Abstract

MERL Annual Report
July 2009 through June 2010

Mitsubishi Electric Research Laboratories

This work may not be copied or reproduced in whole or in part for any commercial purpose. Permission to copy in whole or in part without payment of fee is granted for nonprofit educational and research purposes provided that all such whole or partial copies include the following: a notice that such copying is by permission of Mitsubishi Electric Research Laboratories, Inc.; an acknowledgment of the authors and individual contributions to the work; and all applicable portions of the copyright notice. Copying, reproduction, or republishing for any other purpose shall require a license with payment of fee to Mitsubishi Electric Research Laboratories, Inc. All rights reserved.
Production:
Karen Dickie, Janet O’Halloran, Richard C. Waters
# Table of Contents

Mitsubishi Electric Research Laboratories ..............................................................1  
Awards and Commendations ...................................................................................7  
Technical Staff .........................................................................................................9  
Publications ............................................................................................................23  
Research .................................................................................................................33 
  Digital Communications .......................................................................................35  
  Multimedia ..........................................................................................................43  
  Data Analytics ........................................................................................................51  
  Imaging ..................................................................................................................57  
  Mechatronics .........................................................................................................65  
  Algorithms ............................................................................................................69
Mitsubishi Electric Research Laboratories

Mitsubishi Electric Research Laboratories (MERL) is the North American subsidiary of the corporate research and development organization of Mitsubishi Electric Corporation. MERL conducts application-motivated basic research and advanced development in communications, image/video processing, data analysis and mechatronics technology.

MERL’s mission—our assignment from Mitsubishi Electric—is twofold.

- Generating new technology in areas of importance to Mitsubishi Electric.
- Significantly impacting Mitsubishi Electric’s business: using our technical expertise in partnership with organizations in Mitsubishi Electric to produce new and improved products in Mitsubishi Electric’s main areas of business.

MERL’s vision—our goal for ourselves—is also twofold.

- To be one of the world’s premiere research laboratories, significantly advancing the frontiers of technology and making lasting impacts on the world.
- To be the prime source of technology for Mitsubishi Electric in our areas of expertise.

MERL focuses on five principal technology sectors:

- Digital Communications - featuring wired & wireless transmission technology & networking.
- Multimedia – featuring speech interfaces and the encoding, decoding & analysis of video.
- Data Analytics – featuring predictive and decision analytics.
- Imaging – featuring computer vision algorithms and the observation of people in images.
- Mechatronics – featuring advanced control of electro-mechanical systems.

An Algorithms group supports all five sectors, developing fundamental algorithms.

MERL is small enough to be agile and flexible in the dynamic marketplace of ideas. However, we gain leverage from the size, reputation, and diversity of our strong global parent. We turn our technical achievements into business successes by partnering with Mitsubishi Electric’s business units and with other labs in Mitsubishi Electric’s global R&D network.

We are strongly involved in the R&D community and standards activities, maintaining long-standing cooperative relationships with a number of research universities including MIT, CMU, UC Berkeley, Georgia Tech and Harvard. We encourage our staff to be involved in their professional communities via conferences, papers, and continuing professional development.

MERL’s output ranges from papers and patents, through proof-of-concept hardware and software prototypes, to modules for industry-first products.

This annual report is a snapshot of MERL’s web site. For additional and updated information please visit “http://www.merl.com”.

Richard C. Waters
President, MERL
MERL Organization

MERL is organized as six groups centered on technology areas, which collaborate closely to achieve groundbreaking results. We use a relatively flat organization to enhance the opportunities for collaboration within MERL. The four members of the top management team work closely together, guiding all aspects of MERL’s operation.

Richard C. (Dick) Waters  Ph.D., MIT, 1978
President, Chief Executive Officer & Research Fellow

Dick Waters received his Ph.D. in artificial intelligence (AI). For the next 13 years he worked at the MIT AI Lab as a Research Scientist and co-principal investigator of the Programmer’s Apprentice project. Dick was a founding member of MERL’s Research Lab in 1991. As a MERL researcher, his work centered on multi-user interactive environments for work, learning, and play. For this work, he was made a MERL Research Fellow in 1996. In December 1999, he became CEO of MERL as a whole. In addition to his duties at MERL, Dick is currently a member of the board of directors of the Computing Research Association.
Masahiro Fujita  M.S., The University of Tokyo, 1983  
Executive Vice President, Chief Financial Officer & Chief Liaison Officer

Masahiro Fujita joined Mitsubishi Electric’s Industrial Electronics & Systems Laboratory in 1983 where he developed motion control technologies for industrial robots and other equipment. He moved to the Factory Automation Business Unit’s Nagoya works in 1999. He transferred to the Advanced Technology R&D Center in 2002 where he rose to Senior Manager of the Mechatronics Department, before coming to MERL in 2008.

Joseph Katz  Ph.D., California Institute of Technology, 1981  
Vice President & Director

After working at Caltech’s Jet Propulsion Laboratory for a number of years, Joseph Katz went to Symbol Technologies, where as Senior VP of R&D he participated in, initiated, and led projects in a wide range of technologies, including barcode/RFID data capture, optics, imaging, signal processing, computing, networking, security, biometrics, and communications. He joined MERL’s management in 2004.

Kent Wittenburg  Ph.D., University of Texas at Austin, 1986  
Vice President & Director

Kent Wittenburg performed research at the Microelectronics and Computer Technology Corporation (MCC), Bellcore, and Verizon/GTE laboratories. His research focused on Human-Computer Interaction (HCI) technologies and he managed groups in natural language interfaces and Internet technologies. He joined MERL in 2001 as the leader of speech and HCI research and was promoted to Director in 2002. He is a Senior member of the ACM.
Mitsubishi Electric

One of the world’s largest companies, Mitsubishi Electric Corporation (Mitsubishi Electric) has $36 billion in annual sales, $1 billion in operating profits (in the very difficult year ending in March 2010) and more than 100,000 employees around the world.

Mitsubishi Electric is composed of a wide range of operations. The primary business units are listed below.

<table>
<thead>
<tr>
<th>Mitsubishi Electric Corp.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Information Systems &amp; Network Services</strong></td>
</tr>
<tr>
<td><strong>Public Utility Systems</strong></td>
</tr>
<tr>
<td>Government Systems, Transportation Systems, Very Large Display Devices</td>
</tr>
<tr>
<td><strong>Energy &amp; Industrial Systems</strong></td>
</tr>
<tr>
<td>Electrical Generators, Power Transmission and Distribution Equipment</td>
</tr>
<tr>
<td><strong>Building Systems</strong></td>
</tr>
<tr>
<td>Elevators, Escalators, Building Monitoring/Security/Management Systems</td>
</tr>
<tr>
<td><strong>Electronic Systems</strong></td>
</tr>
<tr>
<td>Satellites, Radar Systems, Antennas, Electronic Toll Collection Systems</td>
</tr>
<tr>
<td><strong>Communication Systems</strong></td>
</tr>
<tr>
<td>Wired &amp; Wireless Communication/Broadcasting Equipment and Systems</td>
</tr>
<tr>
<td><strong>Living Environment &amp; Digital Media Equipment</strong></td>
</tr>
<tr>
<td>Televisions, Blu-ray Recorders, Air Conditioners, Solar Power Systems</td>
</tr>
<tr>
<td><strong>Factory Automation Systems</strong></td>
</tr>
<tr>
<td>Programmable Logic Controllers, Inverters, Servo-motors, Processing Machines</td>
</tr>
<tr>
<td><strong>Automotive Equipment</strong></td>
</tr>
<tr>
<td>Automotive Electrical Equipment, Car Electronics/Multimedia, Car Mechatronics</td>
</tr>
<tr>
<td><strong>Semiconductor &amp; Device</strong></td>
</tr>
<tr>
<td>Optical Devices, High-Frequency &amp; High-Power Semiconductors</td>
</tr>
</tbody>
</table>

Together, these ten business units produce most of Mitsubishi Electric’s revenue. Due to the wide applicability of MERL’s research, MERL works with them all.

It is worthy of note that there are over 30 major independent companies in the world that use the word “Mitsubishi” in their names. These companies include Mitsubishi UFJ Financial Group, Mitsubishi Corporation, Mitsubishi Heavy Industries, Mitsubishi Chemical Holdings and Mitsubishi Motors, all of which are also among the world’s largest companies. They have shared roots in 19th century Japan; however, they have been separate for many years and Mitsubishi Electric has been separate from all of them since its founding in 1921.
Mitsubishi Electric’s US Operations

A significant part of Mitsubishi Electric’s sales are in North America and many of Mitsubishi Electric’s business units have North American subsidiaries. The largest US operations are listed below.

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitsubishi Digital Electronics America, Inc.</td>
<td>Los Angeles, Mexicali MX</td>
</tr>
<tr>
<td></td>
<td>High Definition Projection Televisions, DVD Recorders</td>
</tr>
<tr>
<td>Mitsubishi Electric Automotive America, Inc.</td>
<td>Detroit, Mason OH</td>
</tr>
<tr>
<td></td>
<td>Alternators, Ignition Coils, Automotive Electronics</td>
</tr>
<tr>
<td>Mitsubishi Electric United States, Inc.</td>
<td>Los Angeles &amp; other cities</td>
</tr>
<tr>
<td></td>
<td>Semiconductors, Air Conditioners, Elevators, Photovoltaic Panels</td>
</tr>
<tr>
<td>Mitsubishi Electric Power Products, Inc.</td>
<td>Pittsburgh</td>
</tr>
<tr>
<td></td>
<td>Power Transmission Products</td>
</tr>
<tr>
<td>Mitsubishi Electric Automation, Inc.</td>
<td>Chicago</td>
</tr>
<tr>
<td></td>
<td>Factory Automation Equipment</td>
</tr>
</tbody>
</table>

Mitsubishi Electric Corporate R&D

Mitsubishi Electric has a global R&D network comprising five laboratories. The chart below summarizes the primary activities of these labs. MERL collaborates with all of these labs.

<table>
<thead>
<tr>
<th>Corporate R&amp;D Headquarters (Tokyo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Technology R&amp;D Center (Amagasaki &amp; Nagaokakyō, in greater Osaka)</td>
</tr>
<tr>
<td>Information Technology R&amp;D Center (Ofuna, in greater Tokyo)</td>
</tr>
<tr>
<td>Information, Communications, Multimedia, Electro-Optic and Microwave Technologies</td>
</tr>
<tr>
<td>Industrial Design Center (Ofuna, in greater Tokyo)</td>
</tr>
<tr>
<td>Product, Interface and Concept Design</td>
</tr>
<tr>
<td>Mitsubishi Electric Research Laboratories, Inc. (Boston)</td>
</tr>
<tr>
<td>Communications, Multimedia, Data Analytics, Imaging and Mechatronics Technologies</td>
</tr>
<tr>
<td>Mitsubishi Electric R&amp;D Centre Europe, B.V. (Rennes, France &amp; Guildford, England)</td>
</tr>
<tr>
<td>Communications, Digital Video, Energy &amp; Environment Technologies</td>
</tr>
</tbody>
</table>
Awards and Commendations

The high caliber of MERL’s research and researchers is evident in a variety of ways. Two are highlighted below. The first is the members of our staff that are Fellows of technical societies. The second is best paper awards received from outside organizations. Listed below are awards for the period of this Annual Report.

Current Technical Society Fellows

Dr. Joseph Katz, Fellow Institute of Electrical and Electronic Engineers
Dr. Joseph Katz, Fellow Optical Society of America
Dr. Huifang Sun, Fellow Institute of Electrical and Electronic Engineers
Dr. Jin Zhang, Fellow Institute of Electrical and Electronic Engineers

Best Paper Awards

Venkatraman, V.; Porikli, F.M., "RelCom: Relational Combinatorics Features for Rapid Object Detection", *IEEE Workshop on Object Tracking and Classification Beyond and in the Visible Spectrum*, Robust Object Detection, June 2010. (Best paper award.)


Shibata, H.; Kato, M.; Kori, M.; Yerazunis, W., "An Automatic Training Data Collection Method for Confidential E-mail Detection", *The Forum on Data Engineering and Information Management (DEIM)*, February 2010. (Best paper award.)


It is also worthy of note that MERL’s Imaging group had 7 papers accepted to CVPR 2010 — the most selective and prestigious Computer Vision Conference. Similarly, MERL’s Digital Communications group had 7 papers accepted to GLOBECOM 2009 and 10 papers accepted to ICC 2010 — the two most selective and prestigious Conferences on Digital Communications. These results makes MERL one of the most highly represented research labs in the world at CVPR, GLOBECOM and ICC, with output greater than labs that are much larger.
Technical Staff

The most important assets of MERL are its people. The following pages present the capabilities and interests of MERL’s technical staff members as of the end of the period of this report. Additional information about their work can be found in the publications list and the project descriptions in this report. Complete information can be found in people’s individual web pages at “http://www.merl.com/people”.

Amit K. Agrawal  Ph.D., University of Maryland, 2006
Member Research Staff

Prior to his graduate studies, Agrawal worked as a DSP engineer at Hughes Software Systems, India. His research interests are in computer vision, image processing and computational photography. Current research includes motion photography, flash photography, surface reconstruction from gradient fields, high dynamic range imaging, and image editing under variable illumination using gradient domain methods.

Ramesh Annavajjala  Ph.D., University of California at San Diego, 2006
Member Research Staff

Annavajjala jointed MERL in 2008. Prior to that, he was a Systems Research Engineer at ArrayComm LLC, in San Jose, CA., working for the development of advanced interference cancellation algorithms for next generation wireless standards. He received a best paper award from the IEEE WPMC 2009 conference.

Luigi (Lou) Baccari  B.S., University of Massachusetts of Lowell
Manager Computational & Network Services

Baccari has 23 years of experience in the System and Network Administrations field. For the 6 years prior to joining MERL he worked at HP/Compaq's Cambridge Research Labs providing System and Network. Previous to that he worked for Force Computers, Lycos and Digital Equipment Corp. as Data Center Manger and in various System/Network Support roles.

John C. Barnwell III
Associate Member Research Staff

John Barnwell is a former Software Engineer developing configuration and database systems for the aircraft manufacturing, food processing, large truck manufacturing, and computer manufacturing industries. His current personal interests include amateur radio, CNC control systems, and mechanical and electrical design.
Ghulam M. Bhatti  Ph.D., Boston University, 1998
Principal Member Research Staff
For his thesis, Bhatti specialized in distributed and parallel discrete event simulation. Before joining MERL in 2000, he worked as a Sr. Software Engineer at Evare LLC, Inc, developing software for a network switch and implementing an RSA cryptographic scheme. He also worked at Excel Tech. Ltd. (XLTEK) developing embedded software for a portable EEG device. Currently, he is working on Home Networking and Digital TV.

Scott A. Bortoff  Ph.D., University of Illinois Urbana Champaign, 1992
Mechatronics Group Manager
After receiving his Ph.D., Scott became a professor in the Electrical and Computer Engineering department at the university of Toronto. More recently Scott worked at the United Technology Research Center, where he founded the Control Technology group and then managed that group as well as the Control Systems group.

Petros T. Boufounos  Sc.D., Massachusetts Institute of Technology, 2006
Member Research Staff
Before joining MERL in 2009, he was with the Digital Signal Processing Group at Rice University doing research in the area of Compressive Sensing. In addition to compressive sensing, his immediate research interests include signal processing, data representations, frame theory, and machine learning applied to signal processing.

Matthew E. Brand  Ph.D., Northwestern University, 1994
Distinguished Member Research Staff
Brand studies unsupervised learning from sensory data. His results include spectral solutions for reconstructing manifolds from samples, decision-theoretic elevator group control, a linear-time online SVD, recovery of non-rigid 3D shape from ordinary video, and an entropy optimization framework for learning. He has received best paper awards in computer vision (CVPR2001) and scheduling (ICAPS2003).

Dirk Brinkman  J.D., Suffolk University Law School, 1990
Patent Counsel
Brinkman’s undergraduate and Masters work was in Medical Physics. Prior to joining MERL in 1998, he spent most of his career at Digital Equipment Corporation, first as an engineer and product manager in the Medical Systems Group and then as a Patent Attorney for Digital’s Research Laboratories in Cambridge MA and Palo Alto CA.
Christian M. Chilan  Ph.D., University Illinois Urbana Champaign, 2009
Visiting Member Research Staff
Christian’s research interests include optimal control and numerical optimization. His graduate work focused on the optimization of spacecraft trajectories and missions. He also carried out research in the performance of parallel computing systems while working at the HDF Group.

Robert A. Cohen  Ph.D., Rensselaer Polytechnic Institute, 2007
Principal Member Research Staff
Prior to getting his Ph.D., Robert Cohen worked for 11 years at Philips Research Labs in NY on HDTV, scalable video streaming, video surveillance, and rapid prototyping for VLSI video systems. His current research interests are algorithms and architectures for video coding and communications, and video, image and signal processing. He is currently researching video transcoding and next-generation video coding algorithms.

Chunjie Duan  Ph.D., University of Colorado at Boulder, 2008
Senior Principal Member Research Staff
Prior to joining MERL, he worked for Alcatel, Qualcomm and Ericsson and other telecom companies for over 10 years. His research interests are in wireless and optical communications, digital signal processing and VLSI/CAD technology. He is currently working on Ultra-Wideband system development and LSI implementation.

Huseyin Erdim  Ph.D., University of Connecticut Storrs, 2009
Visiting Member Research Staff
During his master studies, Huseyin worked on improving productivity in free-form surface machining based on the physics of the cutting process, for which he received an Outstanding Young Researcher Award from the Japan Society of Mechanical Engineers in 2005. His research interests include theoretical and computational tools for systematic mechanical design, manufacturing and analysis.

Alan W. Esenther  M.Sc., Boston University, 1993
Principal Member Research Staff
Esenther enjoys human-computer interaction (HCI) design, distributed software development, graphical user interfaces and Internet technologies. His recent work has focused on touch applications that support multiple concurrent users (think multiple mice), rapid image presentation for video browsing, and instant co-browsing (lightweight real-time distributed collaboration using unmodified web browsers).
Tyler W. Garaas  Ph.D., University of Massachusetts Boston, 2009
Visiting Member Research Staff
Garass was a member of the visual attention laboratory at U. Mass. Tyler earned his bachelor's degree in computer science at Montana State University. His work at UMass Boston included human visual attention studies, neural modeling of primate visual systems, and robotics.

Abraham M. Goldsmith  M.S., Worcester Polytechnic Institute, 2008
Associate Member Research Staff
Abraham Goldsmith has five years industry experience as a design Electrical Engineer and holds a masters in Electrical Engineering from Worcester Polytechnic Institute. He's also very good at mechanical design and is a "shop demon".

Jianlin Guo  Ph.D., Windsor University, 1995
Principal Member Research Staff
Jianlin Guo received his Ph.D. from University of Windsor in 1995. He worked at Waterloo Maple as a software developer before joining MERL in 1998. His primary research interests include reliable wireless networks, SmartGrid systems, vehicular communications, broadband wireless communications, and embedded systems.

Bret A. Harsham  B.S., Massachusetts Institute of Technology
Principal Member Research Staff
Harsham joined MERL in 2001 to pursue interests in speech interfaces and speech-centric devices. Previously, Bret spent 3 1/2 years at Dragon Systems designing and implementing handheld and automotive speech products. Earlier, he was a principal architect of a Firewall and Virtual Private Network product. Harsham’s other technical interests include distributed architectures, knowledge representation, and language theory.

Mohamed E. Hussein  Ph.D., University of Maryland, College Park, 2009
Visiting Member Research Staff
Mohamed's Ph.D. research spanned visual object detection and parallel computing on graphics processing units. His research interests include computer vision, machine learning, and parallel computing.
Hiroshi Ichibangase  M.S., The University of Kyusyu, 1984  
Vice President and Director of Liaison

Ichibangase joined Mitsubishi Electric CR&D in 1984, developing optical communication equipment. He spent two years in the US in 2002-4 and then two years in the communications business unit. Returning to CR&D, he rose to become Senior Manager of the Optical Communication Technology Department, before coming to MERL in 2010.

Frederick J. Igo, Jr.  B.A., LeMoyne College, 1982  
Senior Principal Member Research Staff

Igo’s professional interests are in software development and its process. He joined MERL in 1985 and has worked on various software technologies, including Distributed Computing, Distributed OLTP, Message Queuing, Mobile Agents, OLAP/MDDB and Data Mining. Prior to joining MERL Fred worked at IPL systems.

Yuri A. Ivanov  Ph.D., Massachusetts Institute of Technology, 2001  
Senior Principal Member Research Staff

Ivanov’s main research interests lie in the area of Computer Vision, Machine Learning and Data Mining. In particular, he is interested in dynamic observations - video sequences, sounds, gestures, actions and events. He holds a visiting appointment with MIT department of Brain and Cognitive Sciences.

Elena J. Jakubiak  Ph.D., Tufts University, 2009  
Visiting Member Research Staff

Elena first joined MERL as an intern in 2003 and subsequently as a visiting scientist in 2009. During the intervening period, she pursued her PhD in computer graphics, researching problems pertaining to high-quality text rendering in collaboration with MERL. Currently, Elena continues research on text representations and rendering.

Michael J. Jones  Ph.D., Massachusetts Institute of Technology, 1997  
Senior Principal Member Research Staff

Jones joined MERL in 2001 after 4 years at the Digital/Compaq Cambridge Research Laboratory. His main area of interest is computer vision. He is particularly interested in using machine-learning approaches for solving computer vision problems. He has focused on algorithms for detecting and analyzing people in images and video such as face detection, skin detection and facial analysis using morphable models.
**Toshiaki Koike  Ph.D., Kyoto University, 2005**
Visiting Member Research Staff

Prior to joining MERL in 2010, Koike was a postdoctoral researcher at Harvard University. His research interests include cooperative communications, coding theory, information theory, body-area networks and device implementation. He received best paper awards at IEEE GLOBECOM'08 and GLOBECOM'09.

**Keisuke Kojima  Ph.D., University of Tokyo, 1990**
Senior Principal Member Research Staff & Senior Liaison

Kojima spent 8 years in Mitsubishi Electric's Central Research lab and 9 years at AT&T Bell Labs. He has been involved in the research and development of semiconductor lasers, optical communication modules, and optical communication and sensor systems. He has authored/co-authored over 100 technical publications and conference presentations.

**Christopher Laughman  Ph.D., Massachusetts Institute Technology, 2008**
Member Research Staff

Christopher received his Ph.D. in the Building Technology section of the department of Architecture at MIT. His current research includes the investigation of modeling and parameter identification problems for electrical, mechanical, and thermal systems as found in buildings and transportation systems.

**Jonathan Leonard  B.S., Northeastern University, 2008**
Systems & Network Administrator

Jon works in the Central Services Department at MERL. He previously worked at MIT Lincoln Laboratory and graduated from Northeastern University. While not at work, he enjoys martial arts and regularly competes in competitions.

**Tim K. Marks  Ph.D., University of California San Diego, 2006**
Member Research Staff

Tim's research interests lie primarily in developing and applying statistical models for machine learning to problems in vision, both in order to solve problems in computer vision and in order to better understand human vision.
Barton E. Nicholls  Northeastern University  
System & Network Administrator  
Nicholls is a member of MERL’s Computer Network Services Group. He supports primarily UNIX and some Windows client and infrastructure software and hardware, and networking services for MERL. He comes to us from Verizon’s Network Operations Management Group, and before that Information Technology at Art Technology Group.

Daniel N. Nikovski  Ph.D., Carnegie Mellon University, 2002  
Data Analytics Group Team Leader  
Nikovski’s research is focused on algorithms for reasoning, planning, and learning with probabilistic models. His current work is on the application of such algorithms to hard transportation problems such as group elevator control and traffic prediction. He also has varied interests in the field of data mining.

Philip V. Orlik  Ph.D., State University of New York at Stony Brook, 1999  
Mobile Systems Team Leader  
Orlik joined MERL’s digital communications and networking group in 2000. His research interests include wireless and optical communications, networking, queuing theory, and analytical modeling.

Kieran J. Parsons  Ph.D., University of Bristol, UK, 1996  
Senior Principal Member Research Staff  
Prior to joining MERL in 2009, Parsons worked for Nortel, BelAir Networks an AMCC on wireless and optical networking technology. He is currently focused on optical communications architecture and system design.

Ronald N. Perry  B.Sc., Bucknell University, 1981  
Distinguished Member Research Staff  
Prior to joining MERL in 1998, Perry was a consulting engineer at DEC developing a three-dimensional rendering ASIC called Neon. Ron has consulted for many companies including Kodak, Adobe, Quark, and Apple over the last 20 years, developing software and hardware products in the areas of computer graphics, imaging, color, and desktop publishing. Ron’s research interests are centered on key algorithms in computer graphics.
Fatih M. Porikli  Ph.D., Polytechnic University, 2002
Senior Principal Member Research Staff

Porikli’s research interests are in the areas of video processing, computer vision, aerial image processing, 3-D depth estimation, texture segmentation, robust optimization, network traffic management, multi-camera systems, data mining, and digital signal filtering. Before joining MERL in 2000, he worked for Hughes Research Labs, Malibu, CA (1999) and AT&T Research Labs, Holmdel, NJ (1997).

Man-On (Simon) Pun  Ph.D., University of Southern California, 2006
Member Research Staff

Before joining MERL in 2008, Simon was a post-doctoral research fellow at Princeton University, NJ and worked for Sony Corporation in Tokyo where he was engaged in developing DAB/DVB-T receivers. Simon received the best paper award from the IEEE International Conference on Communications (ICC) Beijing, China in 2008.

Srikumar Ramalingam  Ph.D., INRIA Alpes, 2007
Member Research Staff

During his Ph.D. Srikumar worked on multi-view geometry algorithms for omni-directional and non-central camera models. His doctoral thesis received the best thesis prize and an honorable mention for the annual AFRIF thesis prize from the French Association for Pattern Recognition.

Shantanu Rane  Ph.D., Stanford University, 2007
Principal Member Research Staff

Shantanu Rane’s Ph.D. thesis applied distributed source coding concepts to error-resilient video transmission. Shantanu's research interests are in the areas of image communication and information theory. At MERL, he is working on problems involving distributed compression of images and video.

Zafer Sahinoglu  Ph.D., New Jersey Institute of Technology, 2001
Senior Principal Member Research Staff

Sahinoglu worked at AT&T Shannon Labs in 1999, and joined MERL in March 2001. His research interests include home networking, QoS in video streaming and multicasting, wireless image sensor networks, traffic self-similarity and biomedical signal processing. He has made significant contributions to the emerging MPEG-21 and ZigBee standards.
Bent K. Schmidt-Nielsen  
**B.S. Univ. of California at San Diego, 1971**

Speech Team Leader

Schmidt-Nielsen spent 7 years at Dragon Systems applying speech recognition to useful products. At MERL he is paying a lot of attention to making speech interfaces robust and usable. He has very broad interests in science and technology. Among many other activities he has taught genetics at the University of Massachusetts at Boston and he has been a leader in the development of an easy to use mass-market database.

Vijay Shilpiekandula  
**Ph.D., Massachusetts Institute of Technology, 2010**

Member Research Staff

Vijay received the 2008 R.V. Jones Memorial Scholarship from the American Society for Precision Engineering (ASPE) for his doctoral research on the design and control of flexure-based nano-positioning systems. His research interests include system dynamics, constrained linear and non-linear control, system identification, estimation and learning.

Alan Sullivan  
**Ph.D., University of California at Berkeley, 1993**

Senior Principal Member Research Staff

Prior to joining MERL, Alan Sullivan worked on developing and commercializing the DepthCube volumetric 3D display technology. He has 8 issued patents and 15 patents pending in the fields of display technology, computer graphics, material science and optics.

Huifang Sun  
**Ph.D., University of Ottawa, 1986**

MERL Fellow / IEEE Fellow

After four years as a Professor at Fairleigh Dickinson University, Huifang Sun moved to the Sarnoff Research Laboratory in 1990 becoming Technology Leader for Digital Video Communication. In 1995, Huifang joined MERL as the leader of our video efforts. In recognition of his productive career in video processing Huifang was made an IEEE Fellow in 2001. He was made a MERL Research Fellow in 2003.

Wei Sun  
**Ph.D., University of Waterloo, 2006**

Visiting Member Research Staff

Prior to joining MERL in 2008, Wei Sun worked as a research fellow at the University of Waterloo for two years. His main research interests include multimedia security, biometrics, information security and privacy, compressive sensing and information theory. He also has a Ph.D. in cryptography and a Master degree in mathematics.
Yuichi Taguchi  Ph.D. The University of Tokyo, 2009  
Visiting Member Research Staff

Yuichi Taguchi received his B.E., M.E., and Ph.D. degrees in information and communication engineering from the University of Tokyo, Japan, in 2004, 2006, and 2009, respectively. He joined MERL as a postdoc in April 2009 and is currently a visiting scientist. His research interests are in computer vision, image-based rendering, and computational photography.

Koon Hoo Teo  Ph.D., University of Alberta 1990  
Ubiquitous Networks Team Leader

Teo was with Nortel for about 15 years where he was actively involved in the research and implementation issues of a number of 3G and 4G wireless systems including Wireless Mesh Networks and WiMAX systems. His current research interests include Cognitive Radio, location tracking using Ultra Wideband technology, and Wireless Mesh and Multi-Hop Systems.

Jay E. Thornton  Ph.D., University of Michigan, 1982  
Imaging Group Manager

Thornton worked at Polaroid Corporation for many years, first in the Vision Research Laboratory and then as manager of the Image Science Laboratory. There, he worked on problems in color reproduction, image quality and image processing. He joined MERL in 2002 as Manager of the Computer Human Observation project, focusing on the computer vision problems that arise when computers analyze, measure, count, detect, and recognize people.

Kinh Tieu  Ph.D., Massachusetts Institute of Technology, 2006  
Visiting Member Research Staff

Kinh got his PhD from MIT in 2006 and since then has been a Research Fellow (in Radiology) at Brigham and Women's Hospital. At MERL, Kinh is working on medical image processing. He has also had a lot of experience in the application of statistical models to computer vision problems like multi-camera tracking.

Katsuhiko Tsujino  Ph.D., Osaka University, 1989  
Japanese Liaison / Assistant Manager

Tsujino joined Mitsubishi Electric Corp. in 1989 designing and implementing software systems based on his expertise in Artificial Intelligence, Knowledge Engineering, Knowledge Acquisition and Machine Learning. Following two years in the Strategic Planning Department of the Advanced Technology R&D Center, he joined MERL in August 2008.
C. Oncel Tuzel  Ph.D., Rutgers University, 2008
Member Research Staff

Oncel’s doctoral work focused on statistical learning techniques on smooth manifolds and their applications to scene analysis. He received the best paper runner-up award at CVPR 2007. His research interests are in computer vision, machine learning, pattern recognition, and computer graphics.

Ashok Veeraraghavan  Ph.D., Univ. of Maryland, College Park, 2008
Member Research Staff

Ashok’s research interests are in signal, image and video processing, computer vision, pattern recognition and computational photography. His thesis received the Doctoral Dissertation award from the Department of Electrical and Computer Engineering at the University of Maryland.

Anthony Vetro  Ph.D., Polytechnic University, 2001
Multimedia Group Manager

Vetro joined MERL in 1996. His research interests are related to the encoding and transport of multimedia content. He has been an active participant in MPEG standards for several years. Dr. Vetro has contributed several technologies to MELCO products, including MPEG-2/4 transcoding for surveillance, post-filtering for artifact reduction and video down-decoding for a low-cost DTV receiver chip.

Gene V. Vinokur  M.S., Boston University, 2003
Patent Agent

Prior to joining MERL, Vinokur spent four years at Putnam Investments developing software applications for the financial industry. He has been a licensed Patent Agent since 2003. He joined MERL’s Patent Department in 2006.

Bingnan Wang  Ph.D., Iowa State University 2009
Visiting Member Research Staff

Bingnan Wang's graduate work focused on the study of wave propagation phenomena, such as surface waves and negative refraction, in novel electromagnetic materials, including photonic crystals and metamaterials.
**Yebin Wang**  *Ph.D., University of Alberta, 2008*
Member Research Staff

Prior to joining MERL, Yebin was a research assistant of Applied Nonlinear Control Laboratory of the Department of Electrical & Computer Engineering at the University of Alberta. Yebin’s research interests include nonlinear observer/control design and applications, optimization, adaptive system, and mechatronics.

**Yige Wang**  *Ph.D., University of Hawaii at Manoa, 2008*
Visiting Member Research Staff

Yige Wang joined MERL in 2008. Her research interests include error control coding, digital communications, and VLSI implementation of communication algorithms. Her work has applications in the fields of optical communications, wireless communications, secure biometric systems, and IPTV systems.

**Garrett Weinberg**  *B.A., Yale University, 2000*
Member Research Staff

Before coming to MERL, Weinberg designed and internationalized automotive speech user interfaces at Dragon Systems, and was a chief architect and implementer of enterprise solutions for two Boston-area startups specializing, respectively, in Digital Rights Management and portfolio management. At MERL, he is designing and evaluating multi-model interfaces.

**Kevin W. Wilson**  *Ph.D., Massachusetts Institute of Technology, 2006*
Member Research Staff

For his doctoral thesis, Kevin Wilson incorporated aspects of the psychoacoustics of the precedence effect into an algorithm for computerized audio source localization. He is currently working on applications of signal processing and machine learning to audio processing, video processing and equipment condition monitoring.

**Jonathan S. Yedidia**  *Ph.D., Princeton University, 1990*
Distinguished Member Research Staff

Yedidia’s graduate work focused on theoretical condensed-matter physics, particularly the statistical mechanics of systems with quenched disorder. In 1997, he changed his focus to computer software and worked for a company called Viaweb on what has since become Yahoo’s shopping service. At MERL since 1998, his particular interest is in the development of new methods of belief propagation in constraint networks.
William S. Yerazunis  Ph.D., Rensselaer Polytechnic Institute, 1987
Senior Principal Member Research Staff & Hardware Team Leader

Yerazunis has worked in a number of fields including: optics, vision processing, and signal processing, computer graphics, artificial intelligence parallel symbolic computation, radio astronomy and SETI, transplant immunology, virtual and augmented reality (Diamond Park and SPLINE), real-time sensing and ubiquitous computing, and real-time statistical categorization of text (for spam filtering).

Raymond Yim  Ph.D., Harvard University, 2006
Member Research Staff

Raymond has conducted successful research on the design and analysis of cross-layered architectures and protocols for wireless communication networks including cellular systems, wireless LANs, and sensor networks.

Jinyun Zhang  Ph.D., University of Ottawa, 1991
MERL Fellow, IEEE Fellow
Digital Communication Group Manager

Jinyun manages MERL’s digital communications group. Before joining MERL in 2001, she worked for Nortel Networks for 10 years where she held engineering and management positions in the areas of VLSI design and advanced wireless & optical technology development. In recognition for her contributions to broadband wireless transmission and networking technology she became an IEEE Fellow in 2008.

Weihong Zhang  Ph.D., Hong Kong Univ. of Science & Technology, 2001
Visiting Member Research Staff

Weihong Zhang is working on problems involving scheduling, planning, and sequential decision making under uncertainty. His interests and experience are related to developing probabilistic algorithms and applying them to real-word domains.
Recent Major Publications

The following lists the major publications by members of the MERL staff. A publication is considered major if it appeared in a refereed journal, a refereed conference proceeding or some other significant publication such as a book.

An asterisk (*) appears before publications that are subject to highly stringent selection criteria where they were published. Some venues (such as major journals and certain key conferences) are very selective in what they publish and some (such as workshops and many conferences) are not. There are good reasons to publish something in a non-selective venue, the most important of which being that a given workshop or conference may be the best place at which to expose a particular piece of work to the scientific community. However, the mere appearance of a piece of work in a non-selective venue says little if anything about the quality of the work. In contrast, getting a piece of work into a highly selective venue is a mark of distinction that says a lot about the quality of the work in the eyes of the scientific community.

2010


Venkatraman, V.; Porikli, F.M., "RelCom: Relational Combinatorics Features for Rapid Object Detection", *IEEE Workshop on Object Tracking and Classification Beyond and in the Visible Spectrum*, Robust Object Detection, June 2010 (TR2010-036) (Best paper award.)


Joshi, A.J.; Porikli, F.M.; Papanikolopoulos, N., "Breaking the Interactive Bottleneck in Multi-class Classification with Active Selection and Binary Feedback", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, Object Recognition, June 2010 (TR2010-037)


Liu, M-Y.; Tuzel, C.O.; Veeraraghavan, A.N.; Chellappa, R., "Fast Directional Chamfer Matching", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2010 (TR2010-045)


* Shah, V.; Mehta, N.B.; Yim, M.H.R., "A Complete Characterization of an Optimal Timer Based Selection Scheme", *IEEE International Conference on Communications (ICC)*, May 2010 (TR2010-052)

* Fu, W.; Tao, Z.; Zhang, J.; Agrawal, D.P., "Clustering Based Fractional Frequency Reuse and Fair Resource Allocation in Multi-cell Networks", *IEEE International Conference on Communications (ICC)*, May 2010 (TR2010-049)

* Wang, D.; Tao, Z.; Zhang, J.; Abouzeid, A.A., "RPL Based Routing for Advanced Metering Infrastructure in Smart Grid", *IEEE International Workshop on Smart Grid Communications (ICC)*, May 2010 (TR2010-053)

* Sahinoglu, Z.; Gezici, S., "Enhanced Position Estimation via Node Cooperation", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2010.5502319, pp. 1-6, May 2010 (TR2010-066)

Gao, W.; Duan, C.; Zhang, J., "Subcarrier Spreading for ICI Mitigation in OFDM/OFDMA Systems", IEEE International Conference on Communications (ICC), May 2010 (TR2010-047)

Ye, F.; Yim, M.H.R.; Zhang, J.; Roy, S., "Congestion Control to Achieve Optimal Broadcast Efficiency in VANETs", IEEE International Conference on Communications (ICC), May 2010 (TR2010-050)

He, X.; Pun, M-O.; Kuo, C-C. J.; Zhao, Y., "A Change-Point Detection Approach to Power Quality Monitoring in Smart Grids", IEEE International Conference on Communications Workshops (ICC), DOI: 10.1109/ICC.W.2010.5503913, pp. 1-5, May 2010 (TR2010-054)

Ye, F.; Yim, M.H.R.; Guo, J.; Zhang, J.; Roy, S., "Prioritized Broadcast Contention Control in VANET", IEEE International Conference on Communications (ICC), May 2010 (TR2010-046)


Gao, W.; Yan, Y.; Osadciw, L; Duan, C.; Li, C., "A Two Stage PAPR Reduction Method on Frequency Redundant OFDM System", 25th Biennial Symposium on Communications, May 2010 (TR2010-048)


Fu, W.; Tao, Z.; Zhang, J.; Agrawal, D.P., "Differentiable Spectrum Partition for Fractional Frequency Reuse in Multi-Cell OFDMA Networks", IEEE Wireless Communications and Networking Conference (WCNC), ISSN: 1525-3511, pp. 1-6, April 2010 (TR2010-035)


Shibata, H.; Kato, M.; Kori, M.; Yerazunis, W., "An Automatic Training Data Collection Method for Confidential E-mail Detection", *The Forum on Data Engineering and Information Management (DEIM)*, February 2010 (TR2010-065) (Best paper award)


Kim, K-J; Pun, M-O; Itit, R.A., "QRD-Based Precoded MIMO-OFDM Systems with Reduced Feedback", *IEEE Transactions on Communications*, ISSN: 0090-6778, Vol. 58, Issue 2, pp. 394-398, February 2010 (TR2010-007)


2009


Shah, V.; Metha, N.B.; Yim, M.H.R., "Relay Selection and Data Transmission Throughput Tradeoff in Cooperative Systems", *Global Telecommunications Conference (GLOBECOM)*, ISSN 1930-529X, pp. 1-6, November 2009 (TR2009-087)


Porikli, F.M.; Pan, P., "Regressed Importance Sampling on Manifolds for Efficient Object Tracking", IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS), DOI: 10.1109/AVSS.2009.95, pp. 406-411, September 2009 (TR2009-061)


**Wilson, K.W.,** "Probabilistic Inter-disturbance Interval Estimation for Bearing Fault Diagnosis", *IEEE International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives (SDEMPED)*, DOI: 10.1109/DEMPED.2009.5292803, pp. 1-6, August 2009 (TR2009-060)


**El-Rifai, K.; El-Rifai, O.,** "Design of Hybrid Resetting PID and Lag Controllers with Application to Motion Control", *IEEE/ASME International Conference Advanced Intelligent Mechatronics (AIM)*, DOI: 10.1109/AIM.2009.5229931, July 2009 (TR2009-058)

Research

The body and soul of any research lab is the portfolio of research it pursues. Therefore it is appropriate that the main body of this annual report consists of descriptions of research projects being done at MERL. For ease of reference, the reports are grouped into six topic areas.

Digital Communications - High speed wireless and optical communications, highly reliable networking, channel modeling, advanced channel coding/decoding, adaptive signal processing, next generation communication systems and standards.

Multimedia – Efficient representation, transmission, security, processing and interaction of multimedia; including video compression, display processing, information coding for security, compressive sensing, and speech processing.

Data Analytics – Predictive analytics (statistical machine learning, data analysis); Decision analytics (Optimization, scheduling and control); and software Infrastructure (distributed software systems, data stream processing).

Imaging - Detection, classification, and recognition based on machine learning and physical modeling; 3D characterization, reconstruction, location, and inference; computational imaging for optimized information capture; tracking and multi-modal sensor integration.

Mechatronics - Advanced control algorithms, system dynamics, modeling & performance analysis, mechatronics design, innovative system concepts, and 2D/3D adaptively-sampled distance fields applications.

Algorithms - Solution methods for optimization problems involving very large numbers of variables in the areas of information theory & coding; stochastic network utility maximization; sensing, perception, inference & learning.
Digital Communications

The world’s communications and information systems are rapidly accelerating their scale, scope and impact. Beyond traditional telecom offerings, new services and applications are emerging in nearly every vertical. As an example, revitalizing the electric power grid has become one of the top priorities world-wide. By integrating robust two-way communications, advanced sensors and distributed computers with the power transmission and distribution systems, the smart grid improves the efficiency, reliability and safety of power delivery and use. These developments are driving the growth in capacity and connectivity of the underlying infrastructure. As results, it presents historical challenges and opportunities to digital communications.

The Digital Communications at MERL conducts research in the areas of broadband mobile communications and ubiquitous networking. We conduct not only applied research, but also fundamental research to develop breakthrough technologies. Our objective is to improve spectral efficiency, increase system capacity, and achieve highly reliable networking for telecommunication infrastructures as well as other applications. We encourage innovation and creativity, close collaboration with universities and other research organizations, and contribute to international standards and the scientific community.

Responding to the new challenges, we have diversified our research effort in several frontiers. We continued the R&D of broadband communication technologies, especially on MIMO/precoding, interference management, multi-hop relaying, network coding and advanced coding/decoding, for next generation infrastructure systems. We have investigated new technologies for high mobility applications, such as vehicle-to-vehicle ad-hoc networks. In addition, we have been actively participating in smart grid international standardization activities, developing reliable routing algorithms for smart meter networks, and investigating new technologies for power grid monitoring and enhancement in terms of reliability and efficiency.

Recent Research

Unified Analysis of Linear Block Precoding for Distributed Antenna Systems .................................. 36
Codebook-based Quantized MIMO Feedback for Close-Loop Transmit Precoding ......................... 36
Opportunistic Cell Edge Selection in Multi-Cell OFDMA Networks .............................................. 37
On Optimum Regenerative Relaying with Imperfect Channel Knowledge ........................................ 37
Enhanced HARQ Techniques using Self-Interference Cancellation (SICC) with … ........................... 38
Sub-Carrier Spreading for ICI Mitigation in OFDM/OFDMA Systems ........................................... 38
Multi-Antenna analog Network Coding for Multi-Hop Wireless Networks ................................. 39
Congestion Control to Achieve Optimal Broadcast Efficiency in VANETs ................................. 39
Fast Handover between WiMAX and WiFi Networks in Vehicular Environment ............................ 40
RPL Based Routing for Advanced Metering Infrastructure in Smart Grid ................................. 40
A Change-Point Detection Approach to Power Quality Monitoring in Smart Grids ...................... 41
Enhanced Position Estimation via Node Cooperation ................................................................. 41
QoS Harmonization for Home Networks ...................................................................................... 42
Unified Analysis of Linear Block Precoding for Distributed Antenna Systems

Citation: Koike-Akino, T.; Molisch, A.F.; Tao, Z.; Orlik, P.V.; Kuze, T., "Unified Analysis of Linear Block Precoding for Distributed Antenna Systems", Global Telecommunications Conference (GLOBECOM), ISSN: 1930-529X, pp. 1-6, November 2009
Contacts: Toshiaki Koike-Akino, Philip Orlik

Block transmission with cyclic prefix is a promising technique to realize high-speed data rates in frequency selective fading channels. This paper presents a unified performance analysis which shows how the optimal precoding strategy depends on the receiver type and the optimization criterion (capacity and mean-square error). We analyze three variants of TR methods and two-types of pre-equalization. As one application of our framework, we derive optimal power control for OFDM in the presence of interference limitation for distributed antenna systems. We find that without power control, OFDM does not have any capacity advantage over SC transmissions. When comparing SC and TR, we find that for single-antenna systems at high SNRs, SC has a capacity advantage; however, TR performs better in the low SNR regime. For multiple-antenna systems, TR always provides higher capacity, and the capacity of TR can approach that of optimal precoders with a number of distributed antennas.

Codebook-Based Quantized MIMO Feedback for Closed-Loop Transmit Precoding

Citation: Pun, M-O.; Porat, R.; Orlik, P.V.; Zhang, J.; Kuze, T., "Codebook-based Quantized MIMO Feedback for Closed-loop Transmit Precoding", Asilomar Conference on Signals, Systems and Computers, DOI: 10.1109/ACSSC.2009.5469842, pp. 1436-1440, November 2009
Contacts: Man-On Pun, Philip Orlik, Jinyun Zhang

Advanced quantization schemes are proposed for closed-loop transmit precoding over correlated multiple-input multiple-output (MIMO) channels in this work. Unlike the conventional schemes that directly quantize the MIMO channel covariance matrix and feed back each quantized matrix element, the proposed schemes quantize the channel covariance matrix by exploiting the common rank-one codebook shared by mobile stations and base stations. Compared to the conventional quantization schemes, the proposed quantization schemes can achieve comparable throughput performance with more than 50% overhead reduction at the cost of affordable increase in computational complexity.
Opportunistic Cell Edge Selection in Multi-Cell OFDMA Networks

We propose an intercell downlink orthogonal frequency division multiple access (OFDMA) scheduling technique in a sectorized cellular network. Adjacent sectors from neighboring cells form a cluster and each OFDMA resource block is allocated to the rate-maximizing sector. Compared to a cellular network that uses conventional fractional frequency reuse (FFR) technique, our proposed system requires only slightly more backhaul traffic while providing an appreciable performance gain. Intercell scheduling, which grants a resource exclusively to the rate-maximizing cell within a cluster is a simple and powerful base station cooperation technique that balances non-cooperation and full cooperation. We find out that a tri-sectored network is particularly well-suited to applying inter-sector scheduling as each cluster is relatively isolated from other clusters. We provide an option to adjust the load on backhaul traffic by adjusting the granularity of the OFDMA resource under contention. We also provide an option to optimally swap resources.

On Optimum Regenerative Relaying with Imperfect Channel Knowledge

This paper is concerned with the performance of a regenerative relaying protocol on fading wireless channels with imperfect channel knowledge at the receivers. Assuming a single source and a single destination with multiple relay nodes, using binary modulation at the source, we present optimum receivers at the destination on frequency-flat Rayleigh fading channels by taking into account the effect of imperfect channel knowledge at the receivers. Since exact performance analysis of the optimal receiver is complicated due to the non-linear nature of the log-likelihood ratio contribution from the relay, upon using a standard technique in the literature, we present a simple approximate receiver and derive closed-form expression for the average bit error rate (BER) at destination with a single relay node. We also present a simple analytical technique that allows us to numerically evaluate the average BER for an arbitrary number of relay nodes.
Enhanced HARQ Technique Using Self-Interference Cancellation Coding (SICC) with Low-Complexity Decoding Scheme

Citation: Matsumoto, W.; Uchida, S.; Kuze, T.; Yoshida, H.; Orlik, P.V.; Annavajjala, R., "Enhanced HARQ Technique using Self-Interference Cancellation Coding (SICC) with Low-Complexity Decoding Scheme", *International Symposium on Wireless Personal Multimedia Communications (WPMC)*, September 2009

Contacts: Philip Orlik, Ramesh Annavajjala

The paper provides a method for linear combining HARQ along with Self-Interference Cancellation Coding (SICC), so that the reliability of spatial multiplexing MIMO transmissions can be provided. Furthermore we introduce a low-complexity decoding scheme with MMSE and linear combining. The simulation results show that significant gain is achieved over the traditional Chase Combining (CC) despite of the low-complexity decoding with small memory.

Subcarrier Spreading for ICI Mitigation in OFDM/OFDMA Systems

Citation: Gao, W.; Duan, C.; Zhang, J., "Subcarrier Spreading for ICI Mitigation in OFDM/OFDMA Systems", *IEEE International Conference on Communications (ICC)*, May 2010

Contacts: Chunjie Duan, Jinyun Zhang

Two of the major challenges facing OFDM/OFDMA systems are their sensitivity to frequency selective fading and ICI due to CFO or Doppler shift, especially when the subcarrier spacing becomes smaller. We propose an OFDM transceiver design that employs frequency redundant subcarrier mapping to mitigate frequency selective fading and subcarrier spreading to achieve ICI self-cancelation. Both our theoretical analysis and simulation show that such a code-spread-interleaved-redundant OFDM system design offers significant (over 10dB) improvement in CIR and robust BER performance in different channel conditions.
Multi-Antenna Analog Network Coding for Multi-Hop Wireless Networks


Contacts: Ramesh Annavajjala, Jinyun Zhang

This paper proposes a minimum mean-square-error bi-directional amplify-and-forward (MMSE-BAF) relaying protocol for multi-hop wireless networks employing multi-antenna relays. MMSE-BAF is a two-phase relaying protocol which allows for two sources to exchange independent messages via a relay node equipped with multiple antennas. The latter performs a joint linear MMSE filtering of the received signal after the multiple access (MA) phase before amplifying and forwarding using a single transmit antenna. The proposed MMSE-BAF protocol extends upon the so-called analog network coding schemes in the literature in that it inherently exploits the multiple antennas at the relay station to reduce the noise enhanced effects typical of an AF protocol. Owing to its joint linear MMSE filtering approach, it can also compensate for link imbalances between the relay and the sources and is agnostic to sources' modulation and coding schemes (MCS). We derive the instantaneous signal-to-noise ratio expressions for the received signal by the source nodes in the downlink and provide extensive link-level simulation results for the MMSE-BAF protocol subject to both frequency flat and selective fading.

Congestion Control to Achieve Optimal Broadcast Efficiency in VANETs

Citation: Ye, F.; Yim, M.H.R.; Zhang, J.; Roy, S., "Congestion Control to Achieve Optimal Broadcast Efficiency in VANETs", *IEEE International Conference on Communications (ICC)*, May 2010

Contacts: Raymond Yim, Jinyun Zhang

In a vehicular network, every vehicle broadcasts update messages that contain location and speed information periodically to its one hop neighbors. The broadcast efficiency measures the average rate at which a vehicle receives these packets from any of its neighbors. As the node density increases, heightened interference lowers broadcast efficiency if a congestion control mechanism is not used. In this paper, we analyze the broadcast efficiency under a Rayleigh fading channel, and provide congestion control and power control strategies that maximize the efficiency. A worst-case guaranteed strategy achieving at least 95% of the optimal is also provided for cases when the network nodes have high mobility.
Fast Handover Between WiMAX and WiFi Networks in Vehicular Environment

Citation: Guo, J.; Yim, M.H.R.; Tsuboi, T.; Zhang, J., "Fast Handover Between WiMAX and WiFi Networks in Vehicular Environment", World Congress and Exhibition on Intelligent Transport Systems and Services, PaperID 3721, September 2009
Contacts: Jianlin Guo, Raymond Yim, Jinyun Zhang

Fast handover is crucial to provide the best services to mobile users in vehicular environment. WiMAX and WiFi support mobility in vehicular speed. However, WiMAX and WiFi network entry processes may take seconds to complete. In this paper, we propose the fast handover techniques between WiMAX and WiFi networks to speed up handover process. A link layer fast handover approach is proposed to realize fast link layer connectivity. An IP layer fast handover mechanism is proposed to achieve the high speed IP layer connectivity. The proposed fast handover protocols can be utilized to accomplish the seamless handover in vehicular communications.

RPL Based Routing for Advanced Metering Infrastructure in Smart Grid

Citation: Wang, D.; Tao, Z.; Zhang, J.; Abouzeid, A.A., "RPL Based Routing for Advanced Metering Infrastructure in Smart Grid", IEEE International Workshop on Smart Grid Communications, May 2010
Contacts: Jinyun Zhang

In this paper, we present a routing protocol design and implementation for the Advanced Metering Infrastructure (AMI) in Smart Grid. The proposed protocol implementation is based on the framework of the IPv6 Routing Protocol for Low Power and Lossy Networks (RPL), which is proposed by IETF and currently still in its design phase. RPL is based on the idea of maintaining a directed acyclic graph (DAG) structure for the network. We provide a practical implementation of RPL with a number of proper modifications so as to fit into the AMI structure and meet stringent requirements enforced by the AMI. In particular, we propose a novel DAG rank computation method and a reverse path recording mechanism, which enables real-time automated meter reading and real-time remote utility management in the AMI. Our proposed routing protocol design for AMI networks is validated through extensive simulations.
A Change-Point Detection Approach to Power Quality Monitoring in Smart Grids

Citation: He, X.; Pun, M-O.; Kuo, C-C. J.; Zhao, Y., "A Change-Point Detection Approach to Power Quality Monitoring in Smart Grids", *IEEE International Conference on Communications Workshops (ICC)*, DOI: 10.1109/ICCW.2010.5503913, pp. 1-5, May 2010

Contacts: Man-on Pun

In this work, we apply a change-point detection approach to power quality (PQ) monitoring in smart grids. Capitalizing on change-point detection theory with unknown parameters, a sequential cumulative sum (CUSUM)-based scheme is developed with an objective to provide quick and accurate detection of PQ event occurrence in real time. The proposed CUSUM-based scheme evaluates the weighted likelihood ratios by exploiting both the instantaneous and the long-term information of the power waveform. It is shown by computer simulations that the proposed CUSUM-based scheme can achieve a significant performance gain over conventional detection schemes.

Enhanced Position Estimation via Node Cooperation

Citation: Sahinoglu, Z.; Gezici, S., "Enhanced Position Estimation via Node Cooperation", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2010.5502319, pp. 1-6, May 2010

Contacts: Zafer Sahinoglu

Two-way time-of-arrival (TW-ToA) is a widely used ranging protocol that can provide the distance between two devices without time synchronization. One drawback of the TW-ToA is poor positioning accuracy in the absence of a sufficient number of reference ranging devices. Also, for a self-positioning system with a limited battery life, it might be necessary to limit the number of transmissions while satisfying accuracy constraints. In this paper, a cooperative positioning protocol [1] is studied, which can improve positioning accuracy compared to the conventional TW-ToA based positioning systems and also facilitate positioning with fewer packet transmissions; hence, it can prolong battery life on average. The maximum likelihood estimator is obtained for the cooperative technique and the limits on the positioning accuracy are quantified in terms of the Cramer-Rao lower bound (CRLB). Simulation results are provided in order to show performance improvements.
A modern home could contain a large variety of devices and all of them should be able to work together so as to bring a rich experience to the users. Quality of service (QoS) is a critical factor for measuring user satisfaction. It represents the ability to provide different priorities based on the type of the data flows or to guarantee a certain quality of performance to a particular service. Different devices may follow different protocols and each protocol has its own QoS management scheme. These QoS schemes are not necessarily compatible with one another and the inconsistency will significantly impair their efficacy. In this paper, we propose a harmonized protocol for home networks, which unifies all other protocols and solves the inconsistency problem effectively.
Multimedia

Multimedia research at MERL is centered on the efficient representation, processing and security of multimedia as well as enhanced interactions with multimedia. Core technical strengths include digital video, information coding and speech/audio processing.

The digital video area includes both compression and display processing work. A key goal is to improve the compression efficiency of rich video formats, e.g., multiple views and 3D scene information, higher resolution, full color sampling, and greater bit-depth. We also conduct research on the various display processing functions including video noise reduction and format conversions. Our research results are applied to international standards and across a wide range of audio-visual products. We also consider proprietary coding schemes that are applied to closed systems such as surveillance and satellite.

Our research in the area of information coding considers coding technology for both security and sensing applications. We are actively exploring the application of distributed source coding principles to problems in the security area, such as the secure storage of biometric data. Another major research initiative is on a class of technology to perform signal processing on encrypted data. We are also exploring fundamental technology and applications of compressive sensing.

The work on speech and audio processing emphasizes spoken-language interfaces for automotive and handheld devices. We have developed core technology for voice-based retrieval of information. Other areas of work include speech enhancement and technology that aims to improve multimodal interfaces. Our work in this area has been primarily applied to car navigation products.

Recent Research

Intermediate View Generation for Perceived Depth Adjustment of Stereo Video....................... 44
Disparity Search Range Estimation: Enforcing Temporal Consistency ....................................... 44
Representation and Coding Formats for Stereo and Multiview Video......................................... 45
Distributed Video Coding: Trends and Perspectives ................................................................. 45
Privacy and Security of Features Extracted from Minutiae Aggregates....................................... 46
Hiding Information Inside Structured Shapes.............................................................................. 46
Secure Distortion Computation among Untrusting Parties Using Homomorphic Encryption..... 47
Secure Function Evaluation Based on Secret Sharing and Homomorphic Encryption................. 47
Reconstruction of Sparse Signals from Distorted Randomized Measurements ......................... 48
Greedy Sparse Signal Reconstruction from Sign Measurements .............................................. 48
Compressive Sampling for Streaming Signals with Sparse Frequency Content............................ 49
Evaluation of Different Speech and Touch Interfaces to In-Vehicle Music Retrieval Systems... 49
Subword Unit Approaches for Retrieval by Voice....................................................................... 50
Intermediate View Generation for Perceived Depth Adjustment of Stereo Video


Contacts: Alan Sullivan, Anthony Vetro

There is significant industry activity on delivery of 3D video to the home. It is expected that 3D capable devices will be able to provide consumers with the ability to adjust the depth perceived for stereo content. This paper provides an overview of related techniques and evaluates the effectiveness of several approaches. Practical considerations are also discussed.

Disparity Search Range Estimation: Enforcing Temporal Consistency


Contacts: Anthony Vetro

This paper presents a new approach for estimating the disparity search range in stereo video that enforces temporal consistency. Reliable search range estimation is very important since an incorrect estimate causes most stereo matching methods to get trapped in local minima or produce unstable results over time. In this work, the search range is estimated based on a disparity histogram that is generated with sparse feature matching algorithms such as SURF. To achieve more stable results over time, we further propose to enforce temporal consistency by calculating a weighted sum of temporally neighboring histograms, where the weights are determined by the similarity of depth distribution between frames. Experimental results show that this proposed method yields accurate disparity search ranges for several challenging stereo videos and is robust to various forms of noise, scene complexity and camera configurations.
Representation and Coding Formats for Stereo and Multiview Video

Citation: Vetro, A., "Representation and Coding Formats for Stereo and Multiview Video", *intelligent Multimedia Communication: Techniques and Applications*, ISSN: 1860-949x, Vol. 280/2010, pp.51-73, March 2010

Contacts: Anthony Vetro

This chapter discusses the various representation and coding formats for stereo and multiview video in the context of next-generation 3D video services. Several application scenarios are discussed including packaged media such as Blu-ray Disc, as well as the delivery over cable, terrestrial and Internet channels. The various types of 3D displays are also described and the data requirements for each examined. A review of different representation formats for stereo and multiview video is given including multiplexed formats, full-channel formats and depth-based formats. The corresponding compression technology for these formats is then described. The chapter concludes with a discussion of future outlooks and research challenges.

Distributed Video Coding: Trends and Perspectives


Contacts: Anthony Vetro

This paper surveys recent trends and perspectives in distributed video coding. More specifically, the status and potential benefits of distributed video coding in terms of coding efficiency, complexity, error resilience and scalability are reviewed. Multi-view video and applications beyond coding are also considered. In addition, recent contributions in these areas, more thoroughly explored in the papers of the present Special Issue, are also described.
Privacy and Security of Features Extracted from Minutiae Aggregates

Citation: Nagar, A.; Rane, S.D.; Vetro, A., "Privacy and Security of Features Extracted from Minutiae Aggregates", IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), March 2010

Contacts: Shantanu Rane, Anthony Vetro

This paper describes our recent analysis on the security and privacy of biometric feature vectors obtained from fingerprint minutiae. A large number of contiguous regions (cuboids) are selected at random in the minutiae space, and several new features are extracted from the minutiae inside each such cuboid. In terms of matching performance on a public database, the feature vectors provide an equal error rate of 3% even if the imposter is allowed to use the same local patches as the genuine user. Performance within a secure biometrics framework is evaluated by applying an LDPC code to the feature vectors and storing only the syndrome at the access control device, for use in authentication. The paper concludes with a discussion on methods to analyze security and privacy of biometric systems that use such local-aggregate-based feature vectors in a secure biometric recognition framework. This discussion highlights security attacks via template injection, spoofing, and cancelability compromises and also considers the difficulty of privacy attacks via template inversion.

Hiding Information Inside Structured Shapes

Citation: Das, S.; Rane, S.D.; Vetro, A., "Hiding Information Inside Structured Shapes", IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), March 2010

Contacts: Shantanu Rane, Anthony Vetro

This paper describes a new technique for embedding a message within structured shapes. It is desired that my changes in the shape owing to the embedded message are invisible to a casual observer but detectable by a specialized decoder. The message embedding algorithm represents shape outline as a set of cubic Bezier curves and straight line segments. By slightly perturbing the Bezier curves, a single shape can spawn a library of similar-looking shapes each corresponding to a unique message. This library is efficiently stored using Adaptively Sampled Distance Fields (ADFs). Given any modified shape, a forensic detector applies Procrustes analysis to determine the embedded message. Results of an extensive subjective test confirm that the shape modifications are indeed unobtrusive. Message recovery is found to be stable even after multiple rounds of photocopying.
Secure Distortion Computation among Untrusting Parties Using Homomorphic Encryption

Citation: Rane, S.D.; Sun, W.; Vetro, A., "Secure Distortion Computation between Untrusting Parties using Homomorphic Encryption", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2009.5414544, pp. 1485-1588, November 2009

Contacts: Shantanu Rane, Anthony Vetro

Alice and Bob possess sequences \(x^n\) and \(y^n\) respectively and would like to compute \(d(x^n, y^n)\) where \(d(.,.)\) is a distortion measure. However, Alice and Bob do not trust each other and do not wish to reveal their data to each other. This paper describes and analyzes a protocol that uses homomorphic encryption for secure calculation of some special distortion functions without revealing \(x^n\) and \(y^n\). The resulting distortion result is also in encrypted form. An application of the protocol for private biometric authentication is described in which Bob interacts with a remote encrypted fingerprint database (Alice) to achieve access control without revealing his own identity.

Secure Function Evaluation Based on Secret Sharing and Homomorphic Encryption

Citation: Rane, S.D.; Sun, W.; Vetro, A., "Secure Function Evaluation Based on Secret Sharing and Homomorphic Encryption", *Allerton Conference on Communication, Control and Computing*, DOI: 10.1109/ALLERTON.2009.5394944, pp. 827-834, September 2009

Contacts: Shantanu Rane, Anthony Vetro

Consider the following problem in secure multiparty computation: Alice and Bob posses integers \(x\) and \(y\) respectively. Charlie is a researcher who would like to compute the value of some function \(f(x,y)\). The requirement is that Charlie should not gain any knowledge about \(x\) and \(y\) other than that which can be obtained from the function itself. Moreover, Alice and Bob do not trust each other and should not gain knowledge about each other's data. This paper contains initial work on a methodology to enable such secure function evaluation using additive and multiplicative homomorphisms as cryptographic primitives instead of oblivious transfer. It is shown that Charlie can compute the encrypted value of any polynomial in \(x\) and \(y\).
Reconstruction of Sparse Signals from Distorted Randomized Measurements

Citation: Boufounos, P.T., "Reconstruction of Sparse Signals from Distorted Randomized Measurements", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, March 2010

Contacts: Petro Boufounos

In this paper we show that, surprisingly, it is possible to recover sparse signals from nonlinearly distorted measurements, even if the nonlinearity is unknown. Assuming just that the nonlinearity is monotonic, we use the only reliable information in the distorted measurements: their ordering. We demonstrate that this information is sufficient to recover the signal with high precision and present two approaches to do so. The first uses order statistics to compute the minimum mean square (MMSE) estimate of the undistorted measurements and use it with standard compressive sensing (CS) reconstruction algorithms. The second uses the principle of consistent reconstruction to develop a deterministic nonlinear reconstruction algorithm that ensures that measurements of the reconstructed signal have ordering consistent with the ordering of the distorted measurements. Our experiments demonstrate the superior performance of both approaches compared to standard CS methods.

Greedy Sparse Signal Reconstruction from Sign Measurements

Citation: Boufounos, P.T.;, "Greedy Sparse Signal Reconstruction from Sign Measurements", *Asilomar Conference on Signals, Systems and Computers*, DOI: 10.1109/ACSSC.2009.5469926, pp. 1305-1309, November 2009

Contacts: Petro Boufounos

This paper presents Matched Sign Pursuit (MSP), a new greedy algorithm to perform sparse signal reconstruction from signs of signal measurements, i.e., measurements quantized to 1-bit. The algorithm combines the principle of consistent reconstruction with greedy sparse reconstruction. The resulting MSP algorithm has several advantages, both theoretical and practical, over previous approaches. Although the problem is not convex, the experimental performance of the algorithm is significantly better compared to reconstructing the signal by treating the quantized measurement as values. Our results demonstrate that combining the principle of consistency with a scarcity prior outperforms approaches that use only consistency or only scarcity priors.
Compressive Sampling for Streaming Signals with Sparse Frequency Content

Citation: Boufounos, P.T.; Asif, M.S., "Compressive Sampling for Streaming Signals with Sparse Frequency Content", Annual Conference on Information Sciences and Systems (CISS), ISBN 978 1 4244 7416 5, pp. 1-6, March 2010

Contacts: Petro Boufounos

Compressive sampling (CS) has emerged as a significant signal processing framework to acquire and reconstruct sparse signals at rates significantly below the Nyquist rate. However, most of the CS development to-date has focused on finite-length signals and representations. In this paper we discuss a streaming CS framework and greedy reconstruction algorithm, the Streaming Greedy Pursuit (SGP), to reconstruct signals with sparse frequency content. The measurement framework we propose is designed to be causal and implementable using existing hardware architectures. Our reconstruction algorithm provides specific computational guarantees, which makes it appropriate for real-time system implementations. Our experiment results on very long signals demonstrate the good performance of the SGP and validate our approach.

Evaluation of Different Speech and Touch Interfaces to In-Vehicle Music Retrieval Systems


Contacts: Garrett Weinberg, Bent Schmidt-Nielsen, Bret Harsham

In-vehicle music retrieval systems are becoming more and more popular. Previous studies have shown that they pose a real hazard to drivers when the interface is a tactile one that requires multiple entries and a combination of manual control and visual feedback. In this study, each of 17 participants between the ages of 18 and 30 years old was asked to use three different music retrieval systems (one with a multiple entry touch interface, the iPod, one with a multiple turn voice interface, interface B, and one with a single turn voice interface, interface C) while driving through a virtual world. When compared with the touch interface, the voice interfaces reduced the total time drivers spent with their eyes off the forward roadway, especially in prolonged glances, as well as both the total number of glances away from the forward roadway and the perceived workload. Furthermore, when compared with driving without a secondary task, both voice interfaces did not significantly impact hazard anticipation, the frequency of long glances away from the forward roadway, or vehicle control. The multiple turn voice interface (B) significantly increased both the time it took drivers to complete the task and workload.
Subword Unit Approaches for Retrieval by Voice

Citation: Gouvea, E.; Ezzat, T., Raj, B., "Subword Unit Approaches for Retrieval by Voice", IEEE International Conference on Acoustics Speech and Signal Processing (ICASSP), March 2010

Contacts: Anthony Vetro

In this work, we describe a subword unit approach for information retrieval of items by voice. An algorithm based on the minimum description length (MDL) principle converts an index written in terms of words with vocabulary size $V$ into an index written in terms of phonetics subword units of size $M \ll V$. We demonstrate that, with this highly reduced vocabulary of subword units, improvement in ASR decode speed and memory footprint can be achieved, at the expense of a small drop in recall performance. Results on a music lyrics retrieval task are demonstrated.
Data Analytics

The advent of powerful embedded computing, ubiquitous communications, and inexpensive sensors has led to a tidal wave of streaming data coming from both industrial installations and enterprise and public IT systems. The field of data analytics is concerned with harnessing the power and extracting the value of information hidden in such data streams to enable better decision making. This in turn makes it possible to minimize costs, maximize profits, increase reliability, improve energy efficiency, and reduce environmental impact of products. The Data Analytics group at MERL has been working on both predictive and decision analytics, as well as supporting fields such as signal processing and information systems infrastructure. The focus of the group is on innovative high-performance algorithms that can be applied to the product lines of Mitsubishi Electric.

Research on predictive analytics, supported by advances in the field of statistical machine learning, aims to create accurate data-driven models of electromechanical and thermo dynamical systems, as well as models for data managed by enterprise information systems. The developed algorithms for time series prediction, exemplar learning, abrupt change detection, video highlight extraction, non-linear regression, gray-box systems identification, memory-based classification, sequential recommendation, and business process mining are among the best in their class.

Research on decision analytics combines the predictive models learned from data with large-scale optimization methods for planning and scheduling in large problem spaces. Under investigation are formalisms for sequential decision making such as factored Markov decision process models and stochastic Petri nets, with applications to optimal scheduling and control.

Data preprocessing also requires developments in supporting areas such as signal processing, exploratory data analysis, numerical methods, and software infrastructure. Data-base and data-stream management systems have been constructed using novel ideas such as software oriented architectures, web services, and business process management systems. Several innovative signal processing algorithms for dimensionality reduction and feature extraction have been developed, using non-negative matrix factorization and independent component analysis. These methods, combined with predictive and decision algorithms, will lead to a new breed of technology and systems for improved decision making based on data analysis.

Recent Research

Wakame: Sense making of Multi-Dimensional Spatial-Temporal Data ........................................... 52
A Park Transform-Based Method for Condition Monitoring of Three-Phase … .......................... 52
Spectrogram Dimensionality Reduction with Independence Constraints ............................... 53
A Two-Step Method for Estimating the Parameters of Induction Machine Models .................. 53
Probabilistic Inter-disturbance Interval Estimation for Bearing Fault Diagnosis ....................... 54
Memory-Based Modeling of Seasonality for Prediction of Climatic Time Series .................... 54
Fast Adaptive Algorithms for Abrupt Change Detection ....................................................... 55
Optical Performance Monitoring via Histogram: A Data-Driven Approach ......................... 55
As our ability to measure the world around us improves, we are quickly generating massive quantities of high-dimensional, spatial-temporal data. In this paper, we concern ourselves with datasets in which the spatial characteristics are relatively static but many dimensions prevail and data is sampled over different time periods. Example applications include building energy management of HVAC unit diagnostics. We present methods employed in our Wakame visualization system to support such tasks as discovering anomalies and comparing performance across multiple time series. Novel methods include animated transitions that relate data in spatially located 3D views with conventional 2D graphs. Additionally, several components of our prototype employ analytics to guide the user to “interesting” portions of the dataset.

A Park Transform-Based Method for Condition Monitoring of Three-Phase Electromechanical Systems

This paper presents a Park transform-based method for processing stator current data from a motor and transforming it into a form that is useful for fault detection and diagnostics. The proposed method generates power signatures that are invariant to the initial electrical angle of the voltage when the motor is connected to the utility, and can also adapt to variation in the electrical angle of the supply voltage over time. A modified nonlinear least squares algorithm identifies and tracks the parameters of the supply voltage over time, ensuring that the supply voltage and the argument of the Park transformation remain synchronized. Experimental results are presented that illustrate the method’s effectiveness for identifying changes in the mechanical load on a 3/4 HP refrigeration compressor.
Spectrogram Dimensionality Reduction with Independence Constraints

Citation: Wilson, K.W.; Raj, B., “Spectrogram Dimensionality Reduction with Independence Constraints”, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, MLSP-L4.3, March 2010

Contacts: Kevin Wilson

We propose an algorithm to find a low-dimensional decomposition of a spectrogram by formulating this as a regularized non-negative matrix factorization (NMF) problem with a regularization term chosen to encourage independence. This algorithm provides a better decomposition than standard NMF when the underlying sources are independent. It makes better use of additional observation streams than previous nonnegative ICA algorithms.

A Two-Step Method for Estimating the Parameters of Induction Machine Models


Contacts: Christopher Laughman

This paper describes and demonstrates a mathematical algorithm that can monitor the physical parameters of the motor solely by observing the stator electrical currents. This method uses measurements of transient stator currents to identify the parameters of an electromechanical model of the induction motor. These parameters are obtained from a relatively poor initial guess, which is constrained only to be within an order of magnitude of the physical parameters, by using a two-step strategy based upon nonlinear least-squares regression techniques. This makes the approach in this paper useful for diagnostic monitoring and energy scorekeeping. Experimental results are presented which demonstrate the effectiveness of this method on identifying the parameters of a 1 HP induction motor connected to a squirrel cage fan in an air-handling unit.
Probabilistic Inter-disturbance Interval Estimation for Bearing Fault Diagnosis

Citation: Wilson, K.W.; “Probabilistic Inter-disturbance Interval Estimation for Bearing Fault Diagnosis”, IEEE International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives (SDEMPED), DOI: 10.1109/DEMPED.2009.5292803, pp. 1-6, August 2009

Contacts: Kevin Wilson

We describe a new method for detecting characteristic bearing fault signatures from accelerometer vibration data based on a probabilistic model of the fault signal generation process. It is common to assume that single-point bearing defects cause periodic disturbances in bearing vibration signals, but this assumption may not be valid in practice. Our new method is less sensitive to departures from periodicity, such as fault disturbance amplitude and timing variations, than standard spectral or autocorrelation-based approaches. We demonstrate the utility of our method by distinguishing among inner race, outer race, and rolling element faults in a bearing fault test rig. Our method is significantly better than standard techniques at detecting rolling element (ball) faults.

Memory-Based Modeling of Seasonality for Prediction of Climatic Time Series

Citation: Nikovski, D.N.; Ramachandran, G., “Memory-Based Modeling of Seasonality for Prediction of Climatic Time Series”, Lecture Notes in Computer Science, ISSN 0302-9743, Vol. 5632/2009, pp. 734-748, July 2009

Contacts: Daniel Nikovski

The paper describes a method for predicting climate time series that consist of significant annual and diurnal seasonal components and a short-term stochastic component. A memory-based method for modeling of the non-linear seasonal components is proposed that allows the application of simpler linear models for predicting short-term deviations from seasonal averages. The proposed method results in significant reduction of prediction error when predicting error time series of ambient air temperature from multiple locations. Moreover, combining the statistical predictor with meteorological forecasts using linear regression or Kalman filtering further reduces error to typically between 1°C over a prediction horizon of one hour and 2.5 °C over 24 hours.
Fast Adaptive Algorithms for Abrupt Change Detection


Contacts: Daniel Nikovski

We propose two fast algorithms for abrupt change detection in streaming data that can operate on arbitrary unknown data distributions before and after the change. The first algorithm, MB-GT, computes efficiently the average Euclidean distance between all pairs of data points before and after the hypothesized change. The second algorithm, MB-CUSUM, computes the log-likelihood ratio statistic for the data distributions before and after the change, similarly to the classical CUSUM algorithm, but unlike that algorithm, MB-CUSUM does not need to know the exact distributions, and uses kernel density estimates instead. Although a straightforward computation of the two change statistics would have computational complexity of $O(N^4)$ with respect to the size $N$ of the streaming data buffer, the proposed algorithms are able to use the computational structure of these statistics to achieve a computational complexity of only $O(N^2)$ and memory requirement of $O(N)$. Furthermore, the algorithms perform surprisingly well on dependent observations generated by underlying dynamical systems, unlike traditional change detection algorithms.

Optical Performance Monitoring via Histogram: A Data-Driven Approach

Citation: Wen, Y.; Wilson, K.W., "Optical Performance Monitoring via Histogram: A Data-Driven Approach", *Opto Electronics and Communications Conference (OECC)*, DOI: 10.1109/oecc.2009.5222713, pp.1-2, July 2009

Contacts: Kevin Wilson

We apply three alternative statistical learning methods to estimate optical transmission impairments (e.g., noises, chromatic dispersion) from synchronous histograms. Linear regression yields good accuracy. A more sophisticated locally weighted regression technique performs better.
Imaging

The research in the Imaging group at MERL covers all aspects of extracting information from images. For instance, from a picture of a face we can calculate a numerical code for that face that allows recognizing that person again in another picture. Or we can track a moving object in video to quantify its trajectory. In some cases we can modify the actual image creation process to make subsequent information extraction more effective. For instance multiple flash exposures can be used to identify an object's edges. In other cases we can combine information from cameras with information from other sensors, for instance searching a historical database from a network of motion sensors to access stored video that documents the motion at the time and place specified.

Several of our current projects involve analysis of 3D based on 2D images. For example, we have developed algorithms for estimation of object pose so that a robot arm can grasp an object from a cluttered workspace. In another project, we infer automobile position in a city through matching of camera images to a 3D city model. For medical radiation treatment, we align patient position by matching current x-rays to simulated x-rays obtained by project. In all these cases, the algorithms we have developed must be very fast and accurate.

Other projects depend on developing novel models and features to support accurate detection, classification, and recognition based on machine learning. Our work on face detection and recognition is well-known, and we have produced world class results in other forms of detection and classification for human and other objects.

For several years, MERL has been a leader in computational photography and imaging. Given that many images are now computer processed prior to viewing, this research seeks to modify the capture stage to optimize the information transfer into the computer and ultimately into the final usage—perhaps human viewing, or perhaps more computer analysis to extract quantitative measures from the image. In this research MERL has been able to dramatically improve corrections for motion and focus blur, achieve spatial and temporal super-resolution in video, and conceive novel camera optics for wide field of view stereo reconstruction.

Recent Research

Morphable Reflectance Fields for Enhancing Face Recognition .................................................. 58
Fast Directional Chamfer Matching ............................................................................................. 58
Breaking the Interactive Bottleneck in Multi-Class Classification with Active .......................... 59
RelCom: Relational Combinatorics Features for Rapid Object Detection ................................. 59
Rao-Blackwellized Particle Filtering for Probing-Based 6-DOF Localization in Robotic .......... 60
Pose Estimation in Heavy Clutter Using a Multi-Flash Camera ................................................ 60
Needle Picking: A Sampling Based Track-Before-Detection Method for Small Targets ......... 61
Coded Strobing Photography: Compressive Sensing of High-Speed Periodic Events............ 61
Kernel Methods for Weakly Supervised Mean Shift Clustering ............................................... 62
Geolocalization Using Skylines from Omni-Images ................................................................. 62
Invertible Motion Blur in Video ....................................................................................... 63
Object Detection via Boosted Deformable Features .............................................................. 63
Axial Light Field for Curved Mirrors: Reflect Your Perspective, Widen Your View ............ 64

- 57 -
Morphable Reflectance Fields for Enhancing Face Recognition

Citation: Kumar, R.; Jones, M.J.; Marks, T.K., "Morphable Reflectance Fields for Enhancing Face Recognition", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2010.5539972, pp. 2606-2613, June 2010

Contacts: Michael Jones, Tim Marks

In this paper, we present a novel framework to address the confounding effects of illumination variation in face recognition. By augmenting the gallery set with realistically relit images, we enhance recognition performance in a classifier-independent way. We describe a novel method for single-image relighting called Morphable Reflectance Fields (MoRF) that does not require manual intervention and provides relighting superior to that of existing automatic methods. We test our framework through face recognition experiments using various state-of-the-art classifiers and popular benchmark datasets: CMU PIE, Multi-PIE, and MERL Dome. We demonstrate that our MoRF relighting and gallery augmentation framework achieves improvements in terms of both rank-1 recognition rates and ROC curves. We also compare our model with other automatic relighting methods to confirm its advantage.

Fast Directional Chamfer Matching

Citation: Liu, M-Y.; Tuzel, C.O.; Veeraraghavan, A.N.; Chellappa, R., "Fast Directional Chamfer Matching", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2010

Contacts: Oncel Tuzel, Ashok Veeraraghavan

We study the object localization problem in images given a single hand-drawn example or a gallery of shapes as the object model. Although many shape matching algorithms have been proposed for the problem over the decades, chamfer matching remains to be the preferred method when speed and robustness are considered. In this paper, we significantly improve the accuracy of chamfer matching while reducing the computational time from linear to sublinear (shown empirically). Specifically, we incorporate edge orientation information in the matching algorithm such that the resulting cost function is piecewise smooth and the cost variation is tightly bounded. Moreover, we present a sublinear time algorithm for exact computation of the directional chamfer matching score using techniques from 3D distance transforms and directional integral images. Experiments show that the proposed approach improves the speed of the original chamfer matching up to an order of 45x.
Breaking the Interactive Bottleneck in Multi-Class Classification with Active Selection and Binary Feedback

Citation: Joshi, A.J.; Porikli, F.M.; Papanikolopoulos, N., "Breaking the Interactive Bottleneck in Multi-class Classification with Active Selection and Binary Feedback", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Object Recognition, June 2010

Contacts: Fatih Porikli

Multi-class classification schemes typically require human input in the form of precise category names or numbers for each example to be annotated. Providing this can be impractical for the user. We propose a multi-class active learning model that requires only binary (yes/no type) feedback from the user. We first show the interactive benefits of such a scheme with experiments. We then propose a Value of Information (VOI)-based active selection algorithm in the binary feedback model. The algorithm iteratively selects image pairs for annotation to maximize accuracy, while also minimizing user annotation effort. To our knowledge, this is the first multi-class active learning approach that requires only yes/no inputs. Experiments show that the proposed method can substantially minimize user supervision compared to the traditional training model on problems with as many as 100 classes.

RelCom: Relational Combinatorics Features for Rapid Object Detection

Citation: Venkatraman, V.; Porikli, F.M., "RelCom: Relational Combinatorics Features for Rapid Object Detection", IEEE Workshop on Object Tracking and Classification Beyond and in the Visible Spectrum, Robust Object Detection, June 2010

Contacts: Fatih Porikli

We present a simple yet elegant feature, RelCom, and a boosted selection method to achieve a very low complexity object detector. We generate combinations of low-level feature coefficients and apply relational operations such as margin based similarity rule over each possible pair of these combinations to construct a proposition space. From this space we define combinatorial functions of Boolean operators to form complex hypotheses that model any logical proposition. In case these coefficients are associated with the pixel coordinates, they encapsulate higher order spatial structure within the object window. Our results on benchmark datasets prove that the boosted RelCom features can match the performance of HOG features of SVM-RBF while providing 5X speed up and significantly outperform SVM-linear while reducing the false alarm rate 5X~20X. In case of intensity features the improvement in false alarm rate over SVM-RBF is 14X with a 128X speed up.
Rao-Blackwellized Particle Filtering for Probing-Based 6-DOF Localization in Robotic Assembly

Citation: Taguchi, Y.; Marks, T.K.; Okuda, H., "Rao-Blackwellized Particle Filtering for Probing-based 6-DOF Localization in Robotic Assembly", IEEE International Conference on Robotics and Automation (ICRA), ISSN: 105-4729, pp. 2610-2617, Best Automation Paper Award Finalist, May 2010
Contacts: Yuchi Taguchi, Tim Marks

This paper presents a probing-based method for probabilistic localization in automated robotic assembly. We consider peg-in-hole problems in which a needle-like peg has a single point of contact with the object that contains the hole, and in which the initial uncertainty in the relative pose (3D position and 3D angle) between the peg and the object is much greater than the required accuracy (assembly clearance). We solve this 6 degree-of-freedom (6-DOF) localization problem using a Rao-Blackwellized particle filter, in which the probability distribution over the peg's pose is factored into two components: The distribution over position (3-DOF) is represented by particles, while the distribution over angle (3-DOF) is approximated as a Gaussian distribution for each particle, updated using an extended Kalman filter. This factorization reduces the number of particles required for localization by orders of magnitude, enabling real-time online 6-DOF pose estimation. Each measurement is simply the contact position obtained by randomly repositioning the peg and moving towards the object until there is contact. To compute the likelihood of each measurement, we use a mesh model of the object that is based on the CAD model but also explicitly models the uncertainty in the map.

Pose Estimation in Heavy Clutter Using a Multi-Flash Camera

Citation: Liu, M-Y.; Tuzel, C.O.; Veeraraghavan, A.N.; Chellappa, R.; Agrawal, A.K.; Okuda, H., "Pose Estimation in Heavy Clutter Using a Multi-Flash Camera", IEEE International Conference on Robotics and Automation (ICRA), May 2010
Contacts: Oncel Tuzel, Ashok Veeraraghavan

We propose a novel solution to object detection, localization and pose estimation with applications in robot vision. The proposed method is especially applicable when the objects of interest may not be richly textured and are immersed in heavy clutter. We show that a multi-flash camera (MFC) provides accurate separation of depth edges and texture edges in such scenes. Then, we reformulate the problem, as one finding matches between the depth edges obtained in one or more MFC images to the rendered depth edges that are computed offline using 3D CAD models of the objects. We introduce a novel cost function that respects both the position and the local orientation of each edge pixel. This cost function is significantly superior to traditional Chamfer cost and leads to accurate matching even in heavily cluttered scenes where traditional methods are unreliable. We present a sub-linear time algorithm to compute the cost function using techniques from 3D distance transforms and integral images.
Needle Picking: A Sampling Based Track-Before-Detection Method for Small Targets

Citation: Porikli, F.M., "Needle Picking: A Sampling Based Track-before-Detection Method for Small Targets", SPIE Conference on Signal and Data Processing of Small Targets, Vol. 7698, 769803 (2010); DOI: 10.1117/12.850452, April 2010
Contacts: Fatih Porikli

We present a computationally efficient track-before-detect algorithm that achieves more than 50% true detection at 0.000001 false alarm rate for unknown numbers of pixel-sized targets when the signal-to-noise ratio is less than 7dB. Without making any assumptions on the distribution functions, we select a small number of cells, so called as needles, and generate motion hypotheses using the target state transition model. We accumulate cell likelihoods along each hypothesis in the temporal window and append the accumulated values to the corresponding queues of the cell position in the most recent image.

Coded Strobing Photography: Compressive Sensing of High-Speed Periodic Events

Citation: Veeraraghavan, A.N.; Reddy, D.; Raskar, R., "Coded Strobing Photography: Compressive Sensing of High-Speed Periodic Events", IEEE Transactions on Pattern Analysis and Machine Intelligence, ISSN: 0163-8828, pp. I-1, April 2010
Contacts: Ashok Veeraraghavan

We show that, via temporal modulation, one can observe a high-speed periodic event well beyond the abilities of a low-frame camera. By strobing the exposure with unique sequences within the integration time of each frame, we take coded projections of dynamic events. From a sequence of such frames, we reconstruct a high-speed video of the high frequency periodic process. Strobing is used in entertainment, medical imaging and industrial inspection to generate lower beat frequencies. But this is limited to scenes with a detectable single dominant frequency and requires high-intensity lighting. In this paper, we address the problem of sub-Nyquist sampling of periodic signals and show designs to capture and reconstruct such signals. The key result is that for such signals the Nyquist rate constraint can be imposed on strobe-rate rather than the sensor-rate. The technique is based on intentional aliasing of the frequency components of the periodic signal while the reconstruction algorithm exploits recent advances in sparse representations and compressive sensing.
Kernel Methods for Weakly Supervised Mean Shift Clustering

Citation: Tuzel, C.O.; Porikli, F.M.; Meer, P., "Kernel Methods for Weakly Supervised Mean Shift Clustering", IEEE International Conference on Computer Vision (ICCV), DOI: 10.1109/ICCV.2009.5459204, pp. 48-55, September 2009

Contacts: Oncel Tuzel, Fatih Porikli

Mean shift clustering is a powerful unsupervised data analysis technique which does not require prior knowledge of the number of clusters, and does not constrain the shape of the clusters. The data association criteria is based on the underlying probability distribution of the data points which is defined in advance via the employee distance metric. In many problem domains, the initially designed distance metric fails to resolve the ambiguities in the clustering process. We present a novel semi-supervised kernel mean shift algorithm where the inherent structure of the data points is learned with a few user supplied constraints in addition to the original metric. The constraints we consider are the pairs of points that should be clustered together. The data points are implicitly mapped to a higher dimensional space induced by the kernel function where the constraints can be effectively enforced. The mode seeking is then performed on the embedded space and the approach preserves all the advantages of the original mean shift algorithm. Experiments on challenging synthetic and real data clearly demonstrate that significant improvements in clustering accuracy can be achieved by employing only a few constraints.

Geolocalization Using Skylines from Omni-Images

Citation: Ramalingam, S.; Bouaziz, S.; Sturm, P.; Brand, M.E., "Geolocalization using Skylines from Omni-Images", IEEE International Conference on Computer Vision Workshops (ICCV), DOI: 10.1109/ICCVW.2009.5457723, pp. 23-30, September 2009

Contacts: Srikumar Ramalingam, Matthew Brand

We propose a novel method to accurately estimate the global position of a moving car using an omni-directional camera and untextured 3D city models. The camera is oriented upwards to capture images of the immediate skyline, which is generally unique and serves as a fingerprint for a specific location in a city. Our goal is to estimate global position by matching skylines extracted from omni-directional images to skyline segments from coarse 3D city models. Our contributions include a sky segmentation algorithm for omni-directional images using graph cuts and a novel approach for matching omni-image skylines to 3D models.
Invertible Motion Blur in Video

Citation: Agrawal, A.K.; Xu, Y.; Raskar, R., "Invertible Motion Blur in Video", ACM Transactions on Graphics (TOG), ISSN: 0730-0301, Article 95, Vol. 28, Issue 3, August 2009
Contacts: Amit Agrawal

We show that motion blur in successive video frames is invertible even if the point-spread function (PSF) due to motion smear in a single photo is non-invertible. Blurred photos exhibit nulls (zeros) in the frequency transform of the PSF, leading to an ill-posed deconvolution. Hardware solutions to avoid this require specialized devices such as the coded exposure camera or accelerating sensor motion. We employ ordinary video cameras and introduce the notion of null-filling along with joint-invertibility of multiple blur-functions. The key idea is to record the same object with varying PSFs, so that the nulls in the frequency component of one frame can be filled by other frames. The combined frequency transform becomes null-free, making deblurring well-posed. We achieve jointly invertible blur simply by changing the exposure time of successive frames. We address the problem of automatic deblurring of objects moving with constant velocity by solving the four critical components: preservation of all spatial frequencies, segmentation of moving parts, motion estimation of moving parts, and non-degradation of the static parts of the scene. We demonstrate several challenging cases of object motion blur including textured backgrounds and partial occluders.

Object Detection via Boosted Deformable Features

Citation: Hussein, M.E.; Porikli, F.M.; Davis, L., "Object Detection via Boosted Deformable Features", IEEE International Conference on Image Processing (ICIP), DOI: 10.1109/ICIP.2009.5414561, pp. 1445-1448, November 2009
Contacts: Mohammed Hussein, Fatih Porikli

It is a common practice to model an object for detection tasks as a boosted ensemble of many models built on features of the object. In this context, features are defined as subregions with fixed relative locations and extents with respect to the object's image window. We introduce using deformable features with boosted ensembles. A deformable feature adapts its location depending on the visual evidence in order to match the corresponding physical feature. Therefore, deformable features can better handle deformable objects. We empirically show that boosted ensembles of deformable features perform significantly better than boosted ensembles of fixed features for human detection.
Axial Light Field for Curved Mirrors: Reflect Your Perspective, Widen Your View


Contacts: Yuchi Taguchi, Amit Agrawal, Srikumar Ramalingam, Ashok Veeraraghavan

Mirrors have been used to enable wide field-of-view (FOV) catadioptric imaging. The mapping between the incoming and reflected light rays depends non-linearly on the mirror shape and has been well-studied using caustics. We analyze this mapping using two-plane light field parameterization, which provides valuable insight into the geometric structure of reflected rays. Using this analysis, we study the problem of generating a single-viewpoint virtual perspective image for catadioptric systems, which is unachievable for several common configurations. Instead of minimizing distortions appearing in a single image, we propose to capture all the rays required to generate a virtual perspective by capturing a light field. We consider rotationally symmetric mirrors and show that a traditional planar light field results in significant aliasing artifacts. We propose axial light field, captured by moving the camera along the mirror rotation axis, for efficient sampling and to remove aliasing artifacts. This allows us to computationally generate wide FOV virtual perspectives using a wider class of mirrors than before, without using scene priors to depth estimation. We analyze the relationship between the axial light field parameters and the FOV/resolution of the resulting virtual perspective. Real results using a spherical mirror demonstrate generating 140 degrees FOV virtual perspective using multiple 30 degrees FOV images.
Mechatronics

The Mechatronics group conducts fundamental and applied research and develops advanced technology in the areas of mechatronic systems and control, merging advanced control theory, dynamical systems theory, physics and computer science with mechanical and materials engineering, optics, embedded systems, signal and power electronics, all with the intent to expand the performance envelope of Mitsubishi Electric products. The Mechatronics Group has expertise in multivariable, nonlinear and optimal control, nonlinear estimation, nonlinear dynamical systems, mechanical design, laser processing and sensing, 3D CAD and rapid prototyping and is growing its research and development portfolio in these areas with an emphasis on control systems and dynamical systems. The business drivers for this R&D program are twofold. First, the design and control of electromechanical devices is central to many areas of Mitsubishi Electric business. Second, with the rapidly increasing power of embedded computation and sensing technologies, there is the opportunity for synergy among research in mechatronics and control and MERL's existing research strengths in computer and information technology.

Recent Research

Modeling Cutting Forces for 5-Axis Machining of Sculptured Surfaces .............................. 66
Multiple Time Scaling of a Multi-Output Observer Form ..................................................... 66
Keeping the Good Stuff In: Confidential Information Firewalling with the CRM114 ............... 67
Design of Hybrid Resetting PID and Lag Controllers with Application to Motion Control ...... 67
Modeling Current Forces for 5-Axis Machining of Scultped Surfaces

Citation: Boz, Y.; Erdim, H.; Lazoglu, I., “Modeling Cutting Forces for 5-Axis Machining of Sculptured Surfaces”, International Conference Process Machine Interactions, Scientific Session C-Metal Cutting Process, June 2010

Contacts: Huseyin Erdim

5-axis milling processes are used widely in various industries such as aerospace, die-mold and biomedical industries where surface quality and integrity is important and the production tolerances are very tight. Therefore, improving surface quality and integrity without sacrificing productivity is crucial in these industries. Improvements in CAD/CAM, cutting tool and the machine tool technologies allow the production of high precision parts in less cycle times. However, desired quality and productivity can be obtained if process parameters such as feedrate, spindle speed, axial and radial depth of cut are selected appropriately. In general, these parameters are selected conservatively based on engineering expertise or trial and error methods in order to prevent work piece, cutter of the machine to be damaged. Therefore, virtual machining simulation for milling processes is an increasing demand before the production of the part. This paper presents a mechanistic cutting force model for 5-axis ball-end milling process simulation. Cutter/work piece engagement is determined via newly developed solid modeler based engagement model. Two different 5-axis machining tests are conducted on A17039 work piece material for the validation of the proposed model. Validation tests demonstrate that presented model is computationally efficient and force predictions are in good agreement with the experimental data.

Multiple Time Scaling of a Multi-Output Observer Form

Citation: Wang, Y.; Lynch A.F., “Multiple Time Scaling of a Multi-Output Observer Form”, IEEE Transactions on Automatic Control, DOI: 10.1109/TAC.2010.2041616, Vol. 55, Issue 4, pp. 966-971, April 2010

Contacts: Yebin Wang

Time scalings in the multi-output observer form for uncontrolled nonlinear continuous-time systems are considered in this paper. It is the multi-output version of an existing single-input result. Time scaling broadens the class of systems which admits an exact error linearization observer design by including time scaling transformations. The existence conditions of the time scaling transformation and the change of state coordinates to time-scaled observer form are provided.
Keeping the Good Stuff In: Confidential Information Firewalling with the CRM114 Spam Filter & Text Classifier

Citation: Yerazunis, W.S.; Kato, M.; Kori, M.; Shibata, H.; Hackenberg, K., “Keeping the Good Stuff In: Confidential Information Firewalling with the CRM114 Spam Filter & Text Classifier”, Black hat Technical Security Conference, July 2010

Contacts: William Yerazunis

In this whitepaper we consider the problem of outbound-filtering of emails to prevent accidental leakage of confidential information. We examine how to do this with GPLed open-source spam filter CRM114 and test the accuracy of this filter against a 10,000+ document corpus of hand-classified emails (both confidential and non-confidential) in Japanese. We look into what moving parts are involved in these filters, and how they can be set up. The results show that a hybrid of multiple CRM114 filters outperforms a human-crafted regular-expression filter by nearly 100x in recall, by detecting > 99.9% of confidential documents, and with a simultaneous false alarm rate of less than 6%. As the programmers creating the machine-learning programs don't know how to read or write Japanese, this problem is an almost ideal case of the Searle "Chinese Room" problem.

Design of Hybrid Resetting PID and Lag Controllers with Application to Motion Control

Citation: El-Rifai, K.; El-Rifai, O., “Design of Hybrid Resetting PID and Lag Controllers with Application to Motion Control”, IEEE/ASME International Conference Advanced Intelligent Mechatronics (AIM), DOI: 10.1109/AIM.2009.5229931, July 2009

Contacts: Scott Bortoff

In this paper, new designs for hybrid PID and lag controllers with state resetting are presented. Lyapunov stable designs are shown for first and second order plants, which in case of integral reset for first order plants reduces to that of a Clegg integrator but differs from the First Order Reset Elements (FORE)'s commonly used in the literature for non-integral lag controllers. Furthermore, the proposed PID and lag designs utilize different resetting conditions especially for second order plants, which is an important class of systems for motion control. Different solutions to retain a linear integrator's steady-state disturbance rejection capability are presented. Simulations and experiments for motion control of a typical servo motor driven positioning stage show the performance benefits of these hybrid controllers and verify the analysis.
Algorithms

Researchers in the Algorithms group at MERL develop solution methods for optimization problems involving very large numbers of variables. Typically these arise in inference problems involving images, video, or audio; network transport problems; coding and compression problems; or design problems. Usually these problems are characterized by very complicated probability distributions in extremely high dimensional spaces. Because classical approaches to these problems are infeasible, our results can open new business opportunities where there are no competitive technologies. Another main research theme involves adaptively-sampled distance fields, providing superior font and graphical rendering for digital displays.

Most of the group’s work revolves around graph-based optimizations and inference, where the graph is a representation of the problem constraints and a probability distribution over possible solutions. Through formal analysis we identify tractable estimation or approximation schemes. This meshes with MERL’s expertise in fields and technologies such as belief propagation, machine learning, computer vision, dynamic programming, convex optimization, coding and communications theory, and signal processing.

Recent Research

Divide & Concur and Difference-Map BP Decoders for LDPC Codes ......................................................... 70
Cooperative Routing for Wireless Networks Using Mutual-Information Accumulation ...................... 70
Image and Video Retargeting by Darting ............................................................................................... 71
Adaptively Sampled Distance Fields: A General Representation of Shape .............................................. 71
Kizamu: A System for Sculpting Digital Characters ............................................................................... 72
Designing with Distance Fields ............................................................................................................. 72
Multi-Stage Decoding of LDPC Codes ...................................................................................................... 73
Understanding Belief Propagation and its Generalization ................................................................. 73
Stochastic Shortest Paths Via Quasi-convex Maximization ................................................................. 74
Nonrigid Embeddings for Dimensionality Reduction ............................................................................. 74
Divide & Concur and Difference-Map BP Decoders for LDPC Codes


Contacts: Jonathan Yedidia, Yige Wang

The "Divide and Concur" (DC) algorithm, recently introduced by Gravel and Elser, can be considered a competitor to the belief propagation (BP) algorithm, in that both algorithms can be applied to a wide variety of constraint satisfaction, optimization, and probabilistic inference problems. We show that DC can be interpreted as a message-passing algorithm on a constraint graph, which helps make the comparison with BP clearer. The "difference-map" dynamics of the DC algorithm enables it to avoid "traps" which may be related to the "trapping sets" or "pseudo-codewords" that plague BP decoders of low-density parity check (LDPC) codes in the error-floor regime. We investigate two decoders for low density parity-check (LDPC) codes based on these ideas. The first decoder is based directly on DC, while the second decoder borrows the important "difference-map" concept from the DC algorithm and translates it into a BP-like decoder. We show that this "difference-map belief propagation" (DMBP) decoder has dramatically improved error-floor performance compared to standard BP decoders, while maintaining a similar computational complexity.

Cooperative Routing for Wireless Networks Using Mutual-Information Accumulation


Contacts: Jonathan Yedidia

Cooperation between the nodes of wireless multihop networks can increase communication reliability, reduce energy consumption, and decrease latency. The possible improvements are even greater when nodes perform mutual information accumulation using rateless codes. In this paper, we investigate routing problems in such networks. Given a network, a source, and a destination, our objective is to minimize end-to-end transmission delay under energy and bandwidth constraints. We provide an algorithm that determines which nodes should participate in forwarding the message and what resources (time, energy, and bandwidth) should be allocated to each.
Image and Video Retargeting by Darting


Contact: Matt Brand

We consider the problem of altering an image by imperceptibly adding or removing pixels, for example, to fit a differently shaped frame with minimal loss of interesting content. We show how to construct a family of convex programs that suitably rearrange pixels while minimizing image artifacts and distortions. We call this “darting” on analogy to a tailor’s darts—small edits are discreetly distributed throughout the fabric of the image. We develop a reduction to integer dynamic programming on edit trellises, yielding fast algorithms. One- and two-pass variants of the method have $O(1)$ per-pixel complexity. Of the many edits that darting supports, five are demonstrated here: image retargeting to smaller aspect ratios; adding or moving or removing scene objects while preserving image dimensions; image expansion with gaps filled by a rudimentary form of texture synthesis; temporal video summarization by “packing” motion in time; and an extension to spatial video retargeting that avoids motion artifacts by preserving optical flow.

Adaptively Sampled Distance Fields: A General Representation of Shape for Computer Graphics


Contacts: Ronald Perry

Adaptively Sampled Distance Fields (ADFs) are a unifying representation of shape that integrate numerous concepts in computer graphics including the representation of geometry and volume data and a broad range of processing operations such as rendering, sculpting, level-of-detail management, surface offsetting, collision detection, and color gamut correction. Its structure is uncomplicated and direct, but is especially effective for quality reconstruction of complex shapes, e.g., artistic and organic forms, precision parts, volumes, high order functions, and fractals. We characterize one implementation of ADFs, illustrating its utility on two diverse applications: 1) artistic carving of fine detail, and 2) representing and rendering volume data and volumetric effects. Other applications are briefly presented.
Kizamu: A System for Sculpting Digital Characters

Contacts: Ronald Perry

This paper presents Kizamu, a computer-based sculpting system for creating digital characters for the entertainment industry. Kizamu incorporates a blend of new algorithms, significant technical advances, and novel user interaction paradigms into a system that is both powerful and unique. At the heart of the Kizamu system are Adaptively Sampled Distance Fields (ADFs), a volumetric shape representation with the characteristics required for digital clay. In this paper, we describe the system and present the major research advances in ADFs that were required to make Kizamu a reality.

Designing with Distance Fields

Citation: Frisken, S.F.; Perry, R.N., "Designing with Distance Fields", ACM SIGGRAPH, ISBN: 1-59593-364-6, pp. 60-66, July 2006
Contacts: Ronald Perry

Distance fields provide an implicit representation of shape that has advantages in many application areas; in this overview, we focus on their use in digital design. Distance fields have been used in Computer Aided Design since the 1970's (e.g. for computing offset surfaces and for generating rounds and filets). More recently, distance fields have been used for freeform design where their dual nature of providing both a volumetric representation and a high-quality surface representation provides a medium that has some of the properties of real clay. Modern computer systems coupled with efficient representations and methods for processing distance fields have made it possible to use distance fields in interactive design systems. This overview reviews previous work in distance fields, discusses the properties and advantages of distance fields that make them suitable for digital design, and describes Adaptively Sampled Distance Fields (ADFs), a distance field representation capable of representing detailed, high quality, and expressive shapes. ADFs are both efficient to process and have a relatively small memory footprint.
Multi-Stage Decoding of LDPC Codes

Citation: Wang, Y.; Yedidia, J.S.; Draper, S.C., "Multi-Stage Decoding of LDPC Codes", IEEE International Symposium on Information Theory, June 2009
Contacts: Yige Wang, Jonathan Yedidia

We present a three-stage decoding strategy that combines quantized and un-quantized belief propagation (BP) decoders with a mixed-integer linear programming (MILP) decoder. Each decoding stage is activated only when the proceeding stage fails to converge to a valid codeword. The faster BP decoding stages are able to correct most errors, yielding a short average decoding time. Only in the rare cases when the iterative stages fail is the slower but more powerful MILP decoder used. The MILP decoder iteratively adds binary constraints until either the maximum likelihood codeword is found or some maximum number of binary constraints has been added. Simulation results demonstrate a large improvement in the word error rate (WER) of the proposed multi-stage decoder in comparison to belief propagation. The improvement is particularly noticeable in the low crossover probability (error floor) regime. We demonstrate that for certain codes our approach can efficiently approach the optimal ML decoding performance for low crossover probabilities.

Understanding Belief Propagation and its Generalization

Contacts: Jonathan Yedidia

"Inference" problems arise in statistical physics, computer vision, error-correcting coding theory, and AI. We explain the principles behind the belief propagation (BP) algorithm, which is an efficient way to solve inference problems based on passing local messages. We develop a unified approach with examples, notation, and graphical models borrowed from the relevant disciplines. We explain the close connection between the BP algorithm and the Bethe approximation of statistical physics. In particular, we show that BP can only converge to a fixed point that is also a stationary point of the Bethe approximation to the free energy. This result helps explain the successes of the BP algorithm and enables connections to be made with variational approaches to approximate inference.
Stochastic Shortest Paths Via Quasi-convex Maximization


Contacts: Matthew Brand

We consider the problem of finding shortest paths in a graph with independent randomly distributed edge lengths. Our goal is to maximize the probability that the path length does not exceed a given threshold value (deadline). We give a surprising exact $n^{\Theta(\log n)}$ algorithm for the case of normally distributed edge lengths, which is based on quasi-convex maximization. We then prove average and smoothed polynomial bounds for this algorithm, which also translate to average and smoothed bounds for the parametric shortest path problem, and extend to a more general non-convex optimization setting. We also consider a number other edge length distributions, giving a range of exact and approximation schemes.

Nonrigid Embeddings for Dimensionality Reduction


Contact: Matthew Brand

Spectral methods for embedding graphs and immersing data manifolds in low-dimensional spaces are notoriously unstable due to insufficient and/or numerically ill-conditioned constraint sets. Why show shy this is endemic to spectral methods, and develop low-complexity solutions for stiffening ill-conditioned problems and regulatizing ill-posed problems, with proofs of correctness. The regularization exploits sparse but complementary constraints on affine rigidity and edge lengths to obtain isometric embeddings. An implemented algorithm is fast, accurate and industrial-strength: Experiments with problem sizes spanning four orders of magnitude show $O(N)$ scaling. We demonstrate with speech data.