table of data to transmit
{
    0x01,
    0x42,
    0x83,
};
const unsigned char TxData2[] =    // Table of data to transmit
{
    0x00
};

void main (void)
{

    addr_t lAddr;

```

```

WDTCTL = WDTPW + WDTHOLD;          // Stop WDT

{
// delay loop to ensure proper startup before SimpliciTI increases DCO
// This is typically tailored to the power supply used, and in this case
// is overkill for safety due to wide distribution.
volatile int i;
for(i = 0; i < 0xFFFF; i++){}
}
if( CALBC1_8MHZ == 0xFF )           // Do not run if cal values are erased
{
volatile int i;
P1DIR |= 0x03;
BSP_TURN_ON_LED1();
BSP_TURN_OFF_LED2();
while(1)
{
for(i = 0; i < 0x5FFF; i++){}
BSP_TOGGLE_LED2();
BSP_TOGGLE_LED1();
}
}

// SimpliciTI will change port pin settings as well
P1DIR = 0xFF;
P1OUT = 0x00;
P2DIR = 0x27;
P2OUT = 0x00;
P3DIR = 0xC0;
P3OUT = 0x00;
P4DIR = 0xFF;
P4OUT = 0x28;

BSP_Init();

if( Flash_Addr[0] == 0xFF &&
Flash_Addr[1] == 0xFF &&
Flash_Addr[2] == 0xFF &&
Flash_Addr[3] == 0xFF )
{
createRandomAddress();           // set Random device address at initial startup
}
IAddr.addr[0]=Flash_Addr[0];
IAddr.addr[1]=Flash_Addr[1];
IAddr.addr[2]=Flash_Addr[2];
IAddr.addr[3]=Flash_Addr[3];
SMPL_loctl(IOCTL_OBJ_ADDR, IOCTL_ACT_SET, &IAddr);

```

```

BCSCTL1 = CALBC1_8MHZ;          // Set DCO after random function
DCOCTL = CALDCO_8MHZ;

BCSCTL3 |= LFXT1S_2;            // LFXT1 = VLO
TACCTL0 = CCIE;                 // TACCR0 interrupt enabled
TACCRO = 6000;                  // ~ 1 sec
TACTL = TASSEL_1 + MC_1;        // ACLK, upmode

// keep trying to join until successful. toggle LEDS to indicate that
// joining has not occurred. LED3 is red but labeled LED 4 on the EXP
// board silkscreen. LED1 is green.
while (SMPL_NO_JOIN == SMPL_Init((uint8_t (*)(linkID_t))0))
{
    BSP_TOGGLE_LED1();
    BSP_TOGGLE_LED2();
    __bis_SR_register(LPM3_bits + GIE); // LPM3 with interrupts enabled
}
// unconditional link to AP which is listening due to successful join.
linkTo();
}

void createRandomAddress()
{
    unsigned int rand, rand2;
    do
    {
        rand = TI_getRandomIntegerFromVLO(); // first byte can not be 0x00 or 0xFF
    }
    while( (rand & 0xFF00)==0xFF00 || (rand & 0xFF00)==0x0000 );
    rand2 = TI_getRandomIntegerFromVLO();

    BCSCTL1 = CALBC1_1MHZ;        // Set DCO to 1MHz
    DCOCTL = CALDCO_1MHZ;
    FCTL2 = FWKEY + FSSEL0 + FN1; // MCLK/3 for Flash Timing Generator
    FCTL3 = FWKEY + LOCKA;        // Clear LOCK & LOCKA bits
    FCTL1 = FWKEY + WRT;          // Set WRT bit for write operation

    Flash_Addr[0]=(rand>>8) & 0xFF;
    Flash_Addr[1]=rand & 0xFF;
    Flash_Addr[2]=(rand2>>8) & 0xFF;
    Flash_Addr[3]=rand2 & 0xFF;

    FCTL1 = FWKEY;                // Clear WRT bit
    FCTL3 = FWKEY + LOCKA + LOCK; // Set LOCK & LOCKA bit
}

////////////////////////////////////

```

```
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
```

```
void Setup_TX(void){
    _DINT();
    IE2 &= ~UCB0RXIE;
    while (UCB0CTL1 & UCTXSTP);      // Ensure stop condition got sent// Disable RX interrupt
    UCB0CTL1 |= UCSWRST;              // Enable SW reset
    UCB0CTL0 = UCMST + UCMODE_3 + UCSYNC; // I2C Master, synchronous mode
    UCB0CTL1 = UCSSEL_2 + UCSWRST;    // Use SMCLK, keep SW reset
    UCB0BR0 = 12;                     // fSCL = SMCLK/12 = ~100kHz
    UCB0BR1 = 0;
    UCB0I2CSA = 0x48;                 // Slave Address is 048h
    UCB0CTL1 &= ~UCSWRST;              // Clear SW reset, resume operation
    IE2 |= UCB0TXIE;                  // Enable TX interrupt
}
```

```
void Transmit(void){
    PTxData = &MSData;               // TX array start address
    TXByteCtr = NUM_BYTES_TX;          // Load TX byte counter
    while (UCB0CTL1 & UCTXSTP);        // Ensure stop condition got sent
    UCB0CTL1 |= UCTR + UCTXSTT;        // I2C TX, start condition
    __bis_SR_register(CPUOFF + GIE);   // Enter LPM0 w/ interrupts
}
```

```
void Receive(void)
{
    IE2 &= ~UCB0TXIE;
    P3SEL = 0x00;
    volatile unsigned int i;
    volatile unsigned int k;
    int address2[] = {1,1,0,0,0,0,1,1,0,0,0,0,0,0,1,1,0,0,0}; // Address is 0x91
    WDTCTL = WDTPW + WDTHOLD;         // Stop watchdog timer
    P3DIR |= 0x3F;                     // Set P4.5 to output direction
    P3OUT = 0x06;
    P3OUT &= ~0x02;
    //////////////////////////////////Address/////////////////////////////////
    for(k=0; k<=18; k++){
        for(i=0; i<=1; i++){
            P3OUT ^= 0x04;              // Toggle P4.5 using exclusive-OR
            if(address2[k])
                P3OUT |= 0x02;
            else
                P3OUT &= ~0x02;
        }
    }
    P3OUT &= ~0x02;
    for(i=0; i<=1; i++);
}
```

```

P3DIR = 0x3D;          // Set P4.5 to output direction
////////////////////////Receive1////////////////////////
for(k=0; k<=8; k++){
    P3OUT ^= 0x04;      // Toggle P4.5 using exclusive-OR
    if(0x42 & P3IN)
        RxBuffer[k] = 1;
    else
        RxBuffer[k] = 0;
    for(i=0; i<=1; i++);
    P3OUT ^= 0x04;
    for(i=0; i<=1; i++);
}
////////////////////////Receive2////////////////////////
for(k=8; k<=16; k++){
    P3OUT ^= 0x04;      // Toggle P4.5 using exclusive-OR
    if(0x42 & P3IN)
        RxBuffer[k] = 1;
    else
        RxBuffer[k] = 0;
    for(i=0; i<=1; i++);
    P3OUT ^= 0x04;
    for(i=0; i<=1; i++);
}
P3DIR = 0xCF;
P3OUT = 0x06;
for(i=0; i<25; i++);  // Stop condition
}

void linkTo()
{
    linkID_t linkID1;
    uint8_t msg[5];
    int i;

    // keep trying to link...
    while (SMPL_SUCCESS != SMPL_Link(&linkID1))
    {
        __bis_SR_register(LPM3_bits + GIE);  // LPM3 with interrupts enabled
        BSP_TOGGLE_LED1();
        BSP_TOGGLE_LED2();
    }

    // Turn off all LEDs
    if (BSP_LED1_IS_ON())
    {
        BSP_TOGGLE_LED1();
    }
}

```

```

}
if (BSP_LED2_IS_ON())
{
    BSP_TOGGLE_LED2();
}
//UCB0CTL0 = 0x00;
BSP_TURN_ON_LED1();

WDTCTL = WDTPW + WDTHOLD;          // Stop WDT

FLL_CTL0 |= XCAP14PF;              // Configure load caps
for (i = 0; i < 10000; i++);        // Delay for 32 kHz crystal to
                                    // stabilize

SD16CTL = SD16SSEL0;               // 1.2V ref, SMCLK
SD16CTL |= SD16REFON;
SD16CCTL0 |= SD16SNGL + SD16UNI;    // Single conv Unipolar
for (i = 0; i < 0x3600; i++);       // Delay for 1.2V ref startup

// I2C configuration transmit process
P3SEL |= 0x06;                     // Assign I2C pins to USCI_B0
Setup_TX();
RPT_Flag = 1;
MSData = 0x01;
Transmit();
while (UCB0CTL1 & UCTXSTP);         // Ensure stop condition got sent
MSData = 0x42;
Transmit();
while (UCB0CTL1 & UCTXSTP);         // Ensure stop condition got sent
MSData = 0x83;
Transmit();
while (UCB0CTL1 & UCTXSTP);         // Ensure stop condition got sent
MSData = 0x00;
Transmit();
while (UCB0CTL1 & UCTXSTP);         // Ensure stop condition got sent
P3SEL = 0x00;
P3DIR = 0xCF;
P3OUT = 0x06;
for(i=0; i<25; i++);               // Stop condition
SD16CTL |= SD16REFON;               // Internal 1.2V ref on
DAC12_OCTL = DAC12IR + DAC12SREF_3 + DAC12AMP_5 + // SD16 Ref,
DAC12OPS + DAC12ENC + DAC12CALON;
DAC12_0DAT = 0x000;                // 2.58V

while (1)
{

```

```

if(DAC12_ODAT < 0xAAA)
    DAC12_ODAT = DAC12_ODAT + 0x0F0;
else
    DAC12_ODAT = 0x000;
//ADC Conversion
SD16CTL |= SD16REFON;
SD16CCTL0 |= SD16SC;          // Set bit to start conversion
while ((SD16CCTL0 & SD16IFG)==0); // Poll interrupt flag
results = SD16MEM0;           // Save CH0 results (clears IFG)
ADC = results*(1.2/2)/65536;

//Receive process
Receive();
RxData = 0x000;
for(i=0; i<12; i++){
    RxData += RxBuffer[i];
    RxData = RxData << 0x01;
}

__no_operation();           // Set breakpoint >>here<< and
                             // read out the RxBuffer buffer
SMPL_ioctl( IOCTL_OBJ_RADIO, IOCTL_ACT_RADIO_SLEEP, "" );
__bis_SR_register(LPM3_bits+GIE); // LPM3 with interrupts enabled
SMPL_ioctl( IOCTL_OBJ_RADIO, IOCTL_ACT_RADIO_AWAKE, "" );

BSP_TOGGLE_LED2();

//msg[0] = 42;
//msg[1] = 5;
//msg[0] = 0x4E;
//msg[0] = ADC;
ADCtest = 0x4EF;
ADC = ADCtest*2;
msg[0] = ((RxData/1000)%10);
msg[1] = ((RxData/100)%10);
msg[2] = ((RxData/10)%10);
msg[3] = ((RxData/1)%10);
msg[4] = RxBuffer[0];

if (SMPL_SUCCESS == SMPL_Send(linkID1, msg, sizeof(msg)))
{
    BSP_TOGGLE_LED2();
}
else
{

```

```

    BSP_TOGGLE_LED2();
    BSP_TOGGLE_LED1();
}
}
}

/*-----
* ADC10 interrupt service routine
-----
#pragma vector=ADC10_VECTOR
__interrupt void ADC10_ISR(void)
{
    __bic_SR_register_on_exit(CPUOFF);    // Clear CPUOFF bit from 0(SR)
}
*/
/*-----
* Timer A0 interrupt service routine
-----*/
#pragma vector=TIMERAO_VECTOR
__interrupt void Timer_A (void)
{
    __bic_SR_register_on_exit(LPM3_bits);    // Clear LPM3 bit from 0(SR)
}

//-----
// The USCI_B0 data ISR is used to move received data from the I2C slave
// to the MSP430 memory. It is structured such that it can be used to receive
// any 2+ number of bytes by pre-loading RXByteCtr with the byte count.
//-----
#pragma vector = USCIAB0TX_VECTOR
__interrupt void USCIAB0TX_ISR(void)
{
    if (TXByteCtr)            // Check TX byte counter
    {
        UCB0TXBUF = MSData;    // Load TX buffer
        TXByteCtr--;           // Decrement TX byte counter
    }
    else
    {
        if(RPT_Flag == 1){
            RPT_Flag = 0;
            PTxDData = &MSData;    // TX array start address
            TXByteCtr = NUM_BYTES_TX;    // Load TX byte counter
            __bic_SR_register_on_exit(CPUOFF);
        }
    }
}

```

```
else{
    UCB0CTL1 |= UCTXSTP;           // I2C stop condition
    IFG2 &= ~UCB0TXIFG;           // Clear USCI_B0 TX int flag
    __bic_SR_register_on_exit(CPUOFF); // Exit LPM0
}
}
}
```

APPENDIX DANGELO01

A Sensor Network to iPhone Interface separating Continuous and Sporadic Processes in Mobile Telemedicine

Lorenzo T. D'Angelo, Michael Schneider, Paul Neugebauer and Tim C. Lueth, *Member, IEEE*

Abstract – In this contribution, a new concept for interfacing sensor network nodes (motest) and smartphones is presented for the first time. In the last years, a variety of telemedicine applications on smartphones for data reception, display and transmission have been developed. However, it is not always practical or possible to have a smartphone application running continuously to accomplish these tasks. The presented system allows receiving and storing data continuously using a mote and visualizing or sending it on the go using the smartphone as user interface only when desired. Thus, the processes of data reception and storage run on a safe system consuming less energy and the smartphone's potential along with its battery are not demanded continuously. Both, system concept and realization with an Apple iPhone are presented.

I. INTRODUCTION

INDUSTRIALIZED countries are facing a demographic change which will push the social security systems to their limits. In Germany, the ratio between people older than 65 and between 15 and 64 is expected to surpass 50% until 2030 [1]. The number of older people living alone and cannot be taken care of and assisted by their families will also increase. This will lead to a significant increase in health care need and in a loss of quality of life for people dependent of care. For these reasons a great effort is done worldwide to develop systems able to keep people in good health through prevention, early diagnosis and short hospital stays. Assuring that elderly people with cognitive or physical impairments keep self-sufficient is also often issued. Many of these systems use sensor networks to collect health information about the individual in their home or outside and to process it in order to detect deviations and give help based on the findings or alarm relatives or clinicians. As smartphones and small handheld electronic devices are spreading, it makes sense to use their processing power and their user interfaces without needing to embed them redundantly in assistant devices, increasing their mass, volume and price [2]. In this contribution, we present a new concept for interfacing assistant devices and smartphones aiming at increasing the combined system's energy

efficiency and security.

After a state of the art overview about mobile systems for telemedicine and a task description, the concept will be described and a prototypical implementation will be shown.

A. State of the art in mobile systems for telemedicine.

Within the fitness and monitoring of chronic illnesses domains there are many commercial products able to monitor specific vital parameters over the day, e.g. chest straps and sport watches for heart rate, long term electrocardiogram (ECG) or blood pressure monitoring as well as glucose monitoring. Most of these products do not interface smartphones and do not enable mobile uploading of recorded data to a server.

In research, many project focus on mobile acquisition, processing and transmission of vital parameters through personal health management systems (PHMS) enabling telemedicine and e-health solutions. Among those are AMON, MOBIHEART, WEALTHY and MYHEART, to name a few [3]. In WEALTHY, various vital parameter sensors are embedded into garments. Data acquisition, processing and transmission takes place in specifically designed electronics. There is no direct visual feedback for the user [4]. The device has been improved in the Healthwear project [5]. In MYHEART, a mobile system able to send an ECG using a PDA phone over the internet is presented [6]. In [7], a mobile phone based system with direct user feedback is presented. The system also allows data transmission on a server using the scalable Healthcare Integrated Platform (SHIP). A wearable body sensor network interfacing a PDA phone for data upload is presented in [8]. A Smart Personal Health Manager interfacing a Body Area Network with a PDA phone in order to instantly show acquired data is presented in [9]. A similar system using a WLAN infrastructure inside a hospital instead of Bluetooth is presented in [10].

Several groups also work on acquiring behavioral information rather than vital parameters. Activity Recorders and Transceivers are sensor nodes capable of detecting and storing information about interaction [11]. One example is the Eventlogger presented in [12] which uses radio modules to detect interactions with objects. In [13], a platform for acquisition and display of vital parameters measured by body-worn or car-embedded sensor is presented.

An overview of the presented systems and their main characteristics is given in Table I.

Summing up, most presented systems can be distinguished between systems transmitting acquired data

Manuscript received June 20, 2011. This work has received funding from the Bavarian Research Foundation (BFS) under contract number AZ-780-07.

The views expressed here are those of the authors only. The BFS is not liable for any use that may be made of the information contained therein.

L. T. D'Angelo, M. Schneider and T. C. Lueth are with the Institute of Micro Technology and Medical Device Technology, Technische Universitaet Muenchen, Boltzmannstr. 15, D-85748 Garching Germany (phone: +49 89 28915171; fax: +49 89 28915192; e-mail: lorenzo.dangelo@tum.de).

TABLE I
COMPARISON OF STATE OF THE ART IN MOBILE SYSTEMS FOR
TELEMEDICINE

DEVICE	SENSORS	CENTRAL DEVICE	VISUAL USER INTERFACE	DATA UPLOAD
[4]	ECG, Resp, Movement	DD	No	MPN
[5]	"	DD	No	MPN
[6]	ECG	PDA	Yes	MPN
[7]	ECG, Movement, Temp, Imp	Mobile phone	Yes	MPN
[8]	ECG, SpO ₂	PDA	Yes	MPN
[9]	Env, Sound, SpO ₂	PDA	Yes	MPN
[10]	ECG, SpO ₂ , Temp	PDA board	Yes	WLAN
[11-13]	SpO ₂ , SC, BP, Movement, Int	DD	Yes	-

Resp=Respiratory frequency. Temp=Temperature. Imp=Impedance.
Env=Environmental Sensors. Sound=Heart and respiratory sounds.
SC=Skin conductivity. BP=Blood pressure. Int=Interactions.
DD=Dedicated device. MPN=Mobile Phone Network.

directly to a server or using a mobile phone or handheld consumer electronic device for both data transmission and direct user feedback. Systems transmitting data directly could be expanded in order to offer user interfaces. However, this would increase system price, mass and volume as well, in most cases, be redundant, as the user carries a mobile phone anyway. However, using a mobile phone for reception, processing and transmission of private medical data and for time-critical or safety-critical processes can be very risky, especially considering that modern mobile phones are getting more and more complex. Regardless of whether they use an open or a proprietary operating system; proprietary operating systems strongly constrain developers and may abruptly disable third party applications while open operating systems may get unstable or allow running applications which may interfere or stop the telemedicine application.

B. Task description

The goal of the presented concept is to offer a telemedicine platform distinguishing between continuously running time-critical or safety-critical processes and sporadic processes like complex user interaction or user-operated uploads of big data amounts. It should be possible to run the continuous and the sporadic processes on two different devices, in order to optimize the system's safety and energy expenditure.

II. SYSTEM CONCEPT

A. Static system concept description

The presented concept employs a dedicated device, called management device, which is part of the sensor network

used to acquire health information and a smartphone. The management device can receive data from a variety of sensors, e.g. the Eventlogger presented in [12] for behavior recognition, the sensor unit described in [13] for car-embedded vital parameter acquisition or the garment described in [14] for fall detection.

B. Dynamic system concept description

The continuous processes, e.g. data acquisition, processing and time-stamped storage, run on the management device. Should a safety-critical function like alarming also be needed, the management device must also contain a module for this function, e.g. a GSM module. For sporadic processes like user interaction or data visualization, the management device is connected to a mobile phone or smartphone, and data is exchanged between the management device and the smartphone.

In Fig. 1, the proposed concept's components and processes are displayed and compared with a conventional telemedicine system with mobile-phone based user interaction.

III. SYSTEM PROTOTYPE

A. Materials and methods

In the following, only the management device and one exemplary smartphone application developed to demonstrate the concept will be presented.

The management device is very similar to the Eventlogger presented in [12], as it already includes modules for data reception, processing and storage. The first addition is transistor-transistor logic (TTL) level converter for the serial interface of the management device's microcontroller, allowing communication between the smartphone and the

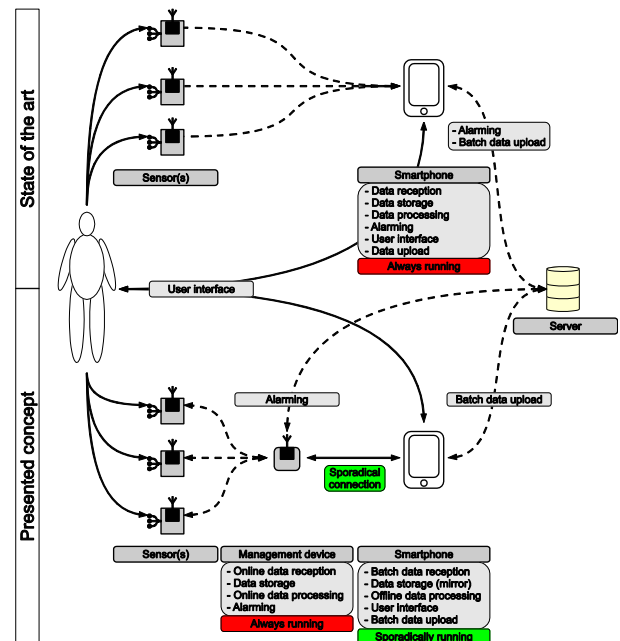


Fig. 1 Comparison between presented concept (bottom) and state of the art (top) in mobile telemedicine systems with smartphone-based visual user interface.

management device. The second addition is a connection between the smartphone's power output pin and the management device's charging pin, allowing to read out the management device with the smartphone even when its battery is empty. A system overview is given in Fig. 2. A third addition, namely a GSM module, is needed to cover all functions according to the presented concept. However, the presented prototype focuses on demonstrating the interface between the management device and the smartphone.

As a smartphone, we used the Apple iPhone 3G. When we chose the smartphone platform, this was the only phone offering a user interface consisting almost exclusively of a touch display, a very good software development kit and thus the ability to easily design intuitive and adaptive user interfaces. The downside of this platform is the very restrictive proprietary operating system, in which both processes of application authorization and becoming a licensed developer are far from transparent. The latter is especially needed when developing applications requiring access to the serial interface, which is the case here. Thus, the presented application can only run on a jailbroken device. However, this is not the case for other smartphones, on which this concept is also applicable.

The management device has a built-in connector which is compatible with the Apple Dock Connector. In addition to this, some pins can be used to program and debug the management device's microcontroller using the Joint Test Action Group (JTAG) interface. The pin assignment is illustrated in Fig. 3.

The management device has been built in two variants; the first one enables continuous connection between iPhone and management device. The second one is an adapter transforming the Eventlogger presented in [12] into a management device just during the connection with the iPhone, i.e. containing the additional components needed to use the Eventlogger as a management device. Prototypes of both devices are shown in Fig. 4.

B. Smartphone application

The realized iPhone application enables transferring the data stored on the microSD card inside the management device to the iPhone via the serial interface. It is stored into an SQLite database and visualized (data being acquired as

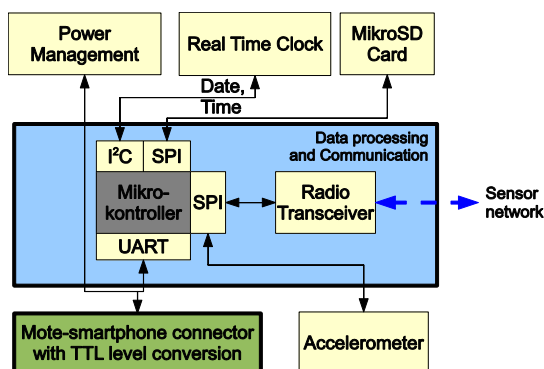


Fig. 2 Parts and interfaces of the management device prototype.

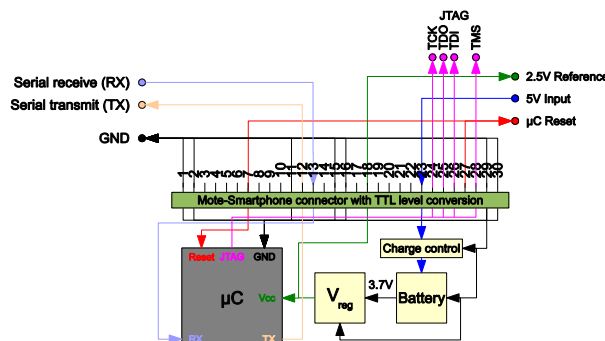


Fig. 3 Pin assignment of the mote-smartphone connector.

well as data stored previously) on the iPhone's display.

Upon starting the application, if the management device is connected to the iPhone, the iPhone-internal SQLite database is synchronized with the data on the management device. To do this, a request is sent to the management device to transmit all the data recorded since the last synchronization (batch data reception, see Fig. 1). Subsequently, a message to synchronize the real time clock inside the management device with the iPhone's time information is sent out from the iPhone application. While the application is running, a request for current data is sent out regularly. Hence data can also be displayed promptly on the iPhone upon acquisition.

The graphical user interface is divided in three views (see Fig. 5):

- 1) Main view
- 2) Graph view
- 3) Options view

In the main view, all the measured variables supported by the database are shown in a table. For each variable, normal upper and lower limits can be set. If a measured value is out of these limits, it is displayed in a distinctive color. The upper and lower limits can be set in the options view (see below).

The graph view is also structured as a table in which each row is associated to a variable. In contrast to the main view, here only rows corresponding to variables for which values are available are being shown. This is done to optimize the display space usage. Values are displayed in a graph on the



Fig. 4 Prototypes of management devices in two variants: integrated into a smartphone cover (left) and as Eventlogger with adapter for smartphone connection (right). On the left, the application for vital parameter visualization is running.

left side of the screen. New values are added scrolling the graph automatically. On the right side, the value is shown as a number along with the corresponding unit and current maximum and minimal value measured. The graph height adapts to these values. Tapping and wiping on the left side, the automatic scrolling can be stopped and the user can scroll through current and older values. Older data sets can also be loaded and displayed. With a double tap, the graph scrolls back to show current values on the right end and the automatic scrolling is reactivated.

In the options view, the user can set the upper and lower limits for each variable using a picker wheel. A screenshot of all three views is shown in Fig. 5.

IV. CONCLUSION

In this contribution, a new concept separating continuous critical processes and sporadic processes in sensor networks for telemedicine applications executing them on separate platforms is presented. Running continuous processes like detection of critical situations and alarming on a stable, reliable platform known to the developer avoid the stability and security risks of using a complex platform like a modern smartphone. Running sporadic processes like user interaction on a complex platform like a mobile phone or smartphone offer their advantages, i.e. an intuitive visual user interface, without the need of integrating big, expensive and energy consuming components like touch displays or keeping them active all the time.

A prototype has been presented connecting a mote and an iPhone in order to show how the concept can be realized with the first smartphone offering a touch-based user interface, although the access to its external interfaces is far from developer-friendly.

As future work, it is planned to extend the application and the system interoperability in order to also show interaction data and to find a method of implementing the presented concept without the need of jailbreaking a smartphone.

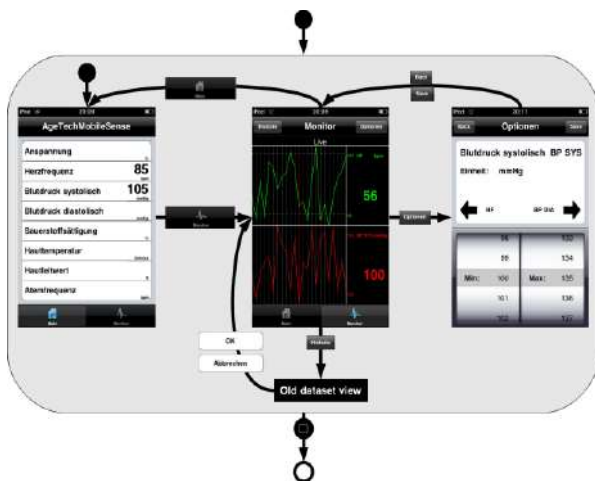


Fig. 5 Screenshots of the iPhone application visualizing acquired vital parameters live and previously recorded datasets.

ACKNOWLEDGMENT

Within the research consortium of the Bavarian Research Foundation (BFS) „FitForAge“ a team of scientists and engineers affiliated to 13 departments of the Bavarian universities Erlangen-Nürnberg, München, Regensburg and Würzburg works together with 25 industrial partners on the development of products and services for the aging society.

The scope of the research consortium is to develop technology based solutions which will help elderly people but eventually also other social groups at home, at their workplace and in their mobility.

REFERENCES

- [1] Federal Statistical Office (2009): „Bevoelkerung Deutschlands bis 2060“. 12th coordinated population forecast. Wiesbaden, Germany.
- [2] Lueth, T.C.; D'Angelo L.T.; Czabke A. (2010) : “TUM-AgeTech – A New Framework for Pervasive Medical Devices”, in Pervasive and Smart Technologies for Healthcare: Ubiquitous Methodologies and Tools, editors Antonio Coronato and Giuseppe De Pietro, Hershey, USA, Medical Information Science Reference, pp. 295-321.
- [3] L. Gatzoulis and I. Iakovidis: “Wearable and portable ehealth systems”. Engineering in Medicine and Biology Magazine, IEEE, 26(5):51-56, Sep.-Oct. 2007.
- [4] R. Paradiso, G. Loriga, and N. Taccini: “A wearable health care system based on knitted integrated sensors”. Information Technology in Biomedicine, IEEE Transactions on, 9(3):337-344, Sep. 2005.
- [5] R. Paradiso, A. Alonso, D. Cianone, A. Milsis, T. Vavouras, and C. Malliopoulos. “Remote health monitoring with wearable non-invasive mobile system: The healthwear project”. In Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE, pages 1699-1702, 20-25 2008.
- [6] Villalba, E.; Ottaviano, M.; Arredondo, M. T.; Martinez, A.; Guillen, S. (2006): “Wearable Monitoring System for Heart Failure Assessment in Mobile Environment”, Computers in Cardiology, 33, pp. 237 – 240.
- [7] Wenxi Chen, D. Wei, Xin Zhu, M. Uchida, S. Ding, and M. Cohen: „A mobile phone based wearable vital signs monitoring system”. In Computer and Information Technology, 2005. CIT 2005. The Fifth International Conference on, pages 950-955, Sep. 2005.
- [8] D.G. Guo, F.E.H. Tay, L. Xu, L.M. Yu, M.N. Nyan, F.W. Chong, K.L. Yap, B. Xu : „A long-term wearable vital signs monitoring system using bsn”. In Digital System Design Architectures, Methods and Tools, 2008. DSD '08. 11th EUROMICRO Conference on, pages 825-830, Sep. 2008.
- [9] D. Ayyagari, Yongji Fu, Jingping Xu, N. Colquitt : “Smart personal health manager: A sensor ban application: A demonstration”. In Consumer Communications and Networking Conference, 2009. CCNC 2009. 6th IEEE, pages 1-2, Jan. 2009.
- [10] B.M. Jang, Y.K. Lee, S.K. Yoo : “Development of the portable monitoring system based on wireless body area sensor network for continuous acquisition and measurement of the vital sign”. In Consumer Electronics, 2008. ICCE 2008. Digest of Technical Papers. International Conference on, pages 1-2, 2008.
- [11] D'Angelo, L.T.; Czabke, A.; Somlai, I.; Niazmand, K. ; Lueth, T.C. (2010): “ART – A new Concept for an Activity Recorder and Transceiver”, EMBS, 32nd Annual International Conference of the IEEE, pp. 2132 – 2135.
- [12] Czabke, A.; Neuhäuser, J. ; Lueth, T.C. (2010): “Detection of Interactions with Objects Based on Radio Modules”, Pervasive Computing Technologies for Healthcare, Fourth International Conference on, pp. 1 – 8.
- [13] D'Angelo L.T.; Parlow J.; Spiessl W.; Hoch S. ; Lueth, T.C. (2010): “A System for Unobtrusive In Car Vital Parameter Acquisition and Processing”, Pervasive Computing Technologies for Healthcare, Fourth International Conference on, pp. 1 – 7.
- [14] Niazmand K.; Jehle C.; D'Angelo L.T.; Lueth T.C. (2010): “A new washable low-cost garment for everyday fall detection”, EMBS, 32nd Annual International Conference of the IEEE, pp. 6377 – 6380.

APPENDIX DANGELO02

INTERNET ARCHIVE

DONATE

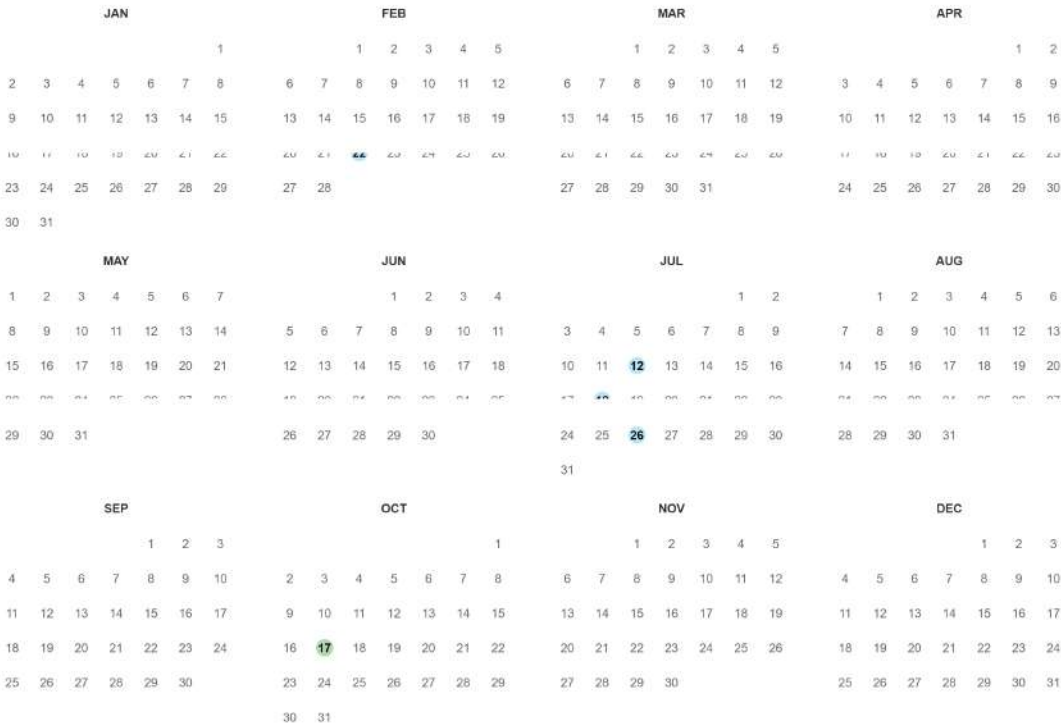
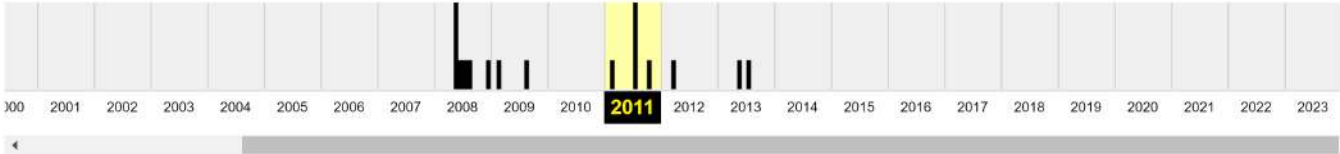
WayBackMachine

Explore more than 823 billion web pages saved over time

http://www.embs.org/conferences/index.html

Calendar · Collections · Changes · Summary · Site Map · URLs

Saved 17 times between May 17, 2008 and July 4, 2013.



Note
This calendar view maps the number of times <http://www.embs.org/conferences/index.html> was crawled by the Wayback Machine, *not* how many times the site was actually updated. More info in the [FAQ](#).
Green indicates redirects (3xx).

[FAQ](#) | [Contact Us](#) | [Terms of Service](#) (Dec 31, 2014)

INTERNET ARCHIVE

waybackmachine

http://www.embs.org/conferences/index.html

Go

FEB JUL OCT

18

2009 2011 2013

About this capture

17 captures

17 May 2008 - 4 Jul 2013

IEEE

EMB

Home | About IEEE EMBS | What's New | Contacts | EMBS Database | EMBS Archive

Google™ Custom Search

Search

Home

We are ... EMBS!

Join IEEE EMBS

Corporate Partnership

Member Center

GOLD Member Center

Student Center

Technology Center

Educator's Toolbox

Publications

Conferences

Geographic Activities

Services

Awards and Recognition

History Center

Career Opportunities

IEEE tv

Advertise with EMBS

Shop with EMBS

Home > IEEE EMBS Conferences

IEEE EMBS Conferences



Mark Your Calendar!

IEEE EMBS 33rd Annual International Conference

August 30 - September 3, 2011

Boston, MA, USA



>> Upcoming Conferences

>> Other Upcoming BME Meetings

>> Past Conferences

Sponsorship Opportunities

Obtaining support and/or sponsorship for your next conference is easy if you are an IEEE EMBS member! For details, contact the [EMBS Executive Office](#). Note that there are [standards](#) for the submission of papers to allow IEEE to index papers using IEEE Xplore.

If you are requesting IEEE EMBS conference sponsorship, please read the [following By-Laws](#) of the EMB Society before contacting our office.

IEEE

EMB

CO

Home

About IEEE EMBS

What's New

Contacts

EMBS Database

EMBS Archive

Google Custom Search

Search

Home

We are ... EMBS!

Join IEEE EMBS

Corporate Partnership

Member Center

GOLD Member Center

Student Center

Technology Center

Educator's Toolbox

Publications

Conferences

Geographic Activities

Services

Awards and Recognition

History Center

Career Opportunities

IEEE.tv

Advertise with EMBS

Shop with EMBS

Home > IEEE EMBS Conferences

IEEE EMBS Conferences

>> Upcoming Conferences

>> Other Upcoming BME Meetings

>> Past Conferences

Sponsorship Opportunities

Obtaining support and/or sponsorship for your next conference is easy if you are an IEEE EMBS member! For details, contact the [EMBS Executive Office](#). Note that there are standards for the submission of papers to allow IEEE to index papers using IEEE Xplore.

If you are requesting IEEE EMBS conference sponsorship, please read the [following By-Laws](#) of the EMB Society before contacting our office.

Technical Co-Sponsorship by IEEE EMBS

The following guidelines apply to all parties requesting to enter into a Technical Co-sponsor relationship with IEEE EMBS:

1. For your conference to be considered, one or more past proceedings must be made available to EMBS for evaluation. If no such proceedings are available, then EMBS will not consider the conference for Technical Co-Sponsorship. If this is the first year for your conference, you are encouraged to create a conference proceeding to submit with your request in a future year.

2. A processing fee of \$500 is required to cover the cost of listing your conference in the IEEE Conference Search Directory and evaluation of your proceedings.

3. IEEE EMBS will include your conference information in regular mailouts to its members and on the website.

4. You may use the IEEE EMBS logo on the Conference Website and promotion material as a sponsoring society.

5. IEEE EMBS will not have any financial involvement and will be limited to participating as a Technical Co-sponsor.

6. The use of IEEE EMBS in the title of the Conference is **prohibited**.

7. **Note: IEEE EMBS will not technically co-sponsor a conference if it falls within a month (either side) of our Annual International Conference or a month (either side) of one of our Special Topic Conferences.**

As a Technical Co-sponsor, IEEE EMBS requires the following items:

All papers submitted to the conference must be peer-reviewed.

The conference must demonstrate that its paper submission process is secure.

The conference organizers have a process to identify and reject fraudulent reviewers and papers.

To verify this information, a detailed description of the paper submission and review process must be submitted with a formal request for EMBS Technical Co-Sponsorship for approval by the EMB VP Conferences. Please include a Call for Papers if one is available. IEEE EMBS will not authorize any publication acquisition for IEEE Xplore until these requirements can be verified. Please submit your request to emb-conferences@ieee.org.

As a Technical Co-sponsor, IEEE EMBS requests that you will:

Acknowledge IEEE EMBS participation in all conference materials, advertisements and on the conference website.

Include the IEEE EMBS Information page in the Final Program and Conference Proceeding.

Agree that IEEE EMBS can acquire the Conference Proceedings, production and shipment at a specific acquisition fee paid by IEEE EMBS. This acquisition of your Conference Proceedings is not guaranteed and is contingent upon the proceedings being evaluated and requested by IEEE and created in the required IEEE compatible format.

Provide to IEEE EMBS one complimentary copy of the Conference Proceeding for the EMBS Executive Office.

Provide to IEEE EMBS in electronic format the conference attendee list to include: name, postal address, email address, telephone and facsimile numbers.

© 2008 IEEE Engineering in Medicine and Biology Society | All rights reserved | Last updated Tuesday, 21 December, 2010

chrome-extension://bpconjcamlapcogcnnelfmaeghhagj/edit.html

136

1/1

APPENDIX DC01



Creating Metadata

Contributors: Stefanie Rühle, Tom Baker and Pete Johnston

Go to [Publishing Metadata](#)

Contents

- [1 About the examples](#)
- [2 Titles](#)
 - [2.1 Title](#)
 - [2.2 Alternative](#)
 - [2.3 Guidelines for the creation of title content](#)
- [3 Relationships between Resource and Agents](#)
 - [3.1 Using agent properties in Dublin Core](#)
 - [3.2 Contributor](#)
 - [3.3 Creator](#)
 - [3.4 Publisher](#)
 - [3.5 RightsHolder](#)
 - [3.6 Guidelines for the creation of content for agents](#)
- [4 Type](#)
 - [4.1 Guidelines for the creation of type content](#)
- [5 Format](#)
 - [5.1 Guidelines for the creation of format content](#)
- [6 Extent](#)

- [6.1 Guidelines for the creation of extent content](#)
- [7 Medium](#)
 - [7.1 Guidelines for the creation of medium content](#)
- [8 Language](#)
 - [8.1 Guidelines for the creation of language content](#)
- [9 Identifiers](#)
 - [9.1 Identifier](#)
 - [9.2 BibliographicCitation](#)
 - [9.3 Guidelines for the creation of identifier content](#)
- [10 Descriptions](#)
 - [10.1 Description](#)
 - [10.2 Abstract](#)
 - [10.3 TableOfContent](#)
 - [10.4 Guidelines for the creation of descriptions](#)
- [11 Subject](#)
 - [11.1 Guidelines for describing the subject of a resource](#)
- [12 Coverage](#)
 - [12.1 Coverage](#)
 - [12.2 Temporal](#)
 - [12.3 Spatial](#)
 - [12.4 Guidelines for describing the coverage, spatial or temporal character of a resource](#)
- [13 Dates](#)
 - [13.1 Date](#)
 - [13.2 Created](#)
 - [13.3 Issued](#)
 - [13.4 Available](#)
 - [13.5 Modified](#)
 - [13.6 Valid](#)
 - [13.7 DateCopyrighted](#)
 - [13.8 DateSubmitted](#)
 - [13.9 DateAccepted](#)
 - [13.10 Guidelines for the creation of content for dates](#)
- [14 Source and Relations](#)

- [14.1 Relation](#)
- [14.2 Source](#)
- [14.3 IsPartOf](#)
- [14.4 HasPart](#)
- [14.5 IsVersionOf](#)
- [14.6 HasVersion](#)
- [14.7 IsFormatOf](#)
- [14.8 HasFormat](#)
- [14.9 Replaces](#)
- [14.10 IsReplacedBy](#)
- [14.11 Requires](#)
- [14.12 IsRequiredBy](#)
- [14.13 References](#)
- [14.14 IsReferencedBy](#)
- [14.15 ConformsTo](#)
- [14.16 Guidelines for the creation of content for relations and source](#)
- [15 Rights](#)
 - [15.1 Rights](#)
 - [15.2 AccessRights](#)
 - [15.3 License](#)
 - [15.4 Guidelines for the creation of rights content](#)
- [16 Special properties for the description of education material](#)
 - [16.1 Audience](#)
 - [16.2 Mediator](#)
 - [16.3 EducationLevel](#)
 - [16.4 InstructionalMethod](#)
 - [16.5 Guidelines for the creation of content for properties describing education material](#)
- [17 Special properties for the description of collections](#)
 - [17.1 AccrualMethod](#)
 - [17.2 AccrualPeriodicity](#)
 - [17.3 AccrualPolicy](#)
 - [17.4 Guidelines for the creation of content for properties describing collections](#)
- [18 Provenance](#)
 - [18.1 Guidelines for the creation of content for provenance](#)

How to create content for DCMI Metadata

About the examples

We are presenting the examples in tables. To interpret these tables please consider that:

- **yellow rows** are standing for statements describing a resource,
- **white rows** are standing for statements describing a resource that is the value of another statement but is not described by another record,
- **bold** strings are standing for properties,
- **italicized** strings are standing for values,
- **red strings** are standing for values linking to records.

example (see turtle explanation)

Titles

Title

Title is a property that refers to the name or names by which a resource is formally known.

Alternative

Alternative is a property that refers to a name or names of a resource used as a substitute or alternative to the formal title. These are secondary titles, abbreviations,

translations of a title, etc.

Guidelines for the creation of title content

For the title use the name given to the resource.

title	<i>Alvar Aalto Chair No. 66</i>
--------------	---------------------------------

as linked data

In most databases title is one of the main criteria to identify search results. So **if there is no formal title resp. name** you should formulate an adequate one by yourself.

title	<i>Data from a survey about the usage of metadata</i>
--------------	---

as linked data

If there is **more than one title resp. name** you should repeat the title property

title	<i>Autumn Leaves</i>
title	<i>The Dead Leaves</i>

as linked data

or use the alternative property.

Typically alternative is used for **secondary titles**,

title	<i>Passion for Pulses</i>
alternative	<i>A Feast of Beans, Peas and Lentils from Around the World</i>

as linked data

or for **abbreviations**.

title	<i>American Meteorological Association Newsletter</i>
alternative	<i>AMA Newsletter</i>

as linked data

If the title resp. name is expressed in **different languages** you should use language tags.

title	<i>La Joconde</i>	fre
title	<i>Mona Lisa</i>	eng
title	<i>La Gioconda</i>	ita

as linked data

the same is true for alternative

title	<i>EU Stability Programm of Belgium</i>	eng
alternative	<i>Council Opinion on the Updated Stability Programm of Belgium 2009 - 2010</i>	eng
alternative	<i>Stellungnahme des Rates zum aktualisierten Stabilitätsprogramm Belgiens für 2009 - 2012</i>	ger

as linked data

It is recommended to describe titles with plain text (as done in the examples above). But sometimes it is necessary to **create a relationship between the described resource and a more detailed title description**.

This should be used to refer to **a title with different transliterations**,

title		
	in greek	<i>Οιδίπους Τύραννος</i>

	in latin	<i>Oidipous Tyrannos</i>
--	-----------------	--------------------------

as linked data

or to refer to a **title authority**.

title	<i>Nibelungenlied Handschrift B</i>
title	<i>nibelungenlied</i>

title	<i>Nibelungenlied Handschrift C</i>
title	

identifier	<i>nibelungenlied</i>
label	<i>Der Nibelunge Not</i>
alternative label	<i>Nibelungenlied</i>
alternative label	<i>Nibelungenklage</i>
alternative label	<i>Nibelungensage</i>
description	<i>The Nibelungenlied exists of 39 aventiuren created between 1180 and 1210</i>

as linked data

Relationships between Resource and Agents

Using agent properties in Dublin Core

Persons, organizations and services can relate to resources in various ways. DCMI defined only a few common properties to describe the relationship between resources and agents. So when necessary other vocabularies should be used describing these relationships more detailed. In these cases we recommend to use the [marcrelator codes](#). How to use them is described in

- [MARC Relator terms and Dublin Core](#)
- [MARC Relator properties in Dublin Core™ metadata](#)

Contributor

The contributor property represents a relationship between the resource and a person, an organization, or a service making a contribution to a resource.

Creator

The creator property represents a relationship between the resource and a person, an organization, or a service primarily responsible for making the content of a resource.

Publisher

The publisher property represents a relationship between the resource and a person, an organization, or a service responsible for making the resource available and provide access to the resource.

RightsHolder

This property represents a relationship between the resource and a person or an organization owning or managing rights over this resource.

Guidelines for the creation of content for agents

If you know there is a **URI standing for a person or organization** you should use it. For further information you should handle the person or organization like another resource.

Example with an **organization**:

rights holder	gnd	39454-3
	name	<i>Bundesarchiv Koblenz</i>
	homepage	http://www.bundesarchiv.de/index.html.de

as linked data

Example with a **person**:

contributor	gnd	135066719
	family name	<i>Elliott</i>
	given name	<i>Missy</i>
	nick name	<i>Missy E</i>

as linked data

Regardless of the existence of a URI **personal names** should be grouped in family name resp. surname as one part of the name and forename resp. given name as the other part .

You should handle the person name like **another resource**,

creator		
	family name	<i>Shakespeare</i>
	given name	<i>William</i>

as linked data

or you could devide these names **by comma**.

creator	<i>Shakespeare, William</i>
----------------	-----------------------------

as linked data

When you **in doubt about family name and given name** give the name as it appears.

contributor	<i>Snoop Dogg</i>
--------------------	-------------------

as linked data

If there is **more than one contributor/creator/publisher/rightsHolder**, each should be listed separately,

like another resource,

publisher	gnd	<i>2125990-2</i>
	name	<i>Rossijskaja Gosudarstvennaja Biblioteka</i>
	homepage	http://www.rsl.ru/
publisher		
	name	<i>Knižnaja Palata</i>

as linked data

or with plain text.

creator	<i>Hubble Telescope</i>
publisher	<i>University of Nowhere</i>
publisher	<i>All Your Data Inc.</i>

as linked data

Type

The type property refers to a description of the nature or genre of the content of a resource (e.g. a stylistic category, a function or an aggregation level). To describe the physical or digital manifestation, use format.

Guidelines for the creation of type content

We recommend to **select a value from a controlled vocabulary** (e. g. DCMI Type Vocabulary).

type	dctype	
		<i>Still Image</i>

as linked data

But you may also use **plain text**.

type	<i>Conference</i>
-------------	-------------------

as linked data

If **no formal controlled vocabulary** exists, you could create a domain specific one.

type	<i>conference</i>
-------------	-------------------

identifier	<i>conference</i>	
label	<i>Conference</i>	eng
label	<i>Tagung</i>	ger

label	съезд	rus
-------	-------	-----

as linked data

Is the resource composed of **multiple components of different types** the property should be repeated.

type	dctype	
		<i>Interactive Resource</i>
type	dctype	
		<i>Text</i>

as linked data

Different communities use a variety of type vocabularies. To ensure interoperability you can use terms from different vocabularies side by side - e.g. a type of the DCMI Type vocabulary in addition to **a non-controlled or domain specific type term**.

type		
		<i>PC Game</i>
type	dctype	
		<i>Software</i>

as linked data

Format

The property format refers to the file format, the physical medium (e.g. the data storage medium), or the dimension (the size or duration) of a resource. The information can be relevant to determine the equipment needed to display or operate a resource (e.g. if the described resource has format pdf you need a pdf reader to use

it). To specify the different categories of format you should use extent and/or medium. To reference to the nature or genre of the content use type.

Guidelines for the creation of format content

For the description of the **file format** we recommend to use a controlled vocabulary - e.g. the list of Internet Media Types(MIME).

format	mime	<i>jpeg</i>
---------------	------	-------------

as linked data

You should repeat the properties when **more than one type of value exists**.

format	mime	<i>jpeg</i>
format		<i>40 × 512 pixels</i>

as linked data

Extent

This property refers to the size (e.g. bytes, pages, inches, etc.) or duration (e.g. hours, minutes, days, etc.) of a resource.

Guidelines for the creation of extent content

Typically the value used for the description of the extent consists of a **numeric value** and a **caption** to specify it. You may use a text string to present it

extent	
	<i>21 minutes</i>

as linked data

or use controlled values for the caption.

extent		
	minutes	21

as linked data

Medium

This property refers to the physical carrier of the resource and may only be used if the resource is of physical nature (e.g. a painting, a sculpture, etc.)

Guidelines for the creation of medium content

Note that the **media types must not be used with the property medium** because medium describes only physical objects.

We recommend to **use a controlled vocabulary**. If no formal controlled vocabulary exist you should nonetheless handle the media type like another resource.

medium	
	<i>oil on wood</i>
	<i>oil</i>
	<i>wood</i>

as linked data

Language

This properties refers to the language of the intellectual content of the resource.

Guidelines for the creation of language content

For the identification of languages please follow [RFC 4646](http://www.sil.org/iso639-3/codes.asp). Best practice would be to **select a value from the three letter language tags of ISO 639** (e.g. <http://www.sil.org/iso639-3/codes.asp>).

title	<i>A great deliverance</i>	
language	ISO 639-3	<i>eng</i>

as linked data

or

title	<i>A great deliverance</i>	
language		
	RFC 4646	<i>eng</i>

as linked data

If the content is in **more than one language**, the property should be repeated.

title	<i>Charlie Wilson's War</i>	
language	ISO 639-3	<i>eng</i>
language	ISO 639-3	<i>hun</i>
language	ISO 639-3	<i>tur</i>

as linked data

But if **every language version has it's own identifier**, they have to be treated like single resources.

Video1

title	<i>Medieval helpdesk with English subtitles</i>	
identifier	http://www.youtube.com/watch?v=pQHx-SjgQvQ&feature=player_embedded	
isVersionOf	<i>Video2</i>	
language	ISO 639-3	<i>nor</i>
language	ISO 639-3	<i>eng</i>

Video2

title	<i>Book help (better version)</i>	
identifier	http://www.youtube.com/watch?v=UOorZQLsmuA&feature=related	
isVersionOf	<i>Video1</i>	
language	ISO 639-3	<i>nor</i>

as linked data

You could also use plain text

title	<i>The Power of Orange Knickers</i>
language	<i>English</i>

as linked data

or create your own language vocabulary.

title	<i>The Power of Orange Knickers</i>
language	<i>english</i>

identifier	<i>english</i>
-------------------	----------------

label	<i>English</i>
ISO 639-1	<i>en</i>
ISO 639-3	<i>eng</i>

as linked data

Identifiers

Identifier

An identifier is an unambiguous reference to a resource. Examples of formal identification systems include the Uniform Resource Identifier (URI) - including the Uniform Resource Locator (URL), the Digital Object Identifier (DOI) or the International Standard Book Number (ISBN).

BibliographicCitation

- `dcterms:bibliographicCitation`

BibliographicCitation is a bibliographic reference to a resource identifying the resource by bibliographic details. Typically the described resource is the child in a parent/child relationship where the bibliographicCitation is not describing the relationship but the location of the described resource within the parent resource (e.g. the bibliographic citation of an article consists of the name of a journal as well as the number of volume, issues and even page references). For the description of parent/child relations see `hasPart` or `isPartOf`. BibliographicCitation may only be used to describe bibliographic resources like books, articles or other documentary resource.

Guidelines for the creation of identifier content

Best practice is to **declare the identification system** from which an identifier is selected.

title	<i>What's a URI and why does it matter?</i>	
identifier	http://www.ltg.ed.ac.uk/~ht/WhatAreURIs/	URI

as linked data

Identifiers should be selected from formal identification systems as above but can also be **local identifiers** as long as there is a proper declaration of these.

title	<i>Small and medium sized companies in Kathmandu</i>	
identifier	03KTM147	local ID

as linked data

Note that the identifier of the description of a resource (e. g. of the metadata record) is not the same as the identifier of the resource itself.

metadata record		
created	2010	W3CDTF
identifier	013234098	database ID
my Video		
title	<i>Medieval helpdesk with English subtitles</i>	
created	2007	W3CDTF
identifier	http://www.youtube.com/watch?v=pQHXSigQvQ&feature=player_embedded	URI

as linked data

If no identifier from a formal identification system exist, the identifier can be generated by a **bibliographic citation**. The bibliographic citation can be created as **text citation**,

title	<i>Prototyping Digital Library Technologies in zetoc</i>
bibliographicCitation	<i>Lecture Notes in Computer Science 2458, 309-323 (2002)</i>

as linked data

or as **machine readable citations**.

title	<i>Prototyping Digital Library Technologies in zetoc</i>
bibliographicCitation	<code>&ctx_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&rft.jtitle=Lecture Notes in Computer Science&rft.volume=2458&rft.spage=309^^info:ofi/fmt:kev:mtx:ctx</code>

as linked data

You can also **structure the bibliographic information**.

title	<i>My first article about metadata</i>	
identifier		
	journal title	<i>My Favorite Journal</i>
	volume	3
	issue	2
	start page	14
	date	2010

as linked data

For additional information on bibliographicCitation see "[Guidelines for Encoding Bibliographic Citation Information in Dublin Core™ Metadata](https://www.dublincore.org/resources/userguide/creating_metadata/)".

Descriptions

Description

This property refers to the description of the content of a resource. The description is a potentially rich source of indexable terms and assist the users in their selection of an appropriate resource. To refine the character of a description use abstract or tableOfContent.

Abstract

This property is used when the description of a resource is a formal abstract.

TableOfContent

This property is used when the description of a resource is a structured list of the contents of a resource.

Guidelines for the creation of descriptions

A description may be a **free text account**,

title	<i>Bugs from New Zealand</i>
description	<i>A box of ten bugs collected in New Zealand between 1845 and 1846</i>

as linked data

an **abstract**,

title	<i>The Foundations of Programm Verification</i>
--------------	---

abstract	<i>This revised edition provides a precise mathematical background to several program verification techniques. It concentrates on those verification methods that have now become classic, such as the inductive assertions method of Floyd, the axiomatic method of Hoare, and Scott's fixpoint induction. The aim of the book is to present these different verification methods in a simple setting and to explain their mathematical background. In particular the problems of correctness and completeness of the different methods are discussed in some detail and many helpful examples are included.</i>
-----------------	---

as linked data

a **table of contents**,

title	<i>Remains of Claire Klawitter</i>
table of content	<i>Diary 1822 - 1824 -- 20 pictures of Indian farmers -- 5 letters to Rudi Ratlos -- 1 map of North India</i>

as linked data

or a **reference to a description**.

title	<i>Thriller</i>
description	http://en.wikipedia.org/wiki/Thriller_(album)

as linked data

You can give some **information about the description you refer to**.

title	<i>Coriandrum sativum</i>	
description	http://en.wikipedia.org/wiki/Coriander	
	title	<i>Coriander</i>
	contributor	<i>Wikipedia</i>

as linked data

If **descriptions in different languages** exist, the property should be repeated with language tags.

title	<i>Delvig and Kjuchelbeker</i>	
abstract	<i>The book is a collection of works of two poets - contemporaries and friends of Pushkin - A. A. Delvig and V. K. Kjuchelbeker. It includes poems and prosa by Kjuchelbeker, parts of his diary, the poem Jurij and Xenia and reviews by Delvig. The attachment presents some retrospections to Delvig and Kjuchelbeker. A detailed biographic description tells us something about the life of the poets.</i>	eng
abstract	<i>Сборник впервые объединяет произведения двух поэтов - современников и друзей Пушкина - А. А. Дельвига и В. К. Кюхельбекера. Наряду со стихотворениями в книгу включены проза Кюхельбекера, фрагменты из его дневника, поэма "Юрий и Ксения", а также рецензии Дельвига. В "Приложении" печатаются воспоминания о Дельвиге и Кюхельбекере. Подробные биографические очерки рассказывают о жизненном пути поэтов.</i>	rus

as linked data

Subject

The property subject represents a relationship between a resource and another resource which is a topic of the first resource resp. describes the intellectual content of the first resource. If the topic of the resource has a spatial or temporal character, use coverage, spatial or temporal.

Guidelines for describing the subject of a resource

To express the topic of a resource we recommend to **use a URI representing another resource describing this topic**,

title	<i>Inviato alla Biennale : Venezia, 1949 - 2009</i>	
subject	http://www.labiennale.org/en/Home.html	
	title	<i>La Biennale di Venezia</i>

as linked data

or a URI representing the value of a controlled vocabulary,

- like **entries from authority file systems** (e.g. the Library of Congress Subject Headings or the authority files of the German National Library, etc.),

title	<i>My Winter Wonderland</i>	
subject	http://id.loc.gov/authorities/sh88004323#concept	
	label	<i>Cross-country skiing--Skating</i>

as linked data

- like **entries from classification systems** ((e.g. the Dewey Decimal Classification, or Linnaean taxonomy, etc.).

title	<i>Transports in Kazakhstan 2000 - 2010</i>
subject	<i>W03_7</i>
subject	<i>G06_3</i>

label	<i>W03.7</i>
name	<i>Freight Transport</i>
broader	<i>W03</i>
narrower	<i>W03.72</i>
narrower	<i>W03.75</i>

label	<i>G06_3</i>
--------------	--------------

name	<i>Kazakhstan</i>
broader	<i>G06</i>
narrower	<i>G06_31</i>
narrower	<i>G06_35</i>

as linked data

You may also use plain text. But if you need **more than one entry to describe the content** you should repeat the property.

title	<i>How to get an aircraft</i>
subject	<i>aircraft</i>
subject	<i>leasing</i>

as linked data

If you want to use a keyword or keyphrase in **different languages**, you should use language tags.

title	<i>KONSTYTUCJA RZECZYPOSPOLITEJ POLSKIEJ</i>	
subject		
	<i>Rzeczpospolita Polska</i>	pol
	<i>Republic of Poland</i>	eng

as linked data

If the **subject is a person or organization** you should use names from formal name authorities (e.g. from the Library of Congress Name Authority Headings [\[1\]](#), or from the Virtuell International Authority File [\[2\]](#)).

title	<i>Candle in the wind</i>	
subject	gnd	118583549
	family name	Monroe
	given name	Marilyn
	born	1926
	died	1962

as linked data

Coverage

Coverage

The property coverage describes a relationship between a resource and another resource which represents the extent or scope of the content of the first resource. This includes the spatial locations (a place name or geographic co-ordinates), temporal periods (a period label, a date or a date range), or jurisdictions (states, counties, or other administrative entities). If you want to make a distinction between the temporal or spatial character of the content use temporal or spatial.

Temporal

This property describes the relationship between a resource and another resource which represent the temporal characteristics of the intellectual content of the first resource expressed by period labels or date encoding. If you want to describe date of the lifecycle of a resource use the date properties.

Spatial

This property describes the relationship between a resource and another resource which represents spatial characteristics of the intellectual content of the first resource expressed by geographic names, latitude/longitude, or other established georeferencing.

Guidelines for describing the coverage, spatial or temporal character of a resource

To describe the **temporal** characteristic of a resource

you may use plain text,

title	<i>Transports in Kazakhstan 2000 - 2010</i>
coverage	<i>2000 - 2010</i>

as linked data

or **structure your entry** using dates,

title	<i>Transports in Kazakhstan 2000 - 2010</i>		
temporal			
	start	<i>2000</i>	W3CDTF
	end	<i>2010</i>	W3CDTF

as linked data

or **period labels**.

title	<i>Analysis of rocks collected in Perth</i>	
temporal		
	start	<i>Cambrian period</i>

	scheme	<i>Geological timescale</i>
	name	<i>Phanerozoic Eon</i>

as linked data

Further information on encoding temporal characteristics you will find in the [DCMI Period Encoding Scheme](#).

To describe the **spatial** character of a resource, you could use plain text,

title	<i>Analysis of rocks collected in Perth</i>
coverage	<i>Perth, W. A.</i>

as linked data

or express it by **georeferencing**,

title	<i>Analysis of rocks collected in Perth</i>	
spatial		
	east	<i>115.85717</i>
	north	<i>-31.95301</i>
	name	<i>Perth, W. A.</i>

as linked data

or **reference to a formal encoding**.

title	<i>The growth of trees in the subtropical highlands</i>	
spatial		
	label	<i>Cwb</i>
	source	<i>Köppen-Geiger Climate Classification</i>

	main Climates	<i>warm temperate</i>
	precipitation	<i>winter dry</i>
	temperature	<i>warmest month averaging below 22°C</i>

as linked data

Further information on encoding spatial characteristics you will find in the [DCMI Box Encoding Scheme](#) and the [DCMI Point Encoding Scheme](#).

Dates

Date

The property date refers to a description of any dates or ranges in the lifecycle of a resource and is typically associated with the creation or availability. If the distinction between different sorts of date is necessary, the following subproperties should be used. If a date is describing the content of a resource the properties coverage or temporal have to be used.

Created

This property refers to a description of the date or range of the creation of a resource. According to the one-to-one principle this has to be the creation date of the resource being described and not the creation date of any other resource from which the described resource derives (e.g. a former version or a superior resource). So a resource is created only once, every other date of creation belongs to another resource that has to be described on its own.

Issued

This property refers to a description of the date of the formal issuance resp. publication of a resource. A resource is issued only once, every other issuance

belongs to another resource that has to be described on its own. If the issuance of a resource is not formal the property "available" should be used.

Available

This property refers to a description of the date a resource did become or will become available. A resource becomes available only once, every other availability belongs to another resource that has to be described on its own. If the availability of a resource starts with the formal issuance resp. publication use "issued".

Modified

This property refers to a description of the date a resource was changed. You may record every date a resource was modified by repeating this property or record only one date (this should be the last one).

Valid

This property refers to a description of the date or range a resource is, was or will be valid. This property should be used if a resource is only valid resp. relevant until a particular date.

DateCopyrighted

This property refers to a description of the date or range of the copyright of the resource.

DateSubmitted

This property refers to a description of the date a resource was submitted (e.g. a thesis at a university department, an article at the editorial board of a journal, etc.).

DateAccepted

This property refers to a description of the date a resource was accepted (e.g. a thesis by a university department, an article by the editorial board of a journal, etc.)

Guidelines for the creation of content for dates

For the structure of date properties we recommend the usage of the **W3CDTF profile of ISO 8601** [W3CDTF]. It allows to sort search results by date and facilitates the merging of metadata of different applications.

You should use this encoding for **a point in time**

created	<i>2003-04-10</i>	W3CDTF
----------------	-------------------	--------

as linked data

but must not use it with **a range**,

valid	<i>2007-05-06/2007-07-15</i>
--------------	------------------------------

as linked data

or when the date is located **before the common area**.

created	<i>-500</i>	gYear
----------------	-------------	-------

as linked data

If you need to **structure range data**, make a distinction of start and end date.

date			
	start	<i>2007-05-06"</i>	W3CDTF

	end	<i>2007-07-15</i>	W3CDTF
--	------------	-------------------	--------

as linked data

If the **complete date is unknown** you should use

month and year

available	<i>2006-07</i>	W3CDTF
------------------	----------------	--------

as linked data

or only the year

issued	<i>2009</i>	W3CDTF
---------------	-------------	--------

as linked data

If **more than one date of the same type** (e.g. modified) is recorded, the property must be repeated.

modified	<i>2009-12-22</i>	W3CDTF
modified	<i>2010-01-08</i>	W3CDTF
modified	<i>2010-02-15</i>	W3CDTF

as linked data

Since a resource has only one date of creation, issuance, availability and/or copyright you may repeat the properties created, issued, available and dateCopyrighted only if you want to **provide the same date in another structure**.

created	<i>1752</i>	W3CDTF
created	<i>probably after 1752</i>	

as linked data

If the described date is **only approximately known**, you may use plain text,

created	<i>aprox. 500 B.C.</i>
----------------	------------------------

as linked data

or describe it.

date		
	year	<i>500</i>
	qualifier	<i>approx.</i>
	epoch	<i>B.C.</i>

as linked data

Another date of creation, issuance, availability and/or copyright however belongs to another resource that has to be described on its own. The relation of both resources may be described by one of the relation properties or by source.

title	<i>Population estimates in Scandinavia</i>		
created	<i>2004</i>	W3CDTF	
source			
	title	<i>World health report 2002 statistical annex</i>	
	created	<i>2002</i>	W3CDTF

as linked data

Source and Relations

Relation

Relation represents the relationship between the described resource and another resource, that is related to the described resource in some way. Such relationship may be expressed reciprocally but this is not required and depends on the sort of relation. If the relation shall be specified more precisely use one of the following properties.

Source

Source describes the relationship between the described resource and another resource, from which the described resource is derived in whole or in part (e.g. data of a climate centre are the source of a forecast, a book or journal is the source of a scan, etc.)

IsPartOf

This property describes the relationship between the described resource and another resource of which the described resource is a physical or logical part (e.g. a painting as part of a collection, an article as part of a journal, etc.). The described resource is like a "child" in a hierarchical or "parent/child" relationship. For the reciprocal statement use hasPart.

HasPart

This property describes the relationship between the described resource and another resource which is a physical or logical part of the described resource (e.g. the described resource is a collection of paintings, or a journal with different articles, etc.). The described resource is like the "parent" in a hierarchical or "parent/child" relationship. For the reciprocal statement use isPartOf.

IsVersionOf

This property describes the relationship between the described resource and another resource, that is a former version, edition or adaptation of the described resource (e.g. the described resource is the revision of a book, or another recording of a song, etc.). Another version implies changes in the content of a resource. For resources with different formats use `isFormatOf`. For the reciprocal statement use `hasVersion`.

HasVersion

This property describes the relationship between the described property and another property, that is a later version, edition or adaptation of the described resource (e.g. the described resource is the older version of a revised book, or of a song, etc.). Another version implies changes in the content of a resource. For resources with different formats use `hasFormat`. For the reciprocal statement use `isVersionOf`.

IsFormatOf

This property describes the relationship between the described resource and another resource, that is a former version of the described resource with the same intellectual content but presented in another format (e.g. the described resource is the microfilm version of a printed book, or the pdf version of a doc document). For intellectual changes between resources use `isVersionOf`. For the reciprocal statement use `hasFormat`.

HasFormat

This property describes the relationship between the described resource and another resource, that is a later version of the described resource with the same intellectual content but presented in another format (e.g. the described resource is a printed book that is also available as a microfilm, or a doc document that is also available as pdf). For intellectual changes between resources use `hasVersion`. For the reciprocal statement use `isFormatOf`.

Replaces

This property describes the relationship between the described resource and another resource, that has been supplanted, displaced or superseded by the described resource. It is used for the valid version in chain of versions (e.g. the described resource is the the last draft of a contract, or the current version of guidelines). For the reciprocal statement use `isReplacedBy`.

IsReplacedBy

This property describes the relationship between the described resource and another resource, that supplants, displaces or supersedes the described resource. It is used, when in chain of versions only one version is valid (e.g. the described resource is one of the former drafts of a contract, or a former version of guidelines). For the reciprocal statement use `replaces`.

Requires

This property describes the relationship between the described resource and another resource supporting the function, delivery or coherence of the content of the described resource (e.g. the described resource is an application that can be used only with a particular software, or hardware). For the reciprocal statement use `isRequiredBy`.

IsRequiredBy

The described resource is necessary for the function, delivery or coherence of the content of the resource the property references to (e.g. the described resource is a software or hardware necessary to use a particular application). For the reciprocal statement use `requires`.

References

This property describes the relationship between the described resource and another resource that is cited, referenced, or otherwise pointed to by the described resource (e.g. the described resource is an article citing a book, or an interview pointing to a play). For the reciprocal statement use `isReferencedBy`.

IsReferencedBy

This property describes the relationship between a resource and another resource that points to the described resource by citation, acknowledgement, etc (e.g. the described resource is a book cited in an article, or a play pointed to in an interview, etc.). For the reciprocal statement use `references`.

ConformsTo

This property describes the relationship between a resource and an established standard, to which the described resource conforms (e.g. a metadata record that conforms to the RDA standard, or a pipe that conforms to ISO 3183, etc.)

Guidelines for the creation of content for relations and source

You may refer to the related resource by plain text or by a URI representing the related resource. If you use plain text, you should **use a formal citation**.

issued	2009	W3CDTF
isFormatOf		
	<i>Eike von Repgow: Sachsenspiegel, Aufßs neue vbersehen mit Summarijs vnd Additionen ...; Leipzig 1561/1563</i>	

as linked data

However recommended best practice is to **use an identifier instead of text**,

conformsTo	http://www.w3.org/2001/XMLSchema	-
-------------------	---	---

as linked data

or to **describe the related resources like another resource.**

references			
	creator	<i>Black, Carl</i>	
	contributor	<i>White, Stuart</i>	
	title	<i>Black and White</i>	
	date	<i>1988</i>	W3CDTF

as linked data

If there is **more than one relation of the same sort** you have to repeat the property:

requires	
	<i>audio</i>
	<i>video</i>

as linked data

If **both resources of a relationship are described** the relation could be expressed reciprocally whereupon reciprocity could be generated automatically

identifier	<i>mySong1</i>	
title	<i>Candle in the wind</i>	
issued	<i>1973</i>	W3CDTF
description	<i>Portayal of the life of Marilyn Monroe</i>	
hasVersion	<i>mySong2</i>	

as linked data

identifier	<i>mySong2</i>	
title	<i>Candle in the wind</i>	
alternative	<i>Goodbye England's Rose</i>	
issued	<i>1997</i>	W3CDTF
description	<i>Tribut to the dead princess of Wales</i>	
isVersionOf	<i>mySong1</i>	

as linked data

Rights

Rights

The rights property represents the relationship between a resource and information about rights held in and over this resource. This includes information like access rights, Intellectual Property Rights (IPR), copyrights, references to legal documents describing how to use a resource, etc. To specify rights more precicely use `accessRights` or `license`.

AccessRights

This property represents the relationship between a resource and information about who can access a resource or an indication of its security status. Access rights provides information about restrictions to view, search or use a resource based on attributes of the resource itself or the category of user.

License

This property represents the relationship between a resource and a legal document giving official permission to do something with the resource (e.g. an otherwise free resource may not be used for reproduction within commercial applications). Examples of such licenses you will find at <http://creativecommons.org/>.

Guidelines for the creation of rights content

A rights statement may be **a text**,

title	<i>Data from my last evaluation</i>
accessRights	
	<i>My colleagues only</i>

as linked data

or **a URI** referencing to formal rights information,

title	<i>You and me</i>
rights	http://creativecommons.org/licenses/by/3.0/legalcode

as linked data

or a **combination of both**.

title	<i>GeoNetwork - Geographic Metadata Catalog</i>
license	http://www.gnu.org/licenses/gpl.html
	<i>GNU General Public License</i>

as linked data

If there are no formal rights statements to use you may also **create your own rights statement**.

title	<i>Diaries of Juanita Ramirez</i>
rights	<i>accessConditions</i>

identifier	<i>accessConditions</i>
title	<i>Access to my stuff</i>
description	<i>Resources under this right can only be read, searched and used by members of the myProject</i>

as linked data

Special properties for the description of education material

Audience

The property audience represents the relationship between a resource and the class of persons for whom the resource is intended or useful (e.g. the resource is a textbook for psychologists, etc.). To specify an audience more precisely use mediator or educationLevel.

Mediator

This property represents the relationship between a resource and the class of persons who mediate access to the resource and for whom it is intended or useful. This might be teachers, parents etc. (e.g. teachers are mediators for a resource intended to be used in elementary school lessons)

EducationLevel

This property refers to information about the progress of an audience through the educational or training context, for which the described resource is intended (e.g. the resource is an English workbook for students of the 4th - 5th grade).

InstructionalMethod

This property refers to the process used to engender knowledge, attitudes and skills, that the described resource is designed to support. Typically it includes ways of presenting instructional materials or conducting instructional activities, patterns of learner-to-learner and learner-to-instructor interactions, and mechanisms by which group and individual levels of learning are measured. Instructional methods include all aspects of the instruction and learning processes from planning and implementation through evaluation and feedback.

Guidelines for the creation of content for properties describing education material

You should use formal or informal **controlled vocabularies**. Though none are registered by DCMI, implementors are encouraged to develop local lists of values, and to use them consistently.

title	<i>Advances Physics</i>
audience	
	<i>elementary school pupils</i>

as linked data

mediator	
	<i>schoolteacher</i>

as linked data

educationLevel	
	<i>3rd - 4th grade</i>

as linked data

InstructionalMethod	
	<i>experimental learning</i>

as linked data

Special properties for the description of collections

AccrualMethod

This property refers to the method by which items are added to a collection.

AccrualPeriodicity

This property refers to the frequency with which items are added to a collection.

AccrualPolicy

This property refers to the policy governing the addition of items to a collection.

Guidelines for the creation of content for properties describing collections

Resources described by these properties **have to be collections**. We recommend to use values of formal or informal **controlled vocabularies**.

title	<i>Pottery in Scandinavia in the second half of 19th century</i>
accrualMethod	
	<i>purchase</i>

as linked data

accrualPeriodicity	
	<i>irregular</i>

as linked data

accrualPolicy	
	<i>Objects of this collection have to be Scandinavian ceramics from 1940s to 1999s.</i>

as linked data

Provenance

This property refers to a description of changes in ownership and custody. The statement should include any changes of the resource that are significant for its authenticity, integrity and interpretation.

Guidelines for the creation of content for provenance

The description of the provenance of a resource includes all changes made to a resource.

The provenance can be **described by text**,

title	<i>Luxor Obelisk</i>
provenance	

	Originally located at the entrance to the Luxor temple the obelisk came to Paris in 1836 as a gift by Muhammad Ali Pasha.
--	---

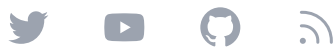
as linked data

or **described like another resource.**

title	<i>The flea circus</i>	
provenance		
	ownedBy	1829 - 1833; Jim Button
	ownedBy	1833 - 1915; My Library
	ownedBy	since 1915; Flea Academy



DCMI is an organization supporting innovation in metadata design and best practices across the metadata ecology.



Specifications

DCMI Metadata Terms

DCMI Specifications

Dublin Core Schemas

LRMI

Organisation

About DCMI

Themes

DCMI Community

Members

[BIBO](#)[Governance](#)[Usage Board](#)[Outreach](#)[Conferences](#)[Website](#)[Webinars](#)[Service Status](#)[News](#)[Privacy](#)[DCMI Blog](#)[Legal](#)[Resources](#)[Contact](#)

Unless indicated otherwise, DCMI documents are licensed under a [Creative Commons Attribution 4.0 International License](#). Please see the [DCMI Document Notice](#) for further instructions.

[Copyright](#) © 1995-2023 DCMI. All Rights Reserved. DCMI liability, trademark/service mark, document use rules apply. Your interactions with this site are in accordance with our privacy statements.

The Dublin Core Metadata Initiative (DCMI) is a project of ASIS&T—a U.S. 501(c)(3) nonprofit under the U.S. Internal Revenue Code. Contributions to DCMI through ASIS&T are tax-deductible to the full extent of the law in the United States.

Deployed with [Hugo v0.98.0](#) on Tue, 04 Jul 2023 10:48:10 UTC

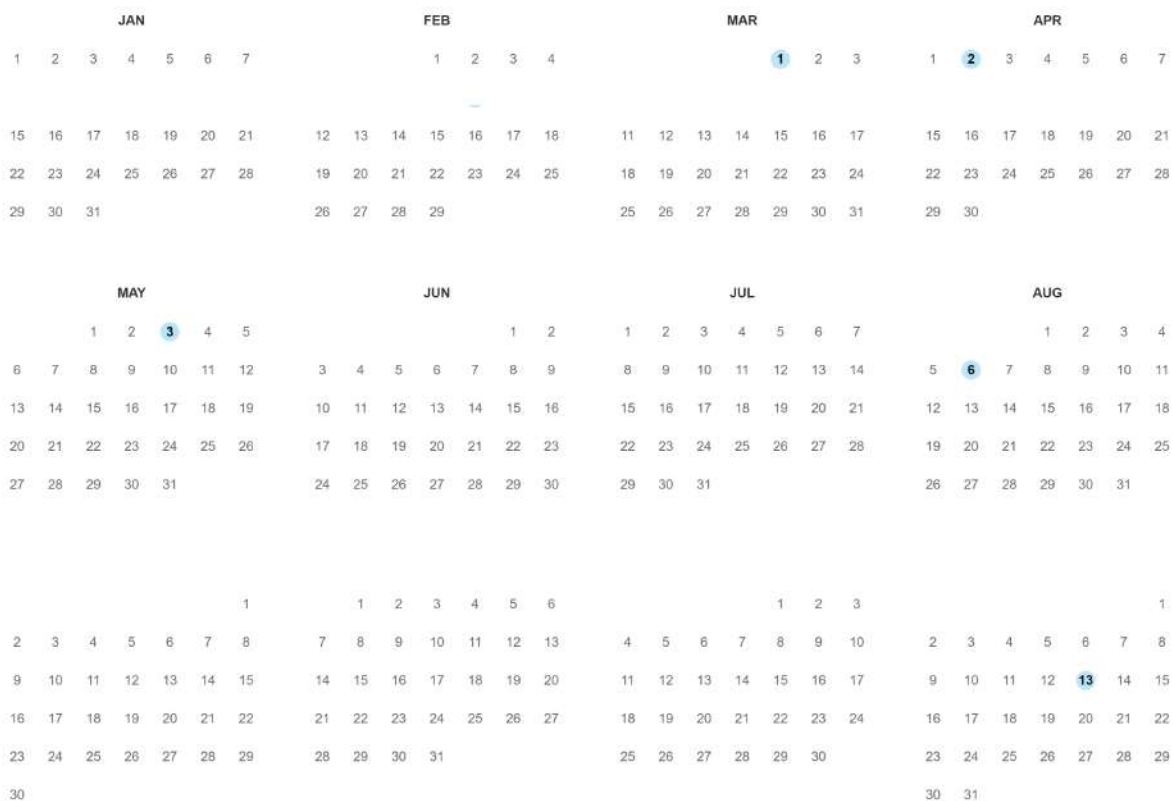
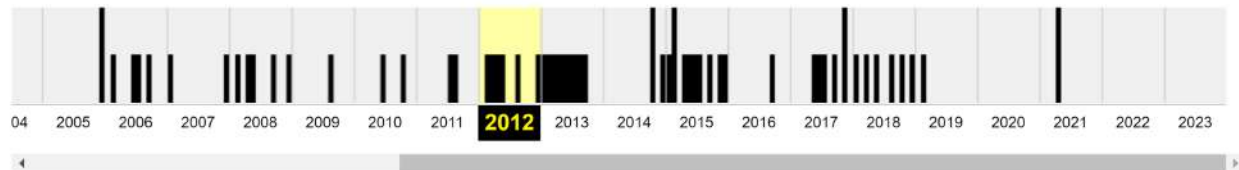
APPENDIX IA01


[ABOUT](#)
[BLOG](#)
[PROJECTS](#)
[HELP](#)
[DONATE](#)
[CONTACT](#)
[JOBS](#)
[VOLUNTEER](#)
[PEOPLE](#)

INTERNET ARCHIVE
WayBackMachine
DONATE Explore more than 818 billion [web pages](#) saved over time

[Calendar](#) · [Collections](#) · [Changes](#) · [Summary](#) · [Site Map](#) · [URLs](#)

Saved **62 times** between December 11, 2005 and April 15, 2021.



Note

This calendar view maps the number of times

<http://www.library.arizona.edu/help/tutorials/dissertations/index.html> was crawled by the Wayback Machine, *not* how many times the site was actually updated. More info in the [FAQ](#).

[FAQ](#) | [Contact Us](#) | [Terms of Service \(Dec 31, 2014\)](#)



The Wayback Machine is an initiative of the [Internet Archive](#), a 501(c)(3) non-profit, building a digital library of Internet sites and other cultural artifacts in digital form. Other projects include [Open Library](#) & [archive-it.org](#).

Your use of the Wayback Machine is subject to the Internet Archive's [Terms of Use](#).

Wayback Machine 62 captures 11 Dec 2005 - 15 Apr 2021

http://www.library.arizona.edu/help/tutorials/dissertations/index.html

Go AUG FEB APR 09 2010 2012 2013 About this capture

THE UNIVERSITY OF ARIZONA®

LIBRARIES HOME SEARCH THIS SITE | NEWS & EVENTS | GIVING TO THE LIBRARIES | MY ACCOUNT

UNIVERSITY LIBRARIES

Enter search terms here All resources SEARCH

Search & Find Services Help About the Libraries University Libraries Ask a Librarian

How Do I...?
Ask a Librarian
Frequently Asked Questions
Send Us Feedback

HELP

Dissertations and Theses in the UA Libraries

- ▶ [UA Dissertations](#)
- ▶ [Non-UA Dissertations](#)
- ▶ [Obtaining Non-UA Dissertations](#)
- ▶ [Obtaining UA Dissertations](#)

UA Dissertations & Theses

Online UA Dissertations & Theses

[ProQuest Dissertations and Theses Full Text](#) - Index of all doctoral dissertations and some master's theses from UA, as well as most North American and many European colleges and universities, back as far as 1637. Full text is



UNIVERSITY LIBRARIES

Enter search terms here

All resources ▾

SEARCH 

▶ Search & Find

▶ Services

Help

▶ About the Libraries

▶ University Libraries



Ask a Librarian

How Do I...?

Ask a Librarian

Frequently Asked Questions

Send Us Feedback

HELP

Dissertations and Theses in the UA Libraries

- ▶ [UA Dissertations](#)
- ▶ [Non-UA Dissertations](#)
- ▶ [Obtaining Non-UA Dissertations](#)
- ▶ [Obtaining UA Dissertations](#)

UA Dissertations & Theses

Online UA Dissertations & Theses

[ProQuest Dissertations and Theses Full Text](#) - Index of all doctoral dissertations and some master's theses from UA, as well as most North American and many European colleges and universities, back as far as 1637. Full text is available for most of those submitted after 1996 and for many before that. Abstracts are included for dissertations published since 1980 and Master's theses published since 1988.

NOTE: Full text for a few recent titles may not be available due to restrictions placed by the author, patents pending or problems regarding use of copyrighted material without permission. (Available only to UA affiliates.)

[Dissertations & Theses @ University of Arizona](#) (formerly Current Research @ UA) - Includes only the UA portion of the above database. Coverage for UA is from 1922 to present. (Master's coverage before 1982 is very limited.) Full text is available for most of those submitted after 1996 and for many before that. (Available only to UA affiliates.)

[UA Theses & Dissertations \(UA Campus Repository\)](#) (open access) - The UA Campus Repository contains full text of approved UA dissertations and theses including:

- Dissertations and many masters theses submitted from 2005-present
- Dissertations (and a few masters theses) from 1982-1996
- Master's reports from the College of Architecture from 2003-present
- Honors College theses submitted from 2008-present
- Hydrology theses and dissertations from 1917-2005

New UA dissertations, masters theses, and honors theses are added to the UA Campus Repository each semester.

[UA Electronic Theses & Dissertations \(ETD\)](#) (open access) -The content of this local database has been migrated into the UA Campus Repository. We are in the process of updating the links to these from the library catalog; once all catalog links have been updated to the UA Campus Repository, we will shut down the ETD database. (NOTE: If you get a message about the file being damaged when attempting to open larger PDF files, you may be using an older version of the Firefox browser. Updating Firefox to a current version or switching to Internet Explorer should solve this problem.)

Paper and Microfiche UA Dissertations & Theses (1895-2005)

All UA dissertations and theses received by the Libraries (paper, microform and electronic copies) are listed in our online [Library Catalog](#).

They may be searched by AUTHOR and/or TITLE or KEYWORDS from the title.

For those after 1990, it is possible to search by UA ACADEMIC DEPARTMENTS which conferred the degrees by selecting a SUBJECT search and entering the department/school name, such as "chemistry" or "music and dance". (If necessary, use the "Limit/Sort" button to limit to Words in *Publisher* "university of arizona") Before 1990, access by academic department is only available using the UA Library's [Checklist of Theses and Dissertations Accepted for Higher Degrees](#), at AS36 A6 C5 Info Commons Ref.

To retrieve lists of print and microform UA dissertations and theses by year (1895-2005) from the online Catalog, [click HERE](#).

Other UA Theses and Reports

Architecture College Master's Reports and Theses are available in the [Fine Arts Library](#). Many of the titles can be found in the [Library's online Catalog](#); you can also browse the [Architecture Theses](#) list to find Architecture, Planning, and



[Landscape Architecture theses.](#)

Geosciences Department maintains a nearly complete paper collection of geosciences theses and dissertations back to 1967. These are available in the [Antevs Library](#) in Gould-Simpson, Rm 208. [Click here for a complete list.](#) (Note: This collection holds a number of Master's Theses not available in the UA Libraries.)

Honors College Theses, from the late 1960s to 2005, are also available *only* in [Special Collections](#). They are not listed in the online catalog, but a separate card catalog for them is available in Special Collections. Honors College Theses submitted electronically since 2008 are included in the UA Library's [Campus Repository](#).

Hydrology & Water Resources Department Library maintains a collection of theses and dissertations from 1956 to present. The UA Libraries have now also digitized most hydrology dissertations and theses submitted at UA from 1917-2005; these are available in the UA Library's [Campus Repository](#) and listed in the library catalog.

Nursing Thesis & Dissertation Library - The University of Arizona [College of Nursing](#) has begun a project to create a digital repository of BSN honor's theses, master's reports, master's theses and dissertations. The purpose is to provide information about the college's theses and dissertations to include in other databases such as CINAHL and to make them electronically available to local and worldwide academic communities.

Poetry and Prose MFA theses, ca. 1969 to the present, are available in [Special Collections](#). They are not listed in the online catalog, but a separate card catalog for them is available in Special Collections.

Other Information about UA Dissertations and Theses

UA Master's Theses are only received and archived by the UA Library and ProQuest if the student has chosen to pay the archiving fee. This has been optional for master's students since 1993, so the Library does not have copies of many master's theses submitted since then. Some academic departments, including those listed above, may keep copies of theses submitted to them.

In the UA Library, print and microform copies of UA dissertations and theses all have a call number that begins with "E9791" followed by the **year** of acceptance. The final element is an **accession number** (starting with "1" at the beginning of each calendar year) which, in general, indicates the order of receipt.

Paper copies of many UA dissertations are available in the stacks up through 1981. Beginning with 1982, only microfiche copies are available, except for paper copies located in the Main Library's [Special Collections](#) on Arizona topics, and those containing special formats that cannot be easily filmed, such as music scores and maps, which are sent to the appropriate branch collections.

All dissertations received full cataloging in OCLC ([WorldCat](#)) until 1990. Since then, brief cataloging has only been done locally in our online Catalog. (Because of this, most of those received from 1990 to 2005 are not listed in WorldCat or WorldCat Local.)

Preparation & Submission of UA Dissertations and Theses

[UA Graduate College Manuals for submission of Theses & Dissertations](#) (includes specific formatting requirements)

[UMI Electronic submission web site for UA](#) (includes formatting requirements, various publishing guides on copyright and other topics, help for creating PDFs and more)

- ▶ [UA Dissertations](#)
- ▶ [Non-UA Dissertations](#)
- ▶ [Obtaining Non-UA Dissertations](#)
- ▶ [Obtaining UA Dissertations](#)

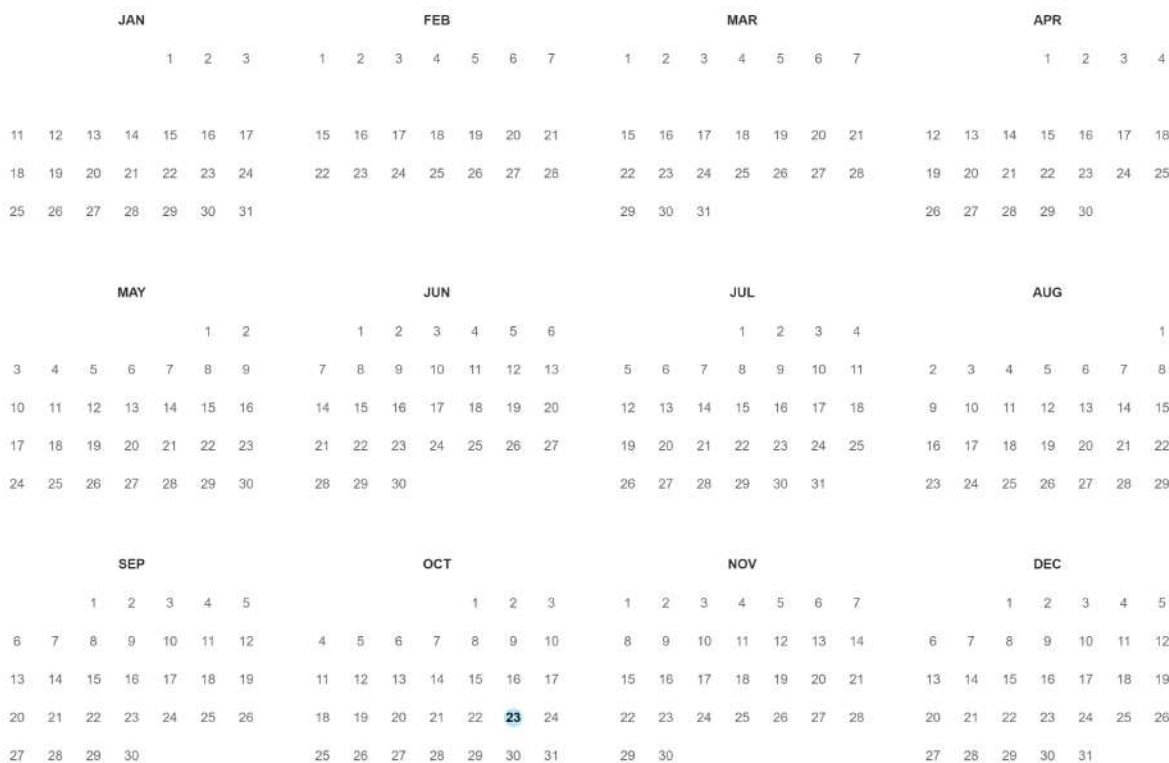
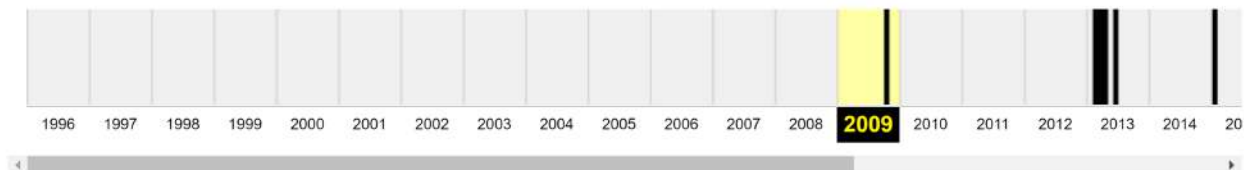
Please refer questions about this page to [Laurie Eagleson](#)

[^top](#)

APPENDIX IA02



Saved **11 times** between [October 23, 2009](#) and [June 27, 2017](#).



<http://www.library.arizona.edu/help/how/keywordsearch.html> was crawled by the Wayback Machine, *not* how many times the site was actually updated. More info in the [FAQ](#).

[FAQ](#) | [Contact Us](#) | [Terms of Service \(Dec 31, 2014\)](#)



Your use of the Wayback Machine is subject to the Internet Archive's [Terms of Use](#)

INTERNET ARCHIVE

Wayback Machine

http://www.library.arizona.edu/help/how/keywordsearch.html

Go

SEP

OCT

FEB

23

2009

2013

About this capture

11 captures

23 Oct 2009 - 27 Jun 2011

THE UNIVERSITY OF ARIZONA®

LIBRARIES HOME

SEARCH THIS SITE | NEWS & EVENTS | GIVING TO THE LIBRARIES | MY ACCOUNT

UNIVERSITY LIBRARIES

Enter search terms here All resources SEARCH

Search & Find

Services

Help

About the Libraries

University Libraries

Ask a Librarian

How Do I...?

Ask a Librarian

Tutorials & Guides

Frequently Asked Questions

Send Us Feedback

HELP

Library Catalog - Advanced Keyword Search Tips

- Wildcards & Truncation
- Phrase Searching
- Phrases containing Boolean or proximity operators (AND, OR, AND NOT, NEAR, AFTER, BEFORE, WITHIN)
- Multiple Word (non-phrase) Searching
- Searching Specific Fields
- Limiting Searches
- Non-Alpha-numeric Character Searching

Keyword search results are sorted by the publication **date** of the book or other item retrieved (most recent first). Look on the search page next to "Search and



Enter search terms here All resources SEARCH

 Ask a Librarian

Library Catalog - Advanced Keyword Search Tips

- Wildcards, & Truncation
- Phrase Searching
- Phrases containing Boolean or proximity operators (AND, OR, AND NOT, NEAR, AFTER, BEFORE, WITHIN)
- Multiple Word (non-phrase) Searching
- Searching Specific Fields
- Limiting Searches
- Non-Alphanumeric Character Searching

Keyword search results are sorted by the publication **date** of the book or other item retrieved (most recent first). Look on the search page next to "Search and Sort" to change this to either **relevance** or **title**.

Wildcards & Truncation

*	An asterisk (*) matches up to five non-space characters, starting at the specified position in the word. The * wildcard may only appear after at least two characters.	inter* finds "interval" and "interstate", but not "international" behav*r finds both "behavior" and "behaviour" *national does not find anything at all
**	Use a double asterisk (**) to search for an unlimited number of characters at the end or middle of a word. This can also be used instead of a keyword to find all items limited to a particular format, language, location, etc. (See Limiting Searches)	intern** finds "internal", "internet", "international", etc.
?	? replaces a single character within a word. The question mark must be preceded by at least three characters.	wom?n finds woman or women

Phrase searching

In the Keyword search, multiple words together are automatically searched as an exact phrase. If any records containing that phrase are present they will be retrieved, **but not** records that contain all of the words in a different order.

For example, searching the phrase "Tucson Arizona map" retrieves only one record where these three words appear together as a phrase:

Title: The University of Arizona, Tucson, Arizona map & visitor's guide, 1990-1991 / Student Publications, University of Arizona.

However, searching "Tucson Arizona AND map" retrieves around 150 records, or searching "Tucson AND arizona AND map" retrieves over 300 records.

If a phrase entered is not present at all, the system will automatically supply **"and"** between each word. For example, searching the phrase "Tucson city map" retrieved no records as a phrase, so the search was automatically changed to "Tucson and city and map" where it retrieved over 80 records. If the search has been changed by the system, there will be an indication of this above the search results:

Your search query has been changed... Tried: ((tucson city map)) no results found...

Tried: ((tucson and city and map))

82 results found, sorted by date.

Phrases containing Boolean or proximity operators (AND, OR, AND NOT, NEAR, AFTER, BEFORE, WITHIN)

If you want to include the words AND, OR, AND NOT, NEAR, AFTER, BEFORE or WITHIN as part of your search, you must enclose these words (or the entire phrase) in quotation marks (") to force the system to search them as normal words, and not to function as operators between words. For example, a search on:

Sex and the city - retrieves over 180 records; in most cases, the words do not appear together because the "and" functions as an operator and causes the system to search for any records containing "sex" and "the city" but not necessarily together. One of results contains a contents note where these words appear as "Indoor life : sex, symposia, and sandals -- The city at work"

However, formulating your search using quotation marks as:



Sex "and" the city (or "sex and the city") – retrieves about 25 records, only those where this exact phrase occurs.

Agony and the ecstasy - retrieves around 19 records, including the following title in a contents note: "The ecstasy of the flight, the agony of the fall".

However, using quotation marks in the search as: agony "and" the ecstasy (or "agony and the ecstasy") – retrieves only about 9 records, where this exact phrase occurs.

near east – retrieves no records.

However, since "near" is a proximity operator, including quotation marks in the search as:

"near" east (or "near east") – retrieves over 1000 records.

Multiple Word (non-phrase) Searching

Available Boolean operators are: **AND, OR, AND NOT**

Available proximity operators are: **AFTER, BEFORE, NEAR, WITHIN #** (number of words)

Boolean operators	Words can be connected to either narrow or broaden a search by using and, and not or or. Word order does not matter when using "and" or "or". If using both and and or, put each group of related terms on their own line of the form, writing "and" or "or" between each word.	
AND	And narrows a search by requiring that both words be found. Word order does not matter.	guggenheim and bilbao will find both "Museo Guggenheim Bilbao" and "Guggenheim Museum Bilbao".
AND NOT	And not excludes words from search results.	cell and not phone will find records with the word "cell" only if they do not include the word "phone".
OR	Or broadens a search by looking for any of the words entered. Word order does not matter.	penguins or puffins (k-6 or primary) and teaching will find records with either "k-6" and "teaching" or "primary" and "teaching".
Proximity Operators	Some words allow you to specify how far apart words can occur and the order of the words. Words that determine proximity include after, before, near and within.	
NEAR	Near retrieves records that contain the specified words within ten (10) of each other. Word order does not matter.	tohoku near mathematics finds records where "tohoku" and "mathematics" are within 10 words of each other.
WITHIN #	Use within # to specify the maximum number of words that may appear between the specified words. The value of # has no limit. Word order does not matter. (WITHIN 10 and NEAR are equivalent.)	oil within 5 middle east finds records where "oil" and "middle east" are within 5 words of each other; for example, "Middle East oil and gas" and "Iran oil; the new Middle East challenge to America".
AFTER	After retrieves records where the second word entered must appear after the first word entered.	
BEFORE	Before retrieves records where the first word entered must appear before the second word entered.	

Searching Specific Fields

Using search field limits searches for words only in specific parts of the citation. Use the drop down menus next to the keyword search boxes, or type in the field name or abbreviation, using a ":". The following field limits are supported:	author:copland title:appalachian spring author:spielberg and note:williams finds items with "spielberg" as an author and "williams" in a note.
• Author (a) • Title (t) • Subject (s) • Note (n)	t:tucson and s:maps finds items with "Tucson" in the title and "maps" in a subject heading.

Limiting Searches

You may search a sub-collection and/or location from the menu next to Limit to: Electronic resources, All Journals, Law	jazz, with Location set to Fine Arts Library, Format set to "VIDEO/FILM" and "2001" in the Year After field, finds videos
--	---

Library, Arizona Health Sciences Library, AHSL+Science-Eng. Library, Fine Arts+CCP Libraries. (The last four location-based sub-collections also include electronic resources.)

You may also limit by language, location, format, publisher or year of publication by using the menus below **Limit to:**.

To find all materials that match a limit criteria, use a double asterisk (**) by itself in the first search box, then choose one or more limit options.

published after 2001 that contain the word "jazz" and are located in the Fine Arts Library.

** (entered in first keyword search box) searched with "View Law Library" and limited to "SPOKEN RECORD" in the Format menu finds all spoken recordings in the Law Library.

** searched with "Spanish" in the Language menu and "VIDEO/FILM" in the Format menu finds all Spanish-language films and videos.

Non-Alpha-numeric Character Searching

The following are searchable characters. Also, & is interchangeable with "and" in a search.

@	"at" sign	\$	Dollar sign	%	Percent sign	#	Pound sign	&	Ampersand (= "and")
---	-----------	----	-------------	---	--------------	---	------------	---	---------------------

The system converts the following punctuation characters to a SPACE in the search expression:

:	Colon	.	Period	_	Underscore	\	Backslash	=	Equals sign
/	Forward slash	;	Semicolon	,	Comma	^	Caret	`	Backtick

Thanks to [University of Oregon Library](#), from which some material was borrowed.

[top of page](#)

APPENDIX MENDELSON01

A Wearable Reflectance Pulse Oximeter for Remote Physiological Monitoring

Y. Mendelson*, *Member, IEEE*, R. J. Duckworth, *Member, IEEE*, and G. Comtois, *Student Member, IEEE*

Abstract—To save life, casualty care requires that trauma injuries are accurately and expeditiously assessed in the field. This paper describes the initial bench testing of a wireless wearable pulse oximeter developed based on a small forehead mounted sensor. The battery operated device employs a lightweight optical reflectance sensor and incorporates an annular photodetector to reduce power consumption. The system also has short range wireless communication capabilities to transfer arterial oxygen saturation (SpO₂), heart rate (HR), body acceleration, and posture information to a PDA. It has the potential for use in combat casualty care, such as for remote triage, and by first responders, such as firefighters.

I. INTRODUCTION

STEADY advances in noninvasive physiological sensing, hardware miniaturization, and wireless communication are leading to the development of new wearable technologies that have broad and important implications for civilian and military applications [1]-[2]. For example, the emerging development of compact, low-power, small-size, light-weight, and unobtrusive wearable devices may facilitate remote noninvasive monitoring of vital signs from soldiers during training exercises and combat. Telemetry of physiological information via a short-range wirelessly-linked personal area network can also be useful for firefighters, hazardous material workers, mountain climbers, or emergency first-responders operating in harsh and hazardous environments. The primary goals of such a wireless mobile platform would be to keep track of an injured person's vital signs, thus readily allowing the telemetry of physiological information to medical providers, and support emergency responders in making critical and often life saving decisions in order to expedite rescue operations. Having wearable physiological monitoring could offer far-forward medics numerous advantages, including the ability to determine a casualty's condition remotely without exposing the first

responders to increased risks, quickly identifying the severity of injuries especially when the injured are greatly dispersed over large geographical terrains and often out-of-site, and continuously tracking the injured condition until they arrive safely at a medical care facility.

Several technical challenges must be overcome to address the unmet demand for long-term continuous physiological monitoring in the field. In order to design more compact sensors and improved wearable instrumentation, perhaps the most critical challenges are to develop more power efficient and low-weight devices. To become effective, these technologies must also be robust, comfortable to wear, and cost-effective. Additionally, before wearable devices can be used effectively in the field, they must become unobtrusive and should not hinder a person's mobility. Employing commercial off-the-shelf (COTS) solutions, for example finger pulse oximeters to monitor blood oxygenation and heart rate, or standard adhesive-type disposable electrodes for ECG monitoring, is not practical for many field applications because they limit mobility and can interfere with normal tasks.

A potentially attractive approach to aid emergency medical teams in remote triage operations is the use of a wearable pulse oximeter to wirelessly transmit heart rate (HR) and arterial oxygen saturation (SpO₂) to a remote location. Pulse oximetry is a widely accepted method that is used for noninvasive monitoring of SpO₂ and HR. The method is based on spectrophotometric measurements of changes in the optical absorption of deoxyhemoglobin (Hb) and oxyhemoglobin (HbO₂). Noninvasive spectrophotometric measurements of SpO₂ are performed in the visible (600-700nm) and near-infrared (700-1000nm) spectral regions. Pulse oximetry also relies on the detection of photoplethysmographic (PPG) signals produced by variations in the quantity of arterial blood that is associated with periodic contractions and relaxations of the heart. Measurements can be performed in either transmission or reflection modes. In transmission pulse oximetry, the sensor can be attached across a fingertip, foot, or earlobe. In this configuration, the light emitting diodes (LEDs) and photodetector (PD) in the sensor are placed on opposite sides of a peripheral pulsating vascular bed. Alternatively, in reflection pulse oximetry, the LEDs and PD are both mounted side-by-side on the same planar substrate to enable readings from multiple body locations where transillumination measurements are not feasible. Clinically, forehead reflection pulse oximetry has been used as an alternative approach to conventional transmission-based

Manuscript received April 3, 2006. This work is supported by the U.S. Army Medical Research and Materiel Command under Contract No. DAMD17-03-2-0006. The views, opinions and/or findings are those of the author and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

*Corresponding author – Y. Mendelson is a Professor in the Department of Biomedical Engineering, Worcester Polytechnic Institute, Worcester, MA 01609 USA (phone: 508-831-5103; fax: 508-831-5541; e-mail: ym@wpi.edu).

R. J. Duckworth is a Professor in the Department of Electrical and Computer Engineering, Worcester Polytechnic Institute, Worcester, MA 01609 USA (rjduck@ece.wpi.edu).

G. Comtois is a M. S. student in the Department of Biomedical Engineering, Worcester Polytechnic Institute, Worcester, MA 01609 USA (comtoisg@wpi.edu).

oximetry when peripheral circulation to the extremities is compromised.

Pulse oximetry was initially intended for in-hospital use on patients undergoing or recovering from surgery. During the past few years, several companies have developed smaller pulse oximeters, some including data transmission via telemetry, to further expand the applications of pulse oximetry. For example, battery-operated pulse oximeters are now attached to patients during emergency transport as they are being moved from a remote location to a hospital, or between hospital wards. Some companies are also offering smaller units with improved electronic filtering of noisy PPG signals.

Several reports described the development of a wireless pulse oximeter that may be suitable for remote physiological monitoring [3]-[4]. Despite the steady progress in miniaturization of pulse oximeters over the years, to date, the most significant limitation is battery longevity and lack of telemetric communication. In this paper, we describe a prototype forehead-based reflectance pulse oximeter suitable for remote triage applications.

II. SYSTEM ARCHITECTURE

The prototype system, depicted in Fig. 1, consists of a body-worn pulse oximeter that receives and processes the PPG signals measured by a small ($\phi = 22\text{mm}$) and lightweight (4.5g) optical reflectance transducer. The system

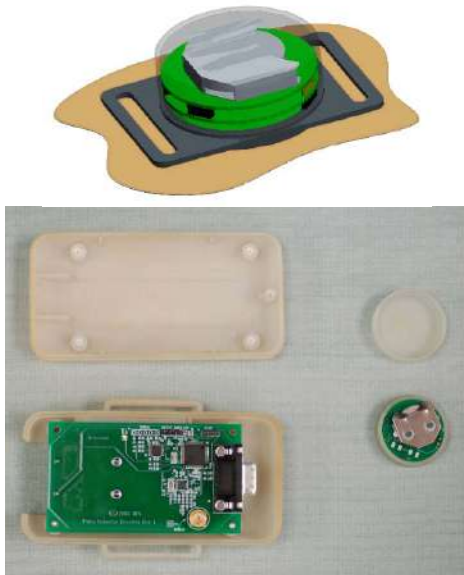


Fig. 1. (Top) Attachment of Sensor Module to the skin; (Bottom) photograph of the Receiver Module (left) and Sensor Module (right).

consists of three units: A Sensor Module, consisting of the optical transducer, a stack of round PCBs, and a coin-cell battery. The information acquired by the Sensor Module is transmitted wirelessly via an RF link over a short range to a body-worn Receiver Module. The data processed by the Receiver Module can be transmitted wirelessly to a PDA. The PDA can monitor multiple wearable pulse oximeters simultaneously and allows medics to collect vital physiological information to enhance their ability to extend more effective care to those with the most urgent needs. The

system can be programmed to alert on alarm conditions, such as sudden trauma, or physiological values out of their normal range. It also has the potential for use in combat casualty care, such as for remote triage, and for use by first responders, such as firefighters.

Key features of this system are small-size, robustness, and low-power consumption, which are essential attributes of wearable physiological devices, especially for military applications. The system block diagram (Fig. 2), is described in more detail below.

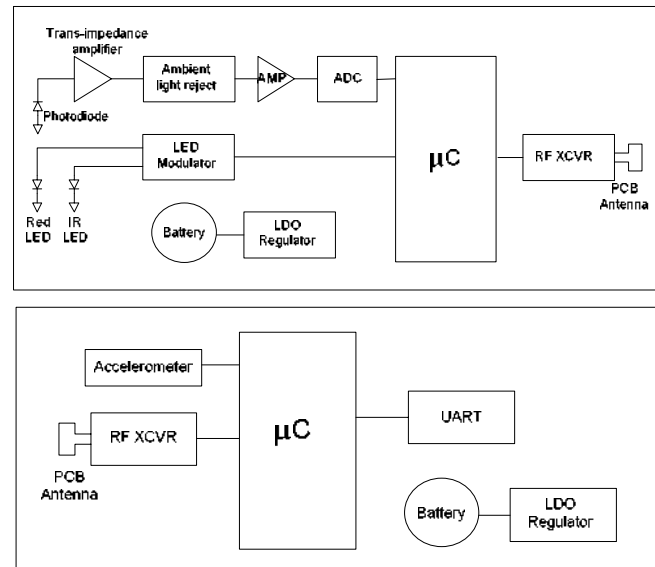


Fig. 2. System block diagram of the wearable, wireless, pulse oximeter. Sensor Module (top), Receiver Module (bottom).

Sensor Module: The Sensor Module contains analog signal processing circuitry, ADC, an embedded microcontroller, and a RF transceiver. The unit is small enough so the entire module can be integrated into a headband or a helmet. The unit is powered by a CR2032 type coin cell battery with 220mAh capacity, providing at least 5 days of operation.

Receiver Module: The Receiver Module contains an embedded microcontroller, RF transceiver for communicating with the Sensor Module, and a Universal Asynchronous Receive Transmit (UART) for connection to a PC. Signals acquired by the Sensor Module are received by the embedded microcontroller which synchronously converts the corresponding PD output to R and IR PPG signals. Dedicated software is used to filter the signals and compute SpO_2 and HR based on the relative amplitude and frequency content of the reflected PPG signals. A tri-axis MEMS accelerometer detects changes in body activity, and the information obtained through the tilt sensing property of the accelerometer is used to determine the orientation of the person wearing the device.

To facilitate bi-directional wireless communications between the Receiver Module and a PDA, we used the DPAC Airborne™ LAN node module (DPAC Technologies, Garden Grove, CA). The DPAC module operates at a frequency of 2.4GHz, is 802.11b wireless compliant, and has a relatively small ($1.6 \times 1.17 \times 0.46$ inches) footprint. The wireless module runs off a 3.7VDC and includes a built-in

TCP/IP stack, a radio, a base-band processor, an application processor, and software for a “drop-in” WiFi application. It has the advantage of being a plug-and-play device that does not require any programming and can connect with other devices through a standard UART.

PDA: The PDA was selected based on size, weight, and power consumption. Furthermore, the ability to carry the user interface with the medic also allows for greater flexibility during deployment. We chose the HP iPAQ h4150 PDA because it can support both 802.11b and Bluetooth™ wireless communication. It contains a modest amount of storage and has sufficient computational resources for the intended application. The use of a PDA as a local terminal also provides a low-cost touch screen interface. The user-friendly touch screen of the PDA offers additional flexibility. It enables multiple controls to occupy the same physical space and the controls appear only when needed. Additionally, a touch screen reduces development cost and time, because no external hardware is required. The data from the wireless-enabled PDA can also be downloaded or streamed to a remote base station via Bluetooth or other wireless communication protocols. The PDA can also serve to temporarily store vital medical information received from the wearable unit.

A dedicated National Instruments LabVIEW program was developed to control all interactions between the PDA and the wearable unit via a graphical user interface (GUI). One part of the LabVIEW software is used to control the flow of information through the 802.11b radio system on the PDA. A number of LabVIEW VIs programs are used to establish a connection, exchange data, and close the connection between the wearable pulse oximeter and the PDA. The LabVIEW program interacts with the Windows CE™ drivers of the PDA’s wireless system. The PDA has special drivers provided by the manufacturer that are used by Windows CE™ to interface with the 802.11b radio hardware. The LabVIEW program interacts with Windows CE™ on a higher level and allows Windows CE™ to handle the drivers and the direct control of the radio hardware.

The user interacts with the wearable system using a simple GUI, as depicted in Fig. 3.



Fig. 3. Sample PDA Graphical User Interface (GUI).

The GUI was configured to present the input and output information to the user and allows easy activation of various

functions. In cases of multiple wearable devices, it also allows the user to select which individual to monitor prior to initiating the wireless connection. Once a specific wearable unit is selected, the user connects to the remote device via the System Control panel that manages the connection and sensor control buttons. The GUI also displays the subject’s vital signs, activity level, body orientation, and a scrollable PPG waveform that is transmitted by the wearable device.

The stream of data received from the wearable unit is distributed to various locations on the PDA’s graphical display. The most prominent portion of the GUI display is the scrolling PPG waveform, shown in Fig. 3. Numerical SpO₂ and HR values are displayed in separate indicator windows. A separate tri-color indicator is used to annotate the subject’s activity level measured by the wearable accelerometer. This activity level was color coded using green, yellow, or red to indicate low or no activity, moderate activity, or high activity, respectively. In addition, the subject’s orientation is represented by a blue indicator that changes orientation according to body posture. Alarm limits could be set to give off a warning sign if the physiological information exceeds preset safety limits.

One of the unique features of this PDA-based wireless system architecture is the flexibility to operate in a free roaming mode. In this ad-hoc configuration, the system’s integrity depends only on the distance between each node. This allows the PDA to communicate with a remote unit that is beyond the PDA’s wireless range. The ad-hoc network would therefore allow medical personnel to quickly distribute sensors to multiple casualties and begin immediate triage, thereby substantially simplifying and reducing deployment time.

Power Management: Several features were incorporated into the design in order to minimize the power consumption of the wearable system. The most stringent consideration was the total operating power required by the Sensor Module, which has to drive the R and IR LEDs, process the data, and transmit this information wirelessly to the Receive Module. To keep the overall size of the Sensor Module as small as, it was designed to run on a watch style coin-cell battery.

It should be noted that low power management without compromising signal quality is an essential requirement in optimizing the design of wearable pulse oximeter. Commercially available transducers used with transmission and reflection pulse oximeters employ high brightness LEDs and a small PD element, typically with an active area ranging between 12 to 15mm². One approach to lowering the power consumption of a wireless pulse oximeter, which is dominated by the current required to drive the LEDs, is to reduce the LED duty cycle. Alternatively, minimizing the drive currents supplied to the R and IR LEDs can also achieve a significant reduction in power consumption. However, with reduced current drive, there can be a direct impact on the quality of the detected PPGs. Furthermore, since most of the light emitted from the LEDs is diffused by the skin and subcutaneous tissues, in a predominantly forward-scattering direction, only a small fraction of the incident light is normally backscattered from the skin. In

addition, the backscattered light intensity is distributed over a region that is concentric with respect to the LEDs. Consequently, the performance of reflectance pulse oximetry using a small PD area is significantly degraded. To overcome this limitation, we showed that a concentric array of either discrete PDs, or an annularly-shaped PD ring, could be used to increase the amount of backscattered light detected by a reflectance type pulse oximeter sensor [5]-[7].

Besides a low-power consuming sensor, afforded by lowering the driving currents of the LEDs, a low duty cycle was employed to achieve a balance between low power consumption and adequate performance. In the event that continuous monitoring is not required, more power can be conserved by placing the device in an ultra low-power standby mode. In this mode, the radio is normally turned off and is only enabled for a periodic beacon to maintain network association. Moreover, a decision to activate the wearable pulse oximeter can be made automatically in the event of a patient alarm, or based on the activity level and posture information derived from the on-board accelerometer. The wireless pulse oximeter can also be activated or deactivated remotely by a medic as needed, thereby further minimizing power consumption.

III. IN VIVO EVALUATIONS

Initial laboratory evaluations of the wearable pulse oximeter included simultaneous HR and SpO₂ measurements. The Sensor Module was positioned on the forehead using an elastic headband. Baseline recordings were made while the subject was resting comfortably and breathing at a normal tidal rate. Two intermittent recordings were also acquired while the subject held his breath for about 30 seconds. Fig. 4 displays about 4 minutes of SpO₂ and HR recordings acquired simultaneously by the sensor.

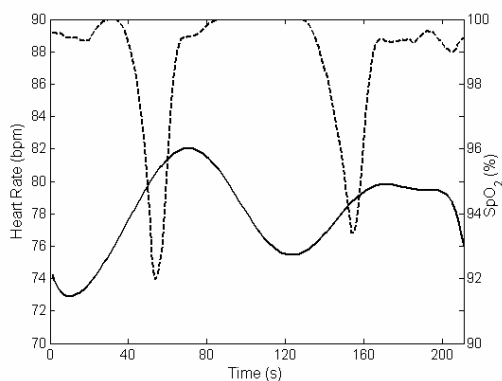


Fig. 4. Typical HR (solid line) and SpO₂ (dashed line) recording of two voluntary hypoxic episodes.

The pronounced drops in SpO₂ and corresponding increases in HR values coincide with the hypoxic events associated with the two breath holding episodes.

IV. DISCUSSION

The emerging development of compact, low power, small size, light weight, and unobtrusive wearable devices can facilitate remote noninvasive monitoring of vital

physiological signs. Wireless physiological information can be useful to monitor soldiers during training exercises and combat missions, and help emergency first-responders operating in harsh and hazardous environments. Similarly, wearable physiological devices could become critical in helping to save lives following a civilian mass casualty. The primary goal of such a wireless mobile platform would be to keep track of an injured person's vital signs via a short-range wirelessly-linked personal area network, thus readily allowing RF telemetry of vital physiological information to command units and remote off-site base stations for continuous real-time monitoring by medical experts.

The preliminary bench testing plotted in Fig. 4 showed that the SpO₂ and HR readings are within an acceptable clinical range. Similarly, the transient changes measured during the two breath holding maneuvers confirmed that the response time of the custom pulse oximeter is adequate for detecting hypoxic episodes.

V. CONCLUSION

A wireless, wearable, reflectance pulse oximeter has been developed based on a small forehead-mounted sensor. The battery-operated device employs a lightweight optical reflectance sensor and incorporates an annular photodetector to reduce power consumption. The system has short range wireless communication capabilities to transfer SpO₂, HR, body acceleration, and posture information to a PDA carried by medics or first responders. The information could enhance the ability of first responders to extend more effective medical care, thereby saving the lives of critically injured persons.

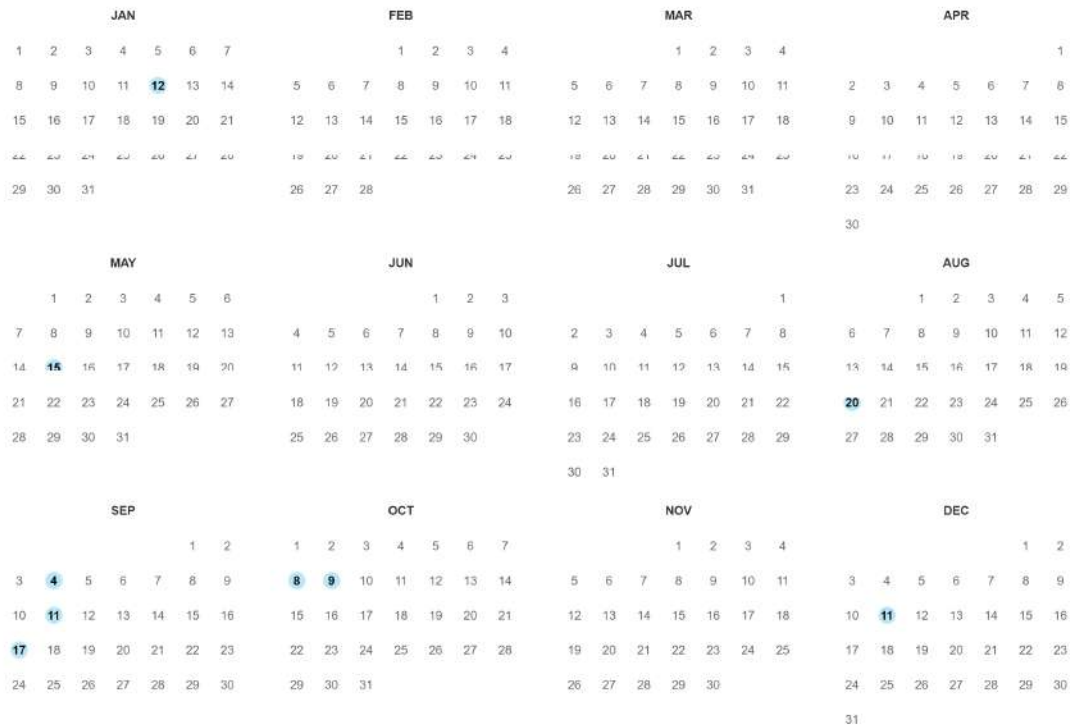
ACKNOWLEDGMENT

The authors would like to acknowledge the financial support provided by the U.S. Army Medical Research and Material Command referenced.

REFERENCES

- [1] G. S. F. Ling, B. K. Day, P. Rhee, and J. M. Ecklund, "In search of technological solutions to battlefield management of combat casualties," *SPIE Conference on Battlefield Biomedical Technologies*, SPIE vol. 3712, Apr. 1999.
- [2] D. Malan, T. Fulford-Jones, M. Welsh, and S. Moulton, "CodeBlue: An ad-hoc sensor network infrastructure for emergency medical care," *International Workshop on Wearable and Implantable Body Sensor Networks*, 2004.
- [3] U. Anliker et al., "AMON: A wearable multiparameter medical monitoring and alert system," *IEEE Trans. on Information Technology in Biomedicine*, 8(4), 2004.
- [4] Y. Mendelson and V. Floroff, "A PDA based ad-hoc mobile wireless pulse oximeter," *Proc. IASTED International Conference Telehealth 2005*, Banff, Canada, 2005.
- [5] Y. Mendelson and C. J. Pujary, "Minimization of LED power consumption in the design of a wearable pulse oximeter," *IASTED International Conference BioMED 2003*, Salzburg, Austria, 2003.
- [6] Y. Mendelson and C. J. Pujary, "Measurement site and photodetector size considerations in optimizing power consumption of a wearable reflectance pulse oximeter," *Proc. of the 25th Annual International IEEE/EMBS Conference*, Cancun, Mexico, 2003.
- [7] P. Branche and Y. Mendelson, "Signal quality and power consumption of a new prototype reflectance pulse oximeter sensor," *Proc. of the 31st Annual Northeast Bioengineering Conference*, Hoboken, NJ, 2005.

APPENDIX MENDELSON02



1/1

INTERNET ARCHIVE <http://embs.gsbme.unsw.edu.au/confs.html> Go JAN MAY AUG 15 2004 2006 2007 About this capture

Wayback Machine 21 captures 11 Dec 2004 - 22 Mar 2009

IEEE Engineering in Medicine and Biology Society



- Information
- EMBS Conferences
- Other BME Meetings
- Past Conferences

IEEE EMBS Sponsorship of Conferences

For those interested in having the IEEE EMBS involved in supporting/sponsoring a conference please contact [Ms Jodi Strock](#) from the EMBS Executive Office. Note that there are [standards](#) for the submission of papers to allow IEEE to index papers using IEEE Xplore.

If you are requesting IEEE EMBS sponsorship of conferences then please read the [following By-Laws](#) of the EMB Society before contacting [Ms Jodi Strock](#).

Technical Co-sponsorship by IEEE EMBS

Should you wish to enter into a Technical Co-sponsoring relationship with the IEEE EMBS for your conference the following points apply:

- IEEE EMBS will include you conference information in regular mailouts to its members and on the Website.
- You may use the IEEE EMBS logo on the Conference Website and promotion material as a sponsoring society.
- IEEE EMBS will not have any financial involvement and will be limited to participating as a Technical Co-sponsor.
- **There is a processing fee of \$300 which covers the cost of listing your conference in the IEEE Conference Search Directory and evaluation of your proceedings.**
- The use of IEEE EMBS in the title of the Conference is prohibited.
- **Note that EMB policy is such that we will not normally technically co-sponsor a conference if it falls within a month (either side) of our Annual International Conference or a month (either side) of one of**

IEEE Engineering in Medicine and Biology Society



- Information
- EMBS Conferences
- Other BME Meetings
- Past Conferences

IEEE EMBS Sponsorship of Conferences

For those interested in having the IEEE EMBS involved in supporting/sponsoring a conference please contact [Ms Jodi Strock](#) from the EMBS Executive Office. Note that there are [standards](#) for the submission of papers to allow IEEE to index papers using IEEE Xplore.

If you are requesting IEEE EMBS sponsorship of conferences then please read the [following By-Laws](#) of the EMBS Society before contacting [Ms Jodi Strock](#).

Technical Co-sponsorship by IEEE EMBS

Should you wish to enter into a Technical Co-sponsoring relationship with the IEEE EMBS for your conference the following points apply:

- IEEE EMBS will include you conference information in regular mailouts to its members and on the Website.
- You may use the IEEE EMBS logo on the Conference Website and promotion material as a sponsoring society.
- IEEE EMBS will not have any financial involvement and will be limited to participating as a Technical Co-sponsor.
- **There is a processing fee of \$300 which covers the cost of listing your conference in the IEEE Conference Search Directory and evaluation of your proceedings.**
- The use of IEEE EMBS in the title of the Conference is prohibited.
- **Note that EMBS policy is such that we will not normally technically co-sponsor a conference if it falls within a month (either side) of our Annual International Conference or a month (either side) of one of our Special Topic Conferences.**

As a Technical Co-sponsor, IEEE EMBS requests the following courtesies:

- Acknowledgement of the participation of IEEE EMBS in all conference materials, advertisements and on the conference web site
- Inclusion of the IEEE EMBS Information page in the Final Program and Conference Proceeding
- Agreement that IEEE EMBS can acquire the Conference Proceedings, production and shipment at a specific acquisition fee paid by IEEE EMBS. This acquisition of your Conference Proceedings is not guaranteed and is contingent upon the proceedings being evaluated and requested by IEEE and created in the required IEEE compatible format.
- Provide to IEEE EMBS one complimentary copy of the Conference Proceeding for the EMBS Executive Office
- Provide to IEEE EMBS in electronic format the conference attendee list to include: name, postal address, email address, telephone and facsimile numbers

Further information for conference organizers are available from the IEEE Web. Go to www.ieee.org and click on the 'Conferences Organizers' link. At the bottom of this page is a conference publication section.

Conference Information



EMBS Annual International Conference in 2006 in New York



The 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society will be held in New York, USA from the 30th August to the 3rd of September, 2006.

Details of the conference are at <http://embs2006.njit.edu/>

27th IEEE EMBS Annual International Conference in 2005 in Shanghai



The 27th Annual International Conference of the IEEE Engineering in Medicine and Biology Society was held in Shanghai, China from the 1st to the 4th of September, 2005 with a record attendance! Details of the conference are at <http://www.ee.cuhk.edu.hk/EMBC05shanghai>

26th IEEE EMBS Annual International Conference in 2004 in San Francisco



The 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society was held in





Painting by M. Cohen

San Francisco, USA from the 1st to the 4th of September.

Details of the conference are at <http://www.fresno.ucsf.edu/embs2004>

Pictures from the conference can be found [here](#).



25th IEEE EMBS Annual International Conference in 2003



The 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society was held in Cancun, Mexico from the 17th to the 21st of September. The science was solid and the location was exceptional!

Details are at <http://itzamna.uam.mx/cancun>

Pictures from the conference can be found [here](#).

24th IEEE EMBS Annual International Conference in 2002



The 2nd Joint Conference of the IEEE Engineering in Medicine and Biology Society and the Biomedical Engineering Society was held on the 23-26 October, 2002 Westin Galleria Hotel Houston, TX.

Full details at <http://embs-bmes2002.org/>

Pictures from the conference can be found [here](#).

23rd IEEE EMBS Annual International Conference in 2001

The 23rd [Annual International Conference](#) of the IEEE-EMBS was held in Istanbul, Turkey, 25th-28th, October, 2001. Despite the recent tragic events throughout the world that limited attendance, set in the backdrop of the beautiful city of Istanbul, the conference was a scientific success and a most exciting social event.



5th

INTERNATIONAL SUMMER SCHOOL on Biocomplexity from System to Gene



In the continuing vein of successful summer schools, this event organized by Metin Akay, was held from June 26 to July 2, 2005 at Dartmouth College, Hanover, NH USA. Two reports (in PDF format) on the summer school can be found [here](#) and [here](#).

More details can be found at <http://www.dartmouth.edu/~bioc2005/>

[Go to top](#)

Last updated: Saturday, 6 May, 2006
EMBS inquiries to [EMBS Office](#)
Feedback or problem reports to [Webmaster](#)

APPENDIX OSU01

OSU.EDU

Help BuckeyeLink Map Find People Webmail Search Ohio State

THE OHIO STATE UNIVERSITY
UNIVERSITY LIBRARIES

LIBRARY CATALOG

Library Home Catalog Search

 Ask Us

 My Account

Catalog home

Save for export

Regular display

Another search

LEADER 00000cas a2200493mi 4500

001 973040125

003 OCoLC

005 20211001152817.0

006 m o d

007 cr |||||||

008 050311c20049999njuar p o 1 0eng d

010 2005243767

022 1557-170X

035 .b9357759x

035 (OCoLC)973040125

040 CASUM|beng|cCASUM|doCLCO|dREB|doCLCA|doCLCQ|duToRBLW

049 OSUU

050 4 R856.A1|bI33x

050 4 R856.A1|bI33x

210 10 Conf Proc Annu Int Conf IEEE Eng Med Biol Soc

210 10 Conf Proc IEEE Eng Med Biol Soc

245 00 Conference proceedings, Annual International Conference of the IEEE Engineering in Medicine and Biology Society

246 13 IEEE Engineering in Medicine and Biology ... Annual Conference

246 13 IEEE Engineering in Medicine and Biology Society Conference proceedings

246 17 Proceedings of the ... Annual International Conference of the IEEE EMBS

264 1 Piscataway, NJ :|bIEEE Service Center,|c[2004-]

264 4 |c@2004-

300 1 online resource (volumes :|billustrations

310 Annual

336 text|btxt|2rdacontent

337 computer|bc|2rdamedia

338 online resource|bcr|2rdacarrier

362 0 26th (2004)-

515 Volumes for 2004- issued in multiple parts. volumes for 2004-2005 numbered as 26th and 27th. Beginning with 2006, issued as vol. 1 each year

650 12 Biomedical Engineering.|0(DNLM)D001698.|0https://id.nlm.nih.gov/mesh/D001698

710 2 IEEE Service Center.,|epublisher

711 2 IEEE Engineering in Medicine and Biology Society Conference

780 00 |tProceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society|g1988-2003|w(CST-L)L248707

910 RDA ENRICHED|aMARS

910 MARS

910 erm5

945 openkb

956 40 |3IEEE|uhttp://ieeexplore.ieee.org/xpl/conhome.jsp?punumber=1000269|zConnect to resource

CALL # R856.A1 I33x

Location Web E-Journals



OSU.EDU

Help BuckeyeLink Map Find People Webmail Search Ohio State

 **THE OHIO STATE UNIVERSITY**
UNIVERSITY LIBRARIES

LIBRARY CATALOG

Library Home Catalog Search

 Ask Us  My Account

 Catalog home  Save for export  MARC display  Another search  OhioLINK catalog  ILL request

RECORD NO Search Full Catalog Search

[Permanent link to this record](#)

TitleConference proceedings, Annual International Conference of the IEEE Engineering in Medicine and Biology Society

ImprintPiscataway, NJ : IEEE Service Center, [2004-]
©2004-

Click on the following to:

[Connect to resource IEEE](#) 

CALL #	R856.A1 I33x
Location	Web E-Journals

Description1 online resource (volumes : illustrations)

FrequencyAnnual

Descriptiontext
computer
online resource

Publ History26th (2004)-

NoteVolumes for 2004- issued in multiple parts. volumes for 2004-2005 numbered as 26th and 27th. Beginning with 2006, issued as vol. 1 each year

ISSN1557-170X

OCLC/Control #973040125

Other SubjectBiomedical Engineering.

Add'l AuthorIEEE Service Center., publisher
IEEE Engineering in Medicine and Biology Society Conference

Other TitleConf Proc Annu Int Conf IEEE Eng Med Biol Soc
Conf Proc IEEE Eng Med Biol Soc
IEEE Engineering in Medicine and Biology ... Annual Conference
IEEE Engineering in Medicine and Biology Society Conference proceedings
Proceedings of the ... Annual International Conference of the IEEE EMBS

ContinuesProceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society 1988-2003

Additional Info:

 Online Journal

 Ask Us

Visit [Ask Us](#) for general assistance.

If you have a disability and experience difficulty accessing this content, please contact:
LIB-a11y@osu.edu

 **THE OHIO STATE UNIVERSITY**
UNIVERSITY LIBRARIES

© The Ohio State University - University Libraries
1858 Neil Avenue Mall | Columbus, Ohio 43210 | 614-292-OSUL (6785)
[Request an alternate format of this page](#) | [Accessibility](#) | [Privacy Policy](#) | [Contact Us](#)


[Copyright Information](#) | [Details and Exceptions](#)

chrome-extension://bpconjcmmllapcogcnnelfmaeghhagj/edit.html

207

1/2



APPENDIX SU01



Summon

SU Libraries

SU College of Law Library

M.L. King Library

SUNY-ESF Library

Call 315.443.4083

Text 315.464.0744

Email

Hours

SEARCHMYSEARCHESMYLISTMYACCOUNTLOGININTERLIBRARYLOANJOURNAL LOCATORHELP

New Search

Go

Search History

Return to Search Results

Prev

9 of 38

Next

Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society.

000 02452cas a2200493 a 4500

001 4057855

005 20230417115258.0

006 m o d

007 cr n

008 050311d200420uunjuar o 1 a0eng

010 _ _ |a 2005243767

016 7 _ |a 101243413 |2 DNLM

022 _ _ |y 1557-170X ||1557-170X

024 7 _ |a ssj0061641 |2 360MARC

035 _ _ |a ocn253966572

037 _ _ |b IEEE, 445 Hoes Lane, Piscataway, NJ 08854

040 _ _ |a NLM |b eng |c NLM |d NLM |d NSD |d DLC |d CDS |d OCLCQ |d DLC |d OCLCO |d OCLCF |d DLC |d OCLCA |d DLC |d OCLCA |d OCL |d OCLCO |d OCLCQ |d OCLCO |d OCLCA |d WaSeSS

042 _ _ |a nsdp |a xlc

050 _4 |a R856.A1 |b l33x

060 00 |a W1 |b lE222K

082 10 |a 610.28 |2 l3

110 2 _ |a IEEE Engineering in Medicine and Biology Society. |b Annual Conference.

210 0 _ |a Conf. proc. |b (IEEE Eng. Med. Biol. Soc., Conf.)

222 _0 |a Conference proceedings |b (IEEE Engineering in Medicine and Biology Society. Conf.)

245 10 |a Conference proceedings : |b ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society.

246 14 |a IEEE Engineering in Medicine and Biology ... Annual Conference

246 17 |a Proceedings of the ... Annual International Conference of the IEEE EMBS

260 _ _ |a Piscataway, NJ : |b IEEE Service Center, |c ©2004-

300 _ _ |a 1 online resource (volumes) : |b illustrations.

310 _ _ |a Annual

336 _ _ |a text |b txt |2 rdacontent

337 _ _ |a computer |b c |2 rdamedia

338 _ _ |a online resource |b cr |2 rdacarrier

362 0 _ |a 26th (2004)-

506 _ _ |a License restrictions may limit access.

515 _ _ |a Vols. for 2004- issued in 7 v.

650 _0 |a Biomedical engineering |v Congresses.

650 12 |a Biomedical Engineering.

655 _0 |a Electronic journals.

780 00 |a IEEE Engineering in Medicine and Biology Society. Annual Conference. |t Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society |x 1094-687X |w (DLC)sn 97000694 |w (OCoLC)18956110

785 00 |a IEEE Engineering in Medicine and Biology Society. Annual International Conference. |t Annual International Conference of the IEEE Engineering in Medicine and Biology Society |x 2375-7477 |w (DLC) 2014204362 |w (OCoLC)893982064

850 _ _ |a DNLM

856 40 |z Full text available from IEEE Xplore: 2004 to present |u https://libezproxy.syr.edu/login?url=https://ieeexplore.ieee.org/servlet/opac?punumber=1000269 |x serx

948 20 |a 20230404 |b auto ||s |f z |t z |p 0

This item

Record View

Staff View

Detailed Record

Actions

Print Title Information

Export Records or Citations

E-mail

Add to My List

Mobile QR Code



Need Help?

Available

Type here to chat.
Press ENTER to send.

chrome-extension://bpconjcamlapcogcnnelfmaeghhagj/edit.html

210

1/2



Search this site...

Syracuse University Libraries

222 Waverly Avenue 
Syracuse NY 13244
315.443.2093
f: 315.443.2060
libref@syr.edu
library.syr.edu

Quick Links

[Accessibility](#)
[Privacy Policy \[PDF\]](#)
[Syracuse University Press](#)
[University Archives](#)
[University Records Management](#)




Copyright © 2017 Syracuse University Libraries. All Rights Reserved.
© 2011 Ex Libris Group. All rights reserved.



[Summon](#) [SU Libraries](#) [SU College of Law Library](#) [M.L. King Library](#) [SUNY-ESF Library](#)

Call 315.443.4083 Text 315.464.0744 Email Hours

[SEARCH](#) [MY SEARCHES](#) [MY LIST](#) [MY ACCOUNT](#) [LOGIN](#) [INTERLIBRARY LOAN](#) [JOURNAL LOCATOR](#) [HELP](#)

New Search

Go

[Search History](#)[Return to Search Results](#)

◀ Prev

9 of 38

Next ▶

Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society.**Title:** Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society.**Publisher:** Piscataway, NJ : IEEE Service Center, ©2004-**Format:** Periodical**Physical Desc:** 1 online resource (volumes) : illustrations.**Subjects:** [Biomedical engineering--Congresses.](#)[Biomedical Engineering.](#)**Holdings Information****Location:** Available via Internet**Call Number:** R856.A1 I33x [Internet]**Linked Resources:** Full text available from IEEE Xplore: 2004 to present[GET IT](#) via SURLinks**Access Note:** [Access restrictions apply.](#)**Persistent link:** <https://catalog.syr.edu/vwebv/holdingsInfo?bibId=4057855>**This item**[Record View](#)[Staff View](#)[Detailed Record](#)**Actions**[Print Title Information](#)[Export Records or](#)[Citations](#)[E-mail](#)[Add to My List](#)**Mobile QR Code****Need Help?****Browse This Shelf**[CRC critical reviews in bioengineering...](#), 1971-79.✓ Available, SU Libraries Facility
Call Number: R856.A1 C5

Search this site...

Search

Syracuse University Libraries

222 Waverly Avenue
Syracuse NY 13244

Quick Links

[Accessibility](#)[Privacy Policy \[PDF\]](#)

315.443.2093	Privacy Policy [PDF]	
f: 315.443.2060	Syracuse University Press	
libref@syr.edu	University Archives	
library.syr.edu	University Records Management	

Copyright © 2017 Syracuse University Libraries. All Rights Reserved.
© 2011 Ex Libris Group. All rights reserved.



APPENDIX UOFM

UNIVERSITY OF MICHIGAN LIBRARY

EXPLORE

M

LIBRARY

SEARCH

Account

Log in

ANN ARBOR

FLINT

Keyword

▼

ieee embs annual

Q

Advanced

Search Tip:

Enter one or more keywords. Use quotes to search for a phrase (e.g., solar power; polar bears; “systems of oppression”). See tips about [Basic Keyword Searching](#).

Everything

Catalog

Articles

Databases

Online Journals

Guides and More

Catalog

Record

Actions

Select what to do with this record.

Email

Text

Citation

Export Citation (EndNote)

Export Citation (RIS)

Copy link

Serial

Conference

□

Proceedings of the annual international conference of the IEEE Engineering in Medicine and Biology Society.

Record info:

Format

Serial

Conference

Main Author

[IEEE Engineering in Medicine and Biology Society. Annual Conference.](#)

Preferred Title

[Proceedings of the annual international conference of the IEEE Engineering in Medicine and Biology Society \(Online\)](#)

Other Titles

[Vols. for 1995 called: IEEE Engineering in Medicine and Biology ... Annual Conference and ... Canadian Medical and Biological Engineering Conference](#)

New Title

[Engineering in Medicine and Biology Society \(EMBC\), Annual International Conference of the IEEE](#)

Previous Title

[Proceedings of the annual conference of the IEEE/Engineering in Medicine and Biology Society](#)

Contributors

[Institute of Electrical and Electronics Engineers.](#)
[Canadian Medical and Biological Engineering Conference.](#)

Published/Created

New York, N.Y. : Institute of Electrical and Electronics Engineers 1988-

Language

English

Numbering

Print began with 10th (1988).

Current Publication Frequency

Annual

Numbering Peculiarities Note

Conference proceedings for 1988- issued in multiple vols.

Source of

Description based on print version record.

Description Note

Latest issue consulted: Vol. 2 (Sept. 1-5, 2004) (viewed IEEEExplore website Sept. 30, 2005).

Note

Title varies slightly.

Media Format

Mode of access: World Wide Web.

ISSN

1558-4615

OCLC Number

61124059

Subjects (LCSH)

[Biomedical engineering -- Congresses.](#)
[Medicine -- Data processing -- Congresses.](#)
[Medical electronics -- Congresses.](#)

Subjects (Other)

[Biomedical engineering.](#)
[Medical electronics.](#)
[Medicine -- Data processing.](#)
[Periodicals.](#)
[Conference papers and proceedings.](#)

The University of Michigan Library aims to describe library materials in a way that respects the people and communities who create, use, and are represented in our collections. Report harmful or offensive language in catalog records, finding aids, or elsewhere in our collections anonymously through our [metadata feedback form](#). More information at [Remediation of Harmful Language](#).

Available at:

 **Online Resources** · 1 item

Link**Description****Source**

[Available online](#)

Available from 1988.

IEEE Electronic Library (IEL)

Date Last Indexed: 20230703

MARC Data

.LDR	00000nasZZ22009257aZ4500
001	99187390296706381
005	20230222213018.0
006	m-----o--d-----
007	cr-un
008	050722c1988999nyuar--so-----1---a0eng-c
010	a 2005212471
022	a 1558-4615
035	a (OCoLC)61124059
035	a (CKB)110978978384291

035		a (CONSER)--2005212471
035		a (EXLCZ)99110978978384291
037		b IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331
042		a nsdp a pcc
050	1 0	a ISSN RECORD
082	1 0	a 610 2 12
110	2	a IEEE Engineering in Medicine and Biology Society. b Annual Conference. 0 http://id.loc.gov/authorities/names/n82234675 0 http://viaf.org/viaf/sourceID/LC/n82234675
210		a IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY INTERNATIONAL CONFERENCE
210		a ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY
210	0	a Proc. annu. int. conf. IEEE Eng. Med. Biol. Soc. b (Online)
222	0	a Proceedings of the annual international conference of the IEEE Engineering in Medicine and Biology Society b (Online)
240	1 0	a Proceedings of the annual international conference of the IEEE Engineering in Medicine and Biology Society (Online)
245	1 0	a Proceedings of the annual international conference of the IEEE Engineering in Medicine and Biology Society.
246	1	i Vols. for 1995 called: a IEEE Engineering in Medicine and Biology ... Annual Conference and ... Canadian Medical and Biological Engineering Conference
260		a New York, N.Y. : b Institute of Electrical and Electronics Engineers
310		a Annual
336		a text b txt 2 rdacontent
337		a computer b c 2 rdamedia
338		a online resource b cr 2 rdacarrier
362	1	a Print began with 10th (1988).
500		a Title varies slightly.
515		a Conference proceedings for 1988- issued in multiple vols.
538		a Mode of access: World Wide Web.
588		a Description based on print version record.
588		a Latest issue consulted: Vol. 2 (Sept. 1-5, 2004) (viewed IEEEExplore website

Sept. 30, 2005).

650	0	a Biomedical engineering v Congresses. 0 http://id.loc.gov/authorities/subjects/sh2007101999
650	0	a Medicine x Data processing v Congresses. 0 http://id.loc.gov/authorities/subjects/sh2008107638
650	0	a Medical electronics v Congresses. 0 http://id.loc.gov/authorities/subjects/sh2010101219
650	7	a Biomedical engineering. 2 fast 0 (OCoLC)fst00832568 0 http://id.worldcat.org/fast/fst00832568
650	7	a Medical electronics. 2 fast 0 (OCoLC)fst01014061 0 http://id.worldcat.org/fast/fst01014061
650	7	a Medicine x Data processing. 2 fast 0 (OCoLC)fst01014924 0 http://id.worldcat.org/fast/fst01014924
655	7	a Periodicals. 2 fast 0 (OCoLC)fst01411641 0 http://id.worldcat.org/fast/fst01411641
655	7	a Conference papers and proceedings. 2 fast 0 (OCoLC)fst01423772 0 http://id.worldcat.org/fast/fst01423772
774	0	t Proceedings of the First Joint BMES/EMBS Conference. 1999 IEEE Engineering in Medicine and Biology 21st Annual Conference and the 1999 Annual Fall Meeting of the Biomedical Engineering Society (Cat. N w (CKB)111026746727282
774	0	t Engineering in Medicine and Biology Society, 1997. Proceedings of the 19th Annual International Conference of the IEEE w (CKB)111026746720596
774	0	t Proceedings of the 20th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Vol.20 Biomedical Engineering Towards the Year 2000 and Beyond (Cat. No.98CH36286) w (CKB)111026746724016
774	0	t Proceedings of the 22nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (Cat. No.00CH37143) w (CKB)111026746729642
774	0	t 2001 Conference Proceedings of the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society w (CKB)111055184253484
774	0	t Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No.03CH37439) w (CKB)111085500350180
774	0	t Proceedings of the Second Joint 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society[]Engineering in Medicine and Biology w (CKB)111055184257836
780	0	0 t Proceedings of the annual conference of the IEEE/Engineering in Medicine and Biology Society w (CKB)991042748338692 w (DLC)sn90003698
785	0	0 t Engineering in Medicine and Biology Society (EMBC). Annual International

		x Engineering and Technology Society (IEEE); Annual International Conference of the IEEE w (CKB)100000000292011 w (DLC)2005243767
776		x 1094-687X 0 http://worldcat.org/issn/1094-687X
710	2	a Institute of Electrical and Electronics Engineers. 0 http://id.loc.gov/authorities/names/n79053217 0 http://viaf.org/viaf/sourceID/LC n79053217
711	2	a Canadian Medical and Biological Engineering Conference. 0 http://id.loc.gov/authorities/names/n85279096 0 http://viaf.org/viaf/sourceID/LC n85279096
906		a CONFERENCE
BIB		u 2023-03-24 08:23:24 US/Eastern c 2012-02-25 20:31:28 US/Eastern s false
E56		4 Access to the IEEE Xplore online version restricted; authentication may be required: m IEEE Xplore n IEEE Electronic Library (IEL) t param u https://na04.alma.exlibrisgroup.com/view/uresolver/01UMICH_INST/openurl?u.ignore_date_coverage=true&portfolio_pid=531120746630006381&Force_direct=true a 2021-06-25 00:54:47 v https://umich.alma.exlibrisgroup.com/view/uresolver/01UMICH_INST/openurl?&rfr_id=info:sid/primo.exlibrisgroup.com&svc_dat=CTO?u.ignore_date_coverage=true?u.ignore_date_coverage=true&rft.mms_id=99187390296706381 3 Available from 1988. q true s Available 8 531120746630006381

[Give feedback about this page](#) 

[Home](#) [Accessibility](#) [Tips for Using Library Search](#) [Get research help](#) [About Library Search](#) [Make an I.L.L. Request](#)

©2023 Regents of the University of Michigan. For details and exceptions, see the [Copyright Policy](#).