

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. 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.
5. 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. 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.

6. I have reviewed Exhibit EX1013, "Distributed rapid prototyping - a framework for Internet prototyping and manufacturing" by Francis E.H. Tay, et al as published in Integrated Manufacturing Systems November 2001.
7. Attached hereto as Appendix TAY01 is a true and correct copy of the MARC record for Integrated Manufacturing Systems as held by the University of Pittsburgh Library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix TAY01 accurately describes the title, publisher and ISSN number of Integrated Manufacturing Systems. The Location Items field present on page 2 of this record indicates the library's collection includes the November 2001 issue of Integrated Manufacturing Systems containing "Distributed rapid prototyping - a framework for Internet prototyping and manufacturing".
8. Attached hereto as Appendix TAY02 is a true and correct copy of "Distributed rapid prototyping - a framework for Internet prototyping and manufacturing" as published in Integrated Manufacturing Systems as held by the University of Pittsburgh Library. These scans were secured from the

library's collection. In comparing Exhibit EX1013 to Appendix TAY02, it is my determination that Exhibit EX1013 is a true and correct copy of "Distributed rapid prototyping - a framework for Internet prototyping and manufacturing" by Francis E.H. Tay, et al as published in Integrated Manufacturing Systems.

9. The 008 field of the MARC record in Appendix TAY01 indicates the date of record creation. The 008 field of Appendix TAY01 indicates the University of Pittsburgh Library first acquired Integrated Manufacturing Systems as of August 20, 1998 and held the journal in perpetuity until the publication of "Distributed rapid prototyping - a framework for Internet prototyping and manufacturing". Considering this information, it is my determination that Integrated Manufacturing Systems November 2001 and therefore "Distributed rapid prototyping - a framework for Internet prototyping and manufacturing" was made available to the public shortly after its initial publication in November 2001.

10. I have reviewed Exhibit EX1011, "Web-based Rapid Prototyping and Manufacturing Systems: A Review" by Hongbo Lan, et al as published in Computers in Industry December 2009.

11. Attached hereto as Appendix LAN01 is a true and correct copy of the MARC record for Computers in Industry as held by the Linda Hall Library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix LAN01 accurately describes the title, publisher and ISSN number of Computers in Industry. The Location Items field present on page 2 of this record indicates the library's collection includes the December 2009 issue of Computers in Industry containing "Web-based Rapid Prototyping and Manufacturing Systems: A Review".
12. Attached hereto as Appendix LAN02 is a true and correct copy of "Web-based Rapid Prototyping and Manufacturing Systems: A Review" as published in Computers in Industry as held by the Linda Hall Library. These scans were secured from the library's collection. In comparing Exhibit EX1011 to Appendix LAN02, it is my determination that Exhibit EX1011 is a true and correct copy of "Web-based Rapid Prototyping and Manufacturing Systems: A Review" by Hongbo Lan, et al as published in Computers in Industry.
13. The 008 field of the MARC record in Appendix LAN01 indicates the date of record creation. The 008 field of Appendix LAN01 indicates the Linda Hall Library first acquired Computers in Industry as of April 9, 1980 and held the

journal in perpetuity until the publication of "Web-based Rapid Prototyping and Manufacturing Systems: A Review". Considering this information, it is my determination that Computers in Industry December 2009 and therefore "Web-based Rapid Prototyping and Manufacturing Systems: A Review" was made available to the public shortly after its initial publication in December 2009.

14.I have reviewed Exhibit EX1014, a document entitled "Rapid Prototyping Modules for Remote Engineering Applications" by Karsten Henke as published in the International Journal of Online Engineering July 2008.

15.Attached hereto as Appendix HENKE01 is a screen capture of a webpage entitled Rapid Prototyping Modules for Remote Engineering Applications as hosted on the International Journal of Online Engineering website. I secured these screen captures myself from <https://online-journals.org/index.php/ijoe/article/view/532>.

16.Appendix HENKE01 includes a true and correct PDF copy of "Rapid Prototyping Modules for Remote Engineering Applications" by Karsten Henke which can be acquired by following the 'PDF' link present on page 1 of Appendix HENKE01. In comparing Appendix HENKE01 to Exhibit

EX1014, it is my determination that Exhibit EX1014 is a true and correct copy of "Rapid Prototyping Modules for Remote Engineering Applications" by Karsten Henke as published in the International Journal of Online Engineering. The 'Published' field of this page indicates "Rapid Prototyping Modules for Remote Engineering Applications" by Karsten Henke was first published as of July 6, 2008.

17. Attached hereto as Appendix HENKE02 is a screen capture of the Internet Archive Wayback Machine entry for <http://online-journals.org:80/index.php/i-joe/index>. I secured these screen captures myself from <https://web.archive.org/web/20080801090911/http://online-journals.org:80/index.php/i-joe/index>. This record was captured as of August 1, 2008.

18. Appendix HENKE02 is an Internet Archive capture of a web page entitled Vol 4 (2008): Special Issue: Rev 2008 as hosted on the International Journal of Online Engineering website. This page describes the July 2008 edition of the International Journal of Online Engineering and includes a table of contents for this issue. A listing for "Rapid Prototyping Modules for Remote Engineering Applications" by Karsten Henke is visible on page 2 of Appendix HENKE02, including a link to download a PDF copy of this

paper. This download link presence in Appendix HENKE02 indicates the International Journal of Online Engineering made a download of "Rapid Prototyping Modules for Remote Engineering Applications" by Karsten Henke available as of August 1, 2008.

19. Attached hereto as Appendix HENKE03 is a true and correct copy of the MARC record for International Journal of Online Engineering as held by the University of Michigan. I secured this record myself from the library's public catalog. The MARC record contained within Appendix HENKE03 accurately describes the title and publisher of International Journal of Online Engineering. The Available online field present on page 1 of this record indicates the library's collection includes the July 2008 issue of International Journal of Online Engineering containing "Rapid Prototyping Modules for Remote Engineering Applications". In comparing Exhibit EX1014 to Appendix HENKE03, it is my determination that Exhibit EX1014 is a true and correct copy of "Rapid Prototyping Modules for Remote Engineering Applications" by Karsten Henke as published in International Journal of Online Engineering.

20. The 008 field of the MARC record in Appendix HENKE03 indicates the date of record creation. The 008 field of Appendix HENKE03 indicates the

University of Michigan first acquired International Journal of Online Engineering as of July 6, 2006 and held the journal in perpetuity until the publication of "Rapid Prototyping Modules for Remote Engineering Applications". Considering this information, it is my determination that International Journal of Online Engineering July 2008 and therefore "Rapid Prototyping Modules for Remote Engineering Applications" was made available to the public shortly after its initial publication in July 2008.

21. 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.

22. 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: 12/12/2024

A handwritten signature in black ink, appearing to read "June Ann Munford", written in a cursive style.

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 TAY01

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001 99954921413399
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016 ##\$a(AMICUS)000027473787
016 7#\$a2029248-X \$2DE-600
022 ##\$a1758-583X
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035 ##\$a(OLC)39722642
035 ##\$a(CKB)954921413399
035 ##\$a(CONSER)--2002238736
037 ##\$bMCB University Press Limited, 60/62 Toller Lane, Bradford, West Yorkshire, England BD8 9BY
042 ##\$apcc
050 00\$aTS155.6
082 04\$a670.285
130 0#\$aIntegrated manufacturing systems (Online)
210 ##\$aINTEGR MANUF SYST
210 ##\$aINTEGRATED MANUFACTURING SYSTEMS IMS
245 10\$aIntegrated manufacturing systems : \$bIMS.
246 13\$aIMS
246 13\$aIMS magazine
260 ##\$aBradford, England : \$bMCB University Press, \$c-2003.
310 ##\$aEight no. a year, \$b<2002->
321 ##\$aFrequency varies
336 ##\$atext \$btxt \$2rdacontent
337 ##\$acomputer \$bc \$2rdamedia
338 ##\$aonline resource \$bcr \$2rdacarrier
362 1#\$aPrint began with vol. 1, no. 1 (Jan. 1990).
362 0#\$a-v. 14, no. 8 (2003).
500 ##\$aAbstracts for 1990- also available online.
538 ##\$aMode of access: World Wide Web.
588 0#\$aVol. 5, no. 1 (1994); title from introductory page (viewed July 18, 2002).
588 1#\$aVol. 14, no. 8 (2003) (Emeraldinsight, viewed June 8, 2018).
650 0#\$aComputer integrated manufacturing systems \$vPeriodicals.
650 0#\$aManufacturing processes \$xAutomation \$vPeriodicals.
650 7#\$aComputer integrated manufacturing systems. \$2fast \$0(OLC)fst00872216
650 7#\$aManufacturing processes \$xAutomation. \$2fast \$0(OLC)fst01008141
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785 00\$tJournal of manufacturing technology management \$w(CKB)111076363736000 \$w(DLC)2004255462 \$x1758-7786
780 00\$tFMS magazine \$w(CKB)958480187941 \$w(DLC)sn84012294
710 2#\$aMCB University Press.
853 20\$81 \$av. \$bno. \$u8 \$vr \$1(year) \$w8
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906 ##\$aJOURNAL





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issue: 8.

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Item in place (0 requests)
v.3 (1992)



Item in place (0 requests)
v.4-5 1993-1994



Item in place (0 requests)
v.6 1995



Item in place (0 requests)
v.7 1996



Item in place (0 requests)
v.8 1997



Item in place (0 requests)



v.9 1998

Item in place (0 requests)
v.10 1999



Item in place (0 requests)
v.11 2000



Item in place (1 request)
v.12 2001



Item in place (0 requests)
v.13 2002



Item in place (0 requests)
v. 14 2003



Details

Title	Integrated manufacturing systems (Online)
Uniform title	Integrated manufacturing systems (Online) >
Other title	IMS IMS magazine
Contributor	MCB University Press >
Language	English
Frequency	Eight no. a year, <2002->
Publisher	Bradford, England : MCB University Press Print began with vol. 1, no. 1 (Jan. 1990). -v. 14, no. 8 (2003).
Date	-2003
Type	Journal
Journal Notes	Print began with vol. 1, no. 1 (Jan. 1990). -v. 14, no. 8 (2003).
Notes	Abstracts for 1990- also available online. Mode of access: World Wide Web.
Subject	Computer integrated manufacturing systems -- Periodicals > Manufacturing processes -- Automation -- Periodicals >
Genre	Periodicals >
Related titles	Earlier title : FMS magazine > Earlier title : International journal of agile management systems (Online) > Earlier title : World class design to manufacture (Online) > Available in other form: Link to related record > Later title : Journal of manufacturing technology management >
Identifier	LC : 2002238736 ISSN : 1758-583X OCLC : (OCoLC)39722642 ISSN : 0957-6061
Dedup Member Ids	999800713406236
Source	Library Catalog

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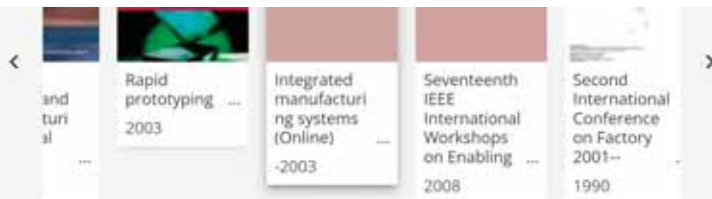
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Appendix TAY02



3 1735 055 138 329

INTEGRATED
MANUFACTURING
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VOL. 12
2001

Do Not Remove This Wrapper



University of Pittsburgh
University Library System

R09-M09-S14-T03

31735055138329



Tray ID: R09-M09-S14-T03

Call No.: TS155.6 .J553

Volume: v.12 2001

Collection: CEN

Title: Integrated manufacturing syste

Banding Label

11/14/2024 13:21:13

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CIRCULATING
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PS1795-5113

Integrated Manufacturing Systems

The International Journal of Manufacturing Technology Management

Volume 12, Number 6, 2001

This issue is part of a comprehensive multiple access information service comprising:



Paper format

Integrated Manufacturing Systems includes seven issues in traditional paper format. Please note that two issues of the journal are bound together consecutively within these covers. The contents of this issue are detailed below.



Internet Online Publishing

with Archive, Reference Linking, Emerald WIRE, Key Reading, Institution-wide Licence, and E-mail Alerting Service. Access via the Emerald Library:

<http://www.emerald-library.com>

See overleaf for full details of subscriber entitlements.

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<i>Richard Greenough, Devendra Fakun and John Kay</i></p> <p>394 Technology enablers for supply chain management
<i>Nourredine Boubekri</i></p> <p>400 Establishment and use of virtual layouts for manufacturing
<i>Ramazan Yaman</i></p> <p>409 Distributed rapid prototyping – a framework for Internet prototyping and manufacturing
<i>Francis E.H. Tay, Yadav P. Khanal, Kwok Kuen Kwong and Kim Cheng Tan</i></p> | <p>416 Just-in-time management in precast concrete construction: a survey of the readiness of main contractors in Singapore
<i>Low Sui Pheng and Choong Joo Chuan</i></p> <p>430 Designing and manufacturing consumer products for functionality: a literature review of current function definitions and design support tools
<i>Wen-Chuan Chiang, Arunkumar Pennathur and Anil Mital</i></p> <p>449 Process improvement in the presence of qualitative response by combining fuzzy sets and neural networks
<i>Kun-Lin Hsieh</i></p> <p>463 Diary</p> |
|--|---|



Integrated Manufacturing Systems online



An advanced knowledge resource for the entire organization

Access via the Emerald Library – <http://www.emerald-library.com>

Subscribers to this journal benefit from access to a fully searchable knowledge resource stretching far beyond the current volume and issue. *Integrated Manufacturing Systems* online is enhanced with a wealth of features to meet the need for fast, effortless, and instant access to the core body of knowledge. Furthermore, this user-friendly electronic library may be networked throughout the subscribing organization to maximize the use and value of the subscription. This is augmented with advanced search facilities and "choice of access" through a variety of online databases.

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Emerald WIRE

A fully searchable subject-specific database, brought to you by Emerald Reviews, providing article abstracts from the world's top management, computing and engineering journals. Directly relating to the journal subject area, the database is updated monthly and gives users details of how to obtain the full text of original articles.

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The table of contents E-mail Alerting Service will e-mail you the contents page of any chosen journal whenever the latest issue becomes available online. For further information

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Abstracts & keywords

Development of a digital manual for a manufacturing system – a case study

Richard Greenough, Devendra Fakun and John Kay

Keywords Maintenance, Manufacturing, Information systems, Manuals

This paper describes the development and evaluation of an information system to identify spare parts associated with an automated assembly machine that is part of a Ford engine assembly line. The information system is a digital manual, similar to a class of document called an integrated electronic technical manual. The requirements of teams of users in the engine plant are described before explaining the use of multimedia tools to create a suitable information system. The result is a collection of digital documents connected by hyperlinks to form a digital manual. Usability trials indicated that maintenance technicians and line operators would actually use such a manual in the factory. Ford maintenance managers indicated that such a manual would benefit them and the benefits are presented in detail. A version of the manual was developed for data collection and it is suggested that, in future, such manuals might be the factory users' interface to a computerised maintenance management system.

Technology enablers for supply chain management

Nouredine Boubekri

Keywords Supply chain, Scheduling, Enterprise resource planning, Cycle time, Product life cycle, Logistics

This paper describes the current business conditions and the four key factors that need to be integrated in order to improve the supply chain. The paper discusses how enterprise resource planning (ERP) is increasingly being used as a technology enabler for supply chain management and problems associated with its implementation.

Establishment and use of virtual layouts for manufacturing

Ramazan Yaman

Keywords Manufacturing, Virtual reality, Factories, Production planning

This study offers a new type of manufacturing approach. This approach may be called virtual manufacturing layouts. The study concerns basic themes of the approach. These are descriptions, elements, and use of the virtual layouts. The approach has been exemplified with a case study. Advantages and disadvantages of this type of layouts have also been summarised.

Distributed rapid prototyping – a framework for Internet prototyping and manufacturing

Francis E.H. Tay, Yadav P. Khanal, Kwok Kuen Kwong and Kim Cheng Tan

Keywords Internet, Rapid prototyping, Manufacturing

This paper focuses on the development of a distributed rapid prototyping system via the Internet to form a framework of Internet prototyping and manufacturing for the support of effective product development. The proposed methodology is targeted at a wide audience using a disparate range of computer systems to access remotely located rapid prototyping facilities via the Internet for prototype fabrication. The methodology is useful for both educational research for teaching evolving rapid prototyping technologies and remote scientific visualization. This approach is based on the merger of object-oriented modular software architecture and client server communications for the remote control of rapid prototyping hardware (called fused deposition modeling) via the Internet. Other Web tools are used to allow the remote user to have higher interactivity with the server applications that have a direct link with the front-end terminals controlling the rapid prototyping hardware.

Distributed rapid prototyping – a framework for Internet prototyping and manufacturing

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Abstract

This paper focuses on the development of a distributed rapid prototyping system via the Internet to form a framework of Internet prototyping and manufacturing for the support of effective product development. The proposed methodology is targeted at a wide audience using a disparate range of computer systems to access remotely located rapid prototyping facilities via the Internet for prototype fabrication. The methodology is useful for both educational research for teaching evolving rapid prototyping technologies and remote scientific visualization. This approach is based on the merger of object-oriented modular software architecture and client server communications for the remote control of rapid prototyping hardware (called fused deposition modeling) via the Internet. Other Web tools are used to allow the remote user to have higher interactivity with the server applications that have a direct link with the front-end terminals controlling the rapid prototyping hardware.

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Introduction

Manufacturing and design technologies are gradually gravitating towards Internet integrated technology to cope with emerging challenges such as the need for shorter time to market, reduced lead time in the supply chain of new products, reduced cost and higher quality. The merging of Internet and manufacturing technologies has resulted in the bridging of the gap between engineering technology (such as rapid prototyping hardware system) and the information system to enable the remote control of engineering resources. As such, geographical constraints can be overcome. In order to realize this concept, more advanced support software such as Java (Siyan *et al.*, 1997) is being developed to integrate manufacturing technology (Jacobs and Prioleou, 1996) with the Internet so that various manufacturing processes can be controlled online. In particular Java has made it possible to integrate interoperable, modular and extensible distributed application together to monitor and control a physical environment (Grimaldi *et al.*, 1998). As to date, there are a number of researches in the application of Internet infrastructure for engineering purposes (Tan *et al.*, 1998; Brown *et al.*, 1998). Most of the research work is mainly focused on the utilization of this technology for virtual reality (Toung *et al.*, 1997) and for faster and effective communications only. However, these approaches cannot fully address the real life engineering problems where real models have to be formed as a result of synthesis of time and resources and where the global market competition of supplying better quality products is very crucial.

The concept of distributed systems has long been widely used in the manufacturing

and design industries to facilitate manufacturing and product development operations. However, traditional distributed systems are hardwired and limited to a particular location and resources and accessibility is limited to a particular location only. Recently, there is considerable interest in the area of Internet enabled distributed systems. Examples of these works include the application of the Internet infrastructure for virtual reality (Broll, 1997) and online measurement (Grimaldi *et al.*, 1998). The proposed methodology is different from others in that it focuses on the formation of physical models online via the Internet when a geographical distance separates the end user and the physical hardware. This approach is applicable for a wide spectrum of end users due to its interoperability, modular functionality and scalability. The targeted audiences include users in the educational sectors who can use the framework for online teaching of new manufacturing technology such as rapid prototyping technology, and secondly for parties involved in product development who can use the facility to view and analyze the prototyping concurrently. In addition, professional prototyping centers can serve as rapid prototyping service providers for low volume manufacturing organizations to utilize the rapid prototyping facilities. The potential applications are numerous and especially so as this technology advances and new challenges arise.

Distributed rapid prototyping via the Internet

In recent years, new technologies have emerged to facilitate the rapid prototyping of 3D CAD models so that complex and aesthetically shaped prototypes can be formed both for end use and for the analysis of design and manufacture as a part of the product development process. For efficient product development and fast return on

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investment, there is a need for a rapid product development cycle that is made possible by decreasing the cycle time for product design and analysis. Product design in the product development cycle is the most critical phase where iterative prototyping is required for various analyses. Traditional prototyping is very slow and ineffective in resources utilization. Consequently, new rapid prototyping technologies have emerged in the last few years and most of the cost-effective prototyping nowadays is carried out by rapid prototyping technique. Complex and aesthetically shaped models can be rapidly fabricated using these rapid prototyping technologies, which resulted in their extensive use by design and manufacturing organizations. However, no technology can stay successful in its stand-alone form in a dynamic and competitive global market. The same applies to the rapid prototyping technology as well. In order to enhance the accessibility of available rapid prototyping services to a broader community of users (organizations or individuals) involved in the product development, research or scientific visualization process either for educational or commercial purpose, an approach has been developed so as to integrate the rapid prototyping technology with the Internet. In this approach, use of interoperable, modular and platform independent application has been developed to integrate the rapid prototyping technology with the Internet infrastructure for integrating the global resources online.

This current effort aims at providing manufacturing facilities to geographically separated partners in low and high volume manufacturing organizations, research institutes and others involved in the field of product development or scientific visualization using rapid prototyping technologies by means of remote access via the Internet. The methodology is based on the principle of Internet based distributed system and is commonly termed as Internet Manufacturing (IMAN). The approach focuses on various aspects of manufacturing and design literature. Firstly, geographically disintegrated resources can be synthesized online for real-time manufacturing. Secondly, geographically separated product development team members can work concurrently for the new product development process. Thirdly, aesthetically shaped complex prototypes can be fabricated remotely for the purpose of rapid tooling, scientific visualization and analyses. Through IMAN, commercial organizations can be engaged in prototype development and customization through a professional rapid

prototyping center without the need for their own investment for setting up costly prototyping facilities.

Brief description of IMAN system

The Internet based distributed rapid prototyping architecture is a common client server model, which centers on object-oriented application model using Java and common Web tools. The four basic components of the approach are:

- 1 Internet: as the standard communications infrastructure;
- 2 Java: as the object-oriented implementation language both for client and server applications;
- 3 Other Web tools (e.g. Virtual Network Computing, Web Cam): as an access and configuration tool for a remote server system; and
- 4 Fused Deposition Modeling (FDM): as the rapid prototyping hardware.

A major benefit of choosing Java (Siyan *et al.*, 1997) is the achievement of portable and object-oriented software (i.e. the developed application is completely platform independent, easy to maintain and extend). Java implementation relies on native methods and driver libraries and the non-portable parts relate only to interface bus drivers of the rapid prototyping hardware. In addition, it delivers a platform neutral framework for the construction of the human computer interface (HCI) (Chen *et al.*, 1998).

Network speed is an important factor to be considered in order to fully harness the advantages of IMAN. With the current trend towards high-speed network development, the IMAN system performance will be better realized with the increasing high-speed network facilities. At this point the mechanism is kept simple to realize a sufficient performance level under the current commercial network links available. Nevertheless it has been ensured that the current architecture is general enough not to limit the potential application areas in the future with the continuous development of a high-speed network such as "Very High Speed Backbone Network Service" (vBNS) (IEEE Spectrum, 1998) that has higher bandwidth capability.

Though the concept has been developed using FDM, the same concept is applied to other rapid prototyping technologies such as Selective Laser Sintering (SLS), Stereo-Lithography Apparatus (SLA) and Laminated Object Manufacturing (LOM). A major benefit of choosing FDM as our test tool for IMAN is the capability of FDM to

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make a complex and aesthetically shaped prototype and also because of its open architecture.

A general architecture (see Figure 1) of IMAN consists of a set of server and front-end terminals (only one is shown in Figure 1). The client and server applications are linked to one another via the Internet. In addition, other common Web tools, such as Web cam and video conferencing software that run independently of each other, are also incorporated in the rapid prototyping center. The client interface is also designed to be very transparent and user friendly so that the user does not need to download and install extra plug-ins to run the application. A general-purpose machine such as Win9x/NT or Sun Solaris with common Web tools installed will be sufficient to support IMAN.

A client interface is also designed to host, on demand, the human computer interface required for configuring and monitoring the remote prototyping system.

Object-oriented architecture of the IMAN system

A distinctive feature of the approach is the adoption of object-oriented software architecture for the development of the IMAN system on both the client and server side. The core module of client server interaction has been developed using Java and is completely object-oriented and platform independent. Java offers versatile,

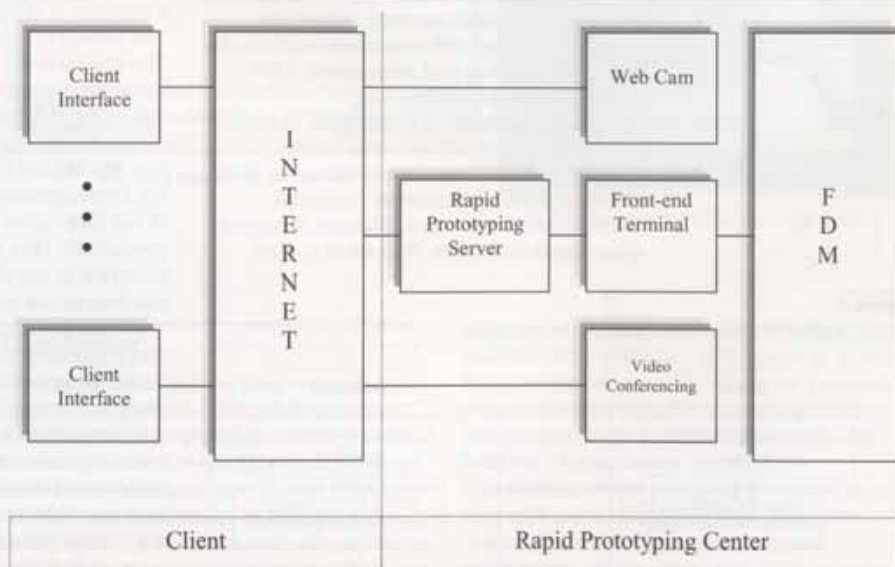
clean and type free object-oriented mechanisms for building the system. It also provides client/server-networking facilities for Internet based communications.

The IMAN system is a three-tier client server architecture consisting of the client interface, server applications and front-end terminal applications dedicated to the rapid prototyping hardware. The front-end terminal is directly connected to the rapid prototyping hardware and is dedicated to the hardware for its locally intensive data manipulation process.

The distributed rapid prototyping system consists of two major Java components, namely, the client application and server application. The client application has been developed using the Java Abstract Window Toolkit (AWT) package that furnishes the graphical user interface (GUI) services. During its lifetime, the client interface interacts with the server partner application running on the server (see Figure 2). The server component of the distributed rapid prototyping system relies on Java object-oriented mechanisms and on the capability of directly interfacing with the native methods of a standard interface driver library of the rapid prototyping hardware.

In reality, as one can see from Figure 2, an application is structured into two sub-components, namely, a Java Server component written in Java and listener threads within the server program. The server component is multi-threaded. It constantly runs and listens for a client asking

Figure 1
IMAN framework on the Internet



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for a connection to a port number representing a particular client instance to form a socket connection for bi-directional interactions with the client. The Internet protocol such as the transfer control protocol and Internet protocol (TCP/IP) is implemented for data transfer process. The receiver server socket is synchronized for each client instance. Until a client instance is completed, no other client's request will be processed.

From the viewpoint of the client application, the socket connection is active only for data transfer and invocation of the rapid prototyping hardware. Other audio and visual feedback from the remote location where the server and rapid prototyping hardware are resided can be obtained by the use of Web cam and video conferencing (see Figure 3). Normally, only one single client connection can exist at any one time to a given port. This complies with the constraint that only one single client request can be processed for using a given set of rapid prototyping hardware at any one time. Interference problems due to concurrent accesses to a shared bus of the rapid prototyping hardware can be handled by mutual exclusion mechanisms (synchronized methods). At the termination point of previous client operation, the socket connection is closed and the server can accept a new connection on the same port, thus starting a new instance of client server connection and so forth.

In a slightly different scenario, multiple clients could be allowed to watch the same fabrication process for discussion and analysis. This facility may be required in a distributed system where the active process needs to be instantaneously viewed by several people at different client stations for concurrency (Roy and Bharadwaj, 1997; Yoshimura *et al.*, 1998).

The client interface is designed to enable the client to interact with the server transparently. Clients are required to have common Web tools such as Netscape Communicator browser. The use of server component and other Web tools to run

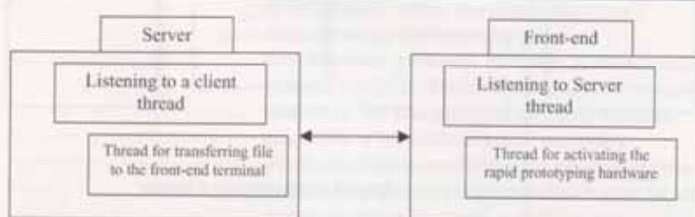
independently isolates the two kinds of tasks in the rapid prototyping center. These are critical tasks such as data transfer to the front-end terminal via the server and non-critical ones such as video conferencing and concurrently viewing of the rapid prototyping status. This kind of isolation frees up the burden of the server to handle extra loads for these lower value-added jobs while concentrating more on other server and front-end terminal intensive tasks such as data conversion to machine format with the QuickSlice. Access to the QuickSlice is synchronized for one client at a time. As a security measure the distributed rapid prototyping system is designed to disallow multiple user-access to a single or a limited number of physical hardware at anyone time.

Tests and results

Tests were carried out in collaboration with Osaka University (Osaka, Japan). The main concerns were to validate reliable data transfer (see Figure 4) and successful access to the remotely located server applications for data conversion to machine format, remote fabrication of prototype and validation of the quality of the fabricated prototype. To validate the reliability of data transfer, network performance reliability was monitored in the rapid prototyping laboratory. Figure 4 shows the average distribution of network traffic in a week recorded in the rapid prototyping laboratory. The Internet connection from the laboratory to Osaka University is via the Asia and Pacific Advanced Network (APAN) link with a nominal 2 Megabit per second bandwidth. The network route is as shown in Figure 4. The multi-routed connection had heterogeneous transfer mode in each hub and obviously it was much slower in the international traffic from Singapore to the hub 203.181.248.217 (Osaka, Japan). Despite the heterogeneous data transfer, the quality of the fabricated prototype was very consistent. This implies that the data integrity is not dependent upon the heterogeneous data transfer mode.

The main factor of the validation is the fact that the converted CAD data should maintain its integrity to avoid any flaws over the long distance transmission so that its conversion to the machine format by the QuickSlice translator is not misinterpreted to form a bad prototype. It is shown that the quality of the prototype fabricated using the IMAN system is not susceptible to varying conditions of the network link, especially the data transfer mode.

Figure 2
Client, server and front-end terminal interaction



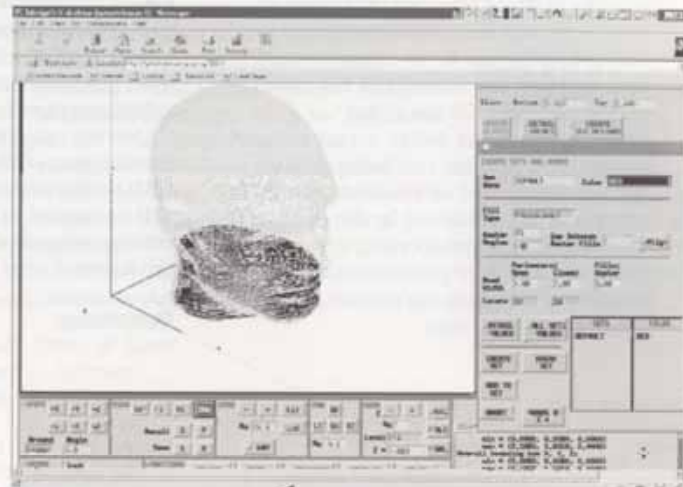
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Figure 3

(a) File conversion to machine format (b) Data transfer in the server (c) Remote viewing of prototyping status

(a) File conversion to machine format



(b) Data transfer in the server



(c) Remote viewing of prototyping status

Conclusion

Distributed rapid prototyping using the Internet is a powerful tool in the product development process and scientific visualization field to enable the distributed resources to communicate in real time both virtually and physically. In this project, IMAN, which is based on modular software architecture, was developed to enable

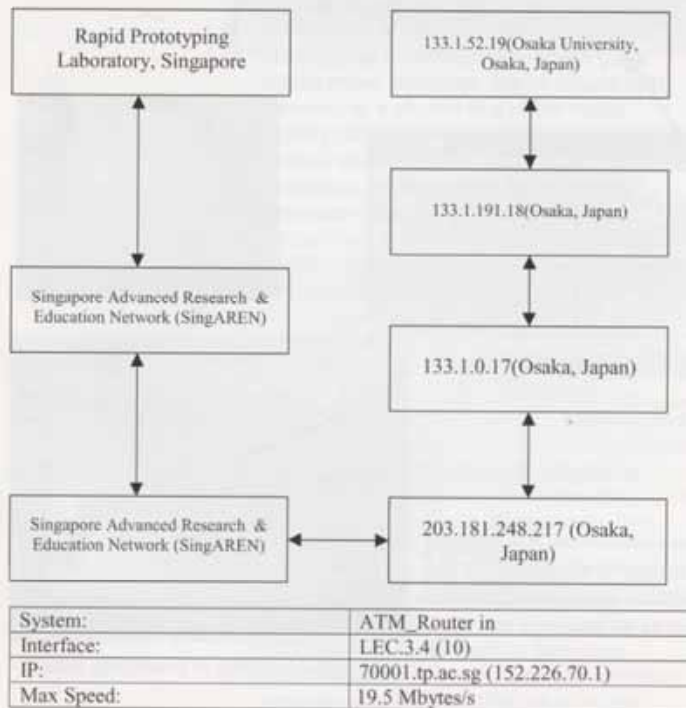
distributed rapid prototyping via the Internet. The approach is targeted at a wide range of audiences with disparate research and commercial interests in using rapid prototyping technologies remotely via the Internet. In particular, platform independency was a critical factor to ensure that end users using different computer systems can interact with the rapid prototyping center effectively. The modular

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software architecture for the IMAN system is also highly scalable for further research and development. With IMAN, it becomes possible to collaborate in real time between two geographically distributed resources (partners). More effective utilization of geographically distributed resources is realized using one at the cheapest source of data carrier – the Internet as the means of communications. In the global manufacturing and design arena, industrial competition through successful product development based on efficient prototyping can be further enhanced by the use of the distributed rapid prototyping system via the Internet for remote prototyping to considerably reduce the product development lead time.

Figure 4
Network link and performance reliability



The statistics were last updated on Friday, 12 February 1999 at 15:47, at which time the ATM_Router had been up for 10 days, 1:12:19.

Monthly Graph (2 Hour Average)

Max In:	3591.0 kb/s (2.3%)
Average In:	189.2 kb/s (0.1%)
Current In:	86.7 kb/s (0.1%)
Max Out:	2019.8 kb/s (1.3%)
Average Out:	41.2 kb/s (0.0%)
Current Out:	14.3 kb/s (0.0%)

Future research works

The proposed distributed rapid prototyping system is presently being developed for other prototyping hardware other than FDM. A highly interactive GUI will also be designed to communicate with the Programmable Logic Controller that will be connected to the front-end terminal to achieve more intelligent functions of the system remotely.

Current research work also involves the development of object-oriented collaborative CAD on the Internet. These two approaches will be merged in the near future to facilitate collaborative product development using the Internet.

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Appendix LAN01

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Survey paper

Web-based rapid prototyping and manufacturing systems: A review

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ABSTRACT

Rapid prototyping and manufacturing (RP&M) technique has shown a high potential to reduce the cycle and cost of product development, and has been considered as one of crucial enabling tools in digital manufacturing to effectively aid rapid product development. Manufacturing industry is evolving toward digitalization, network and globalization. The Internet, incorporating computers and multimedia, has provided tremendous potential for remote integration and collaboration in business and manufacturing applications. RP&M technique using the Internet can further enhance the design and manufacturing productivity, speed, and economy, as well as share the RP machines. Web-based RP&M systems have been developed and employed to implement remote service and manufacturing for rapid prototyping, enhance the availability of RP&M facilities and improve the capability of rapid product development for a large number of small and medium sized enterprises. This paper provides a comprehensive review of recent research on Web-based RP&M systems. Various architectures proposed for Web-based RP&M systems are presented. Furthermore, some key issues and enabling tools to implement the remote RP&M systems, which involve (1) RP&M process selection, (2) RP price quotation, (3) STL Viewer, (4) RP data pre-processing, (5) job planning and scheduling, (6) remote control and monitoring for RP machines, (7) security management, (8) applying new technologies and concepts to the systems, are described in detail. Finally, this review gives an outlook on possible future development and research direction for Web-based RP&M systems.

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1. Introduction

Due to the pressure of international competition and market globalization in the 21st century, there continues to be strong

driving forces in industry to compete effectively by reducing time-to-market and cost while assuring high quality product and service. Quick response to business opportunity has been considered as one of the important factors to ensure company competitiveness. Rapid prototyping and manufacturing (RP&M) technique has shown a high potential to reduce the cycle and cost of product development, and has been considered as one of critical

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enabling tools in digital manufacturing to effectively aid rapid product development. RP&M mainly involves rapid prototyping (RP) and rapid tooling (RT). RP is a new forming process which fabricates physical parts layer by layer under computer control directly from 3D CAD models in a very short time. In contrast to traditional machining methods, the majority of rapid prototyping systems tend to fabricate parts based on additive manufacturing process, rather than subtraction or removal of material. Therefore, this type of fabrication is unconstrained by the limitations attributed to conventional machining approaches [1–3]. The application of RP technique as a compelling tool can provide benefits throughout the process of developing new products. Specifically, there are serious benefits that RP can bring in the areas of market research, sales support, promotional material, and the ever-important product launch. Physical RP can also become a powerful communication tool to ensure that everyone involved in the development process fully understands and appreciates the product being developed. Hence, it can help to reduce substantially the inevitable risks in the route from product concept to commercial success, and help shorten time-to-market, improve quality and reduce cost. In general, the application of RP to the product development process has shown a 60% decrease in lead-time over traditional methods [4]. From the emergence of the first RP system in 1988, RP technology has been introduced successfully in the industries of automotives, aerospace, electronics, toy and so on. The RP methods commercially available include StereoLithography (SL), Selective Laser Sintering (SLS), Fused Deposition Manufacturing (FDM), Laminated Object Manufacturing (LOM), Ballistic Particle Manufacturing (BMP), and Three-Dimensional Printing (3D printing) [1,3,5]. RP is newly evolving toward rapid tooling (RT). RT is a technique that transforms the RP patterns into functional parts, especially metal or plastic parts. It offers a fast and low cost method to produce moulds and functional parts. Furthermore, the integration of both RP and RT in development strategy promotes the implementation of concurrent engineering in companies. Numerous processes have been developed for producing molds from RP systems. The RT methods can generally be divided into direct and indirect tooling categories, and also soft (firm) and hard tooling subgroups. Indirect RT requires some kinds of master patterns, which can be made by conventional methods (e.g. High-speed Machining, HSM), or more commonly by an RP process such as SL or SLS. Direct RT, as the name suggests, involves manufacturing a tool cavity directly on the RP system, hence eliminating the intermediate step of generating a pattern [6]. Soft tooling can be obtained via replication from a positive pattern or master. Soft tooling is associated with low costs; used for low-volume production and uses materials that have low hardness levels such as silicones, epoxies, low melting point alloys, etc. RTV silicone rubber moulds, epoxy moulds, metal spraying moulds, etc., are some of these typical soft molds. Hard tooling is associated with higher volume of production, and the use of materials of greater hardness. Keltool process, Quickcast process, and the ExpressTool process are some of these hard toolings. Electrical discharge machining (EDM) seems to be an interesting area in which rapid tooling finds a potential application. Some methods of making EDM electrodes based on RP technique have developed such as abrading process, copper electroforming and net shape casting, etc. [1,2,4].

Manufacturing industry is evolving toward digitalization, network and globalization. With the fast advance and extensive usage of the Internet technologies, they have been widely employed in developing manufacturing systems to associate various product development activities, such as marketing, design, process planning, production, customer service, etc., distributed at different locations into an integrated environment [7]. It has now been widely accepted that the future of manufacturing organiza-

tions will be information-oriented, knowledge driven and much of their daily operations will be automated around the global information network that connects everyone together [8]. The integration and collaboration among different partners of the product development team can largely improve the product quality, reduce the product development cost and lead-time, and extend the use capability of critical equipments. Therefore, it can better satisfy the requirements of different users, and provide better global competitiveness of products in the marketplace [7]. The Internet, incorporating computers and multimedia, has provided tremendous potential for remote integration and collaboration in business and manufacturing applications. RP&M technique using the Internet can further enhance the design and manufacturing productivity, speed, and economy, as well as share the RP machines. In addition, various RP machines are currently too expensive to be offered by a large number of small and medium size enterprises. Web-based RP&M systems, however, will let these small and medium size companies make prototypes remotely, without owning the expensive RP machines. RP can be made by designer from anywhere in the world [9]. All currently commercial RP processes can be obtained through RP&M providers (service bureaus). However, most service providers generally specialize in one of these processes, although some offer two or more methods. It is necessary to depend on numerous partners to carry out the remaining tasks that this service provider has no such manufacturing capabilities to accomplish in time. For RP service providers, Web-based RP&M systems can closely integrate various RP machines and enable the RP resources are shared on the Web to increase competitiveness. Therefore, integrated RP&M with Web-based manufacturing technologies, the Web-based RP&M system provides a production collaborative environment among users and RP&M providers to implement remote service and manufacturing for rapid prototyping, enhances the availability of RP&M facilities and can improve the capability of rapid product development for small and medium sized enterprises. Since the mid-1990s, the research and development of the Web-based RP&M systems have received much attention [4]. Substantial investments have been made to support the research and practice of Web-based RP&M systems from both the academic community and industrial bodies all over the world. A number of studies from both the academia and industrial bodies have been performed to explore the architecture, key issues and enabling tools for developing Web-based RP&M systems. The objective of this paper is to present a comprehensive review of recent advances in Web-based RP&M systems, and discuss the future research directions. That may provide a reference and direction for the development of Web-based RP&M systems. The rest of this paper is organized as follows. Section 2 presents various architectures of Web-based RP&M systems. Section 3 discusses the key issues and enabling tools in developing the Web-based RP&M systems. Finally, Section 4 summarizes this paper.

2. Various architectures for Web-based RP&M systems

A variety of frameworks for developing Web-based RP&M systems have been proposed. The Tele-Manufacturing Facility (TMF) is probably the first system that provides users with direct access to a rapid prototyping facility over the Internet. TMF allows users to easily submit jobs and have the system automatically maintain a queue. It can automatically check many flaws in STL files, and in many cases, fix them. A LOM machine was first connected with network, and then the STL file of a part to be built could be submitted to this machine by a line command [10–12]. Luo et al. [9,13–17] presented an E-manufacturing application framework of the Web-based RP system which mainly includes five components. (1) Open STL file and display it using Open GL

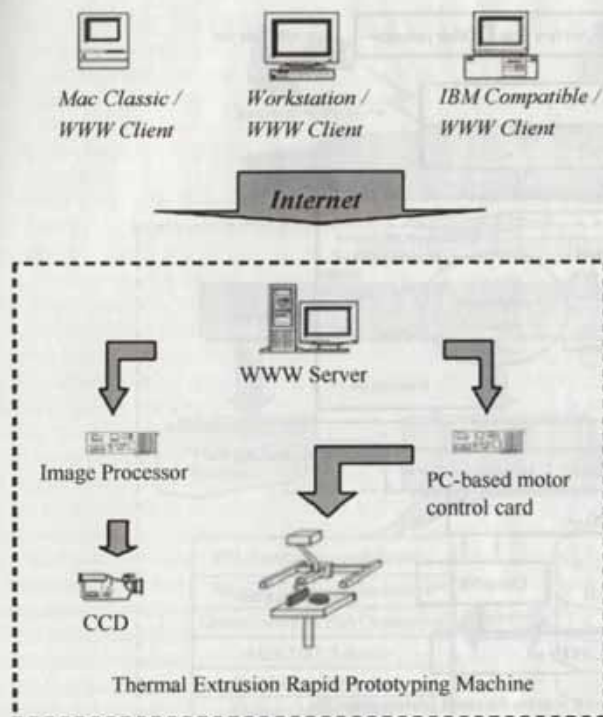


Fig. 1. Overall system architecture of automated tele-manufacturing system [16].

technology, (2) product quotation system, (3) select a suitable RP system, (4) joint alliance system, and (5) order scheduling program. The Open GL technology can be used to show 3D models with different color on different directions. The product quotation system supplies an on-line automated cost estimation related to the option of materials, manufacturing time and RP machines before the RP part being manufactured. This Web-based RP selection system can help users to select an appropriate RP

machine. After evaluating, the system shows the manufacturing time and cost. When customers are satisfied with this estimation, they can transmit STL file via the Internet to the RP Web server. After scheduling, the Web server can transmit the STL file to the RP machine that chosen by the customers. Then the RP part can be fabricated in the chosen RP machine. During manufacturing process, customers also can watch a live image of RP part via Internet, and monitor the RP machine which fabricates physical part through CCD camera. If customers or companies want to joint the alliances, they can joint the system as a member of the association and upload the information of their RP machine to the RP Web server. Fig. 1 shows the framework of the Web-based rapid prototyping system. Jiang and Fukuda [18,19] described a methodology to create an Internet-based infrastructure to service and maintain RP-oriented tele-manufacturing. One of the most important applications of such an infrastructure is to support the closed-loop product development practice. The Java-enabled solution based on WWW/Internet computing model is used to implement the infrastructure. The main functions include the remote part submitting, queuing and monitoring. Under the control of different access competences, manufacturing sites and queues can be maintained, respectively, in distributed locations. A software test platform has been developed in Java to verify the methodology. A Java-enabling architecture to implement RP-oriented tele-manufacturing is illustrated in Fig. 2. Liu et al. [20] addressed the development of a Web-based tele-manufacturing service system for rapid prototyping. Fig. 3 illustrates the architecture of the tele-manufacturing service system for rapid prototyping. The system provides geographically dispersed enterprises with a platform that permits them to share RP machines. In contrast with other similar systems, the proposed system is comprised of three parts: the on-line commerce, the on-line manufacturing service, and the on-line data management. Three supporting software packages are provided: a software package for self-check and self-repair of STL files, a software package for real-time collaboration, and a software package for remote scout and control. Lan et al. [21,22] developed a tele-service system for RP service bureaus to support the implementation of the Web-based RP manufacturing. The overall framework

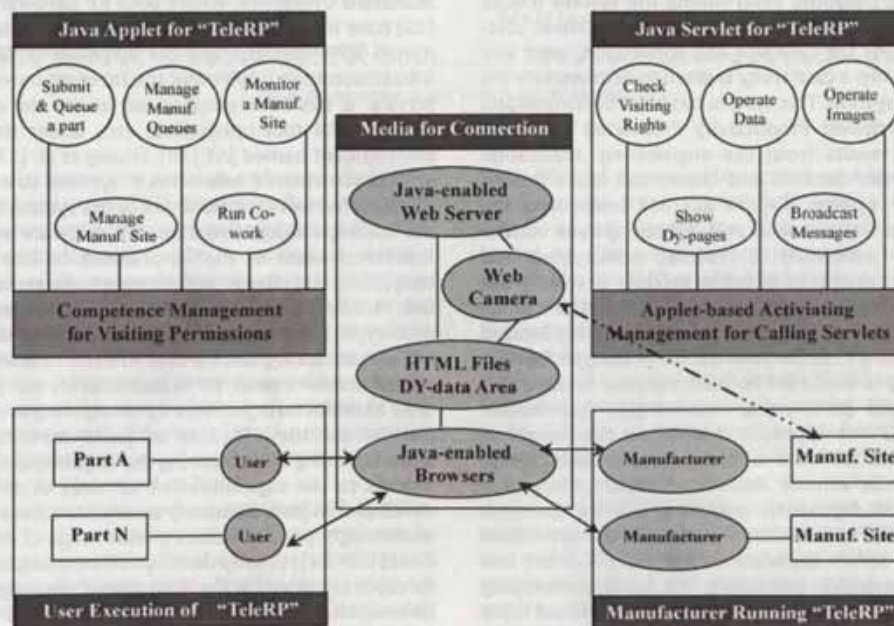


Fig. 2. A Java-enabled architecture to implement RP-oriented tele-manufacturing [18].

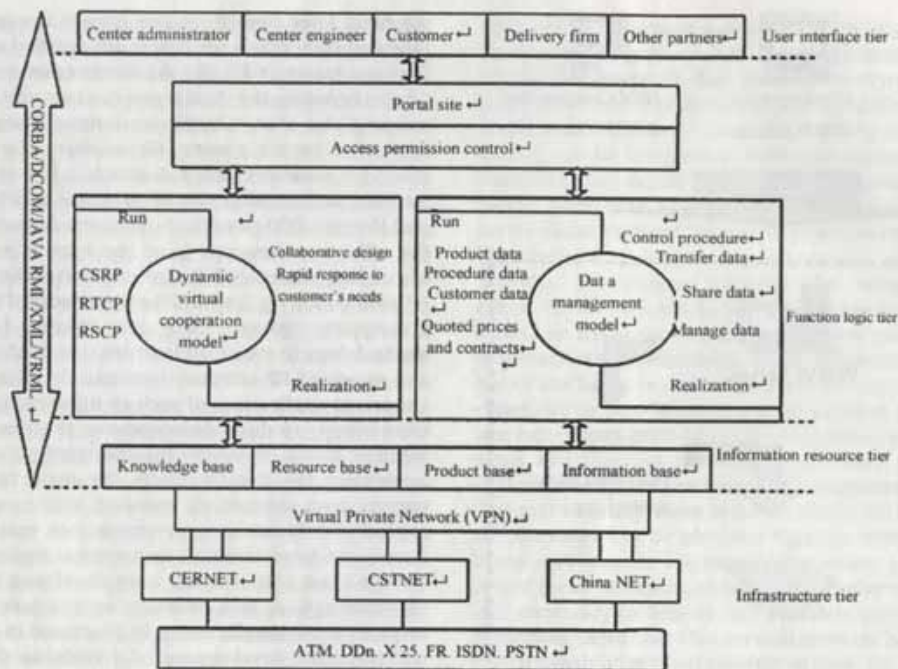


Fig. 3. Architecture of the tele-manufacturing service system for rapid prototyping [20].

for the tele-service system is shown in Fig. 4. The tele-service system consists of two components: software sub-system and hardware sub-system. The hardware involves not only the RP&M facilities of the service bureau itself but also the RP&M equipments from the other service bureaus. The software module includes eight functional components: the information center, ASP (application service providers) tool set, client management, E-commerce, manufacturing service, system navigation and collaborative tools. The crucial issues for developing the system which involve deploying the running platform, determining the system model, choosing a Server-side language, constructing development platform as well as designing the database and application, were also discussed in detail. Finally, a case study is given to demonstrate the use of the tele-service system. This system has been developed and employing in the Northwest Productivity Promotion Center in China. The practical results from the engineering application indicate that both service bureaus and clients can much benefit from the tele-service system. Tay et al. [23] introduced the development of a distributed rapid prototyping system via the Internet to form a framework of Internet prototyping and manufacturing for the support of effective product development. The proposed methodology is targeted at a wide audience using a disparate range of computer systems to access remotely located rapid prototyping facilities via the Internet for prototype fabrication. The methodology is useful for both educational research for teaching evolving rapid prototyping technologies and remote scientific visualization. This approach is based on the merger of object-oriented modular software architecture and client server communications for the remote control of rapid prototyping hardware (called fused deposition modeling) via the Internet. Other Web tools are used to allow the remote user to have higher interactivity with the server applications that have a direct link with the front-end terminals controlling the rapid prototyping hardware. Xu et al. [24] presented an Internet-based virtual rapid prototyping system named VRPS-I which was implemented by using Java and Virtual Reality Modeling Language (VRML). With

the aid of this system, not only the visual rapid prototyping process can be dynamically previewed, but the forming process and some part-quality-related parameters can also be predicted and evaluated. Therefore, the reasonable rapid prototyping parameters can be predetermined according to the simulated results without any physical RP machine. Hence, it can help optimize the prototyping process, improve part-quality, enhance fabrication efficiency, and lower the model making cost significantly. A RP-related tele-manufacturing investigation was also conducted at Stanford University, where both RP hardware [25] and software [26] have been developed. The hardware deals with an integrated mould-SDM machine and the software includes an agent-based infrastructure to implement the Internet-based RP manufacturing service. It has been emphasized to use the concepts of plug-in, broker, local tool integration, etc., under the Java-based agent environment named JAT [18]. Huang et al. [27] developed a rapid prototype-oriented tele-service system based on Internet and Intranet. Network construction of the system and configuration of the corresponding hardware and software were presented. The functional units of the SL-oriented on-line quotation, on-line bargaining and clients' information management were implemented. Huang et al. [28] introduced an Internet/Web-based rapid prototyping oriented tele-manufacturing service center to share a RP manufacturing service over Internet. Under the support of this virtual service center, RP manufacturers can provide and publish their manufacturing service by configuring their RP sites and users can submit the STL files of parts to their desired sites for manufacturing by comparing the requirements of their prototype models to the capabilities of RP sites. A software testbed was developed in Java. Remotely accessible laboratories are becoming increasingly popular across a wide range of disciplines. Fidan and Ghani [29–31] recently developed a remotely accessible laboratory for rapid prototyping. The objective of this project is to develop and disseminate a Remotely Accessible Rapid Prototyping (RRP) Laboratory at Tennessee Technological University (TTU). This laboratory facility is physically located on the TTU Campus, but

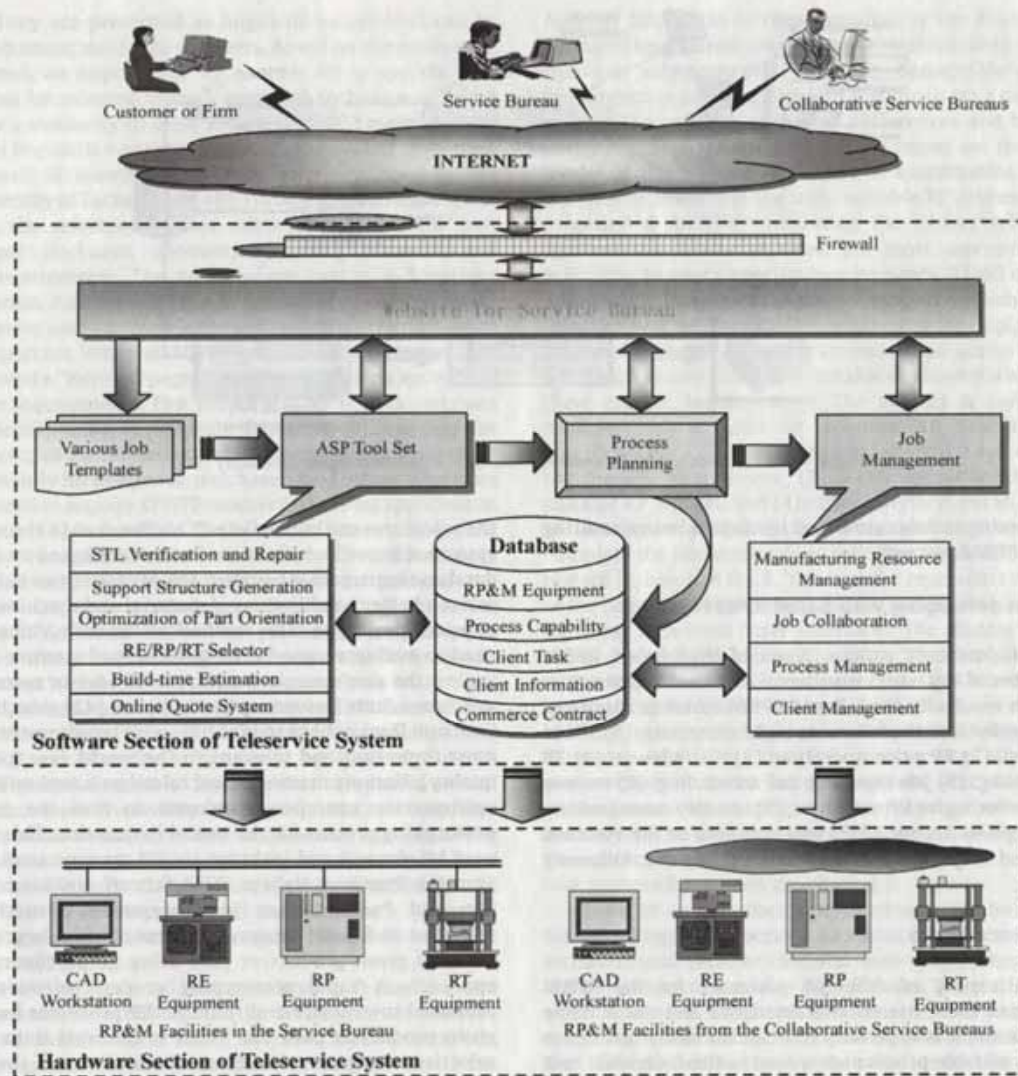


Fig. 4. Architecture of the Web-based RP&M system.

Internet-based controls, interactive tutorials and scheduling allow this equipment to be used across TTU, Tennessee Board of Regent (TBR) technology centers and community colleges across the state of Tennessee and eventually nationwide. In particular, adding a remote access capability allows many more users to benefit from state-of-the-art RP technology, thereby better justifying the cost of purchasing and maintaining the overall facility. Furthermore, the successful development of a remote RP lab provides new insights into the strengths and weaknesses of the remote access environments, and therefore provides vital insights for both the design/manufacturing technology and distance education communities alike. The overall architecture of the Remotely Accessible Rapid Prototyping Laboratory is illustrated in Fig. 5.

Based on above presentations, various architectures of Web-based RP&M systems have been proposed. Most systems mainly focus on functional implementation. For the architecture design of the Web-based systems, designers must simultaneously consider the implementing methods, whether Server-side or Client-side? Client-side scripting means all calculations are done by the computer of the visitor. Most of the time the script is interpreted by

their Internet browser (Javascript) or a specific browser plug-in (Flash action script or Active X control). Server-side scripting means all calculations are done by the Server your website is hosted on. The script is interpreted by the supported language parser, like JSP, PHP or ASP. Many factors like security issues have led to restrictions in both Server-side and Client-side possibilities. Both types have advantages and disadvantages, but the better solution is to attempt to combine both. According to the actual requirements of the Web-based RP&M systems and different functional modules, the suitable modes are determined.

In addition, in contrast to the Web-based RP&M systems, Web-based manufacturing systems have been profoundly and systematically investigated. During the architecture design for the Web-based RP&M systems, it is a good solution for designers to refer the previous research results from Web-based manufacturing systems [7,32–35]. The combination of Web services and software agents provides a promising computing paradigm for efficient service selection and integration of inter-organizational business processes. It is a good scheme for Web-based RP&M systems to establish an agent-based service-oriented open architecture to

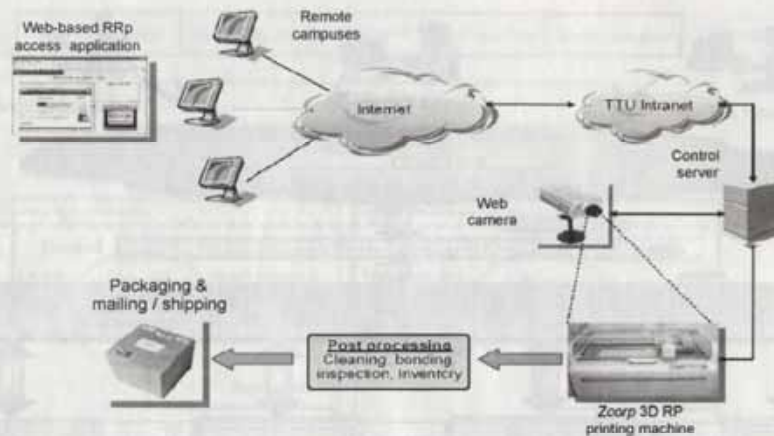


Fig. 5. Overall architecture of the Remotely Accessible Rapid Prototyping Laboratory [31].

better implementing collaborative and intelligent manufacturing for Web-based RP&M systems.

3. Key issues in developing Web-based RP&M systems

In the development of various types of Web-based RP&M systems, a number of key issues have been discussed. Based on the current research results for Web-based RP&M systems, these key issues can be divided into the following eight categories: (1) RP&M process selection, (2) RP price quotation, (3) .STL Viewer, (4) RP data pre-processing, (5) job planning and scheduling, (6) remote control and monitoring for RP machines, (7) security management, and (8) applying new technologies and concepts to the systems. Details of these key issues are described in the following subsections.

3.1. RP&M process selection

There are a variety of different processes for the RP&M technique, each of them has its characteristics and the suitable scope of application. It is especially difficult for many novices to select the most suitable process according to the individual task requirements and actual conditions. A number of studies have been carried out into the development of methodologies, decision support techniques and software tools for assisting RP users in selecting the most suitable RP&M process.

Early attempts in selecting a conformable RP system based on benchmarking studies that compared different RP systems. Some benchmarking studies have been carried out in an attempt to determine working accuracy and strength of the systems that can then be used by industry to determine process suitability for their application. A variety of measurement methodologies have also been presented in papers previously published on the subject of the benchmarking of RP systems [36–38]. This approach may be time consuming and quite expensive. Hornberger [39] developed the Rapid Prototyping Program at Santa Clara University in 1993, which was perhaps the first attempt to develop a computer-based program in assisting the selection of a proper RP system. The program basically serves as an educational tool to provide general information on RP processes. There have been attempts at developing RP selection system which are based on relational database. Campbell and Bernie [40] established a database of the RP system capabilities to help RP users make the most effective use of RP. The system is based on the hypothesis that "once the capability of an RP system has been determined for individual features it's capability for any component containing

these features can be predicted". Muller et al. [41] developed a "RP system selector" which is a software tool based on the relational database management system MS Access. It can help RP users to select a better combination of material and machine to produce a physical prototype. The method of "Benefit Value Analysis" is used to evaluate various combinations of machine and material against the user's requirements. The RP advisor system developed at Arizona State University by Phillipson [42], which uses Quality Function Deployment to identify those requirements that are the most important and relevant to the model (i.e. speed, cost and quality). Various mathematical relations based on multi-criteria optimization are then employed to find the most suitable prototyping process for the model in question. This program also uses MS Access, and includes six RP systems available from 3D Systems, Stratasys, Helisys, DTM, Schroff, and Sanders Prototype. Rao and Padmanabhan [43] presented a methodology for selection of a rapid prototyping process that best suits the end use of a given product or part using graph theory and matrix approach. A 'rapid prototyping process selection index' was proposed to evaluate and rank the RP processes for producing a given product or part. The index is obtained from a RP process selection attributes function, obtained from the RP process selection attributes digraph. The digraph is developed considering RP process selection attributes and their relative importance for the considered application.

More recent studies have been concentrated on developing the knowledge-based expert systems for RP process selection. Bibb et al. [44] introduced a RP design advice system that can recommend the most appropriate route to creating a physical prototype. Masood and Soo [45] presented a rule based expert system for the selection of RP system from all the commercial RP systems manufactured in the USA, Japan, Germany, and Israel. Bernard and Deglin [46] described a knowledge-based system for the choice of RP process which combines the cases based reasoning and examining of the compatible inputs–outputs of the primary secondary, and tertiary steps in a process chain in order to arrive at a solution. Byun and Lee [47] described the selection of an optimal RP system that best suits the end use of a part by using multiple-attribute decision making and the test part designed with conjoint analysis to reflect users' preference. Evaluation factors include only the major attributes that significantly affect the performance of an RP system such as accuracy, roughness, strength, elongation, part cost and build time. Crisp values such as accuracy and surface roughness are obtained with a new test part developed in this study. The part cost and build time are identified as falling within approximate ranges due to varying costs and many variable

parameters. They are presented as linguistic values that can be described with triangular fuzzy numbers. Based on the evaluation values obtained, an appropriate RP process for a specific part application can be selected using a modified technique of order preference by a similarity to ideal solution (TOPIS) method given crisp data and linguistic variables as the alternatives of attributes.

A Web-based RP system selector has been developed by the Helsinki University of Technology [48]. Through answering a series of questions, the selector acquires information about the part accuracy, layer thickness, geometric features, material, and application requirements. The user chooses one of 4–5 options for each question. Additionally, the user specifies preferences for each requirement using a five-element scale from insignificant to average to important. When all 10–12 questions are answered, the user will receive a “Results” page which lists three best systems to satisfy his/her requirements. This program is not perfect, not even close, but a friendly pointer to the right direction [49]. A RP Selector has been developed by IVF Industrial Research and Development Corporation mainly for designers, purchasers and others who from time to time need to acquire RP/FFF models for various applications and want fast, un-biased advice. The intention is not to give “the correct answer” to a question which most often does not have only one correct answer. Rather the Selector aims at guiding and educating the user, and at serving as a number of important functions. The RP Selector handles both plastic and metallic parts and covers all the way from making parts for an early design study to the production of small series. The program deals with many methods and process chains that are based on FFF and includes both rapid tooling, when FFF methods are used for manufacturing of tools, and Rapid Manufacturing, direct applications for the completed FFF part. A number of Swedish user companies as well as service bureaux were involved in the development and they have strongly influenced the design and verified the contents. The approach of guiding and informing instead of giving a fixed solution was decided upon as the best way to compensate for the fact that the fast FFF development will always make a system of this kind lagging somewhat behind as regards the influence of new product releases [50,51].

From the above analysis and literature review, it can be found that the RP process selection should be considered as a multi-alternative and multi-criteria fuzzy decision making problem. Most of existing systems are incomplete prototypes that have considered only a limited number of RP alternatives and criteria.

Another limitation of these systems is the failure to take into account the inherent vagueness and uncertainty on the descriptions and judgments of RP processes. Some of the decision criteria are subjective and qualitative, it is difficult for a decision maker to express the strength of his/her preferences and to provide exact judgment. Few research works are based on the mathematical model or the integrated method of quantitative and qualitative analysis to determine the most suitable RP process. Lan et al. [52] proposed a method integrating the expert system and fuzzy synthetic evaluation to select the most appropriate RP process according to user's specific requirements. Based on the proposed approach, a Web-based decision support system for RP process selection was developed. The system provides a platform mounted on the server. RP users or customers can access the system via Internet/Intranet to make a suitable decision making according to their specific requirements. The system is composed of four modules: (1) a database to store RP processes with their specifications; (2) a knowledge-based expert system for selecting the feasible alternatives; (3) a FSE model to choose the most suitable RP process; and (4) a user interface and an expert interface to interact with the system. Four modules work together to complete the decision making task. The overall architecture of this system is shown in Fig. 6. The first tier represents the visual aspect of the program, where the user keys in some required information by filling in a form (user interface). The middle tier is the web server and related logical functions. The third tier is associated with a database and a knowledge base (MS Access database used here). Using such a three-tier B/S structure, we are able to work with the same visual representation, independent of the remote database. Moreover, the B/S architecture allows developing professionals to focus on development and maintenance tasks on the Server-side in spite of the increasing number of distributed customers. The user interface of the system is illustrated in Fig. 7. The system has been run at a RP&M networked service platform that authors have been developing.

Chung et al. [53] discussed a methodology for the selection of rapid tooling (RT) processes based on a number of user-specified attributes and relative cost and lead-time comparisons across a wide spectrum of available RT processes. The method is based on a combination of weighted functional and on the approximate mathematical models of metal casting process costs and their lead-time. The method has been put on the Internet for easy access. It is currently limited to only several of the most common RT processes

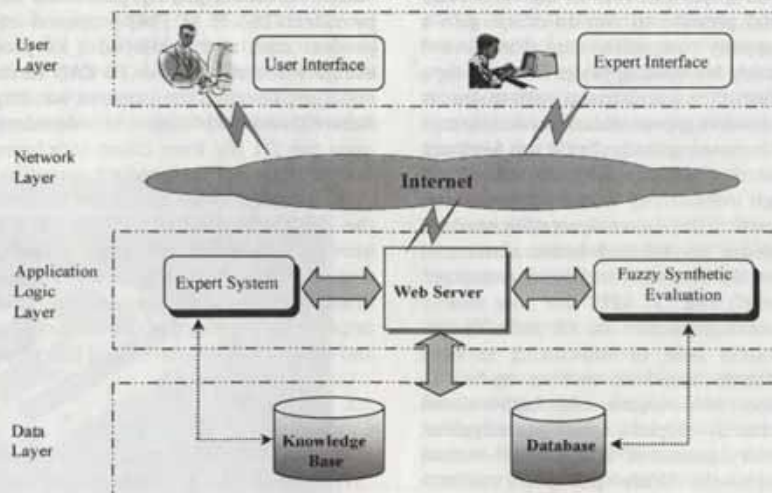


Fig. 6. Architecture of a Web-based RP process decision making system.

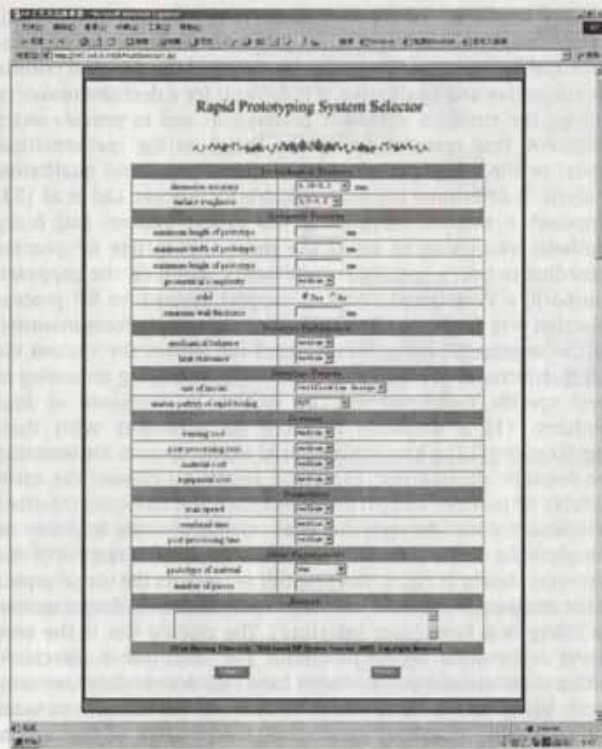


Fig. 7. User interface of a Web-based RP process system.

and materials. However, the database should be further expanded to include a majority if not all of the metal casting processes.

As one of the most important modules for Web-based RP&M systems, RP&M process selection has been profoundly studied. However, most investigations focus on RP selection, few research works involve RT processes selection, particularly RP&M process chain (RP, RT and functional parts) selection and decision making.

3.2. RP price quotation

In today's competitive market, quick and accurate price quotation for RP part plays an important role in the RP service process, is also a fundamental premise to win an order, gain a potential client and keep company competitiveness. The current major practice in the RP industry for quoting prices for building a RP part is either by experience or by comparison with a similar product. Web-based price quotation approach can provide instant price quotation for remote customer, quickly obtain the feedback from customer, and show a number of advantages: easy to use and update, simple operation, high interactivity with customer, user-friendly interface. In order to satisfy the current quotation needs of RP service bureaus and providers, several Web-based automated quotation systems have been developed. The "Quickparts.com" (and its software "QuickQuote") and "3T RPD" are now mainly commercial on-line price quotation system for RP parts. Quickparts.com, which is a privately held manufacturing services company dedicated to providing customers with an on-line E-commerce system to procure low-volume and high-volume custom manufactured parts, has developed a QuickQuote system. The QuickQuote is a proprietary geometric analysis and instant quoting engine behind Quickparts. With Quickparts' patent-pending QuickQuote technology, users simply upload their 3D CAD data (STL files), define their project specifications, and a

custom, binding quote is presented instantly. The new version instant quoting software, MyQuote 3.0 does not require the upload of CAD files. Geometry analysis is performed right on a desktop within the MyQuote software. To get an Instant Quote, users select a process, select CAD files for quote, select material, finish, and quantity, and then click on "Create Quote". The unique, binding quote is instantly calculated and presented to users. The system would be provided an instant price quote for SL, SLS, FDM, and Cast Urethanes/RTV Molding. Users can also compare these processes based on materials available, applications, and lead-time. The principle of quotation for QuickQuote is based on the geometry analysis of model (model and define Specs) [53]. 3T RPD developed an automatic quoting system that can be accessed around the clock. Working from key data precludes the need to upload sensitive information to a central server. The system can respond instantly with prices, as well as E-mailing out an official quotation. The quotation principle of 3T RPD is also based on the data model and product details (e.g. product quantity, material, finishing/coloring, desired delivery date, etc.). The system seems to upload several data models. The best way to send the data is recommended by E-mail [54]. Unfortunately, maybe due to the reason of commercial know-how (or secret), both of them do not describe and report the implementation mechanism of quotation, application effect and development details. Two quoting approaches which include the rough quotation based on weight and precise quotation based on build time were proposed to determine the price quotation for SL parts by using STL modes of parts built [55]. Based on the proposed methods, Lan et al. [56] developed a Web-based automated quotation system which can provide instant price quotations for SL parts to support effectively the Web-based RP&M systems. The system can provide the two quotation methods mentioned above and two use modes (Server-side and Client-side) according to the requirements from different users. For usage modes, users can upload their STL file or download and install the application of Active X control with functions for using the STL file, calculating volume and surface area, estimating build time on the desktop, by which users can get an instant price quotation. The functional model of the on-line quotation system for SL parts is shown in Fig. 8. The Web-based automated quotation system can satisfy the engineering requirements of price quotation at the early stage of product development, and offers a new option for RP customers to allow them to instantly quote and compare multiple rapid prototyping processes. The further service will be extended to allow customers to convert quotations into orders, which are subsequently processed by RP service bureaus and providers. Luo et al. [14] proposed an equation to estimate RP product cost, and developed a RP product quotation system to evaluate the cost of the 3D CAD models base on the proposed equation. The quotation system was implemented by using Visual Basic 6.0 with COM Object to code interface engine. Customers can open the STL file from Client-side homepage program, and carry out the action of the product quotation.

Web-based RP&M quotation systems have been considered as the most useful enabling tool for a number of RP&M service providers, many service bureaus have successfully developed the remote RP&M quotation modules and applied to the Web-based RP&M systems or service website. Future research should further improve the accuracy of the RP quotation, predigest the operation, and expand Web-based RT and functional parts quotation systems.

3.3. STL Viewer

Rosen [57] developed a collaborative design tool, called "STLViewer," which allows remote users to view STL model over the Internet. This software operated through a Java Applet in the user's Web browser reads the STL (Stereolithography) file format

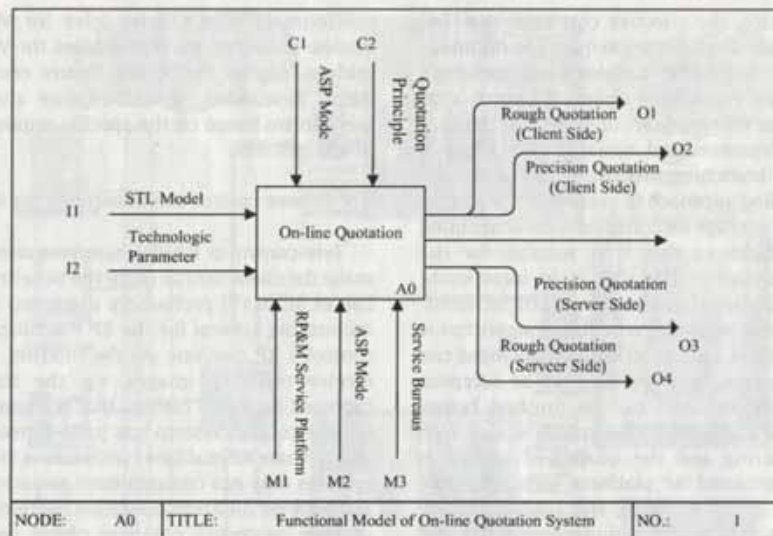


Fig. 8. Functional model of a Web-based RP quotation system.

(the *de facto* file format for rapid prototyping) and displays the model for the remote user to inspect. The user is able to rotate, pan, and zoom the model. Utilities are also provided for verification of the validity of the model. STL Viewer has a wide variety of potential applications. On-line 3D catalogs, infusion into an on-line ordering process for a SLA laboratory, and sharing of design concepts over the Internet are all potential uses for this software. STL Viewer provides a crucial enabling tool (a collaborative visualization tool) to effectively aid the Web-based RP manufacturing systems. Fig. 9 shows the complex shapes visualized by STL Viewer. Further investigations would be to thoroughly check STL file, correct the STL File, and increase inherent robustness.

Apart from the STL Viewer, other Web-based collaborative visualization tools in distributed product development have also been applied to the Web-based RP&M systems, e.g., Auto View for Java, 3D Visualization and Collaboration, etc. [58–60].

3.4. RP data pre-processing

Because the various data pre-processing of RP process in different RP vendors are incompatible now, Lan et al. [61] described an ASP tool set for RP data pre-processing based on STL model to aid effectively the networked service for RP&M. The architecture and functional model of ASP tool set were established. The checking and fixing system for STL models, as a typical example, was systematically studied and developed, and used to demonstrate the detailed

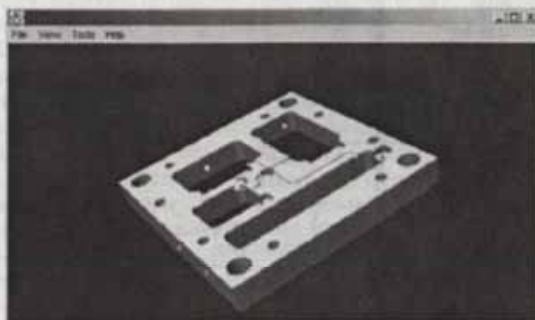


Fig. 9. Complex shapes visualized by STL Viewer [57].

development process of the ASP tool set. In order to meet the demands for the distributed application, a new algorithm was discussed. The J2EE architecture was employed to carry out the ASP tool kits based on the three-tier Browser/Server mode. The ASP tool set has been integrated the networked service system of RP&M that the authors have developed. Various parts with different complex geometries have been chosen to verify these ASP tool kits, and the actual results show that the ASP tool set provides an effective tool to aid the implementation of RP&M networked service. Liu et al. [20] developed a software package for self-check and self-repair of STL files. Roy and Cargian [62] described the implementation of an object slicing algorithm that runs through the World Wide Web (WWW). The WWW allows this software to connect to other CPD products to be utilized after design for tele-manufacturing. In addition, they also addressed enhancements to the current slicing algorithms. This work was completed with tools such as HTML and Java. In the intelligent Web-based rapid prototyping manufacturing system [14], Luo et al. presented a new adaptive slicing algorithm for RP system. According to the algorithm, the 3D CAD model can be sliced with different thickness automatically by comparing contour circumference or the center of gravity of the contour with those of the adjacent layer. In addition, Zhang et al. [63] addressed Web-based study on rapid prototyping data intelligent processing techniques. They proposed some algorithms for correcting common errors, and optimized the algorithm of gaps or holes errors leading to open loops in the data structure based on analyses of the rules and errors in the STL file. Furthermore, effectiveness of the approach is demonstrated by a simple model view example of STL files based on Java 3D technology.

Currently, studies on RP data pre-processing based on Web are very lack compared with other key units. It is necessary for designers to further explore the issue based on ASP.

3.5. Job planning and scheduling

Today's commercial RP systems rely on human intervention to load and unload build jobs. Hence, jobs are processed subject to both the machine's and the operator's schedules. In particular, first-in-first-out (FIFO) queuing of such systems will result in machine idle time whenever a build job has been completed and an operator is not available to unload that build job and start up the next one. These machine idle times can significantly affect the

system throughput, and, hence, the effective cost rate. Wu [64] addressed this problem by rearranging the job queue to minimizing the machine idle time, subject to the machine's and operator's schedules. This is achieved by employing a general branch-and-bound search method, that, for efficiency, reduces the search space by identifying contiguous sequences and avoiding reshuffling of those sequences during the branching procedure. Lin et al. [65] proposed a real-time scheduling approach to maximize the system utilization and minimize the average response time for scheduling non-preemptive aperiodic tasks so that it is suitable for the distributed Web-based RP systems. The idea is to incorporate Shortest-Job-First (SJF) into Earliest-Deadline-First (EDF) scheduling algorithm. The result of the proposed scheduling algorithm is very close to the optimal solution and the scheduling overhead can be neglected. Using the approach, new requests can be accepted dynamically and all accepted requests can be finished before deadlines. The Web-based RP platform is able to fully utilize Web resources for RP manufacturing and the quality of service is significant improved. A distributed RP platform scheduler proposed by authors is shown in Fig. 10. Jiang and Fukuda [18,19] addressed the selection of a feasible RP manufacturing site and submitting and queuing a part for remote RP manufacturing. Selection a valid and feasible RP manufacturing site registered in the RP tele-manufacturing web server depends on mainly on two factors, i.e., site manufacturing capability and delivery time constraints concerning all the queues inside the site. Here, the delivery time constraints deal with the total manufacturing time of all submitted parts in each queue. They presented the build time estimation of a RP part. Furthermore, together with the browsing manufacturing capability, remote users can select a suitable RP through calculating possible delivery time. After determining the RP manufacturing site, a part in .STL file format can be uploaded to the dynamic data area of the web server, and then be put into the corresponding queue by using the Applet-Servlet pair. Tzou [13] presented a framework of order scheduling system, as shown in Fig. 11. In TMF [10] queuing a part depended only on the time when the part arrived in the queue.

Networked manufacturing enterprises need a wider support from external manufacturing resources. A challenging issue on networked manufacturing resource services is how to discover these socialized manufacturing resources and provide the effective resource support services. Optimizing external manufacturing resources, integration and interoperability in a collaborative

environment play crucial roles for Web-based manufacturing modes. However, current studies for Web-based RP&M systems seldom involve the points. Future research must be reinforced them. Researches should explore the suitable approach and mechanism based on the specific requirements of the Web-based RP&M systems.

3.6. Remote control and monitoring for RP machines

Tele-control or WWW-based remote control of RP machine can make the client user to share the benefit of the remote RP machine. Luo et al. [9,17] profoundly discussed a tele-control and remote monitoring system for the RP machine. It allows user to directly control a RP machine via the Internet. Also the remote user can receive real-time images, e.g. the completed RP model parts captured by a CCD camera that is mounted on a RP machine. The remote control system has proven itself as a feasible and useful tool to share RP machines with others via Internet. The different RP systems may not communicate to each other easily because they are built on different operation systems, using different communication protocols, common object request broker architecture (CORBA) has been proposed to integrated heterogeneous environments such that these different RP systems can be easily integrated regardless of what language they are written in or where these applications reside with any commercial CORBA solutions [13,15]. Instead of using a CCD camera, Wang et al. [66] addressed a Java 3D-based remote monitoring system for a FDM machine. A project was introduced to solve the problem of the model motion simulation based on the sensor signal data which was transformed from the application server so as to meet the requirements of remote real-time monitoring. Gao et al. [67] described the development of a tele-control system for rapid prototyping machine based on Internet. Among different remote control methods, Winsock was adopted to implement of tele-controlling a RP machine. Kang et al. [68] investigated a remote monitoring and diagnosis of breaking-down fault for a FDM rapid prototyping machine. To solve the problem of remote diagnosing faults for high-automatic long-period minute machines in their running period, the VPON remote monitoring system and image processing technology were used to carry out the remote diagnosis of a FDM rapid prototyping machine breaking-down fault.

Web-based remote control and monitoring techniques (networked control and monitoring) have been studied for many years,

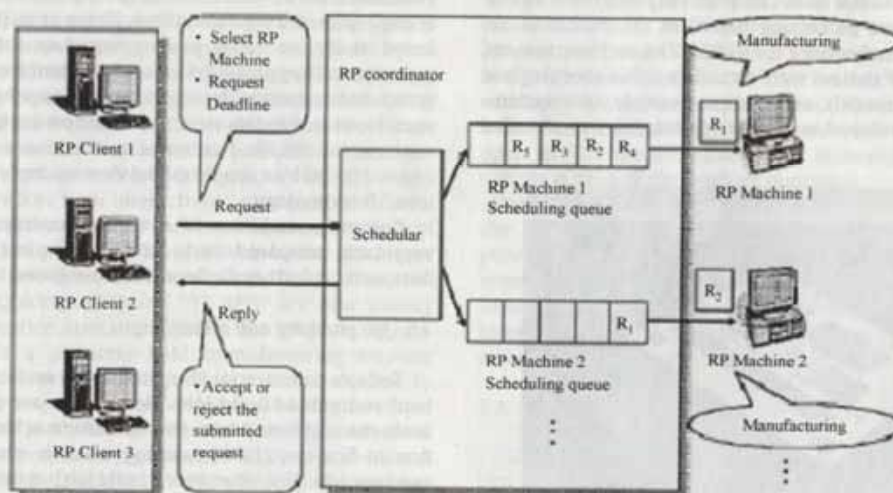
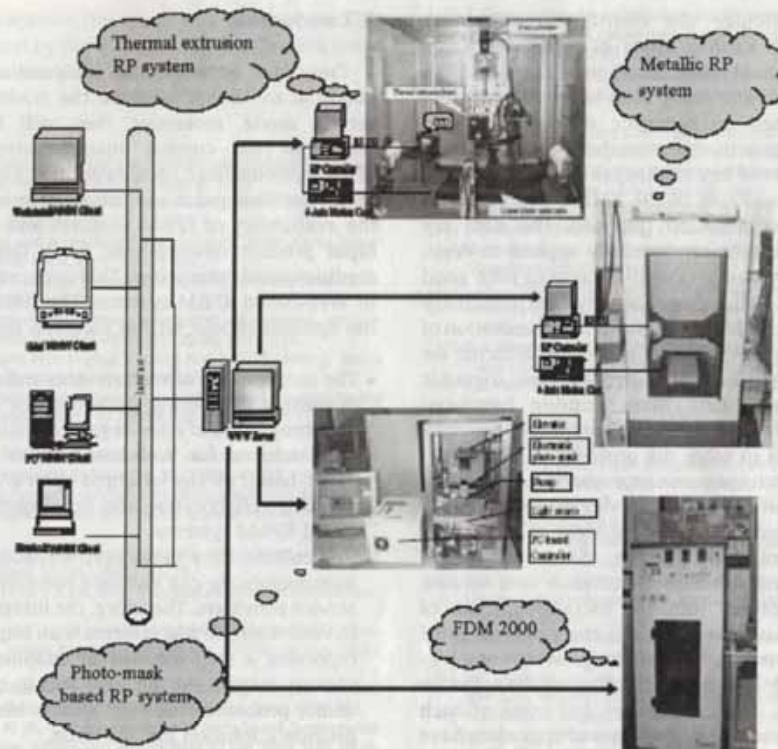


Fig. 10. Distributed RP platform scheduler [65].



and widely applied in various industrial fields. Compared with other modules, remote control and monitoring for RP machines cannot be considered as a difficult issue, designers can refer and use the previous research results related to Web-based remote control and monitoring techniques [69–71].

3.7. Security management

Since Web-based manufacturing systems allow the clients to download client application programs from the Server-side, access the client programs using local Web browsers, and execute programs at the remote Server-side, security management mechanisms are required to specify different levels of accessibility permissions for different users for preventing the local machines from being damaged by poor programs and viruses from the remote Server sides and preventing the Server machines from being visited by the unauthorized clients [1]. In the Tele-RP system developed by Jiang and Fukuda [18,19], the general security strategy is mainly concerned with (1) collection of information from clients and confirmation of the clients' certificates at different levels, (2) clients' access security considerations to Web servers, directories, and files inside the servers, including individual Web pages and (3) secure encrypted data transaction over the Internet. In their research, the currently available data encryption transaction methodologies, including RSA, digital signatures of users for payment and reliability, Security Socket Layer (SSL), and Secure HTTP (SHTTP), were investigated [1]. In the Web-based RP system presented by Lan et al. [21,22], in order to prevent hacking system, two firewalls based on package filtration and proxy Server, namely, Cisco2511 router and Proxy Server 2.0, were utilized.

For practical application of Web-based RP&M systems, security management is indeed a crucial issue. However,

designers can be directly consult and employ the methods and schemes of other Web-based application systems (e.g., Web-based manufacturing system, Web-based information management system, etc.).

3.8. Applying new technologies and concepts to Web-based RPG&M systems

As advances in Internet and distributed computing, some new technologies and concepts such as, Web services, XML, common object request broker architecture (CORBA), Agent, Grid manufacturing, Application service providers (ASP), E-manufacturing, e-Service have been applied to Web-based systems (e.g., networked collaborative design and manufacturing systems) [72–85]. Service-oriented computing (SOC) is considered as a new computing paradigm after the object-oriented paradigm. It utilizes services as fundamental elements for developing applications/solutions. Services are autonomous platform independent computational elements that can be described, published, discovered, orchestrated and programmed using XML for the purpose of developing massively distributed interoperable applications. Web services technology is part of the SOC paradigm and can be considered as an implementation of the SOC model. Web services are featured with application, platform and provider independence. They provide an appropriate paradigm for building open large-scale application environments. In such environments, services are not treated as isolated and one-time affairs but rather as elements of an interactive, dynamic and collaborative architecture. Web services technology provides a higher level interoperability for leveraging business activities across the Web either within an enterprise or among collaborating. Web services provide an industrial standard for deploying, publishing, discovering and invoking enterprise's services. From its emergence, many specialists have predicted that

Web services will revolutionize the distributed computing paradigm and it will make various kinds of e-business (e.g., inter-enterprise collaboration and ASP paradigms) a reality [77]. Web services have been applied to many Web-based manufacturing systems. Solutions based on semantic web services are promising and they are being actively researched. These technologies can offer answers to some key challenges such as semantic mediation and interoperability [72,74,78,79]. XML is a standard for data representation and exchange on the web. The data are represented in XML schema, as it can be easily applied to Web-based systems. XML-based resource is well-structured with good expandability and flexibility. XML has been widely used in industry for the publishing of enterprise information and communication of enterprise business process [76,80]. It is especially difficult for current technologies to meet industrial demands on dynamic sharing of various resources. Grid Manufacturing has been suggested as an efficient method to share dynamical resources through the Internet. It aims to solve the problem of distributed and heterogeneous manufacturing resource sharing and collaborative operation [82,83]. An application service provider (ASP) is a business that provides computer-based services to customers over a network. Software offered using an ASP model is also sometimes called On-demand software or software as a service. The need for ASP has evolved from the increasing costs of specialized software that have far exceeded the price range of small to medium sized businesses. As well, the growing complexities of software have led to huge costs in distributing the software to end-users. Through ASP, the complexities and costs of such software can be cut down. In addition, the issues of upgrading have been eliminated from the end-firm by placing the onus on the ASP to maintain up-to-date services, 24 × 7 technical support, physical and electronic security and in-built support for business continuity and flexible working. Nowadays, networked manufacturing system based on ASP has become one of the hotspots of research and application. E-manufacturing is a system methodology that enables the manufacturing operations to successfully integrate with the functional objectives of an enterprise through the use of Internet, tether-free (i.e. wireless, web, etc.) and predictive technologies. It covers all aspects of manufacturing—sales, marketing, customer service, new product development, supplier relationships, logistics, manufacturing, strategy development and so on. E-manufacturing is opening up opportunities for data intensive activities such as on-line monitoring and diagnostics of machine tools conditions and knowledge intensive processes including new product development, complex systems modeling and simulation, and real-time decision making supports and complex problems solving. It has been considered as an essential and inevitable technology for the future manufacturing organizations, working along the extended supply chains in particular [84,85]. Using these new technologies and philosophies, the development of Web-based application systems can become much simpler and effective. For example, in order to better fulfill the intercommunication and interoperability of heterogeneous software and hardware systems among different RP service providers and users, these implementation techniques, which include desktop sharing, remote procedure calling and service encapsulation by distributed component object model (DCOM), common object request broker architecture (CORBA), Web services, etc., can be introduced to the remote RP&M systems. Furthermore, the developed systems using these new technologies and concepts have better functions, higher reliability and intelligence. However, the development of current Web-based RP&M systems is seldom based on these new technologies. In the future, it is necessary to develop the Web-based RP&M systems using these new technologies and concepts, in particular ASP, Grid Manufacturing and Multi-agent.

4. Conclusions

Computer network and information technologies have the potential to further improve the traditional manufacturing and service mode, moreover, they will become more and more important for current manufacturing industry. Web-based RP&M systems have been developed and employed to implement remote service and manufacturing for rapid prototyping, enhance the availability of RP&M facilities and improve the capability of rapid product development for a large number of small and medium sized enterprises. This paper reviews the state-of-the-art in Web-based RP&M systems. The future improvement tasks for the systems should further focus on the following four aspects:

- The combination of Web services and software agents provides a promising computing paradigm for efficient service selection and integration of inter-organizational business processes. It is a good scheme for Web-based RP&M systems to establish an agent-based service-oriented open architecture to better implementing collaborative and intelligent manufacturing for Web-based RP&M systems.
- In a collaborative networked environment, the integration and interoperability can enhance the competitive advantages of RP service providers. Therefore, the integration and interoperability in Web-based RP&M systems is an important issue. Web services represent a step forward in enabling collaborations between various entities on the web and in overcoming the interoperability problems that may appear. Web services technique may provide a solution for this issue.
- Some new technologies and concepts such as, Web services, XML, CORBA, Agent, Grid manufacturing, ASP, E-manufacturing, e-Service, provide effective enabling tools for Web-based application systems. Future research and development on Web-based RP&M systems should be based on these new technologies and concepts, in particular ASP, Grid Manufacturing and Multi-agent.
- Further research will be focused on collaborative product commerce (CPC), collaborative planning and control of production, enabling tools, concurrent process for RP and RT, optimizing external manufacturing resources, remote fault diagnosis, on-line services to customers, and the detailed structure and formulation of the central-monitoring mechanism of such a partnership system.

Web-based design and manufacturing system is a new product mode in term of mission, structure, infrastructure, capabilities, and design process, which need more detailed research and theory building. The significant contribution of this paper is to present a comprehensive review of recent advances in Web-based RP&M systems, and discuss the future research directions. That may provide a reference and direction for the development of Web-based RP&M systems.

Although Web-based technologies have been applied to collaborative product design and manufacturing for many years, real industrial applications have not been in place yet. As one of the most typical cases for Web-based collaborative product design and manufacturing system, Web-based RP&M system has shown a promising prospect for networked manufacturing and service modes. However, there is still a long way for really commercial application of the Web-based RP&M systems.

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Appendix HENKE01

Rapid Prototyping Modules for Remote Engineering Applications

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Keywords: Web-based education, Virtual and Remote Labs, Web-based design tools, Distance Learning

ABSTRACT

This contribution describes the concept and implementation for an integration of microcontroller and FPGA based Rapid Prototyping modules into a Remote Lab system. This implementation enables a Web-based access to electro-mechanical models. A student uploads a source file implementation to the Remote Lab server in order to test an implementation directly within a hardware environment. The Remote Lab server offers the interfaces to integrate specific project and hardware plug-ins. These plug-ins access a hardware specific software environment to automatically compile and program the resulting firmware. To stimulate this design, the Remote Lab server exchanges digital signals via a serial interface. To allow the student to compare architectures of different designs using the same hardware model, a specific controller (using the Remote Lab interface) can be selected. For this, an IP-based multiplexer provides the control connection between the respective controller and the hardware model. In our contribution we would like to give examples of such a complex design task and how the students can use different tools during several design steps.

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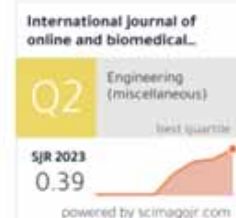
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Platform &
workflow by
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Rapid Prototyping Modules for Remote Engineering Applications

K. Henke, H.-D. Wuttke and Tobias Braune
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Abstract—This contribution describes a concept for an integration of microcontroller- and FPGA- based Rapid Prototyping modules into a Remote Lab system and its implementation. The implementation enables a Web-based access to control electro-mechanical models. The electro-mechanical models can be controlled by different platforms (microcontroller or FPGA-based). Students have the possibility to test a designed control algorithm directly within a hardware environment by uploading a source file to the Remote Lab server. That way the students can compare architectures of different control-platforms as well as different design approaches to control electro-mechanical models. The paper starts with an introduction into the design process and describes the tool set, which is provided to the students. After that the different platforms and their integration in the Web-server are introduced. Finally we would like to give examples of such complex design tasks and show, how the students can use different tools during several design steps.

Index Terms—Web-based education, Virtual and Remote Labs, Web-based design tools, Distance Learning

I. INTRODUCTION

The development of Remote Engineering becomes more and more important in a knowledge based society and is used in a wide range of education and social important fields (virtual and Remote Laboratories, teleworking /e-working environments, remote engineering etc.).

New technologies in Remote Engineering have been widely deployed and explored in Europe in the last few years. The Internet is widely used in the whole world and is nowadays the most popular communication network. Therefore, new technologies and mobile networks have to be improved in the next future. This means, that the number of specialists in these fields has to increase dramatically in the next years.

The same trend we can see in overseas. This is related to the growing technical opportunities of the Internet (bandwidth) and new methods in e- and distance learning. The forerunners in this area are engineering disciplines and natural sciences.

Due to the:

- growing complexity of engineering tasks,
- more and more specialized and expensive equipment as well as software tools and simulators,
- required use of these equipment and software tools/simulators in short time projects,
- application of high tech equipment also in small and medium-sized enterprises (SME),

- need of high qualified staff to control recent equipment and
- demand of globalization and division of labour

It is more and more necessary to allow and organize a shared use of equipment, but also specialized software, for example simulators.

Users in the workplace can access the labs without travelling. This flexibility is important for tele-working, education and life long learning. Using online laboratories has the potential of removing the obstacles of cost, time-inefficient use of facilities, inadequate technical support and limited access to laboratories.

This also would benefit people with special needs and people working from their home, as they would not need to travel to their companies' facilities to perform their work. Even employees, working at their company's facilities, can use remote specialized equipment at another company without travelling. This may provide new opportunities and benefit for small and medium-sized enterprises (SME) that would not be able to use such equipment otherwise [1].

Our Department of Integrated Hardware and Software Systems at the Ilmenau University of Technology has 10 years experience dealing with Internet-supported teaching in the field of digital system design [2, 3]. We have developed a new teaching concept, called "Living Pictures" [4], that we use in several phases of the learning process. Living Pictures are highly interactive Java applets that can be used for demonstration, as well as for experimental purposes, and serve also as tools in certain steps of the design process of digital systems. To complete the teaching concept by own experiences, the students have to pass a practical examination in a laboratory. A task during this examination is to design a digital control system that controls one of various electro-mechanical models, for instance a model of a traffic light, a lift, a positioning table etc.

The design of complex digital control systems for Bachelor and Master Courses includes the following lectures:

- "Technical Informatics"
- "Design of Digital Control Systems"
- "Design and Validation of Complex Parallel Systems"

The lecture *Technical Informatics* is held for Bachelor students in the first semester. It deals with the basics of Boolean algebra, combinational logic and simple sequential circuits. Students learn different functional specification techniques (e.g. logical equation, truth table, schematic diagram and automaton based techniques). This

course is supported by “Living Pictures” as well as the Web-based usage of a Remote Prototyping board [5,6].

Main topics in the lecture *Design of Digital Control Systems* are various minimization techniques for logical expressions, dynamic effects in combinational and sequential circuits and the design of digital control systems – mainly based on Finite State Machine (FSM) descriptions. This lecture is accompanied by a set of tools, which students can use in a 4-hour laboratory [7].

Students in Master level courses have the opportunity to deepen their knowledge in the lecture *Design and Validation of Complex Parallel Systems*. In this course, the students learn different methods and tool concepts to design and validate complex design tasks. For a better understanding, some accompanying practical designs are beneficial. Unfortunately such complex designs are too complex for a single lecture or a 4-hour laboratory lesson. That's why, we organize “project seminars” during a whole semester. The time for the project seminar is calculated with a workload of 120 hours – 4 ECTS.

In our contribution, we would like to give examples of such a complex design task and how the students can use different tools during several design steps.

II. THE DESIGN PROCESS

The design process of Digital Control Systems usually consists of the conceptual formulation and the design of the control algorithm to finally achieve a validated control. Figure 1 gives an overview of this process and describes the design phases with more detail.

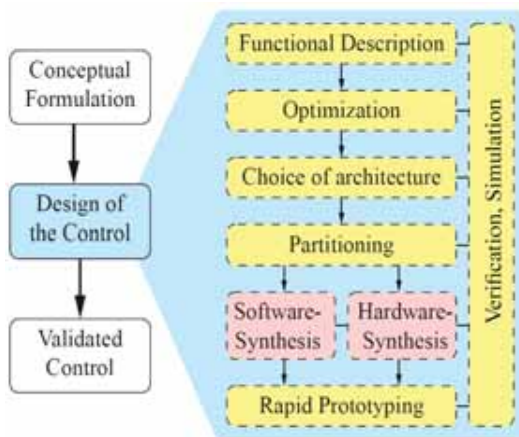


Figure 1. Design Process of Digital Control Systems

For the *functional description* we use e.g. parallel Finite State Machines (FSM), Hardware Description Languages (AHDL, VHDL) or software notations (Assembler, C) as description techniques [8,9].

These description methods allow a formal *optimization*, *verification* and *validation* of the design.

Simulation and visual prototyping help to find functional errors. Run-up to the practical, simulations and animations in “virtual worlds” are often used to verify the developed solutions. The physical behaviour of the actual model, and its environment as well, will be emulated (e. g. as simulation model). The user can influence his “virtual world” and analyse the caused reaction of his control algorithm. Dynamic activities will be animated and in

some cases supported by corresponding engine sounds. Figure 2 shows an example of such a visual model - a Water level control, used for a design task.

These steps have to be executed until errors are detected. But there is an essential disadvantage in this method. *Real disruptive factors* (e. g. failure of single components, mechanical problems) can't be recognized by the underlying virtual environmental model.

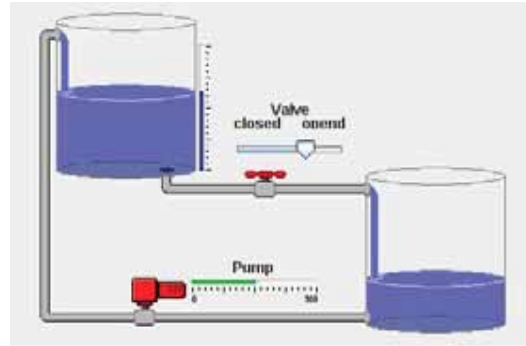


Figure 2. Visual model of the Water level control task

Generally, only a simulation of predetermined malfunctions is possible. After some times all these effects are well known in the student's community. Unconsidered sources of errors lead to undetected failures of the control because the corresponding environmental situation was not simulated before [10].

That's why, a fault free design algorithm finally should be tested on real electro-mechanical models (e. g. the Water level control unit, shown in Figure 3) in the Remote Laboratory (*rapid prototyping*).



Figure 3. Hardware model of the Water level control unit

The *partitioning* of the control task into software and a hardware part is an essential step in the design process.

During the *synthesis* phase, code for the processor (software) and/or for the programmable logic (hardware) is generated by different design tools. Both parts (software and hardware) can be executed and evaluated on the hardware platform directly.

Assuming real laboratory conditions, disturbances can occur, causing special working conditions. Including such real disruptive factors to an algorithmic test leads in contrary to simulation to a distinctly closer relation to practical conditions. Furthermore, it should stimulate student's interest in the design of safety critical control

systems. Additionally, we would like to give the students the chance to verify their prepared control algorithms and to correct or modify them accordingly to the received results.

III. A TOOL SET FOR RAPID PROTOTYPING BASICS

Especially for Bachelor studies, we developed – in cooperation with the University of Cooperative Education Thuringia in Gera – a Rapid Prototyping board, shown in Figure 4 [6].



Figure 4. Stand-alone Rapid Prototyping board

Because of the special conceptual design of this board, students can test all the taught topics of the given lectures, e.g. basics of Boolean algebra, combinational logic and simple sequential circuits. Furthermore, they can apply and compare different functional specification techniques (e.g. logical equation, truth table, schematic diagram) with the ability for both local and Web-based remote access.

By using common design tools (e.g. MaxPlus+, QuartusII from Altera [11]), the student is able to specify his design via

- *text based* design methods,
- Here the student can enter his design by means of logical equations, truth tables or hardware description languages (AHDL, VHDL or Verilog).
- *graphically* based design methods,
- The student can use block or schematic diagrams to input his design.
- *integrated FSM editors*.
- In case of sequential design tasks he can directly enter the derived automaton graph (or graphs of parallel automata) with the built in FSM editor.
- The editor itself generates VHDL code for the further design steps.

Another use case of the Rapid Prototyping board is to identify the function of a given design (black box). The FPGA was programmed by the teacher - the student has no ability to reprogram the device.

By manipulating the inputs of the design (e.g. to enter all the input sets of a truth table or special input test vectors), the student attempts to analyse the response (the output signals) in order to find out the function of the given design.

For the Web-based Rapid Prototyping ability we have developed a Web-interface as Java applet. By using this Web-interface, the student is able to

- upload his design,
- program the FPGA,
- handle the lab procedure.

The applet allows the student to manipulate all the inputs of the Rapid Prototyping board (slide switches, HEX-code switches, and pushbuttons).

He can observe the outputs of the board (7-segment displays, row of LEDs) virtual inside the Java applet.

For the look-and-feel of the applet, we use a “photo” of the board as background. All the inputs are realized as Java control elements and can be manipulated via the mouse interactively. The outputs are illuminated directly inside the “photo” elements. That’s why, it is not necessary to use an additional Webcam to observe the board in the lab room. The control and communication between the applet and the Rapid Prototyping board is established via text based Telnet commands. Debug messages are displayed in a status window (placed over the FPGA circuit). Figure 5 gives an impression of the applet’s Web-interface including the photo of the Rapid Prototyping board.

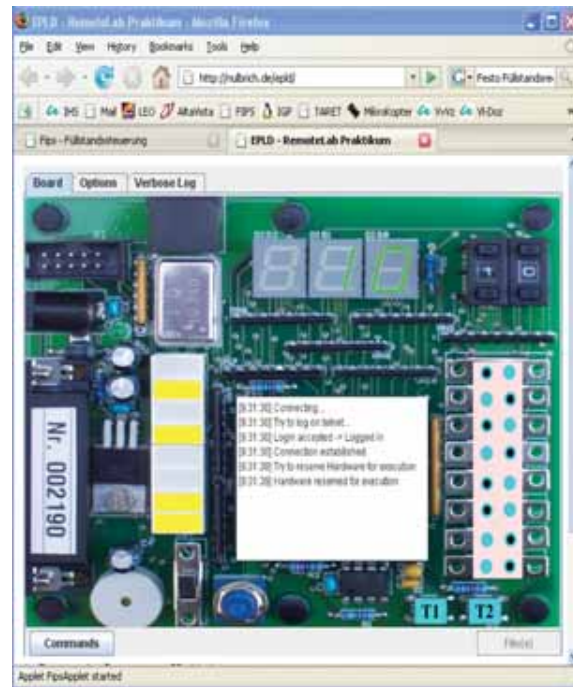


Figure 5. Web-interface of the Rapid Prototyping board

IV. ARCHITECTURE OF A WEB-BASED RAPID PROTOTYPING PLATFORM

An example for a tool set, supporting all the above mentioned design steps for complex control tasks, is the *REAL*¹ system, developed at the Department of Integrated Hardware and Software Systems at the Ilmenau University of Technology [12] – see Figure 6. As mentioned in many papers (for instance [13-15]), Remote Labs can open opportunities, allowing an experimental approach for a wider audience and an independence of opening times of the laboratory as well.

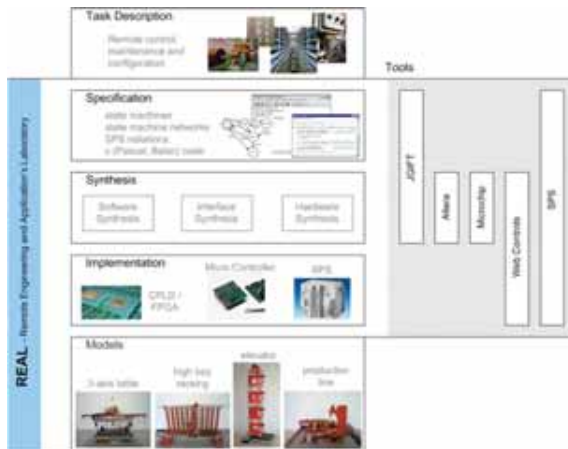


Figure 6. Overview of the *REAL* project

The *REAL* system offers various features. Visualization and animation allow observing and testing the properties of the design. In connection with formal design techniques, simulation and prototyping are used to establish a foundation for the development of a reliable system design during the first iterations of a cyclic design approach.

To check the functionality of the whole design, some special simulation and validation features are included as integral part of the *REAL* system. This offers various possibilities for the execution of simulations, e. g.:

- generation of executable visual prototypes from the general design and parts of it as well,
- properties for step by step and parallel execution of these prototypes,
- visualization of the simulation process with the tools, used for specification as well,
- features for test pattern generation,
- possibilities for analysing the simulation process offline afterwards,
- code generation for hardware and software synthesis as a result of the partitioning process.

REAL offers a Web-based environment including verification and simulation features to generate and execute a design within visual prototypes (e.g. the visual prototype of the Water level control, shown in Figure 7).

¹ Goal of the project *REAL* (Remote and Applications Laboratory) is to show new ways and chances of remote controlling and remote observation of real processes (e. g. in the fields of control engineering, robotics, tele-control engineering), dealing with integrated and interactive usage of modern internet and intranet technologies, like WWW, HTML, Java etc.

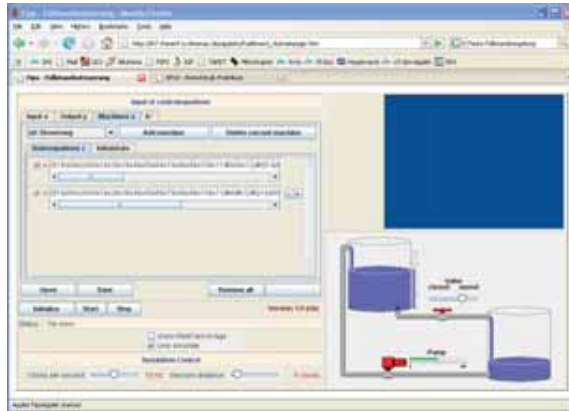


Figure 7. Visual Prototyping (offline control) of the Water level control - without Internet connectivity to the Remote Lab

As discussed in the beginning, it is furthermore necessary for students to test their design under real environmental conditions in the Remote Lab. For these purposes, we have developed a Web-interface to control the tools and models. By using this Web-interface (as shown in Figure 8), the student is able to

- download the synthesized hardware and/or software design algorithms - generated and already validated by the *REAL* environment - to test his control algorithm on the real hardware model in the lab room,
- handle the laboratory procedure (start, stop, reset),
- change environmental variables if necessary and
- watch the laboratory procedure by supervising the model and environmental variables inside an I/O monitor or by observing the hardware model directly via a Web-Cam.

At any time the student has the chance to adjust his algorithm in case of fault. Therefore, he is able to achieve a fault free solution (a validated control algorithm) step by step. For more details see [3,10,19].

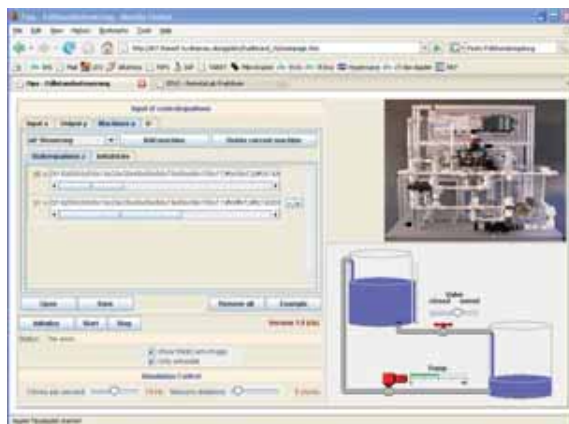


Figure 8. Online control of the Water level control - with Internet connectivity to the Remote Lab

To provide a single user access, a kind of “locking” has to be implemented. It is also required to restrict the access time to the server. This restriction offers an equal chance to work with the Remote Lab for students. That’s why, the following mechanisms will be examined:

- authentication,
- locking using a file,
- locking using a background process,
- locking interactions.,

Apart from the design of the hardware equipment, the focus is set to the “**Remote Lab Server**” (RLS), developed at the Department of Integrated Hardware and Software Systems [5]. It supports various ways of

- client or server based operation of the designed control algorithms,
- access controlling of different users (authentication, LDAP interface),
- global or local networking/communication,
- interactive process manipulation (starting/stopping of the system, influencing environmental variables),
- supervising the hardware equipment via Web-Cam (a video camera with internet connectivity) as well as
- additional support e.g. by mail, chat etc.

On the basis of the plug-in structure of the RLS, new lab tasks, new control mechanisms, new hardware models or even Remote Labs, located at other universities, can be integrated in a flexible way.

In order to ensure an even larger flexibility and utilization of the Remote Lab, it is necessary to connect various variants of the existing Web-control units (Beck-IPC, Microcontroller, FPGA etc. – see next section) directly to a hardware model via the Internet. This is done by an “IP-switch” – a Web-based multiplexer (see Figure 9). Furthermore, this switch can handle necessary support functions like lighting of the hardware setup for each model.

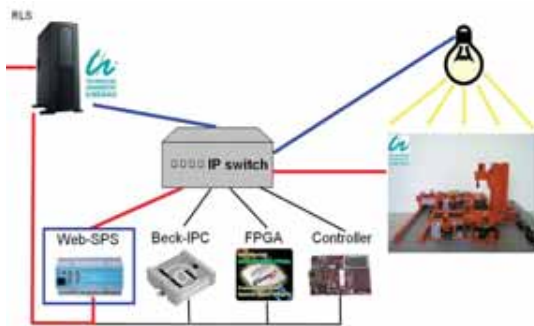


Figure 9. IP switch for the connection model – control unit

V. FIELDS OF APPLICATION OF THE *REAL* SYSTEM

As shown in Figure 10, the *REAL* system supports the design of control algorithms with different specification techniques by an integration and usage of proprietary design environments (e.g. the *JGIFT* system – see next section) as well as non-commercial software products (e.g. using Quartus II for a hardware-oriented VHDL design or using MPLAB respectively to develop Assembler or C software projects).

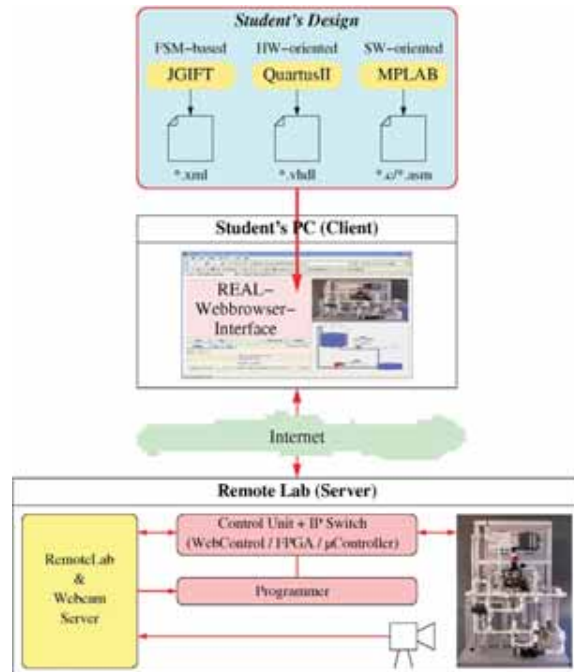


Figure 10. Usage of different description techniques for the design

The students only have to develop the actual control implementation – all additional tasks like

- model self protection mechanisms,
- interface declaration and
- voltage conversion 5/24V

are implemented in separate hardware/software modules, which will be included automatically and compiled within the whole hardware/software project.

One implementation problem, we had to solve, is to protect the Remote Lab against wrong control algorithms of unskilled students. We didn’t want to define so many constraints that only one solution of a design is possible. On the contrary, students should be free in their decisions and develop own creative solutions. They can create their own design strategies and can decide the granularity of control steps as well. The solution, to protect the Remote Lab, is to have a **reference design** and a method to check the students design against this reference design step by step [16] during the execution. Figure 11 shows this idea.

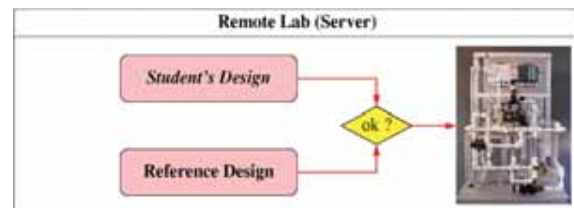


Figure 11. “Observation” of the Student’s design

All input values are inspected by the reference design and the student's design. If the student's design as well as the reference design produces the same output value, the result can be sent to the real hardware model.

The possibilities of the *REAL* system (as shown in Figure 10) we present here exemplarily. Some examples of the Student's design will be discussed in the following.

A. Stand-alone usage of system components

The simplest way to use various components of the *REAL* system is a stand-alone solution to control an application (without internet connectivity). This approach should not be focus of this article and is therefore not discussed.

B. FSM oriented control

In case of using Finite State Machines as specification technique, based upon an automaton graph, a student can use the *JGIFT* system – a built in design environment of the *REAL* platform.

The abbreviation “*JGIFT*” describes the objectives of this experimental system and stands for

- Java based
- Graphical
- Interactive
- FSM
- Tools

The *JGIFT* system offers different features. Visualization and animation allow observing and testing the properties of the design. In connection with formal design techniques, simulation and prototyping are used, leading to a foundation for the development of a reliable system design during the first iterations of a cyclic design approach.

To check the functionality of the whole design, some special simulation and validation features are included as integral part of the *JGIFT* system. This offers various possibilities for the execution of simulations, e.g.:

- generation of executable visual prototypes from the general design and parts of it as well,
- possibilities for step by step and parallel execution of these prototypes,
- visualization of the simulation process in the tools, used for specification (e.g., FSM editor),
- features for test pattern generation,
- possibilities for analysing the simulation process offline afterwards,
- code generation for hardware and software synthesis as a result of the partitioning process.

Figure 12 gives an impression of the integrated *JGIFT* design environment. The modules of the system can be used as stand-alone Java applet or via the Internet, embedded into any Web-browser. For more details see [7,18].

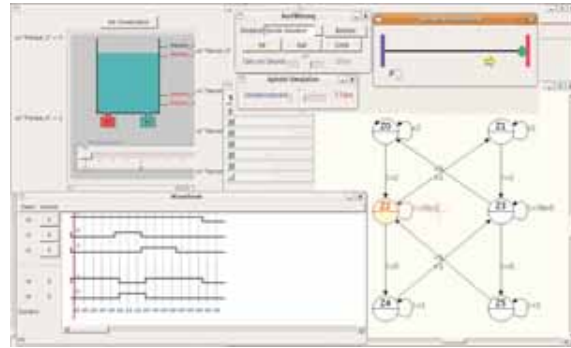


Figure 12. Some features of the *JGIFT* design environment

Assuming, the student achieved a validated design, he gets the required next state and the output equations. By accessing the Web browser interface of the *REAL* system (see Figure 10), he is able to enter his created control algorithm (the received equations), handle the laboratory procedure (start, stop, reset) and change environmental variables if necessary.

These equations for model control, are executed through an *interpreter* – located either on the client or server side.

When using the „client based“ remote control the hardware model will be controlled “from a distance” through the interpreter running inside the client (implemented e.g. as Java applet). In this case, only the input and output signals of the model will be transferred via Internet.

When executing the control algorithm “server based”, the required equations have to be transferred from the browser via the Web server to the interpreter running inside (on the spot) the embedded system only once a time. In this case, the interpreter exchanges data with the model I/O interface directly.

For a detailed description see [4,5].

C. Software oriented control

Students can implement their design task directly into a microcontroller for a software oriented specification.

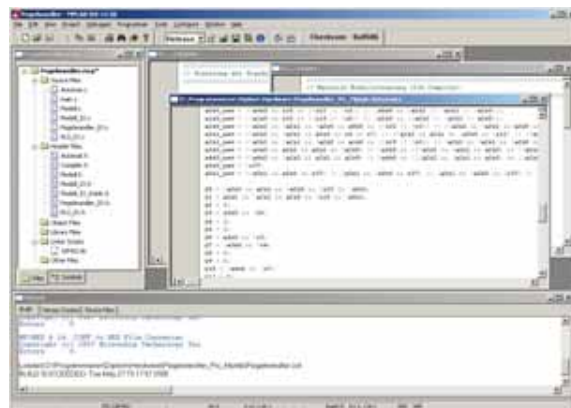


Figure 13. Usage of the MPLAB IDE for a software oriented design

Therefore, they use common (non-commercial) development tools, (e. g. MPLAB IDE and/or C18 C compiler from Microchip [17] to develop Assembler and/or C software projects) shown in Figure 13.

The generated software control module (Assembler or C code) is then transferred via *REAL* Web-interface to the Remote Lab Server (see Figure 10). The Server automatically embeds the control module into a locally stored workbench project which ensures model safety etc. After compilation, the project is programmed into the microcontroller. Now, the student can begin with his lab work to proof, if his algorithm fulfils the requirements of the given task.

A software implementation of the control task is suitable for simple and non time-critical requirements.

D. Hardware oriented control

If a student prefers an exclusive hardware oriented design (without any software components), using a hardware description language like VHDL or AHDL as specification technique, he can prepare his design task with common development tools - e.g. MaxPlus+, Quartus II- shown in Figure 14. The generated hardware module (e.g. a VHDL module) is uploaded via the *REAL* Web-interface to the Remote Lab Server (see Figure 10) which will synthesize the code using a locally stored workbench project to ensure model safety, etc. After programming the connected FPGA, the student can begin his lab work.

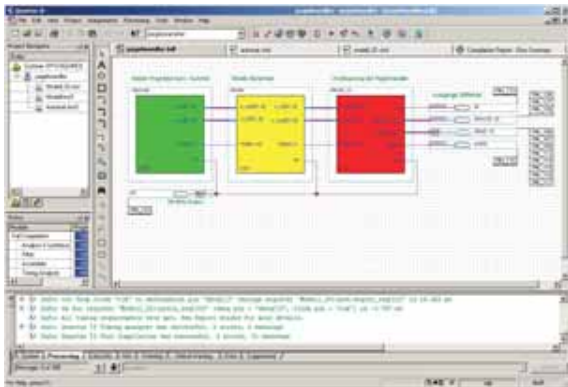


Figure 14. Usage of the QuartusII IDE for a hardware orientated design

For time-critical as well as parallel applications, a hardware implementation of the control task is the preferred solution.

VI. CONCLUSION

A universal hardware platform has been discussed which can be used for Rapid Prototyping of digital control systems for complex control design tasks including the ability for both local and Web-based remote access.

In the projects present state, only one student at a time can gain access to the hardware model (single user mode). In future, this project will offer cooperative work features (multi user mode). Therefore, it is possible to manipulate the hardware model simultaneously via several parallel control algorithms of a distributed control prepared by various students.

For an effective usage of the *REAL* system within Learning Management Systems (LMS), the reference

design and a method to check the students design against this reference design step by step will be traced by the LMS. Figure 15 shows this idea.

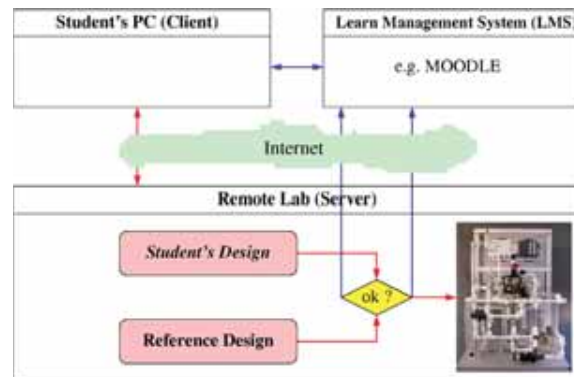


Figure 15. Observation of the student's design under LMS control

If the student's design as well as the reference design produces the same output value, the result can be sent to the Remote Lab. Otherwise, the LMS will be informed and the student gets some hints to correct his design. For a detailed description see [16,20].

Our Department of Integrated Hardware and Software Systems at the Ilmenau University of Technology is involved in different national and international e-Learning projects ([1,21]) where it is increasingly necessary to allow and organize a shared use of equipment. That's why, the main focus of the project *REAL* is a Web-wide usage of different design tools as well as Remote Labs for digital control tasks.

Using both, online tool support and laboratories, has the potential of removing the obstacles of cost, time-inefficient use of facilities, inadequate technical support and limited access to design and laboratory resources. It is also a benefit for students and researchers with special needs and students/researchers working from home, so they do not have to travel to their companies' facilities to perform their needed work. Even students/researchers working at their university's facilities can easily access remote specialized equipment located at another university without travelling.

Students will learn more about the opportunities and limits of remote control and observation via Internet on practical examples. The student – beside knowledge consolidation through design and practical experiments using these new Internet technologies – is forced to estimate the technologies critically.

During the implementation of the *REAL* system, great importance was attached to the

- reuse of the applied methods and tools for similar problems,
- reuse of the developed software modules,

which will finally lead to synergy effects in the production process of different Remote Engineering tools.

It is planned to use the *REAL* system within the TARETⁱ summer school "Remote and virtual Applications" 2009 in Maribor/Slovenia. The goal is to mediate fundamentals, applications and experiences in these fields of remote engineering by an interdisciplinary approach in

combination with “learning by doing” phases. In this way, we promote transnational cooperation and exchanges between students and teachers of five universities; encourage efficient and multinational teaching of special topics, which could not be taught in this quality in the partner universities of the MARE project [1].

We believe that Remote Engineering provides the ideal framework for exploring new ideas in collaborative virtual reality environments, advanced scientific visualization and advanced interfaces to high-performance computing systems and laboratories.

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ⁱ TARET – The intensive program “Training in advanced remote technologies” is part of the implementation of the MARE (Master study program in Remote Engineering – see [21]) curriculum.

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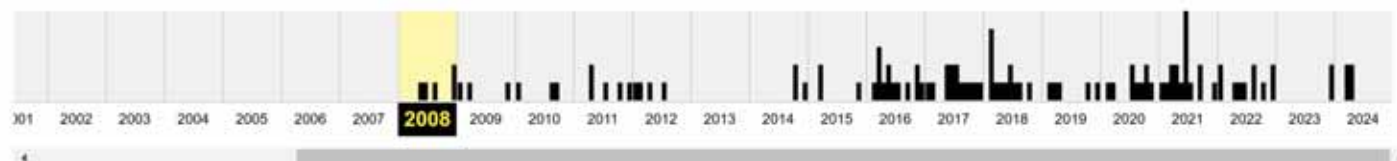
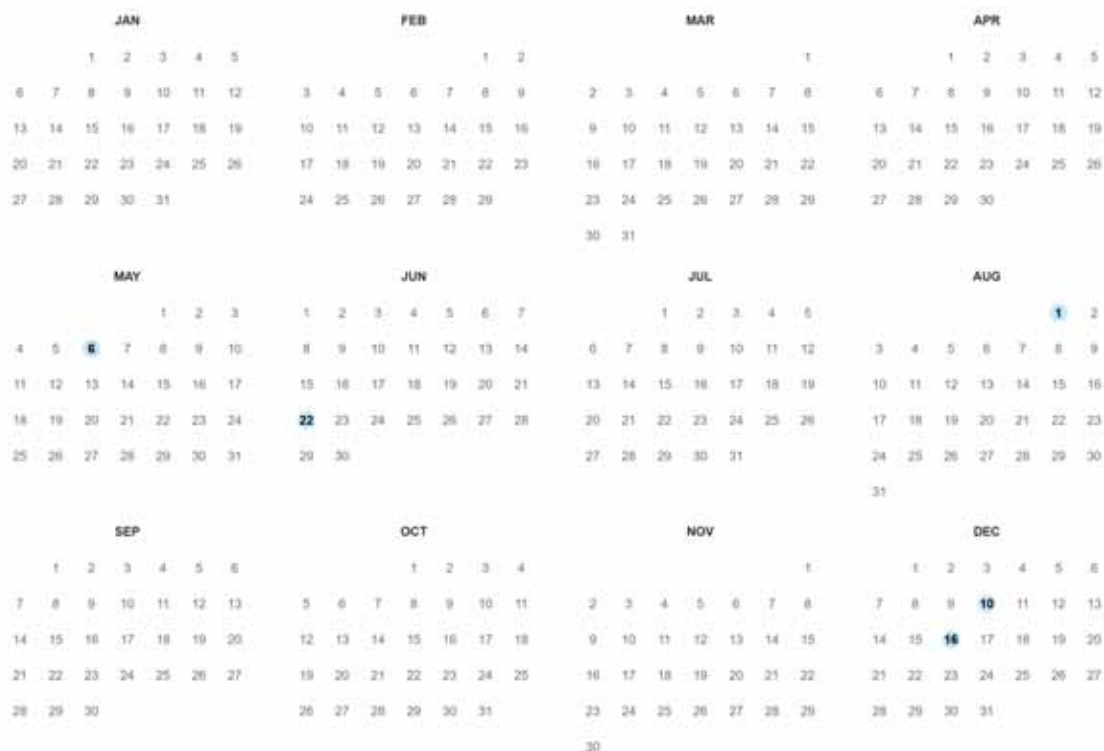
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