Mitsubishi Electric Research Laboratories (MERL)

Annual Report

April 2011 through March 2012

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Welcome to Mitsubishi Electric Research Laboratories (MERL), the North American corporate R&D arm of Mitsubishi Electric Corporation. In this report, you will find descriptions of MERL and our projects.

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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:

- Generating new technology and intellectual property 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:

- Being one of the world's premiere research laboratories, doing long-term fundamental research that advances the frontiers of technology and makes lasting impacts on the world.
- Being the prime source of technology for Mitsubishi Electric in our areas of expertise.

MERL's values—how we operate:

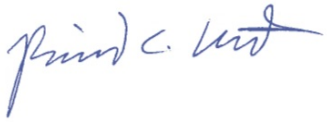
- Hiring very high quality researchers and supporting them strongly with a flexible work environment featuring teamwork both inside MERL and with our colleagues at Mitsubishi Electric.
- Participating in the world research community, publishing our work while maintaining the confidentiality of business information, and collaborating with interns and university researchers.

MERL focuses on five principal technology sectors:

Digital Communications - featuring wired & optical transmission technology & networking.
Multimedia – featuring speech interfaces, video (de)coding & compressive sensing.
Data Analytics – featuring simulation, planning and optimization.
Imaging – featuring 2D and 3D imaging processing algorithms.
Mechatronics – featuring advanced control of electro-mechanical systems.

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

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's 20th Anniversary

MERL was founded in Cambridge MA in 1991 by Mitsubishi Electric CR&D. During the early and mid 1990s, MERL grew steadily to approximately 25 researchers. In the late 1990s, it tripled in size through merger with two other laboratories that were part of Mitsubishi Electric: a laboratory focused on software systems research and another on video and communications research. This consolidated all of Mitsubishi Electric's North American research in one organization creating the MERL that exists today.

The poster on the next page (reproduced in color on the back cover) was created in 2011 to honor MERL's 20th anniversary. It summarizes the rich history of research and innovation at MERL.

Computer Vision research at MERL includes developments such as:

- Generalized Belief Propagation, a fundamentally improved Belief Propagation algorithm that provides more accurate results with fewer convergence problems, and
- The first real-time face detection algorithm, which was later extended to face recognition.

Graphics research includes:

- An ASIC chip that was the first system capable of rendering volume data (e.g., from a CAT scan machine) in real time,
- Adaptively-Sampled Distance Fields (ADFs) a highly accurate and highly efficient, digital representation of shapes with both smoothly curved surfaces and surfaces with fine detail,
- Saffron, a 2-dimensional application of ADFs that is best system for rendering high-quality scalable type on digital displays, and
- An ADF-based Numerical-Control (NC) milling machine simulator that has high accuracy and low computational requirements.

Human Computer Interaction (HCI) research includes:

- Diamond Park, the first distributed virtual environment allowing multiple geographically separated users to speak to each other and arbitrarily extend the virtual environment at runtime,
- Diamond Touch, the first touch surface that allows multiple people to use their bare hands to simultaneously interact with the surface without interfering with each other, and
- Spoken Query, a Pioneering voice search technology.

Video research includes:

- Key parts of the first ASIC chip set capable of decoding US HDTV signals,
- The first automatic video playback system that can locate sports highlights,
- Innovative multi-view video coding research adopted by the H.264/AVC standard (which is the 3D format for Blu-ray Discs), and
- A Novel scheme for rate reduction of Synthetic Aperture Radar (SAR) data that maintains reconstruction quality.

Communications research includes:

- Pioneering ad-hoc networking research adopted by the Zigbee low cost, low power, wireless network standard,
- The first Ultra Wide Band (UWB) communication approach based on multi-band Orthogonal Frequency Division Multiplexing (OFDM),

- Ten key technologies adopted by the impulse-radio-based, IEEE 802.15.4a, Ultra Wide Band (UWB) standard and the first precise location system using that standard,
- Eleven key technologies adopted by the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) cell phone standard.

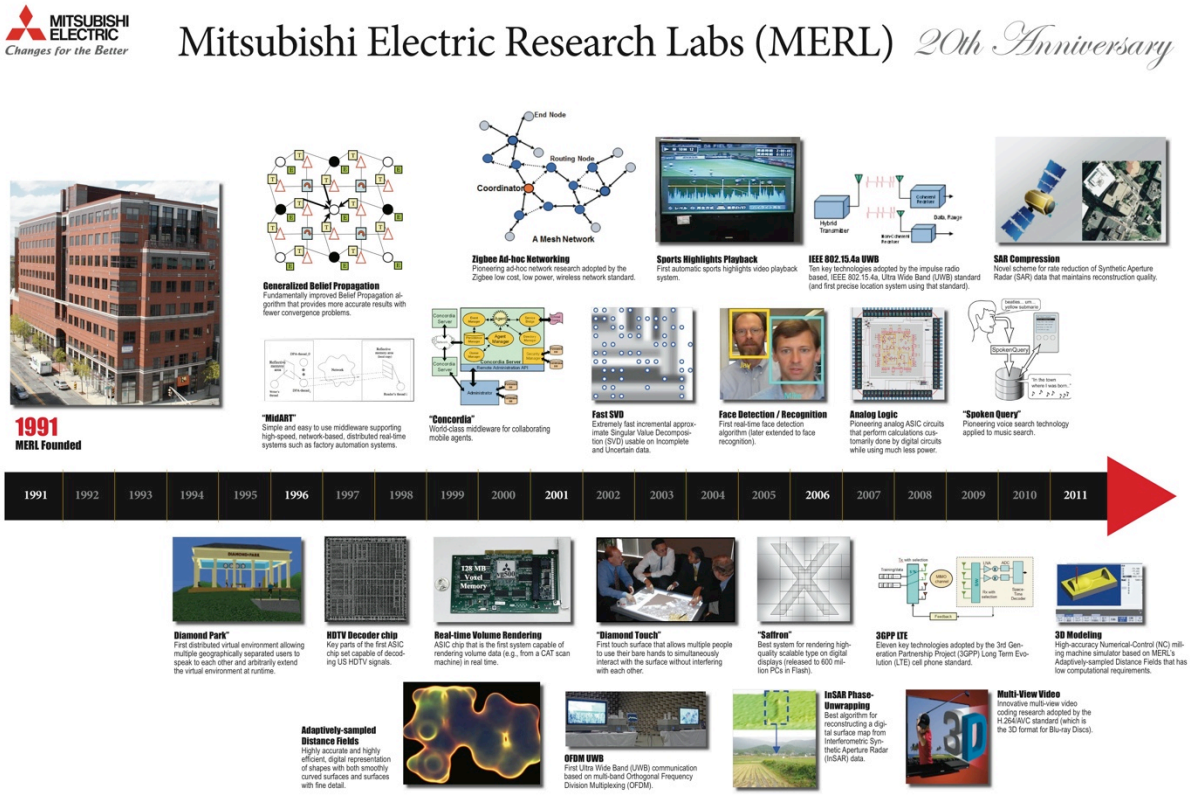
Optimization and Control research includes:

- IISVD, an Extremely fast incremental approximate Singular Value Decomposition (SVD) usable on Incomplete and Uncertain data, and
- The best algorithm for reconstructing a digital surface map from Interferometric Synthetic Aperture Radar (InSAR) data.

Other notable research items from past years include:

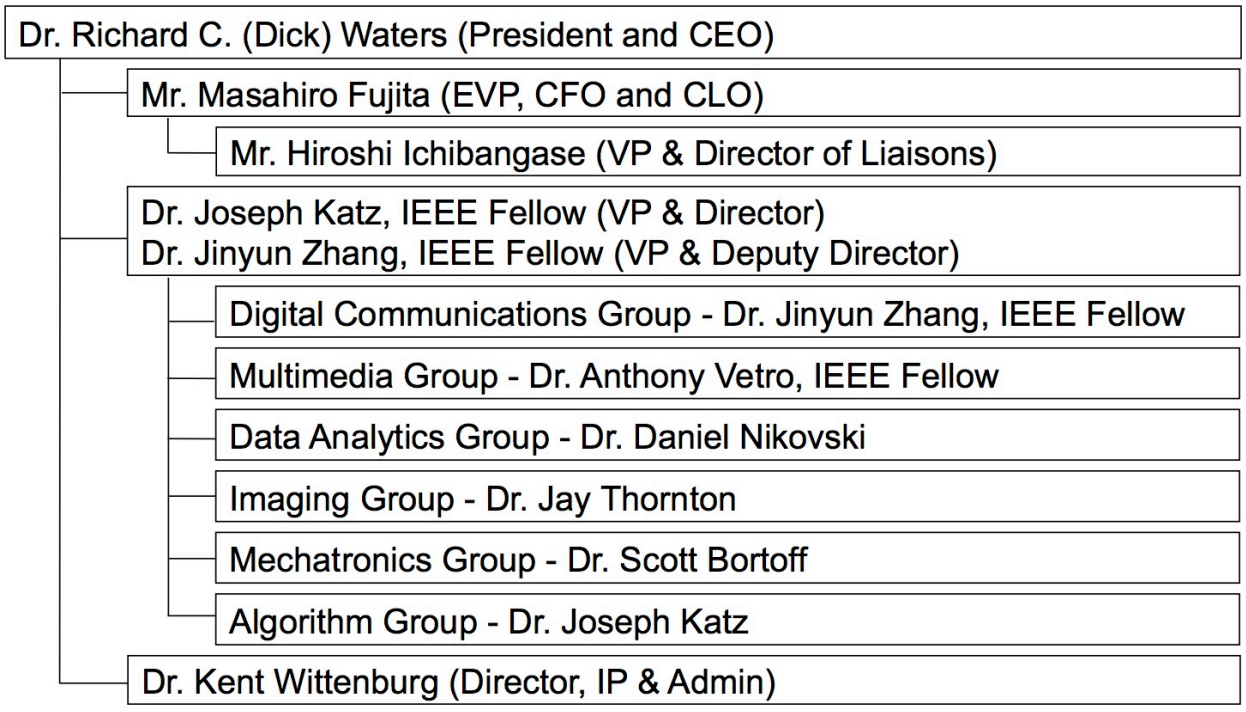
- MidART, Simple and easy to use middleware supporting high-speed, network-based, distributed real-time systems such as factory automation systems,
- Concordia, world-class middleware for collaborating mobile agents and
- Pioneering analog ASIC circuits that perform calculations customarily done by digital circuits while using much less power.

MERL continues vibrant research in all of the main areas above; however, over the years the emphasis between areas has changed. In the late 1990s, Computer Graphics was MERL's greatest area of focus. Today that honor goes to Optimization and Control.



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 five 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. Dick is an ACM Distinguished Scientist.

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.

Jinyun Zhang *Ph.D., University of Ottawa, 1991*
Vice President, Deputy director, MERL Fellow, IEEE Fellow

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 of her contributions to broadband wireless transmission and networking technology she became an IEEE Fellow in 2008.

Kent Wittenburg *Ph.D., University of Texas at Austin, 1986*
Director Intellectual Property & Administration

Kent manages MERL's intellectual property activities and the admin group. He was formerly a Director at MERL for 9 years. Prior to joining MERL, he held positions at the Microelectronics and Computer Technology Corporation (MCC), Bellcore and Verizon/GTE Laboratories. His research interests have included natural language processing, multimodal interfaces, visual languages, and information visualization. He is a Senior member of the ACM.

Mitsubishi Electric

One of the world's largest companies, Mitsubishi Electric Corporation has $45 billion in annual sales, $2.8 billion in operating profits (in the very difficult year ending in March 2012) and more than 100,000 employees around the world (see www.mitsubishielectric.com).

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

Mitsubishi Electric Corp.

- **Information Systems & Network Services**
  IT Systems, Information Security/Encryption Systems, Business Solutions
- **Public Utility Systems**
  Government Systems, Transportation Systems, Very Large Display Devices
- **Energy & Industrial Systems**
  Electrical Generators, Power Transmission and Distribution Equipment
- **Building Systems**
  Elevators, Escalators, Building Monitoring/Security/Management Systems
- **Electronic Systems**
  Satellites, Radar Systems, Antennas, Electronic Toll Collection Systems
- **Communication Systems**
  Wired & Wireless Communication/Broadcasting Equipment and Systems
- **Living Environment & Digital Media Equipment**
  Televisions, Blu-ray Recorders, Air Conditioners, Solar Power Systems
- **Factory Automation Systems**
  Programmable Logic Controllers, Inverters, Servo-motors, Processing Machines
- **Automotive Equipment**
  Automotive Electrical Equipment, Car Electronics/Multimedia, Car Mechatronics
- **Semiconductor & Device**
  Optical Devices, High-Frequency & High-Power Semiconductors

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 (see www.mitsubishielectric-usa.com).

Mitsubishi Electric Automotive America, Inc. (Detroit, Mason OH)
Alternators, Ignition Coils, Automotive Electronics

Mitsubishi Electric Power Products, Inc. (Pittsburgh)
Power Transmission Products

Mitsubishi Electric & Electronics USA, Inc. (Los Angeles & other cities)
Air Conditioners, Elevators, Photovoltaic Panels, Semiconductors

Mitsubishi Electric Visual Solutions America, Inc. (Irvine CA)
High Definition Projection Televisions, Digital Projectors, Display Walls, Photo Printers

Mitsubishi Electric Automation, Inc. (Chicago)
Factory Automation Equipment

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.

Corporate R&D Headquarters (Tokyo)

- **Advanced Technology R&D Center** (Amagasaki & Nagaokakyo, in greater Osaka)
  Power Electronics, Electro-mechanical, Ecology, Energy, Materials, Devices, Systems and Imaging Technologies
- **Information Technology R&D Center** (Ofuna, in greater Tokyo)
  Information, Communications, Multimedia, Electro-Optic and Microwave Technologies
- **Industrial Design Center** (Ofuna, in greater Tokyo)
  Product, Interface and Concept Design
- **Mitsubishi Electric Research Laboratories, Inc.** (Cambridge, in greater Boston)
  Communications, Multimedia, Data Analytics, Imaging and Mechatronics Technologies
- **Mitsubishi Electric R&D Centre Europe, B.V.** (Rennes, France & Edinburgh, Scotland)
  Communications, Energy & Environmental Technologies

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. Anthony Vetro - Fellow, Institute of Electrical and Electronic Engineers
Dr. Jin Zhang - Fellow, Institute of Electrical and Electronic Engineers

Awards and Major Events

Anthony Vetro became chair of the US MPEG committee (INCITS L3.1) in October 2011.

"Data Driven Frequency Mapping for Computationally Scalable Object Detection", Fatih Porikli and Huseyin Ozkan, IEEE Advanced Video and Signal Based Surveillance (AVSS), August 2011. (Best paper award).

"Rapid Object Detection using a Boosted Cascade of Simple Features" by Paul A. Viola and Michael J. Jones, Conference on Computer Vision and Pattern Recognition (CVPR), ISSN: 1063-6919, Vol. 1, pp. 511-518, December 2001. (Won the 2011 CVPR Longuet-Higgins Prize for being the paper from 10 years ago with the largest impact on the field.)

It is also worthy of note that MERL's Imaging group had 7 papers accepted to CVPR 2011 — the most selective and prestigious Computer Vision Conference. Similarly, MERL's speech and signal processing researchers had 7 papers accepted to ICASSP 2012 — the most selective and prestigious conference in their field. These results make MERL one of the most highly represented research labs in the world at CVPR, and ICASSP, 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.

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

Amit's research is focused on computer vision and computational photography with emphasis on developing novel cameras and algorithms for scene interpretation, and designing physics based models for vision. He has co-authored more than 30 papers in computer vision and computer graphics conferences including ECCV, CVPR, ICCV, and SIGGRAPH.

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

Lou 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 is a former Software Engineer developing configuration and database systems for the aircraft manufacturing, food processing, large truck manufacturing, and computer manufacturing industries. His interests include CNC control systems, and mechanical and electrical design. His current work involves the design and creation of the mechanical and electrical systems in support of experiments in all areas of MERL's research.

Mouhacine Benosman *Ph.D., Ecole Centrale de Nantes, 2002*
Principal Member Research Staff

Before coming to MERL in 2010, Mouhacine worked at universities in Rome, Italy, Reims, France and Glasgow, Scotland before spending 5 years as a Research Scientist with the Temasek Laboratories at the National University of Singapore. His research interests include modeling and control of flexible systems,non-linear robust and fault tolerant control, vibration suppression in industrial machines and multi-agent control with applications to smart-grid.

Ghulam M. Bhatti *Ph.D., Boston University, 1998*
Principal Member Research Staff

Prior to joining MERL, Ghulam developed system software for medical devices and communication switches. At MERL, his interests include prototyping, localization, security, algorithms, and communication protocols. He is listed as one of the major contributors into the IEEE 802.15.4e standard

Scott A. Bortoff *Ph.D., University of Illinois Urbana-Champaign, 1992*
Mechatronics Group Manager

Scott's research interests are in applications of nonlinear and optimal control theory to motion control, path planning and process control problems. Before joining MERL in 2009, Scott led the Controls Group at the United Technology Research Center and previously was an Associate Professor at the University of Toronto.

Petros T. Boufounos *Sc.D., Massachusetts Institute of Technology, 2006*
PrincipalMember Research Staff

Since joining MERL Petros has contributed in areas such as high-speed video acquisition, radar and ultrasonic imaging, and privacy-reserving secure embeddings. His interests include signal acquisition and processing, signal representations and compressive sensing. He is a visiting scholar at Rice University and an associate editor for IEEE Signal Processing Letters.

Matthew E. Brand *Ph.D., Northwestern University, 1994*
Distinguished Member Research Staff

Matt 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*
Senior Patent Counsel

Dirk'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.

Daniel J. Burns *Ph.D., Massachusetts Institute of Technology, 2010*
Member Research Staff

At MIT, Burns developed mechanical designs and controllers for atomic force microscopes that image nano-scale features 1,000 times faster than commercially available instruments. Previously, Dan worked at the Commercial Aviation Systems division of Honeywell, and NASA's Goddard Space Flight Center. Currently, Dan works on control systems design and multi-physical modeling.

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 VLSI rapid prototyping. His current research interests are video coding & communications, and video, image & signal processing. He is an active participant in JCT-VC on the HEVC video coding standard.

Stefano Di Cairano *Ph.D., Carnegie Mellon University, 2004*
Principal Member Research Staff

Stefano's interests are model predictive control, constrained control, networked control systems, optimization algorithms, stochastic systems, and their applications to automotive, aerospace, logistics, and factory automation. Stefano is a member of the IEEE CSS Conference Editorial Board, and the Chair of the IEEE CSS Technical Committee on Automotive Controls.

Chunjie Duan *Ph.D., University of Colorado at Boulder, 2008*
Senior Principal Member Research Staff

Prior to joining MERL, Chunjie 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.

Huseyin Erdim *Ph.D., University of Connecticut Storrs, 2009*
Member Research Staff

Huseyin's research interests are in the areas of computational geometry, computer aided manufacturing, computer graphics, geometric and physical modeling. His doctoral work focused on fundamentals and computational properties of sweeps. His earlier graduate work focused on improving productivity in free-form surface machining, for which he received an Outstanding Young Researcher Award.

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 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*
Member Research Staff

Tyler's graduate work focused on high performance computing, neural simulation, computer graphics, and computer vision. His current work focuses on fast parallel algorithms, particularly those using modern computer graphics hardware. He has made contributions in the areas of NC simulation and font rendering.

Abraham M. Goldsmith *M.S., Worcester Polytechnic Institute, 2008*
Associate Member Research Staff

While at WPI, Abraham researched 3D ultrasound imaging, particularly the reconstruction of 3D volumes from sequences of 2D images. Since joining MERL he has worked in areas ranging from wireless sensor networks to optical metrology and control. In addition to his research responsibilities, Abraham provides electrical and mechanical engineering support to the entire laboratory.

Piyush Grover *Ph.D., Virginia Polytechnic Institute & State Univ., 2010*
Member Research Staff

Piyush works at the intersection of dynamical systems, mechanics and control. He is interested in applying geometric and statistical methods for exploiting structure in nonlinear dynamical systems. Areas of applications include low-fuel space mission design, chaotic mixing, model reduction of distributed systems and nonlinear estimation.

Jianlin Guo *Ph.D., University of Windsor, 1995*
Principal Member Research Staff

Jianlin 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

Before joining MERL in 2001, Bret worked at Dragon Systems on handheld and automotive speech products. At MERL, he works on research projects in the area of speech and multimodal applications, with a focus on effectiveness and usability. Past research projects have included work on multi-user touch interfaces and the safety & usability of in-car speech applications.

John R. Hershey *Ph.D., University of California San Diego, 2004*
Speech and Audio Team Leader

Before coming to MERL in 2010, Hershey was a researcher at IBM's Watson Research Center in New York, in the Speech Algorithms and Engines group, where he was team leader of the Noise Robustness project. He is now working on machine learning for signal enhancement and separation, speech recognition, language processing, and adaptive user interfaces.

Hiroshi Ichibangase *M.S., The University of Kyusyu, 1984*
Vice President and Director of Liaisons

Ichibangase joined Mitsubishi Electric CR&D in 1984, developing optical communication equipment. He spent two years in the US in 2002-04 and then two years in the communications business unit. Returning to CR&D, he rose to Senior Manager of the Optical Communication Technology Department, before coming to MERL in 2010.

Frederick J. Igo, Jr. *B.A., Le Moyne College, 1982*
Senior Principal Member Research Staff

Fred'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.

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

During graduate school, Elena collaborated with MERL to develop an improved representation for stroke-based fonts and a method for the automatic conversion of outline fonts to this format. Upon completing her Ph.D., she joined MERL to implement her research. Currently, she focuses on next generation text display technology.

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

Mike's main areas of interest are computer vision, machine learning and data mining. He has focused on algorithms for detecting and analyzing people in images and video including face detection and recognition and pedestrian detection. He is a co-inventor of the popular Viola-Jones face detection method. Mike has been awarded the Marr Prize at ICCV and the Longuet-Higgins Prize at CVPR.

Toshiaki Koike-Akino *Ph.D., Kyoto University, 2005*
Member Research Staff

Prior to joining MERL in 2010, Toshiaki was a postdoctoral researcher at Harvard University. His research interests include signal processing, cooperative communications, coding theory, and information theory. He received best paper awards at IEEE GLOBECOM'08 and IEEE GLOBECOM'09.

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

During his 8 years at the Central Research Laboratory, Mitsubishi Electric Corp. (Amagasaki, Japan), and 13 years at major US laboratories and companies, Keiske worked on R&D of semiconductor lasers and optical metro/access systems as a researcher and later as a manager. At MERL he is currently working on simulations of optical devices and systems. He has more than 100 publications in journals and conference proceedings.

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

Christopher's interests lie in the intersection of the modeling of physical systems and the experimental construction and testing of these systems, including simulation, numerical methods, and fault detection. He has worked on a variety of multi-physical systems, such as thermo-fluid systems and electromechanical energy conversion systems.

Jonathan Le Roux *Ph.D., University of Tokyo, 2009*
Member Research Staff

Jonathan completed his B.Sc. and two M.Sc. in Mathematics at the Ecole Normale Supérieure de la Rue d'Ulm, Paris, France. Before joining MERL in 2011, he spent several years in Beijing and Tokyo, where he got his PhD and worked as a postdoctoral researcher at NTT's Communication Science Laboratories. His research interests are in signal processing and machine learning applied to speech and audio.

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.

Feng Li *Ph.D., University of Delaware, 2011*
Visiting Member Research Staff

Feng worked as a technical marketing engineer at Intel China before studying at UD for his Ph.D. His research interests are image/video enhancement (de-noising, de-blurring, super-resolution), multi-camera system design and applications, and fluid surface reconstruction.

Dehong Liu *Ph.D., Tsinghua University, 2002*
Visiting Member Research Staff

Prior to joining MERL in 2010, Dehong worked at Duke University as a post-doctoral Research Associate (2003-2008), Research Scientist (2008-2010) and Sr. Research Scientist (2010). His main research interests include compressive sensing, signal processing and machine learning.

Ming-Yu Liu *PhD, University of Maryland College Park, 2012*
Visiting Member Research Staff

Before joining MERL in 2012, Ming-Yu was a graduate research assistant in the computer vision research laboratory in University of Maryland. His dissertation was about discrete optimizations methods for segmentation and matching. His research interests are in computer vision and machine learning.

Rui Ma *Ph.D., University of Kassel, 2009,*
Visiting Member Research Staff

Prior to joining MERL, Rui was a Sr. Power Amplifier Research Engineer at Nokia Siemens Networks. His research interests include RF Power Device Modeling, Power Amplifier / Radio Front-End Architectures, non-linear microwave circuit design and high frequency measurement techniques.

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

Prior to joining MERL's Imaging Group in 2008, Tim did postdoctoral research in robotic Simultaneous Localization and Mapping in collaboration with NASA's Jet Propulsion Laboratory. His research at MERL spans a variety of areas in computer vision and machine learning, including face recognition under variations in pose and lighting, and robotic vision and touch-based registration for industrial automation.

Daniel N. Nikovski *Ph.D., Carnegie Mellon University, 2002*
Data Analytics Group Team Leader

Dan'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

Prior to joining MERL in 2000, Phil worked as a simulation engineer for the MITRE Corporation. His current research interests include wireless communications and networking, signal processing for communication systems, queuing theory, and analytical modeling.

Kieran Parsons *Ph.D., University of Bristol, UK, 1996*
Digital Communications Deputy Group Manager

Before coming to MERL in 2009, Kieran spent 12 years at Nortel, BelAir Networks and AMCC on the system design, simulation and development of wireless and optical technologies, including early work on digital dispersion compensation for optical links. At MERL his research interests include optical communications network architecture and digital signal processing algorithms for coherent optical communications.

Ronald N. Perry *B.Sc., Bucknell University, 1981*
Distinguished Member Research Staff

Ron's fundamental research in computer graphics has resulted in numerous publications, a comprehensive patent portfolio, and the development of several meticulously crafted software and hardware products. Ron is best known for the Saffron Type System. The other highlight of his research is the development of 3D ADFs for CAD related products, including an NC simulation system demonstrating unprecedented precision and compactness.

Fatih M. Porikli *Ph.D., New York University (NYU), 2002*
Distinguished Member Research Staff

Fatih's work covers areas of computer vision, machine learning, pattern recognition, multimedia processing, structured and manifold learning, online and active learning, biomedical, surveillance and radar systems with over 100 papers and 60 patents. He has received a 2006 R&D100 Award in addition to 3 IEEE Best Paper Awards.

Arvind Raghunathan *Ph.D., Carnegie Mellon University, 2004*
Principal Member Research Staff

Arvind's research focuses on algorithms for optimization of large-scale nonlinear and mixed integer nonlinear programs with applications in power grid, transportation systems and model-based control of processes. He previously worked at the United Technologies Research Center for 7 years developing optimization algorithms for aerospace, elevator, energy systems and security businesses.

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

Srikumar's PhD thesis on generic imaging models received the INPG best thesis prize and the AFRIF thesis prize (honorable mention) from the French Association for Pattern Recognition. His research interests include multi-view geometry and discrete optimization. At MERL, he has been working on robotics and car-navigation projects.

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

Shantanu's research interests are in the broad areas of signal processing and information theory. His Ph.D. thesis applied distributed source-coding concepts to error-resilient video transmission. He is currently working on problems involving distributed source coding, biometrics, and secure multiparty computation.

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

Prior to joining MERL, Zafer worked at AT&T's Shannon Research Labs. His current research interests include real time space-time adaptive processing, remote sensing, and electric vehicle charging solutions. He made contributions to the IEEE 802.15.4a/4e, ZigBee, & MPEG21 standards, and is currently a participating member of the ANSI EVSP and NIST SGIP standards.

Bent K. Schmidt-Nielsen *B.S. Univ. of California at San Diego, 1971*
Senior Principal Member Research Staff

Bent 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 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

First at U.C. Berkeley, then at Lawrence Livermore National Laboratory, Alan Sullivan studied interactions between ultra-high intensity femtosecond lasers and plasmas. Prior to joining MERL in 2007, Dr. Sullivan worked at a series of start-ups where he developed a novel volumetric 3D display technology. At MERL His research interests include computational geometry and computer graphics.

Hongbo Sun *Ph.D., Chongqing University, 1991*
Principal Member Research Staff

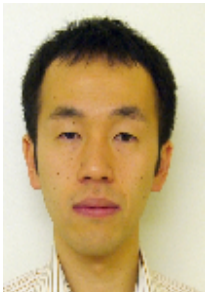
Prior to Joining MERL in 2010, Hongbo was a principal applications Engineer at Oracle, and a technical architect at SPL WorldGroup. He is a registered professional engineer and has more than 20 years' experience in technical consulting, product development and research on electrical transmission and distribution system planning, analysis, operation, and automation.

Huifang Sun *Ph.D., University of Ottawa, 1986*
MERL Fellow / IEEE Fellow

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

Wei Sun *Ph.D., University of Waterloo, 2006*
Visiting Member Research Staff

Prior to joining MERL in 2008, Wei worked as a research fellow at the University of Waterloo. His main research interests include multimedia security, biometrics, information security and privacy, compressive sensing and information theory. He has a Master degree in mathematics.



Yuichi Taguchi *Ph.D. The University of Tokyo, 2009*
Member Research Staff

Yuichi worked on light field compression and conversion techniques for 3D TV during his Ph.D. After joining MERL in 2009, he has worked on algorithms and sensors for industrial robotics and catadioptric imaging. His current research interests include computational photography and 3D reconstruction.

Koon Hoo Teo *Ph.D., University of Alberta 1990*
Power Electronics Team Leader

Koon Hoo was with Nortel for 15 years where he was actively involved in research and implementation issues of a number of 3G and 4G wireless systems, including Wireless Mesh Networks, WiMAX systems and cognitive radios. He joined MERL in 2006.

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

Prior to joining MERL in 2002, Jay worked at Polaroid Corporation for many years on human vision and image science problems concerning color reproduction, image quality, half toning, and image processing. At MERL he has become absorbed in research on vision for robotics, medical imaging, computational photography, computer human observation, dictionary learning, and processing of the 3D world.

Dong Tian *Ph.D., Beijing University of Technology, 2001*
Principal Member Research Staff

Dong has been working in the field of image/video compression and processing for over 10 years. He was deeply involved in the standardization of H.264/MPEG-4 AVC, and then worked for its extension Multiview Video Coding. After joining MERL in 2010, he has continued research in 3D video coding/processing and has been an active participant in the 3DV group. He served as a software coordinator for a few relevant AhGs in AVC and 3DV.

C. Oncel Tuzel *Ph.D., Rutgers University, 2008*
Principal Member Research Staff

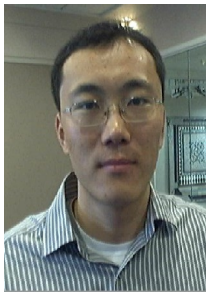
Prior to his graduate studies, Oncel worked for 4 years as a senior software engineer where he developed game engine and 3D driving simulator. His doctoral work focused on statistical learning techniques on smooth manifolds and their applications to scene analysis. At MERL, he is working on geometry and inference algorithms for robot and 3D vision. His research interests are in computer vision, machine learning, and computer graphics.

Anthony Vetro *Ph.D., Polytechnic University, 2001*
Multimedia Group Manager / IEEE Fellow

Vetro joined MERL in 1996 and has been conducting research in the area of multimedia signal processing. He has contributed to the transfer and development of several technologies to digital television, surveillance, automotive, and satellite imaging systems. He has been an active participant in video coding standards and currently serves as Head of the US Delegation to MPEG.

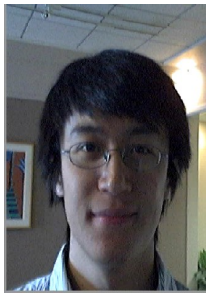
Gene V. Vinokur *J.D., Suffolk University Law School, 2011*
Patent Counsel

Mr. Vinokur graduated cum laude with distinction in Intellectual Property law. In addition, Mr. Vinokur holds advanced degrees in Mechanical Engineering and Computer Science. He is a member of Massachusetts Bar and has been a licensed patent practitioner since 2003.



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

Bingnan's doctoral work focused on the study of wave propagation in novel electromagnetic materials, including photonic crystals and meta-materials. He joined MERL in 2009. His research interests include electromagnetics and photonics, and their applications to communications, imaging, and energy systems.



Ye Wang *Ph.D., Boston University, 2011*
Visiting Member Research Staff

Ye was a member of the Information Systems and Sciences Laboratory at Boston University, where he studied information-theoretically secure multiparty computation. His current research interests include information security, biometric authentication, and data privacy.

Yebin Wang *Ph.D., University of Alberta, 2008*
Member Research Staff

Prior to joining MERL, Yebin was a research assistant in the 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.

Shinji Watanabe *Ph.D., Waseda University, 2006*
Visiting Member Research Staff

Prior to joining MERL in 2012, Shinji was a research scientist at NTT Communication Science Laboratories in Japan for 10 years, working on Bayesian learning for speech recognition, speaker adaptation, and language modeling. His research interests include speech recognition, spoken language processing, and machine learning.

Jingyang Xu *Ph.D., University of Buffalo, 2010*
Adjunct Member Research Staff

Jingyang worked on developing optimization algorithms for complex scheduling problems while he was pursuing Ph.D. His main research area is identifying new application areas of stochastic discrete optimization. After he joined MERL in 2010, his work is mainly related to statistical modeling and operation optimization for building thermal/energy system and railroad transportation systems.

William S. Yerazunis *Ph.D., Rensselaer Polytechnic Institute, 1987*
Senior Principal Member Research Staff & Hardware Team Leader

Bill has worked in numerous fields, including parallel computation, SETI, jet engine production, real-time signal processing, expert systems, pattern recognition, text classification, wireless power, and meta-materials. He is the author of the CRM114 spam filter, and has appeared as a continuing character in educational science television, and was voted one of the 50 most important people in computer network security by Network World magazine.

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

Weihong 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.

Yiming Zhao *Ph.D., Georgia Institute of Technology, 2012*
Adjunct Member Research Staff

Yiming's current research focuses on the modeling, simulation, and control of mechanical and thermal systems, real-time trajectory optimization, and motion control. Before joining MERL in 2012, he worked as a research assistant in the Dynamics and Control Systems Lab at Georgia Tech on numerical optimal control, aircraft landing trajectory optimization, and air traffic modeling & simulation.

Recent Major Publications

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 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.

As a basis for assessing the selectivity of various venues, the list below uses acceptance rates. For instance, certain key conferences such as ICCV, and CVPR accept only small percentages of the papers submitted to them, rejecting many papers that in fact describe fine work. In contrast, many workshops and regional conferences accept most of the papers submitted, taking everything but the truly awful. The list puts an asterisk before a conference or workshop paper only if the acceptance rate was less than 25%, or the paper received a best paper award. In addition, asterisks appear before papers in major archival Journals.

2012

Heaukulani, C.; LeRoux, J.; Hershey, J.R., "Latent Dirichlet Reallocation for Term Swapping", *International Workshop on Statistical Machine Learning for Speech Processing (IWSML)*, March 2012 (TR2012-022)

Wang, B.; Ellstein, D.; Teo, K.H., "Analysis on Wireless Power Transfer to Moving Devices Based on Array of Resonators", *European Conference on Antennas and Propagation (EuCAP)*, March 2012 (TR2012-021)

Sundaresan, R.; Porikli, F.M., "Additive Noise Removal by Sparse Reconstruction on Image Affinity Nets", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper 9, March 2012 (TR2012-019)

LeRoux, J.; Hershey, J.R., "Indirect Model-based Speech Enhancement", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper: SP-L3.5, March 2012 (TR2012-016)

Wang, P.; Sahinoglu, Z.; Pun, M-O; Li, H., "Parametric Multichannel Adaptive Signal Detection: Exploiting Persymmetric Structure", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper SAM-L2.6, March 2012 (TR2012-018)

Boufounos, P.T., "Depth Sensing Using Active Coherent Illumination", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper: SS-L11.1, March 2012 (TR2012-020)

Schnelle, S.R.; Slavinsky, J.P.; Boufounos, P.T.; Davenport, M.A.; Baraniuk, R.G., "A Compressive Phase-Locked Loop", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper: SPCOM-L4.6, March 2012 (TR2012-015)

Liu, D.; Boufounos, P.T., "Dictionary Learning Based Pan-Sharpening", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper MMSP-P3.6, March 2012 (TR2012-013)

Wang, Y.; Porikli, F.M., "Multiple Dictionary Learning for Blocking Artifacts Reduction", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper: IVMSP-P4.8, March 2012 (TR2012-014)

Rao, N.; Porikli, F.M., "A Clustering Approach to Optimize Online Dictionary Learning", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper IVMSP-P8.11, March 2102 (TR2012-017)

Huang, D.; Urzhumov, Y.; Smith D.R.; Teo, K.H.; Zhang, J., "Magnetic Superlens-enhanced Inductive Coupling for Wireless Power Transfer", *Journal of Applied Physics*, DOI: 10.1063/1.3692757, Vol. 111, Issue 6, pp. 64902, March 2012 (TR2012-023)

LeRoux, J.; Hershey, J.R., "Speech Enhancement by Indirect VTS", *Acoustical Society of Japan (ASJ)*, March (TR2012-011)

Wang, P.; Sahinoglu, Z.; Pun, M-O; Li, H., "Persymmetric Parametric Adaptive Matched Filter for Multichannel Adaptive Signal Detection", *IEEE Transactions on Signal Processing*, DOI: 10.1109/TSP.2012.2190411, Vol. 60, Issue 6, pp. 3322-3328, March 2012 (TR2012-031)

Wang, B.; Teo, K.H., "Metamaterials for Wireless Power Transfer", *IEEE International Workshop on Antenna Technology (iWAT)*, pp. 161-164, March 2012 (TR2012-010)

Koike-Akino, T.; Parsons, K.J.; Kojima, K.; Duan, C.; Yoshida, T.; Sugihara, T.; Mizuochi, T., "Fractionally-Spaced Statistical Equalizer for Fiber Nonlinearity Mitigation in Digital Coherent Optical Systems", *Optical Fiber Communication Conference (OFC)*, Nonlinearity Mitigation (OTh3C), March 2012 (TR2012-008)

Duan, C.; Parsons, K.J.; Koike-Akino, T.; Annavajjala, R.; Kojima, K,; Yoshida, T.; Sugihara, T.; Mizouchi, T., "A Low-Complexity Sliding-Window Turbo Equalizer for Nonlinearity Compensation", *Optical Fiber Communication Conference (OFC)*, Poster Session 1 (JW2A), March 2012 (TR2012-009)

* Sun, H.; Nikovski, D.N.; Ohno, T.; Takano, T.; Kojima, Y., "A Hybrid Decoupled Power Flow Method for Balanced Power Distribution Systems", *Journal of Electronic Science and Technology (JEST)*, Vol.10, Issue 1, pp 15-21, DOI: 10.3969/j.issn.1674-862X.2012.01.003, March 2012 (TR2012-005)

Grover, P.; Andersson, C., "End to End Optimization of Low-Energy Lunar Missions", *American Astronautical Society (AAS) American Institute of Aeronautics and Astronautics (AIAA) Space Flight Mecahnics Meeting*, January 2012 (TR2012-024)

Koike-Akino, T.; Duan, C.; Parsons, K.J.; Kojima, K.; Yoshida, T.; Sugihara, T.; Mizuochi, T., "Fractionally-Spaced Equalizer Based on High-Order Statistics in Nonlinear Fiber Optics", *IEICE Optical Communication Systems (OCS)*, Vol. 111, No. 411, OCS2011-108, pp. 17-22, January 2012 (TR2012-004)

* Joshi, A.J.; Porikli, F.M.; Papanikolopoulos, N., "Scalable Active Learning for Multi-Class Image Classification", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, DOI: 10.1109/TPAMI.2012.21, Vol. PP, Issue 99, January 2012 (TR2012-026)

* Porikli, F.M.; Yilmaz, A., "Object Detection & Tracking", *Video Analytics for Business Intelligence*, Studies in Computational Intelligence, DOI: 10.1007/978-3-642.28598-1_1, Vol. 409, pp. 3-41, January 2012 (TR2012-003)

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Nikovski, D.N.; Esenther, A.W., "Construction of Embedded Markov Decision Processes for Optimal Control of Non-Linear Systems with Continuous State Spaces", *IEEE Conference on Decision and Control and European Control Conference (CDC-ECC)*, DOI: 10.1109/CDC.2011.6161310, pp. 7944-7949, December 2011 (TR2011-081)

Feng, P.; Teo, K.H.; Oishi, T.; Nakayama, M.; Duan, C.; Zhang, J., "Design and Simulation of Enhancement-mode N-polar GaN Single-channel and Dual-channel MIS-HEMTs", *International Semiconductor Device Research Symposium (ISDRS)*, DOI: 10.1109/ISDRS.2011.6135163, pp. 1-2, December 2011 (TR2011-079)

* Koike-Akino, T.; Duan, C., "Secrecy Rate Analysis of Jamming Superposition in Presence of Many Eavesdropping Users", *Global Telecommunications Conference (GLOBECOM)*, DOI: 10.1109/GLOCOM.2012.6133990, pp. 1-6, December 2011 (TR2011-080)

Weinberg, G.; Harsham, B.A.; Medenica, Z., "Evalutating the Usability of a Head-Up Display for Selection from Choice Lists in Cars", *International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, November 2011 (TR2011-076)

Boufounos, P.T.; Rane, S., "Secure Binary Embeddings for Privacy Preserving Nearest Neighbors", *IEEE International Workshop on Information Forensics and Security (WIFS)*, DOI: 10.1109/WIFS.2011.6123149, pps. 1-6, November 2011 (TR2011-077)

* Wu, J.; Mehta, N.B.; Molisch, A.F.; Zhang, J., "Unified Spectral Efficiency Analysis of Cellular Systems with Channel-Aware Schedulers", *IEEE Transactions on Communications*, DOI: 10.1109/TCOMM.2011.11071.100510, Vol. 59, Issue 12, pps. 3463-3474, November 2011 (TR2011-078)

* Boufounos, P.T., "Universal Rate-Efficient Scalar Quantization", *IEEE Transactions on Information Theory*, DOI: 10.1109/TIT.2011.2173899, Vol. 58, Issue 3, pp. 1861-1872, November 2011 (TR2011-083)

* Asthana, A.; Marks, T.K.; Jones, M.J.; Tieu, K.H.; Rohith, M., "Fully Automatic Pose-Invariant Face Recognition via 3D Pose Normalization", *IEEE International Conference on Computer Vision (ICCV)*, DOI: 10.1109/ICCV.2011.6126336, pp. 937-944, November 2011 (TR2011-074)

Bahmani, S.; Boufounos, P.T.; Raj, B., "Greedy Sparsity-Constrained Optimization", *Asilomar Conference on Signals, Systems and Computers*, DOI: 10.1109/ACSSC.2011.6190194, pp. 1148-1152, November 2011 (TR2012-012)

Laska, J.N.; Boufounos, P.T.; Davenport, M.A., Baraniuk, R.G., "Democracy in Action: Quantization, Saturation and Compressive Sensing", *Applied and Computational Harmonic Analysis*, Vol. 31, Issue 3, pp. 429-443, November 2011 (TR2011-049)

Porikli, F.M.; Bovik, A.; Plack, C.; AlRegib, G.; Farrell, J.; LeCallet, P.; Huynth-Thu, Q.; Moeller, S.; Winkler, S., "Multimedia Quality Assessment", *IEEE Signal Processing Magazine*, ISSN: 1053-5888, Vol. 28, Issue 6, pp. 164-177, October 2011 (TR2011-075)

Wittenburg, K.B.; Pekhteryev, G., "Singleton Set Distribution Views for Set-Valued Attribute Visualization", *InfoVis*, October 2011 (TR2011-073)

Teo, K.H., "Charging Technology Enabler for Electric Vehicle", *International Low Carbon Earth Summit*, October 2011 (TR2011-072)

Wang, B.; Teo, K.H.; Yamaguchi, S.; Takahashi, T.; Konishi, Y., "Flexible and Mobile Near-Field Wireless Power Transfer using an Array of Resonators", *Institute of Electronics Information and Communication Engineers*, October 2011 (TR2011-071)

Sun, H.; Nikovski, D.N.; Ohno, T.; Takano, T.; Kojima, Y., "A Fast and Robust Load Flow Method for Distribution Systems with Distributed Generations", *IEEE International Conference on Smart Grid and Clean Energy Technologies (ICSGCE)*, September 2011 (TR2011-070)

Taguchi, Y.; Marks, T.K.; Hershey, J.R., "Entropy-Based Motion Selection for Touch-Based Registration Using Rao-Blackwellized Particle Filtering", *IEEE / RSJ International Conference on Intelligent Robots and Systems (IROS)*, DOI: 10.1109/IROS.2011.6094767, pp. 4690=4697, September 2011 (TR2011-067)

Brand, M.E.; Chen, D., "Parallel Quadratic Programming for Image Processing", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6116089, pps. 2261-2264, September 2011 (TR2011-064)

Ramalingam, S.; Russell, C.; Ladicky, L.; Torr, P.H.S., "Efficient Minimization of Higher Order Submodular Functions using Monotonic Boolean Functions", arXiv.org, September 2011 (TR2011-066)

Nguyen H.V.; Porikli, F.M., "Concentric Ring Signature Descriptor for 3D Objects", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6116153, September 2011 (TR2011-063)

Tian, D.; Vetro, A.; Brand, M.E., "A Trellis-based Approach for Robust View Synthesis", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6116623, pp. 605-608, September 2011 (TR2011-065)

Wang, Y.; Rane, S.; Boufounos, P.T.; Vetro, A., "Distributed Compression of Zerotrees of Wavelet Coefficients", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6115819, September 2011 (TR2011-062)

Porikli, F.M.; Ozkan, H., "Data Driven Frequency Mapping for Computationally Scalable Object Detection", *IEEE International Conference on Advanced Video and Signal-based Surveillance (AVSS)*, DOI: 10.1109/AVSS.2011.6027289, pp. 30-35, August 2011 (TR2011-054)

Asthana, A.; Jones, M.J.; Marks, T.K.; Tieu, K.H.; Goecke, R., "Pose Normalization via Learned 2D Warping for Fully Automatic Face Recognition", *British Machine Vision Conference (BMVC)*, August 2011 (TR2011-055)

Brand, M.E.; Shilpiekandula, V.; Bortoff, S.A., "A Parallel Quadratic Programming Algorithm for Model Predictive Control", *International Federation of Automatic Control (IFAC)*, Vol. 18, Part 1, August 2011 (TR2011-056)

Shilpiekandula, V.; Youcel-Toumi, K., "Integrated Design and Control of Flexure-Based Nanopositioning Systems - Part I: Methodology", *World Congress of the International Federation of Automatic Control*, August 2011 (TR2011-053)

Liu, W.; Duan, C.; Wang, Y.; Koike-Akino, T.; Annavajjala, R.; Zhang, J., "Secret Key Sharing and Rateless Coding for Practical Secure Wireless Transmission", *International Conference on Dependability (DEPEND)*, August 2011 (TR2011-057)

Zhang, W.; Nikovski, D.N., "State-space Approximate Dynamic Programming for Stochastic Unit Commitment", *North American Power Symposium (NAPS)*, DOI: 10.1109/NAPS.2011.6025113, pp. 1-7, August 2011 (TR2011-046)

Liu, D.; Boufounos, P.T., "High Resolution SAR Imaging Using Random Pulse Timing", *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, DOI: 10.1109/IGARSS.2011.6050132, pp. 4091-4094, July 2011 (TR2011-058)

Wang, Y.; Utsunomiya, K.; Bortoff, S.A,, "Nonlinear Control Design for a Semi-active Vibration Reduction System", *Chinese Control Conference (CCC)*, pp. 5833-5837, July 2011 (TR2011-050)

Polatkan, G.; Tuzel, C.O., "Compressed Inference for Probabilistic Sequential Models", *Conference on Uncertainty in Artificial Intelligence (UAI)*, July 2011 (TR2011-051)

Weinberg, G.; Harsham, B.A.; Medenica, Z., "Investigating HUDs or the Presentation of Choice Lists in Car navigation Systems", *International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, June 2011 (TR2011-060)

Wang, B.; Teo, K.H.; Nichino, T.; Yerazunis, W.S.; Barnwell, J.C.; Zhang, J., "Experiments on Wireless Power Transfer with Metamaterials", *Applied Physics Letters*, DOI: 10.1063/1.3601927, Vol. 98, Issue 25, pp. 254101-254101-3, June 2011 (TR2011-048)

* Gupta, M.; Agrawal, A.K.; Veeraraghavan, A.; Narasimhan, S., "Structure Light under Global Light Transport", *IEEE Computer Vision & Patter Recognition (CVPR)*, June 2011 (TR2011-038)

* Hussein, M.; Porikli, F.M.; Li, R.; Arsian, S., "CrossTrack: Robust 3D Tracking from Two Cross-Sectional Views", *IEEE Computer Vision & Patter Recognition (CVPR)*, DOI: 10.1109/CVPR.2011.5995429, pp. 1041-1048, June 2011 (TR2011-037)

* Agrawal, A.K.; Taguchi, Y.; Ramalingam, S., "Beyond Alhazen's Problem: Analytical Projection Model for Non-Central Catadioptric Cameras with Quadric Mirrors", *IEEE Computer Vision & Patter Recognition (CVPR)*, DOI: 10.1109/CVPR.2011.5995596, pp. 2993-3000, June 2011 (TR2011-040)

* Gupta, M.; Agrawal, A.K.; Veeraraghavan, A.; Narasimhan, S., "Structured Light 3D Scanning in the Presence of Global Illumination", *IEEE Computer Vision & Patter Recognition (CVPR)*, DOI: 10.1109/CVPR.2011.5995321, June 2011 (TR2011-036)

* Liu, M-Y, Tuzel, C.O.; Ramalingam, S.; Chellappa, "Entropy Rate Superpixel Segmentation", *IEEE Computer Vision & Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2011.5995323, pp. 2097-2104, June 2011 (TR2011-035)

* Reddy, D.; Veeraraghavan A.; Chellappa, R., "P2C2: Programmable Pixel Compressive Camera for High Speed Imaging", *IEEE Computer Vision & Patter Recognition (CVPR)*, DOI: 10.119/CVPR.2011.5995542, pp. 329-336, June 2011 (TR2011-039)

* Ramalingam, S.; Bouaziz, S.; Sturm, P.; Torr, P., "The Light-Path Less Traveled", *IEEE Computer Vision & Patter Recognition (CVPR)*, ISSN: 1063-6919, pp: 3145-3152, June 2011 (TR2011-034)

Annavajjala, R.; Orlik, P.V.; Zhang, J., "Resource Block Embedding: Towards High Throughput Broadband Multimedia Wireless Networks", *IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, DOI; 10.1109/BMSB.2011.5954947, pp. 1-6, June 2011 (TR2011-033)

Koike-Akino, T.; Orlik, P.V., "Non-Coherent Grassmann TCM Design for Physical-Layer Network Coding in Bidirectional MIMO Relaying Systems", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2011.5963122, pp. 1-5, June 2011 (TR2011-032)

Pun, M-O; Molisch, A.F.; Orlik, P.V.; Okazaki, A., "Super-Resolution Blind Channel Modeling", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2011.5963346, pp. 1-5, June 2011 (TR2011-028)

Koike-Akino, T.; Molisch, A.F., Annavajjala, R.; Orlik, P.V.; Pun, M-O., "Order-Extended Sparse RLS Algorithm for Doubly-Selective MIMO Channel Estimation", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2011.5963228, pp. 1-6, June 2011 (TR2011-030)

Koike-Akino, T.; Pun, M-O.; Orlik, P.V., "Network-Coded Interference Alignment in K-Pair Bidirectional Relaying Channels", *IEEE International Conference on Communications (ICC)*, DOI: 10.2209/ICC.2011.5962901, pp. 1-5, June 2011 (TR2011-031)

Ma, J.; Orlik, P.V.; Zhang, J.; Li, G.Y., "Reduced-Rate OFDM Transmission with Statistics-based ICI Mitigation", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/icc.2011.5963310, pp. 1-5, June 2011 (TR2011-029)

* Boufounos, P.T.; Kutynoik, G.; Rauhut, H., "Sparse Recovery from Combined Fusion Frame Measurements", *IEEE Transactions on Information Theory*, DOI: 10.1109/TIT.2011.241.3890, Vol. 57, Issue 6, pp. 3864-3876, May 2011 (TR2011-009)

Wang, P.; Pun, M.O.; Sahinoglu, Z., "Low Complexity STAP via Subspace Tracking in Compound-Gaussian Environment", *IEEE Radar Conference (RadarCon)*, DOI: 10.1109/RADAR.2011.5960559, pp. 356-361, May 2011 (TR2011-018)

Pathak, M.; Rane, S.; Sun, W.; Raj, B., "Privacy Preserving Probabilistic Inference with Hidden Markov Models", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2011.5947696, pp. 5868-5871, May 2011 (TR2011-017)

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* Vetro, A.; Wiegand, T.; Sullivan, G. J., "Overview of the Stereo and Multiview Video Coding Extensions of the H.264/MPEG-4 AVC Standard", *Proceedings of the IEEE*, DOI: 10.1109/JPROC.2010.2098830, pp.626-642, April 2011 (TR2011-022)

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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 - Advanced wireless and optical communications, highly reliable machine-to-machine networks, advanced coding/decoding, adaptive signal processing, and smart grid standards and technologies.

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 reconstruction, location, and inference; computational imaging for optimized information capture; Dictionary Learning for signal processing; tracking and multi-modal sensor integration.

Mechatronics - Advanced control algorithms, nonlinear dynamical systems, system modeling & dynamic analysis, mechatronics design, innovative system concepts, and 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 sector. As an example, revitalizing the electric power grid has become one of the top priorities worldwide. By integrating robust two-way communication, advanced sensors and distributed computing with the power transmission and distribution system, a "smart grid" can improve the efficiency, reliability and safety of power delivery and use. These developments are driving the growth in capacity and connectivity of the underlying infrastructure. These present major challenges and opportunities to digital communications.

The Digital Communications Group at MERL conducts research in the areas of next generation wireless and optical communications, reliable machine-to-machine networking, and advanced signal processing. We conduct not only applied research, but also fundamental research to develop breakthrough technologies. Our objectives are 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.

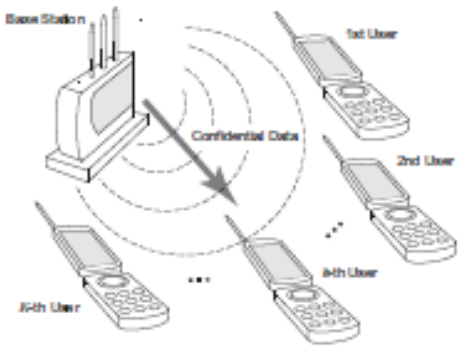
Responding to the new challenges, we have diversified our research effort on several fronts. We continue R&D on broadband communication technologies, especially precoding, interference management, multi-hop mesh networking and advanced coding/decoding. We are developing new technologies for high mobility systems; advanced signal processing algorithms for power equipment and systems; and are actively participating in smart grid international standardization activities. In addition, we are investigating emerging technologies, such as wireless power transfer.

Recent Research

Secrecy Rate Analysis of Jamming Superposition in Presence of Many Eavesdropping Users

Citation: Koike-Akino, T.; Duan, C., "Secrecy Rate Analysis of Jamming Superposition in Presence of Many Eavesdropping Users", Global Telecommunications Conference (GLOBECOM), DOI: 10.1109/GLOCOM.2012.6133990, pp. 1-6, December 2011

Contacts: Toshiaki Koike-Akino, Chunjie Duan



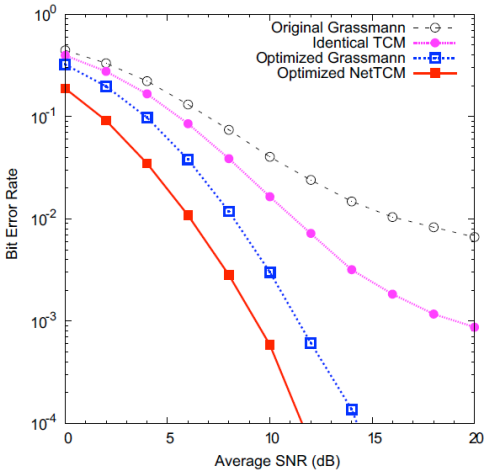
It has been shown that the secrecy capacity of a wireless network is pushed rapidly towards zero as the number of users in the network grows. To deal with this issue, a secure method which intentionally superposes precoded jamming signals has been proposed. In this paper, we analyze its advantage to realize a secure wireless network in the presence of a large number (e.g., hundreds) of eavesdropping users, for transmitting confidential messages. Our analysis and simulations demonstrate that the jamming superposition achieves high secrecy rate even for undesired cases where the channels for many eavesdroppers are noise-less and highly correlated with the intended receiver.

Non-Coherent Grassmann TCM Design for Physical-Layer Network Coding in Bidirectional MIMO Relaying Systems

Citation: Koike-Akino, T.; Orlik, P., "Non-Coherent Grassmann TCM Design for Physical-Layer Network Coding in Bidirectional MIMO Relaying Systems", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2011.5963122, pp. 1-5, June 2011

Contacts: Toshiaki Koike-Akino

We investigate a bidirectional relaying system that uses physical layer network coding and non-coherent multi-input multi-output (MIMO) signal processing. With non-coherent codes on a Grassmannian manifold, a receiver employing generalized likelihood ratio test (GLRT) algorithm offers maximum-likelihood performance even without any channel state information (CSI). We propose a new family of non-coherent Grassmann codes which enjoy a significant coding gain by introducing a trellis-coded modulation (TCM) through an affine-lattice convolution with exponential mapping. We develop a design method of individual TCM code-books for multiple users in non-coherent two-way relaying channels with network coding.



Super-Resolution Blind Channel Modeling

Citation: Pun, M-O; Molisch, A.F.; Orlik, P.; Okazaki, A., "Super-Resolution Blind Channel Modeling", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2011.5963346, pp. 1-5, June 2011

Contacts: Philip V.Orlik

We consider the problem of extracting a wide-band channel model when only measurements in parts of this band are available, specifically in disjoint frequency sub-bands. Conventional channel modeling techniques cannot model at all those parts of the band where no sounding signals are available; or, if they use conventional interpolation, suffer from poor performance. To circumvent this obstacle, we develop in this paper a three-step super-resolution blind algorithm. First, the path delays are estimated by exploiting super-resolution algorithms such as MUSIC or ESPRIT based on the transfer function of each sub-band, separately. Exploiting such a set of delay estimates, the proposed algorithm performs blind (i.e., without training signal) channel estimation over the unmeasured sub-bands, and subsequently derives the frequency response over the whole wide-band channel. Finally, estimates derived from different sub-bands are combined via a soft combining technique. Computer simulations show that the proposed super-resolution blind algorithm can achieve a significant performance gain over conventional methods.

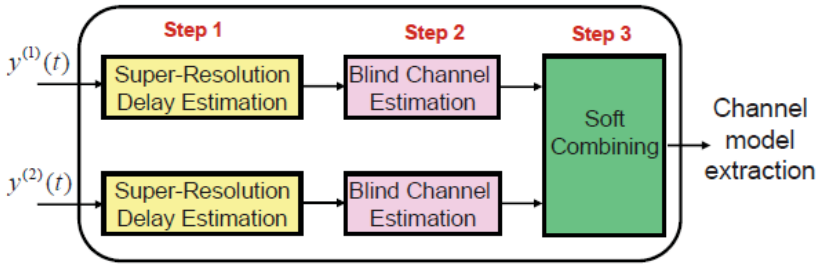


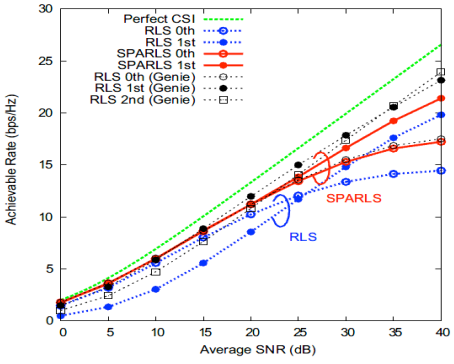
Fig. 3. Block diagram of the proposed super-resolution blind channel modeling algorithm

Order-Extended Sparse RLS Algorithm for Doubly-Selective MIMO Channel Estimation

Citation: Koike-Akino, T.; Molisch, A.F., Annavajjala, R.; Orlik, P.; Pun, M-O., "Order-Extended Sparse RLS Algorithm for Doubly-Selective MIMO Channel Estimation", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2011.5963228, pp. 1-6, June 2011

Contacts: Toshiaki Koike-Akino, Philip V. Orlik

We develop a recursive least squares (RLS) algorithm which employs L1-Lq regularized sparse regressions to estimate a sparse channel matrix in frequency time selective fading for multi output (MIMO) wireless communications. We propose an improved sparse RLS by using an order extension technique for rapid fading channels. Simulation results demonstrate that the proposed sparse RLS algorithm offers a significant improvement over the conventional RLS algorithm.

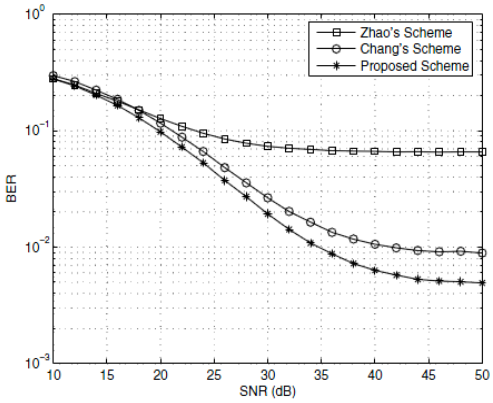


Reduced-Rate OFDM Transmission with Statistics-based ICI Mitigation

Citation: Ma, J.; Orlik, P.; Zhang, J.; Li, G.Y., "Reduced-Rate OFDM Transmission with Statistics-based ICI Mitigation", *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/icc.2011.5963310, pp. 1-5, June 2011

Contacts: Philip V. Orlik, Jinyun Zhang

We develop a general reduced-rate orthogonal frequency division multiplexing (OFDM) transmission scheme for inter-sub-channel interference (ICI) mitigation in a high-mobility environment. By transmit and receive preprocessing, we transform the original OFDM system into an equivalent one with fewer sub-carriers and significantly reduced ICI. A general structure of transmit and receive preprocessing matrices is developed so that all sub-channels in the transformed OFDM system have a common average signal-to-interference ratio (SIR). By utilizing channel statistics, we further optimize the preprocessing coefficients to maximize the SIR. Numerical and simulation results demonstrate that the proposed reduced-rate OFDM transmission achieves significant performance improvement over the existing ICI self-cancellation schemes.



(a) $K = \frac{N}{2}$ and $F_d = 0.3$

Performance Evaluation of Cross-Polarized Antenna Selection over 2 GHz Measurement-Based Channel Models

Citation: Nishimoto, H.; Taira, A.; Kubo, H.; Pun, M.O.; Annavajjala, R.; Molisch, A.F., "Performance Evaluation of Cross-Polarized Antenna Selection over 2 GHz Measurement-Based Channel Models", *IEEE Vehicular Technology Conference (VTC)*, DOI: 10.1109/VETECS.2011.5956130, pp. 1-5, 15 May 2011

Contacts: Jinyun Zhang

In a multiple-input multiple-output (MIMO) system, cross-polarized antenna selection yields significant reduction in cost and hardware size. However, actual benefits of the technique are dependent on the propagation characteristics including channel polarization. To accurately characterize the target 2 GHz-band MIMO channels, the authors conduct 2 GHz cross-polarized channel measurement campaigns. Based on the measured data, novel channel models specifically for the 2 GHz bands are established. Simulation results reveal that antenna selection is particularly useful in the low SNR regime, and that the system capacity at cell edges can be increased up to 13%.

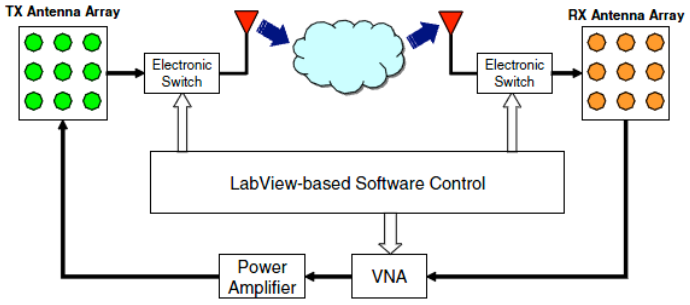


Fig. 2. Measurement block diagram.

Pilot Matrix Design for Estimating Cascaded Channels in Two-Hop MIMO Amplify-and-Forward Relay Systems

Citation: Ma, J.; Orlik, P.; Zhang, J.; Li, G.y., "Pilot Matrix Design for Estimating Cascaded Channels in Two-Hop MIMO Amplify-and-Forward Relay Systems", IEEE Transactions on Wireless on Wireless Communications, DOI: 10.1109/TWC.20111.041311.101477; Vol. 10, Issue 6, pp. 1956-1965, April 2011

Contacts: Philip V. Orlik, Jinyun Zhang

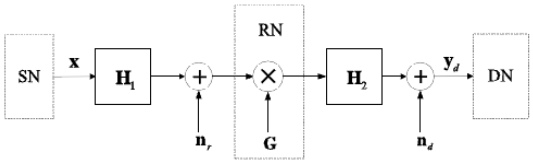


Fig. 1. Two-hop MIMO AF relay system model

We consider a two-hop multi-input multi-output (MIMO) amplify-and-forward (AF) relay system consisting of a source node (SN), a destination node (DN), and a relay node (RN) that simply amplifies and forwards its received signal to the DN without any further processing. We investigate the estimation of the two cascaded relay channels at the DN based on the predefined amplifying matrix applied at the RN and the corresponding overall channel obtained through the conventional channel estimation algorithms with the help of pilots transmitted by the SN. In particular, we find necessary and sufficient conditions on the pilot amplifying matrix sequence at the RN to ensure feasible relay channel estimation at the DN. Based on these conditions, we present rules to design diagonal or quasi-diagonal pilot amplifying matrices so that the cascaded relay channels can be estimated with minimum complexity at the RN.

Persymmetric Parametric Adaptive Matched Filter for Multichannel Adaptive Signal Detection

Citation: Wang, P.; Sahinoglu, Z.; Pun, M-O; Li, H., "Persymmetric Parametric Adaptive Matched Filter for Multichannel Adaptive Signal Detection", *IEEE Transactions on Signal Processing*, DOI: 10.1109/TSP.2012.2190411, Vol. 60, Issue 6, pp. 3322-3328, March 2011

Contacts: Zafer Sahinoglu

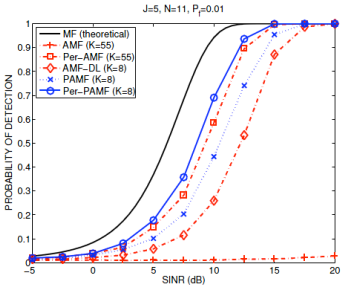


Fig. 4. Probability of detection versus SINR for $K = 8$ when $J = 5$, $N = 11$, and $P_f = 0.01$.

This paper considers a parametric approach for multi-channel adaptive signal detection in Gaussian disturbance which can be modeled as a multichannel auto-regressive (AR) process and, moreover, possesses a persymmetric structure induced by a symmetric antenna geometry. By introducing the persymmetric AR (PAR) modeling for the disturbance, a persymmetric parametric adaptive matched filter (Per-PAMF) is proposed. The developed Per-PAMF extends the classical PAMF by exploiting the underlying persymmetric properties and, hence, improves the detection performance in training-limited scenarios. The performance of the proposed Per-PAMF is examined by the Monte-Carlo simulations and simulation results demonstrate the effectiveness of the Per-PAMF compared with the conventional PAMF and non-parametric detectors.

Low Complexity STAP via Subspace Tracking in Compound-Gaussian Environment

Citation: Wang, P.; Pun, M.O.; Sahinoglu, Z., "Low Complexity STAP via Subspace Tracking in Compound-Gaussian Environment", *IEEE Radar Conference (RadarCon)*, DOI: 10.1109/RADAR.2011.5960559, pp. 356-361, May 2011

Contacts: Zafer Sahinoglu

This paper considers the subspace tracking approach for low complexity space-time adaptive processing (STAP) in a non-homogeneous compound-Gaussian environment. Specifically, a normalized subspace tracking (NST) and an instantaneously normalized subspace tracking (iNST) detectors are proposed to mitigate the effect of the time-varying texture (power) component on the detection performance and track the subspace of the stationary speckle component. On one hand, the two proposed detectors can be considered as a fast implementation of the normalized eigen-canceler by replacing the conventional eigen-decomposition with the subspace tracking techniques. On the other hand, they improve existing subspace tracking-based STAP detectors which mostly deal with homogeneous environment and ignore the power variation among rang bins. Extensive simulations confirm that the proposed detectors are able to provide performance gain over conventional subspace tracking-based STAP detectors in the compound-Gaussian environment.

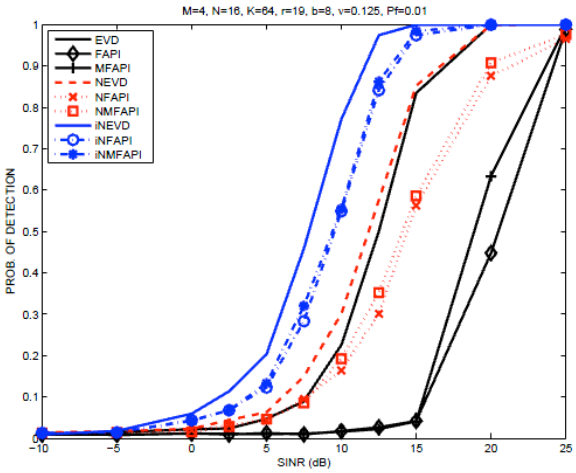


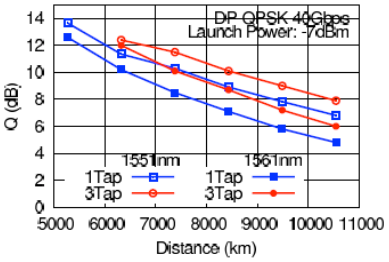
Fig. 3. Probability of detection versus SINR with strong power variation ($b = 8$ and $v = 0.125$) and limited training signals ($K = MN$).

Fractionally-Spaced Statistical Equalizer for Fiber Nonlinearity Mitigation in Digital Coherent Optical Systems

Citation: Koike-Akino, T.; Parsons, K.; Kojima, K.; Duan, C.; Yoshida, T.; Sugihara, T.; Mizuochi, T., "Fractionally-Spaced Statistical Equalizer for Fiber Nonlinearity Mitigation in Digital Coherent Optical Systems", *Optical Fiber Communication Conference (OFC)*, Nonlinearity Mitigation (OTh3C), March 2012

Contacts: Toshiaki Koike-Akino, Chunjie Duan, Keisuke Kojima, Kieran J. Parsons

We propose a fractionally-spaced equalizer with trained second-order statistics to deal with nonlinear impairment in coherent optical communications. The proposed 3-tap equalizer improves Q-factor by more than 2 dB for long-haul transmissions of 5,230 km.



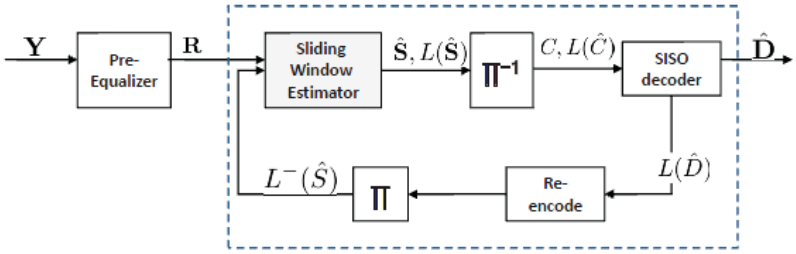
(f) Q vs Distance of DP-QPSK (−7 dBm)

A Low-Complexity Sliding-Window Turbo Equalizer for Nonlinearity Compensation

Citation: Duan, C.; Parsons, K.; Koike-Akino, T.; Annavajjala, R.; Kojima, K.; Yoshida, T.; Sugihara, T.; Mizouchi, T., "A Low-Complexity Sliding-Window Turbo Equalizer for Nonlinearity Compensation", *Optical Fiber Communication Conference (OFC)*, Poster Session 1 (JW2A), March 2012

Contacts: Chunjie Duan, Toshiaki Koike-Akino, Keisuke Kojima, Kieran J. Parsons

We propose a low-complexity turbo equalizer consisting of a sliding window MAP estimator, and a low overhead LDPC decoder. By utilizing 2nd order statistics, we obtain 2.5 - 4dB gain with additional improvement with turbo loop.

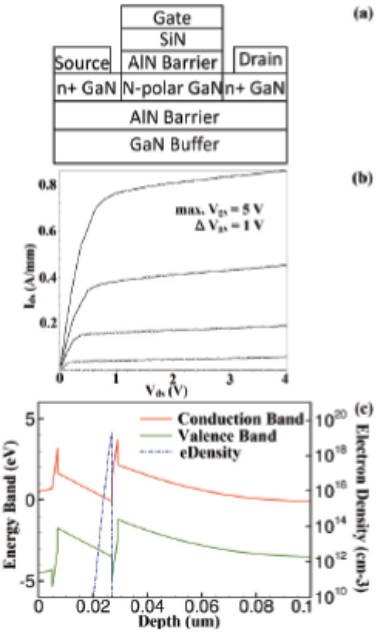


Design and Simulation of Enhancement-mode N-polar GaN Single-channel and Dual-channel MIS-HEMTs

Citation: Feng, P.; Teo, K.H.; Oishi, T.; Nakayama, M.; Duan, C.; Zhang, J., "Design and Simulation of Enhancement-mode N-polar GaN Single-channel and Dual-channel MIS-HEMTs", *International Semiconductor Device Research Symposium (ISDRS)*, DOI: 10.1109/ISDRS.2011.6135163, pp. 1-2, December 2011

Contacts: Koon Hoo Teo, Chunjie Duan, Jinyun Zhang

GaN HEMTs have demonstrated higher power density and efficiency over existing technologies such as silicon and gallium arsenide (GaAs) based RF and microwave transistors [1]. Until recently, improvements in the design of GaN semiconductor device had focused on Ga-polar GaN based HEMTs. Lately, N-polar GaN shows the advantage over Ga-polar device in making enhancement-mode (E-mode) device with low access resistance, and in particular, for low voltage operation. An E-mode N-polar GaN MISFET device was demonstrated to achieve a threshold voltage of 1 V and a record-high drive current 0.74 A/mm at a gate length of 0.62 [2]. Unfortunately, there are few analytical and simulation models developed for E-mode N-polar GaN HEMT. Moreover, the drive current under low voltage bias for N-polar GaN HEMT is smaller than the state-of-the-art Ga-polar GaN HEMT. In this work, by 2-D simulations in Synopsys TCAD [3], we, for the first time, (1) investigated N-polar E-mode single channel GaN MIS-HEMT through simulations; (2) designed an E-mode N-polar GaN dual channel MIS-HEMT and identified the mechanism of the drive current enhancement.

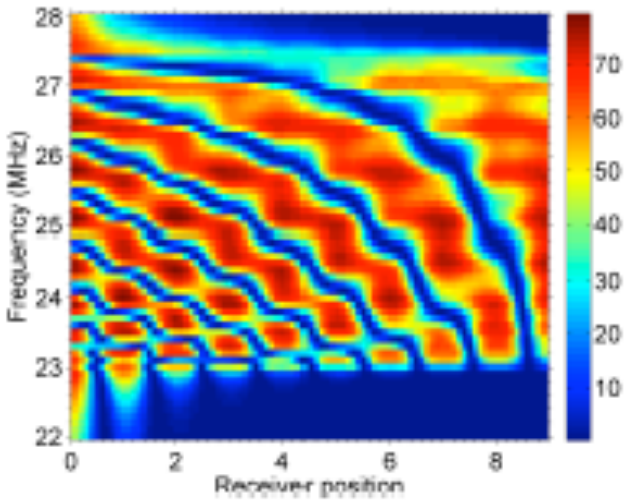


Analysis on Wireless Power Transfer to Moving Devices Based on Array of Resonators

Citation: Wang, B.; Ellstein, D.; Teo, K H, "Analysis on Wireless Power Transfer to Moving Devices Based on Array of Resonators", *European Conference on Antennas and Propagation (EuCAP)*, March 2012

Contacts: Bingnan Wang, Koon Hoo Teo

We describe a wireless power transfer (WPT) system based on electromagnetic coupling of resonators in an array. The system can not only extend the effective range of a conventional resonant coupling based WPT system, but also provide power continuously to multiple moving devices, such as electric vehicles and robots. In this paper, the system is presented and analyzed with a transmission line model. The performance and characteristics of the system are studied and discussed.

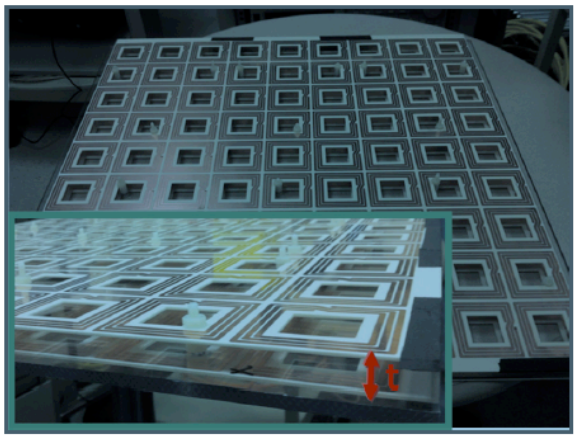


Experiments on Wireless Power Transfer with Metamaterials

Citation: Wang, B.; Teo, K.H.; Nichino, T.; Yerazunis, W.; Barnwell, J.; Zhang, J., "Experiments on Wireless Power Transfer with Metamaterials", *Applied Physics Letters*, DOI: 10.1063/1.3601927, Vol. 98, Issue 25, pp. 254101-254101-3, June 2011

Contacts: Bingnan Wang, John C. Barnwell, Koon Hoo Teo, William S. Yerazunis, Jinyun Zhang

In this letter, we propose the use of metamaterials to enhance the evanescent wave coupling and improve the transfer efficiency of a wireless power transfer system based on coupled resonators. A magnetic metamaterial is designed and built for a wireless power transfer system. We show with measurement results that the power transfer efficiency of the system can be improved significantly by the metamaterial. We also show that the fabricated system can be used to transfer power wirelessly to a 40 W light bulb.



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 including high resolution video formats, as well as multi-view and 3D video. 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, airborne and space systems.

Our research in the area of information coding considers technology for both security and sensing applications. One major research initiative is on a class of technology for privacy-preserving signal processing. This work supports a broad range of applications from secure verification of encrypted biometric data to secure cloud computing. We are also exploring fundamental technology and applications of compressive sensing, including sampling and reconstruction techniques, for a wide range of industrial and consumer uses.

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.

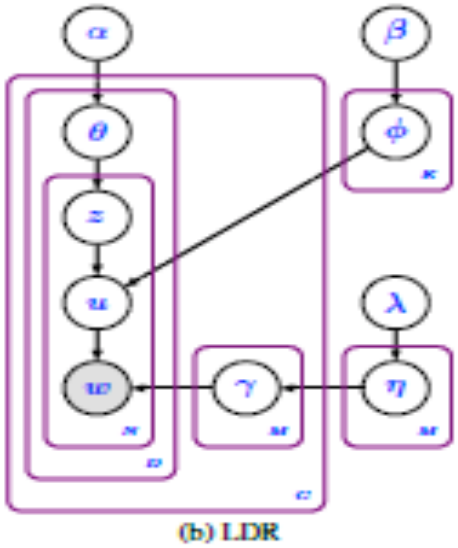
Recent Research

Latent Dirichlet Reallocation for Term Swapping

Citation: Heaukulani, C.; LeRoux, J.; Hershey, J.R., "Latent Dirichlet Reallocation for Term Swapping", *International Workshop on Statistical Machine Learning for Speech Processing (IWSML)*, March 2012

Contacts: Jonathan Le Roux, John R. Hershey

This paper is an extended abstract of a work in progress, which proposes latent Dirichlet reallocation (LDR), a probabilistic model for text data from different dialects over a shared vocabulary. LDR first uses a topic model to allocate word probabilities to vocabulary terms; it then uses a subtopic model to allow for a possible reallocation of probability between a few potentially swappable terms between dialects. An MCMC inference procedure is derived, combining Gibbs sampling with Hamiltonian Monte-Carlo. Finally, we demonstrate the ability of LDR to correctly switch the probabilities for swappable terms under the subtopics using a toy example.

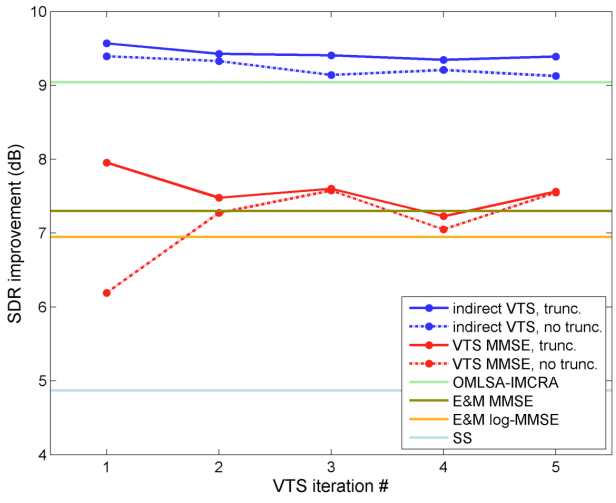


Indirect Model-Based Speech Enhancement

Citation: LeRoux, J.; Hershey, J.R., "Indirect Model-based Speech Enhancement", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper: SP-L3.5, March 2012

Contacts: Jonathan Le Roux, John R. Hershey

Model-based speech enhancement methods, such as vector-Taylor series-based methods (VTS), share a common methodology: they estimate speech using the expected value of the clean speech given the noisy speech under a statistical model. We show that it may be better to use the expected value of the noise under the model and subtract it from the noisy observation to form an indirect estimate of the speech. Interestingly, for VTS, this methodology turns out to be related to the application of an SNR-dependent gain to the direct VTS speech estimate. In results obtained on an automotive noise task, this methodology produces an average improvement of 1.6 dB signal-to-noise ratio (SNR), relative to



conventional methods.

Depth Sensing Using Active Coherent Illumination

Citation: Boufounos, P.T., "Depth Sensing Using Active Coherent Illumination", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper: SS-L11.1, March 2012
Contacts: Petros T. Boufounos

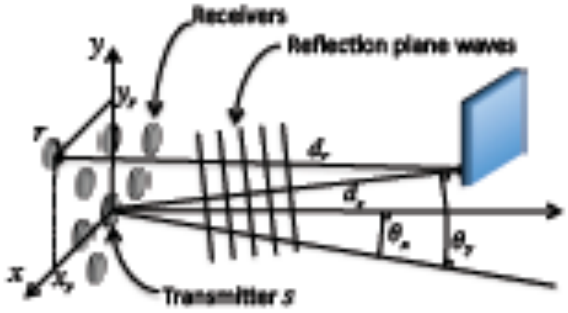


Fig. 1. Array geometry in the far-field approximation

We examine the use of active coherent sensing an increasingly available technology for sensing the depth of scenes. A scene is a sparse signal but also exhibits significant structure that cannot be exploited using standard sparse recovery algorithms. Instead, inspired by the model-based compressive sensing literature we develop a scene model that incorporates occlusion constraints in recovering the depth map. Our model is computationally tractable; we develop a variation of the well-known model-based Compressive Sampling Matching Pursuit (CoSaMP) algorithm, and we demonstrate that our approach significantly improves reconstruction performance.

Dictionary Learning Based Pan-Sharpening

Citation: Liu, D.; Boufounos, P.T., "Dictionary Learning Based Pan-Sharpening", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, Paper MMSP-P3.6, March 2012
Contacts: Dehong Liu, Petros T. Boufounos


(a) DL based MS image (b) Interpolated MS image
Fig. 5. MS image using (a) DL, and (b) Bicubic interpolation.

Pan-sharpening is an image fusion process in which high resolution (HR) panchromatic (Pan) imagery is used to sharpen the corresponding low resolution (LR) multi-spectral (MS) imagery. Pan-sharpened MS images generally have high spatial resolutions, but exhibit color distortions. In this paper, we propose dictionary learning based pan-sharpening process to reduce the color distortion caused by the interpolation of the MS imagery. Instead of interpolating the LR MS image before fusion, we generate an improved MS image which is sparse with respect to a dictionary learned from the image data. Our experiments on degraded QuickBird and IKONOS images demonstrate that the distortion in the MS images produced using our approach is significantly reduced.

Greedy Sparsity-Constrained Optimization

Citation: Bahmani, S.; Boufounos, P.; Raj, B., "Greedy Sparsity-Constrained Optimization", *Asilomar Conference on Signals, Systems and Computers*, DOI: 10.1109/ACSSC.2011.6190194, pp. 1148-1152, November 2011

Contacts: Petros T. Boufounos

Algorithm 1: The GraSP algorithm

input : $f(\cdot)$ and s
output: $\widehat{\mathbf{x}}$

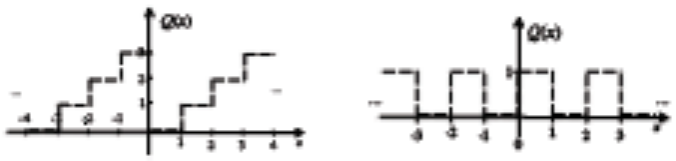
initialize: $\widehat{\mathbf{x}} = \mathbf{0}$
repeat
  compute local gradient: $\mathbf{z} = \nabla f(\widehat{\mathbf{x}})$
  identify directions: $\Omega = \operatorname{supp}(\mathbf{z}_{2s})$
  merge supports: $\mathcal{T} = \Omega \cup \operatorname{supp}(\widehat{\mathbf{x}})$
  minimize over
  support: $\mathbf{b} = \arg\min f(\mathbf{x})$ s.t. $\mathbf{x}|_{\mathcal{T}^c} = \mathbf{0}$
  prune estimate: $\widehat{\mathbf{x}} = \mathbf{b}_s$
until *terminating condition holds*

Finding optimal sparse solutions to estimation problems, particularly in under-determined regimes has recently gained much attention. Most existing literature study linear models in which the squared error is used as the measure of discrepancy to be minimized. However, in many applications discrepancy is measured in more general forms such as log-likelihood. Regularization by `1-norm has been shown to induce sparse solutions, but their sparsity level can be merely suboptimal. In this paper we present a greedy algorithm, dubbed Gradient Support Pursuit (GraSP), for sparsity constrained optimization. Quantifiable guarantees are provided for GraSP when cost functions have the Stable Hessian Property.

Universal Rate-Efficient Scalar Quantization

Citation: Boufounos, P.T., "Universal Rate-Efficient Scalar Quantization", *IEEE Transactions on Information Theory*, DOI: 10.1109/TIT.2011.2173899, Vol. 58, Issue 3, pp. 1861-1872, November 2011

Contacts: Petros T. Boufounos



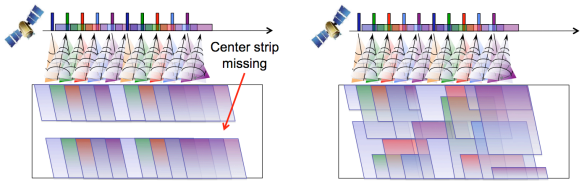
(c) (d)

Scalar quantization is the most practical and straightforward approach to signal quantization. However, it has been shown that scalar quantization of oversampled or compressively sensed signals can be inefficient in terms of the rate-distortion trade-off, especially as the oversampling rate or the sparsity of the signal increases. In this paper, we modify the scalar quantizer to have discontinuous quantization regions. We demonstrate that with this modification it is possible to achieve exponential decay of the quantization error as a function of the oversampling rate instead of the quadratic decay exhibited by current approaches. Our approach is universal in the sense that prior knowledge of the signal model is not necessary in the quantizer design, only in the reconstruction. Thus, we demonstrate that it is possible to reduce the quantization error by incorporating side information on the acquired signal, such as sparse signal models or signal similarity with known signals. In doing so, we establish a relationship between quantization performance and the Kolmogorov entropy of the signal model.

High Resolution SAR Imaging Using Random Pulse Timing

Citation: Liu, D.; Boufounos, P.T., "High Resolution SAR Imaging Using Random Pulse Timing", *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, DOI: 10.1109/IGARSS.2011.6050132, pp. 4091-4094, July 2011

Contacts: Dehong Liu, Petros T. Boufounos



(a) Uniform pulse timing (b) Randomized pulse timing

Fig. 2. Ground coverage with high PRF. (a) With uniform pulse timing the same range length is always missing, and cannot be recovered. (b) With randomized pulse timing the missing data is spread uniformly in the range length, and the ground is well covered.

Synthetic Aperture Radar (SAR) is a fundamental technology with significant impact in remote sensing applications. SAR relies on the motion of the radar platform to synthesize a large aperture, and achieve high resolution imaging of a large area. However, current strip-map SAR designs, relying on uniform pulsing, suffer from a fundamental trade-off between the azimuth resolution and the range coverage length. In this paper we overcome this trade-off using a randomized pulsing scheme combined with non-linear compressive sensing (CS) reconstruction. Our experimental results demonstrate significant improvement in the azimuth resolution using the proposed approach, without compromise on the range length of the imaged area.

Secure Binary Embeddings for Privacy Preserving Nearest Neighbors

Citation: Boufounos, P.; Rane, S., "Secure Binary Embeddings for Privacy Preserving Nearest Neighbors", *IEEE International Workshop on Information Forensics and Security (WIFS)*, DOI: 10.1109/WIFS.2011.6123149, pps. 1-6, November 2011

Contacts: Petros T. Boufounos, Shantanu D. Rane

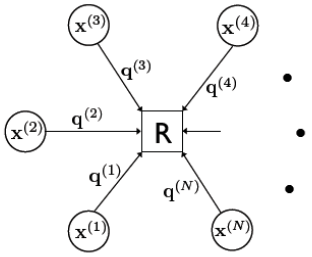


Fig. 4. Researcher can perform approximate nearest neighbor clustering of star-connected parties without discovering their data.

We present a novel method to securely determine whether two signals are similar to each other, and apply it to approximate nearest neighbor clustering. The proposed method relies on a locality sensitive hashing scheme based on a secure binary embedding, computed using quantized random projections. Hashes extracted from the signals preserve information about the distance between the signals, provided this distance is small enough. If the distance between the signals is larger than a threshold, then no information about the distance is revealed. Theoretical and experimental justification is provided for this property. Further, when the randomized embedding parameters are unknown, then the mutual information between the hashes of any two signals decays to zero exponentially fast as a function of the distance between the signals. Taking advantage of this property, we suggest that these binary hashes can be used to perform privacy-preserving nearest neighbor search wit significantly lower complexity compared to protocols which use the actual signals.

Privacy Preserving Probabilistic Inference with Hidden Markov Models

Citation: Pathak, M.; Rane, S.; Sun, W.; Raj, B., "Privacy Preserving Probabilistic Inference with Hidden Markov Models", IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), DOI: 10.1109/ ICASSP. 2011.5947696, pp. 5868-5871, May 2011

Contacts: Shantanu D. Rane, Wei Sun

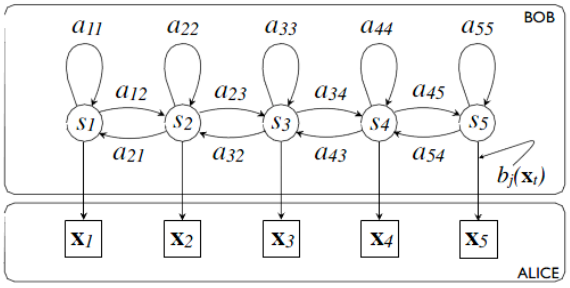


Fig. 1. An example of a 5-state HMM. In this work, Alice (client) possesses the data or features extracted from the data to be classified, while Bob (server) possesses a privately trained HMM.

Alice possesses a sample of private data from which she wishes to obtain some probabilistic inference. Bob possesses Hidden Markov Models (HMMs) for this purpose, but he wants the model parameters to remain private. This paper develops a framework that enables Alice and Bob to collaboratively compute the so-called forward algorithm for HMMs while satisfying their privacy constraints. This is achieved using a public-key additively homomorphic cryptosystem. Our framework is asymmetric in the sense that a larger computational overhead is incurred by Bob who has higher computational resources at his disposal, compared with Alice who has limited computing resources. Practical issues such as the encryption of probabilities and the effect of finite precision on the accuracy of probabilistic inference are considered. The protocol is implemented in software and used for secure keyword recognition.

A Trellis-based Approach for Robust View Synthesis

Citation: Tian, D.; Vetro, A.; Brand, M., "A Trellis-based Approach for Robust View Synthesis", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6116623, pp. 605-608, September 2011

Contacts: Dong Tian, Matthew E. Brand, Anthony Vetro

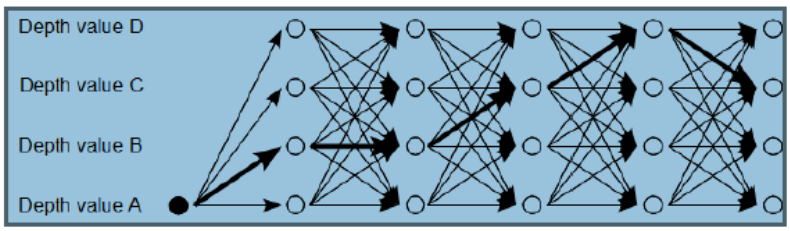


Fig. 1: Trellis based view synthesis

View synthesis is an essential function for a number of 3D video applications including free-viewpoint navigation and view generation for auto-stereoscopic displays. Depth Image Based Rendering (DIBR) techniques are typically applied for this purpose. However, the quality of the rendered views is very sensitive to the quality of the depth image. In this paper, a novel trellis- based view synthesis framework is proposed to overcome the above limitations in depth images and reduce artifacts in the rendered picture. Our results demonstrate that the proposed approach offers visible improvements in rendering quality compared to existing view synthesis techniques.

Distributed Compression of Zero-trees of Wavelet Coefficients

Citation: Wang, Y.; Rane, S.; Boufounos, P.; Vetro, A., "Distributed Compression of Zerotrees of Wavelet Coefficients", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6115819, September 2011

Contacts: Shantanu D. Rane, Petros T. Boufounos, Anthony Vetro

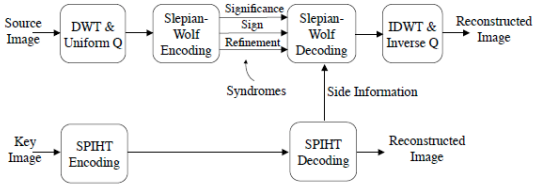


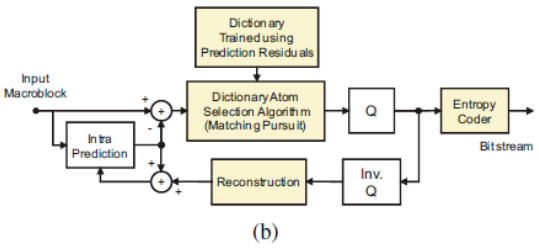
Fig. 1. Distributed coding scheme exploiting spatial orientation trees of wavelet coefficients. The significance map syndromes are decoded first followed by the sign syndromes and finally the refinement syndromes.

A distributed coding algorithm is presented for compression of wavelet transformed data. Data structures based on zero trees are exploited for efficient compression of the significance map of wavelet coefficients. The coefficients are scanned in two stages, with a significance pass and refinement pass, similar to the SPIHT algorithm. The bits resulting from these passes are Slepian-Wolf coded using an LDPC syndrome code selected from a bank of available codes. A key realization is that, for each bitplane of the wavelet coefficients, the significance pass of the source data can be synchronized with that of the side information. This allows distributed compression of the significance pass. This is substantially different from previous mixed approaches in which the refinement pass was Slepian-Wolf coded, but the significance pass was coded independently. Ratedistortion results are presented for images from the ALOS AVNIR-2 multispectral dataset and compared against those obtained with SPIHT and JPEG2000.

Efficient Dictionary Based Video Coding with Reduced Side Information

Citation: Kang, J-W; Kuo, C-C J; Cohen, R.; Vetro, A., "Efficient Dictionary Based Video Coding with Reduced Side Information", *IEEE International Symposium on Circuits and Systems (ISCAS)*, DOI: 10.1109/ISCAS.2011.5937513, pp. 109-112, May 2011

Contacts: Robert A. Cohen, Anthony Vetro



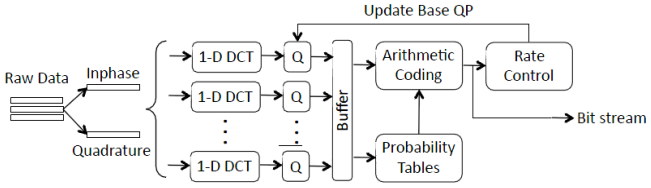
(b)

In this paper, we propose a novel dictionary based video coding technique with adaptive construction of over complete dictionaries and advanced coding methods tailored to sparse signal representations. A set of dictionaries is trained off-line using inter or intra predicted residual samples and is applied for encoding. New coding tools are developed so that the encoder can more compactly represent the residual signal. The same set of dictionary elements can be reused for neighboring blocks, and the optimal number of dictionary elements can be decided using rate-distortion optimization. Experimental results demonstrate that the proposed algorithm yields both improved coding performance and improved perceptual quality at low bit rates.

Low-Complexity Efficient Raw SAR Data Compression

Citation: Rane, S.; Boufounos, P.; Vetro, A.; Okada, Y., "Low-Complexity Efficient Raw SAR Data Compression", *SPIE Defense, Security and Sensing, Algorithms for Synthetic Aperture Radar Imagery XVIII*, April 2011

Contacts: Shantanu D. Rane, Petros T. Boufounos, Anthony Vetro

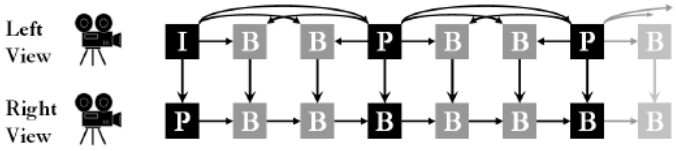


We present a low-complexity method for compression of raw Synthetic Aperture Radar (SAR) data. Raw SAR data is typically acquired using a satellite or airborne platform without sufficient computational capabilities to process the data and generate a SAR image on-board. Hence, the raw data needs to be compressed and transmitted to the ground station, where SAR image formation can be carried out. To perform low-complexity compression, our method uses 1-dimensional transforms, followed by quantization and entropy coding. In contrast to previous approaches, which send uncompressed or Huffman-coded bits, we achieve more efficient entropy coding using an arithmetic coder that responds to a continuously updated probability distribution. We present experimental results on compression of raw Ku-SAR data. In those we evaluate the effect of the length of the transform on compression performance and demonstrate the advantages of the proposed framework over a state-of-the-art low complexity scheme called Block Adaptive Quantization (BAQ).

Overview of the Stereo and Multi-view Video Coding Extensions of the H.264/MPEG-4 AVC Standard

Citation: Vetro, A.; Wiegand, T.; Sullivan, G. J., "Overview of the Stereo and Multiview Video Coding Extensions of the H.264/MPEG-4 AVC Standard", *Proceedings of the IEEE*, DOI: 10.1109/JPROC.2010.2098830, pp.626-642, April 2011

Contacts: Anthony Vetro



Significant improvements in video compression capability have been demonstrated with the introduction of the H.264/MPEG-4 Advanced Video Coding (AVC) standard. Since developing this standard, the Joint Video Team of the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) has also standardized an extension of that technology that is referred to as multi-view video coding (MVC). MVC provides a compact representation for multiple views of a video scene, such as multiple synchronized video cameras. The standard enables inter-view prediction to improve compression capability, as well as supporting ordinary temporal and spatial prediction. It also supports backward compatibility with existing legacy systems by structuring the MVC bit-stream to include a compatible "base view". Each other view is encoded at the same picture resolution as the base view.

Data Analytics

Data Analytics technologies aim to improve the performance of devices, systems, and business processes by means of collecting data, constructing predictive models from that data, and making improved decisions based on the constructed models. The Data Analytics group at MERL has been working on both predictive and decision analytics, as well as supporting fields such as signal processing, numerical methods, and information systems infrastructure. The focus of the group is on innovative high-performance algorithms that can be applied to various product lines of Mitsubishi Electric, including electrical power systems, transportation systems, and enterprise information technology. The application of these algorithms minimizes costs, maximizes profits, increases reliability, improves energy efficiency, and reduces environmental impact of products.

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

Numerical methods for fast solution of network problems find application in the analysis of electrical power systems and Smart Grids that include renewable power sources with intermittent output, as well as highly variable loads such as electrical vehicles. In addition, research on supporting technologies such as signal processing has resulted in algorithms for dimensionality reduction and feature extraction based on 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

Factored Markov Decision Process Models for Stochastic Unit Commitment

Citation: Nikovski, D.; Zhang, W., "Factored Markov Decision Process Models for Stochastic Unit Commitment", *IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES)*, ISBN 978-1-4244-6076-2, pp. 28-35, September 2010

Contacts: Daniel Nikovski

In this paper, we consider stochastic unit commitment problems where power demand and the output of some generators are random variables. We represent stochastic unit commitment problems in the form of factored Markov decision process models, and propose an approximate algorithm to solve such models. By incorporating a risk component in the cost function, the algorithm can achieve a balance between the operational costs and blackout risks. The proposed algorithm outperformed existing non-stochastic approaches on several problem instances, resulting in both lower risks and operational costs.

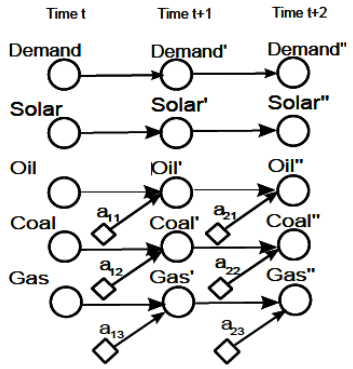


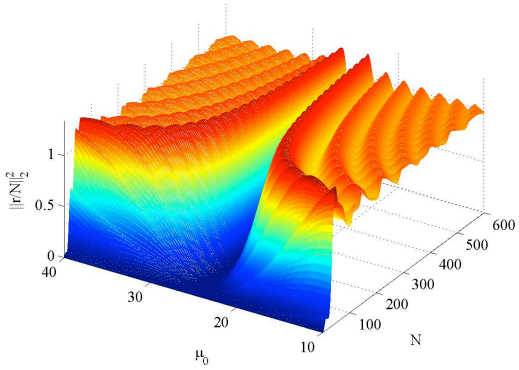
Figure II.1. DBN for a power generation problem with three controllable and one uncontrollable power generators.

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

Citation: Laughman, C.R.; Lesh, S.B.; Norford, L.K.; Shaw, S.R.; Armstrong, P.R., "A Park Transform-Based Method for Condition Monitoring of Three-Phase Electromechanical Systems", *Power Electronics Machines and Drives (PEMD)*, April 2010

Contacts: Christopher Laughman

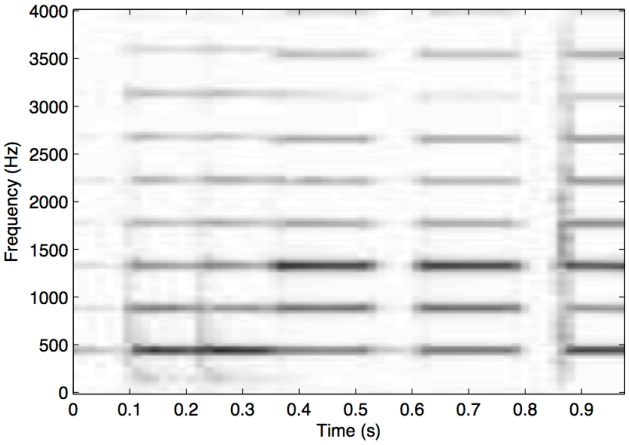
This paper presents a Park transform-based method for processing stator current data from a motor and transforming it into a form that is useful for fault detection and diagnostics. The proposed method generates power signatures that are invariant to the initial electrical angle of the voltage when the 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 o Acoustics, Speech and Signal Processing (ICASSP)*, MLSP-L4.3, March 2010
Contacts: Kevin Wilson

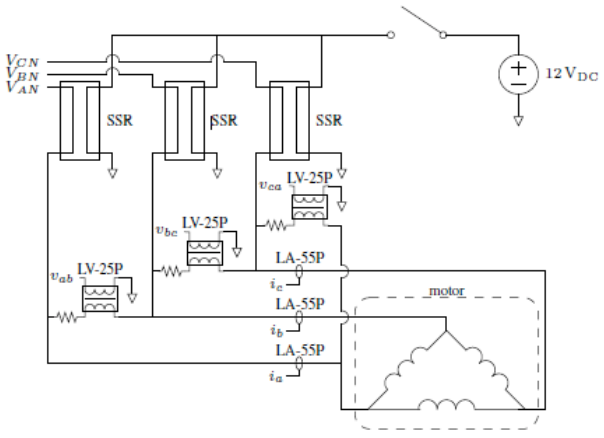
We propose an algorithm to find a low-dimensional decomposition of a spectrogram by formulating this as a regularized non-negative matrix factorization (NMF) problem with a regularization term chosen to encourage independence. This algorithm provides a better decomposition than standard NMF when the 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

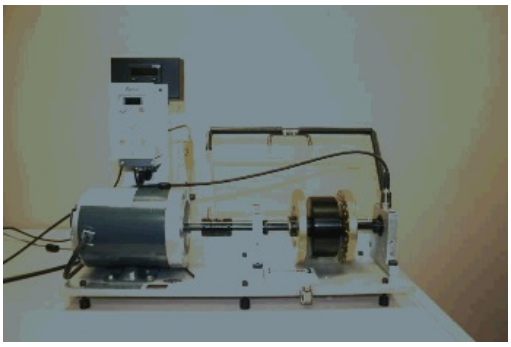
Citation: Laughman, C.R.; Leeb, S.B.; Norford, L.K.; Shaw, S.R.; Armstrong, P.R., "A Two-Step Method for Estimating the Parameters of Induction Machine Models", *IEEE Energy Conversion Congress and Exposition (ECCE),* DOI: 10.1109/ECCE.2009.5316204, pp. 262-269, September 2009
Contacts: Christopher Laughman

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

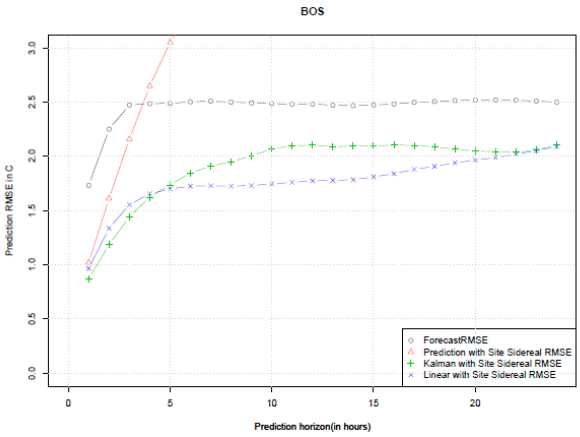
Citation: Wilson, K.W.; "Probabilistic Inter-disturbance Interval Estimation for Bearing Fault Diagnosis", IEEE International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives (SDEMPED), DOI: 10.1109/DEMPED.2009.5292803, pp. 1-6, August 2009
Contacts: Kevin Wilson



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

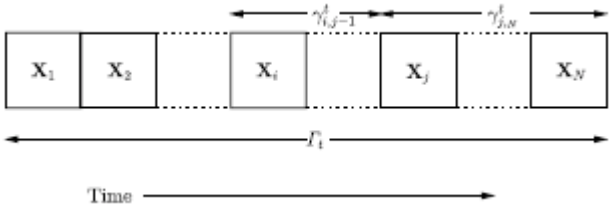


The paper describes a method for predicting climate time series that consist of significant annual and diurnal seasonal components and a short-term stochastic component. A memory-based method for modeling of the non-linear seasonal components is proposed that allows the application of simpler linear 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

Citation: Nikovski, D.N.; Jain, A., "Fast Adaptive Algorithms for Abrupt Change Detection", *Machine Learning*, ISSN 0885-6125; DOI 10.1007/s10994-009-5122-x, July 2009

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 $O(N)$.

A Hybrid Decoupled Power Flow Method for Balanced Power Distribution Systems

Citation: Sun, H.; Nikovski, D.; Ohno, T.; Takano, T.; Kojima, Y., "A Hybrid Decoupled Power Flow Method for Balanced Power Distribution Systems", *Journal of Electronic Science and Technology (JEST)*, Vol.10, Issue 1, pp 15-21, DOI: 10.3969/j.issn.1674-862X.2012.01.003, March 2012

Contacts: Hongbo Sun, Daniel N. Nikovski

This paper proposes a hybrid decoupled power flow method for balanced power distribution systems with distributed generation sources. The method formulates the power flow equations in active power and reactive power decoupled form with polar coordinates. Second-order terms are included in the active power mismatch iteration, and constant Jacobian and Hessian matrices are used. A hybrid direct and indirect solution technique is used to achieve efficiency and robustness of the algorithm. The impact of zero-impedance branches is explicitly modeled through reconfiguring of the adjacent branches with impedances. Numerical examples on a sample distribution system with widespread photovoltaic installations are given to demonstrate the effectiveness of the proposed method.

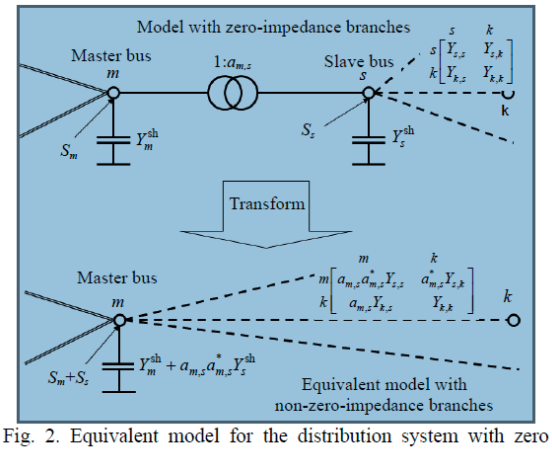
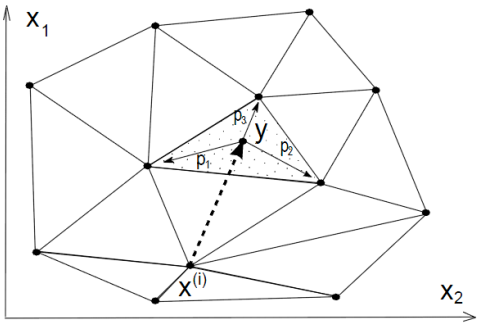


Fig. 2. Equivalent model for the distribution system with zero impedance branches.

Construction of Embedded Markov Decision Processes for Optimal Control of Non-Linear Systems with Continuous State Spaces

Citation: Nikovski, D.; Esenther, A., "Construction of Embedded Markov Decision Processes for Optimal Control of Non-Linear Systems with Continuous State Spaces", *IEEE Conference on Decision and Control and European Control Conference (CDC-ECC)*, DOI: 10.1109/CDC.2011.6161310, pp. 7944-7949, December 2011

Contacts: Daniel N. Nikovski, Alan W. Esenther

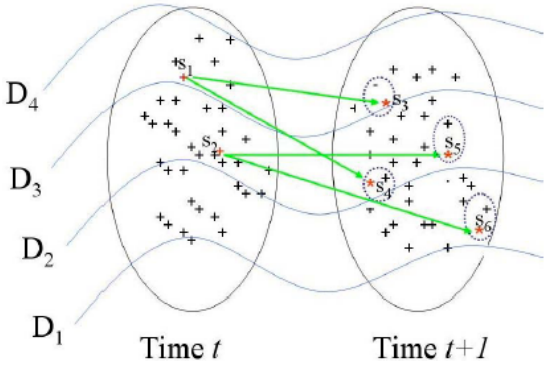


We consider the problem of constructing a suitable discrete-state approximation of an arbitrary non-linear dynamical system with continuous state space and discrete control actions that would allow close to optimal sequential control of that system by means of value or policy iteration on the approximated model. We propose a method for approximating the continuous dynamics by means of an embedded Markov decision process (MDP) model defined over an arbitrary set of discrete states sampled from the original continuous state space. The mathematical similarity between sets of barycentric coordinates (convex combination) and probability mass functions is exploited to compute the transition matrices and initial state distribution of the MDP.

State-space Approximate Dynamic Programming for Stochastic Unit Commitment

Citation: Zhang, W.; Nikovski, D., "State-space Approximate Dynamic Programming for Stochastic Unit Commitment", *North American Power Symposium (NAPS)*, DOI: 10.1109/NAPS.2011.6025113, pp. 1-7, August 2011

Contacts: Daniel N. Nikovski

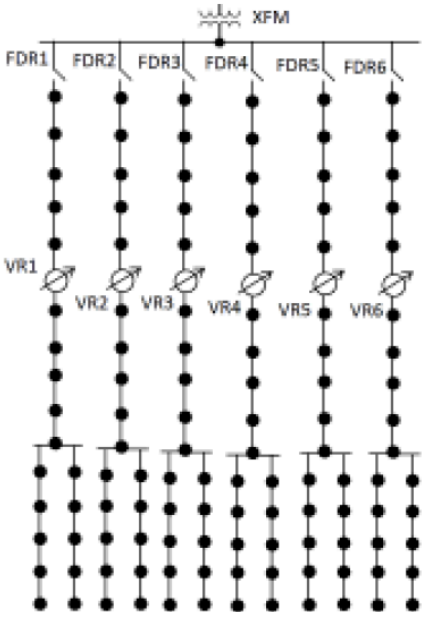


It is known that unit commitment problems with uncertainties in power demands and the outputs of some generators can be represented as factored Markov decision process models. In this paper we propose a state space approximate dynamic programming algorithm to solve such models. The algorithm features a method to generate representative system configurations (states) and a functional metric to measure the similarity among system configurations. Experimental results show that the algorithm outperforms two deterministic approaches in resulting in both lower risks and operational costs, and that it can solve larger problems than a stochastic approach based on decision space approximate dynamic programming.

A Fast and Robust Load Flow Method for Distributiion Systems with Distributed Generations

Citation: Sun, H.; Nikovski, D.; Ohno, T.; Takano, T.; Kojima, Y., "A Fast and Robust Load Flow Method for Distribution Systems with Distributed Generations", *IEEE International Conference on Smart Grid and Clean Energy Technologies (ICSGCE)*, September 2011

Contacts: Hongbo Sun, Daniel N. Nikovski



This paper proposes a fast and robust load flow method for balanced power distribution systems with distributed generation sources. The method formulates generation sources. The method formulates the power flow equations in PQ decoupled form with polar coordinates. Second-order terms are included in the active power mismatch iteration, and resistances are fully modeled without any simplifications. The impacts of zero-impedance branches are explicitly modeled through reconfiguring of the adjacent branches with impedances. Typical distribution generation models and distribution load models are included. A hybrid direct and indirect solution technique is used to achieve efficiency and robustness of the algorithm. Active power correction is solved by means of a sparse LU decomposition algorithm with partial pivoting, and the reactive power correction is solved by means of restarted Generalized Minimal Residual algorithm with incomplete LU pre-conditioner. The numerical examples on a sample distribution system with widespread Photovoltaic installations are given to demonstrate the effectiveness of the proposed method.

Imaging

The research in the Imaging group at MERL covers all aspects of extracting information from images. For instance, from a picture of a scene we can compute features that allow the detection and location of specific objects. Or we learn a dictionary for the appearance of local patches in an image and use it to classify regions and objects or to improve the image quality. 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.

Several of our current projects involve 3D analysis 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. We have also developed algorithms that operate directly on 3D data for reconstruction, detection, and recognition.

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

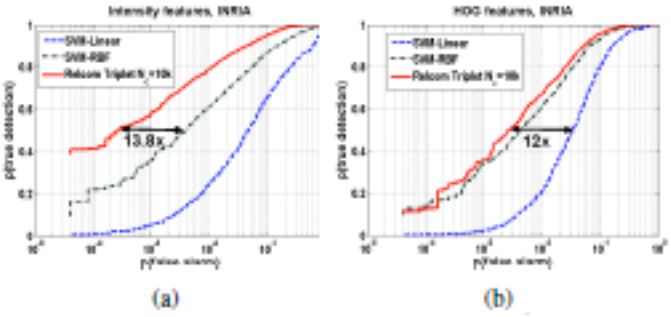
Fast Directional Chamfer Matching

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.

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

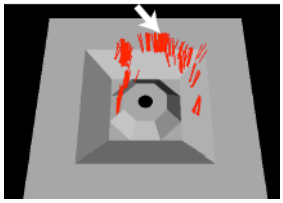


We present a simple yet elegant feature, RelCom, and a boosted selection method to achieve a very low complexity object detector. We generate combinations of low-level feature coefficients and apply relational operations such as margin based similarity rule over each possible pair of these combinations 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



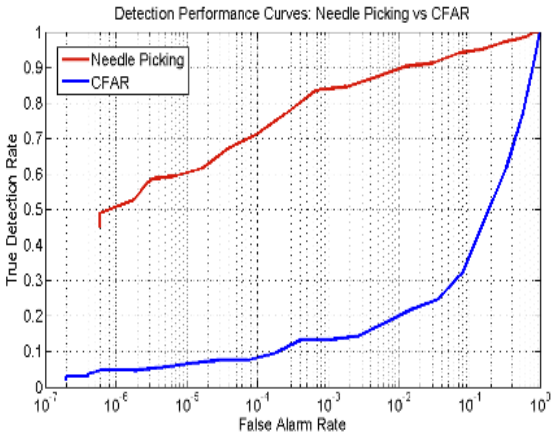
This paper presents a probing-based method for probabilistic localization in automated robotic assembly. We consider peg-in-hole problems in which a needle-like peg has a single point of contact with the object that contains the hole, and in which the initial uncertainty in the relative pose (3D position 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.

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

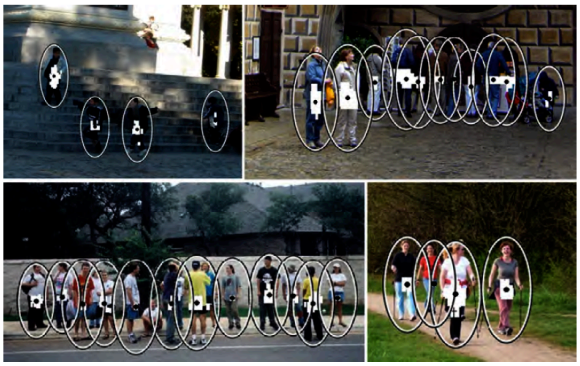
Contacts: Fatih Porikli

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.



Learning on Manifolds

Citation: Porikli, F., "Learning on Manifolds", *Joint IAPR International Conference on Structural, Syntactic and Statistical Pattern Recognition (SSPR & SPR)*, August 2010
Contacts: Fatih Porikli



Mathematical formulation of certain natural phenomena exhibits group structure on topological spaces that resemble the Euclidean space only on a small enough scale, which prevents incorporation of conventional inference methods that require global vector norms. More specifically in computer vision, such underlying notions emerge in differentiable parameter spaces. Here, two Riemannian manifolds including the set of affine transformations and covariance matrices are elaborated and their favorable applications in distance computation, motion estimation, object detection and recognition problems are demonstrated after reviewing some of the fundamental preliminaries.

Axial-Cones: Modeling Spherical Catadioptric Cameras for Wide-Angle Light Field Rendering

Citation: Taguchi, Y.; Agrawal, A.; Veeraraghavan, A.; Ramalingam, S.; Raskar, R., "Axial-Cones: Modeling Spherical Catadioptric Cameras for Wide-Angle Light Field Rendering: ", *ACM Transactions on Graphics (TOG)*, ISBN: 978-1-4503-0439-9, Vol. 29, Issue 6, December 2010
Contacts: Yuchi Taguchi, Amit Agrawal, Srikumar Ramalingam

Catadioptric imaging systems are commonly used for wide-angle imaging, but lead to multi-perspective images which do not allow algorithms designed for perspective cameras to be used. Efficient use of such systems requires accurate geometric ray modeling as well as fast algorithms. We present accurate geometric modeling of the multi-perspective photo captured with a spherical catadioptric imaging system using axial-cone cameras: multiple perspective cameras lying on an axis each with a different viewpoint and a different cone of rays. This modeling avoids geometric approximations and allows several algorithms developed for perspective cameras to be applied to multi-perspective catadioptric cameras. We present several applications such as spherical distortion correction, digital refocusing for artistic depth of field effects in wide-angle scenes, and wide-angle dense depth estimation.

P2Pi: A Minimal Solution for registration of 3D Points to 3D Planes

Citation: Ramalingam, S.; Taguchi, Y.; Marks, T.K.; Tuzel, O., "P2Pi: A Minimal Solution for Registration of 3D Points to 3D Planes", *European Conference on Computer Vision (ECCV)*, ISBN: 3-642-15554-5 978-3-642-15554-3, September 2010

Contacts: Srikumar Ramalingam, Yuichi Taguchi, Tim Marks, Oncel Tuzel

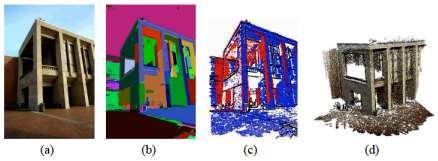


Fig. 7. Registering two point clouds, each generated by applying multi-view reconstruction techniques to 15 images. **(a)** One of the images used in 3D reconstruction. **(b)** superpixel segmentation of the image shown in (a). **(c)** The 3D points from the first (blue) and second (red) clouds are reprojected onto the superpixel image. The points from the first point cloud are used to compute the superpixel plane parameters, while the second point cloud is preserved as points. The correspondence between the points from the second cloud and the planes obtained from the first cloud are determined by the underlying superpixel. **(d)** 3D model after merging the two partial reconstructions from the two clusters. [**Best viewed in color**]

This paper presents a class of minimal solutions for the 3D-to-3D registration problem in which the sensor data are 3D points and the corresponding object data are 3D planes. In order to compare the 6 degrees-of-freedom transformation between the sensor and the object, we need at least six points on three or more planes. We systematically investigate and develop pose estimation algorithms for several configurations, including all minimal configurations, which arise from the distribution of points on planes. The degenerate configurations are also identified. We point out that many existing and unsolved 2D-to-3D and 3D-to-3D pose estimation algorithms involving points, lines, and planes can be transformed into the problem of registering points to planes. In addition to simulations, we also demonstrate the algorithm's effectiveness in two real-world applications: registration of a robotic arm with an object using a contact sensor, and registration of 3D point clouds that were obtained using multi-view reconstruction of planar city models.

Sensor Placement Tool for Rapid Development of Video Sensor Layouts

Citation: Garaas, T.W., "Sensor Placement Tool for Rapid Development of Video Sensor Layouts", *Symposium on Simulation for Architecture and Urban Design (SimAUD)*, pp. 134-137, April 2011

Contacts: Tyler W. Garaas

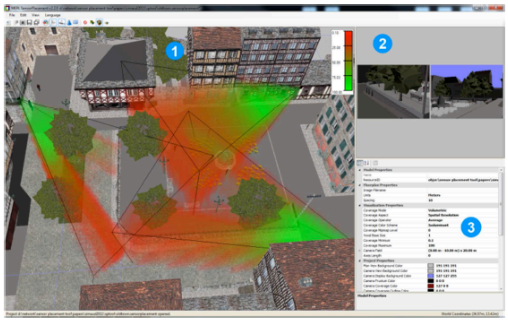


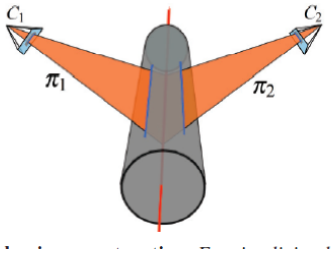
Figure 1. Illustration of the SPtool GUI and the components that comprise it. Component 1 is the primary view window, where users interact with the environment and video sensors. Component 2 provides a virtual view from sensors within the environment. Finally, component 3 is a properties grid, where users can customize the parameters of selected 3D models, selected video sensors, environment parameters, or the sensor coverage analysis and visualization.

The arrangement of video sensors in closed-circuit television (CCTV) systems, for instance can have drastic effects on the efficiency and cost of the final system. In the present work, I describe a tool designed for rapid construction of simulated video sensor layouts that allows quantification of sensor coverage and cost estimation to be determined prior to installation; thus, avoiding costly changes during or after the installation. Most previous work in this area either considers sensor coverage only in a 2D space or requires significant preparation to achieve accurate results in 3D. In the present work, I describe an implementation of a novel coverage-analysis algorithm that uses the geometry of image formation to cast rays from simulated video sensors through the monitored area to estimate sensor coverage at every 3D location. Visualization techniques of the acquired sensor coverage data are additionally presented.

Find a Needle in a Specular Haystack

Citation: Shroff, N.; Taguchi, Y.; Tuzel, O.; Veeraraghavan, A.; Ramalingam, S.; Okuda, H., "Finding a Needle in a Specular Haystack", *IEEE International Conference on Robotics and Automation (IRCA)*, DOI: 10.1109/ICRA.2011.5979857, pp. 5963-5970, May 2011

Contacts: Yuichi Taguchi, Takaaki Sakaguchi, C. Oncel Tuzel

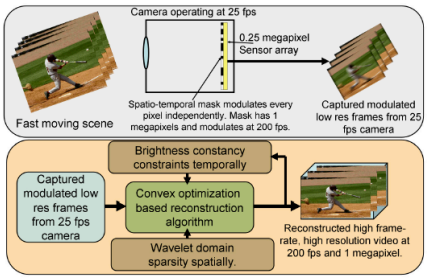


Progress in machine vision algorithms has led to widespread adoption of these techniques to automate several industrial assembly tasks. Nevertheless, shiny or specular objects which are common in industrial environments still present a great challenge for vision systems. In this paper, we take a step towards this problem under the context of vision-aided robotic assembly. We show that when the illumination source moves, the specular highlights remain in a region whose radius is inversely proportional to the surface curvature. This allows us to extract regions of the object that have high surface curvature. These points of high curvature can be used as features for specular objects. Further, an inexpensive multi-flash camera (MFC) design can be used to reliably extract these features. We show that one can use multiple views of the object using the MFC in order to triangulate and obtain the 3D location and pose of the shiny objects. Finally, we show a system consisting of a robot arm with an MFC that can perform automated detection and pose estimation of shiny screws within a cluttered bin, achieving position and orientation errors less than 0.5 mm and 0.8 respectively.

P2C2: Programmable Pixel Compressive Camera for High Speed Imaging

Citation: Reddy, D.; Veeraraghavan A.; Chellappa, R., "P2C2: Programmable Pixel Compressive Camera for High Speed Imaging", *IEEE Computer Vision & Patter Recognition (CVPR)*, DOI: 10.119/CVPR.2011.5995542, pp. 329-336, June 2011

Contacts: Jay Thornton



We describe an imaging architecture for compressive video sensing termed programmable pixel compressive camera (P2C2). P2C2 allows us to capture fast phenomena at frame rates higher than the camera sensor. In P2C2, each pixel has an independent shutter that is modulated at a rate higher than the camera frame-rate. The observed intensity at a pixel is an integration of the incoming light modulated by its specific shutter. We propose a reconstruction algorithm that uses the data from P2C2 along with additional priors about videos to perform temporal super-resolution. We model the spatial redundancy of videos using sparse representations and the temporal redundancy using brightness constancy constraints inferred via optical flow. We show that by modeling such spatio-temporal redundancies in a video volume, one can faithfully recover the underlying high-speed video frames from the observed low speed coded video. The imaging architecture and the reconstruction algorithm allows us to achieve temporal super-resolution without loss in spatial resolution.

Concentric Ring Signature Descriptor for 3D Objects

Citation: Nguyen H.V.; Porikli, F., "Concentric Ring Signature Descriptor for 3D Objects", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6116153, September 2011

Contacts: Fatih M. Porikli

Fig. 7. Top four retrieval results for a sample query of human object. CORS retrieves correct matches.

We present a 3D feature descriptor that represents local topologies within a set of folded concentric rings by distances from local points to a projection plane. This feature, called as Concentric Ring Signature (CORS), possesses similar computational advantages to point signatures yet provides more accurate matches. It produces more compact and discriminative descriptors than shape context. It robust to noise and occlusions. As opposed to spin images, CORS does not require the point normal estimations; therefore it is directly applicable to sparse point clouds where the point densities are insufficiently low. Under the same settings, we demonstrate that the discriminative power of CORS is superior to conventional approaches producing twice as good estimates with the percentage of correct match scores improving from 39% to 88%.

Pose Normalization via Learned 2D Warping for Fully Automatic Face Recognition

Citation: Asthana, A.; Jones, M.J.; Marks, T.K.; Tieu, K.H.; Goecke, R., "Pose Normalization via Learned 2D Warping for Fully Automatic Face Recognition", *British Machine Vision Conference (BMVC)*, August 2011

Contacts: Michael J. Jones, Tim K. Marks

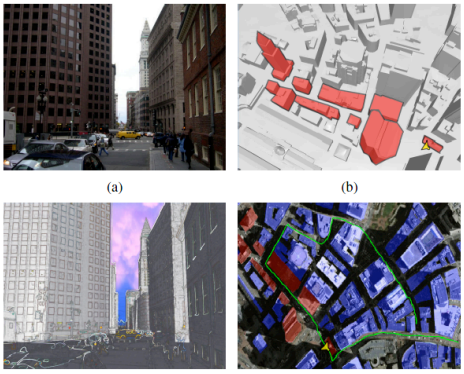
Figure 3: Overview of our fully automatic pose-invariant face recognition system.

We present a novel approach to pose-invariant face recognition that handles continuous pose variations, is not database-specific, and achieves high accuracy without any manual intervention. Our method uses multi-dimensional Gaussian process regression to learn a nonlinear mapping function from the 2D shapes of faces at any non-frontal pose to the corresponding 2D frontal face shapes. We use this mapping to take an input image of a new face at an arbitrary pose and pose-normalize it, generating a synthetic frontal image of the face that is then used for recognition. Our fully automatic system for face recognition includes automatic methods for extracting 2D facial feature points and accurately estimating 3D head pose, and this information is used as input to the 2D pose-normalization algorithm. The current system can handle pose variation up to 45 degrees to the left or right (yaw angle) and up to 30 degrees up or down (pitch angle). The system demonstrates high accuracy in recognition experiments on the CMU-PIE, USF 3D, and Multi-PIE databases, showing excellent generalization across databases and convincingly outperforming other automatic methods.

Pose Estimation using Both Points and Lines for Geo-Localization

Citation: Ramalingam, S.; Bouazia, S.; Sturm, P., "Pose Estimation using Both Points and Lines for Geo-Localization", *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA.2011.5979781, pp. 4716-4723, May 2011

Contacts: Srikumar Ramalingam

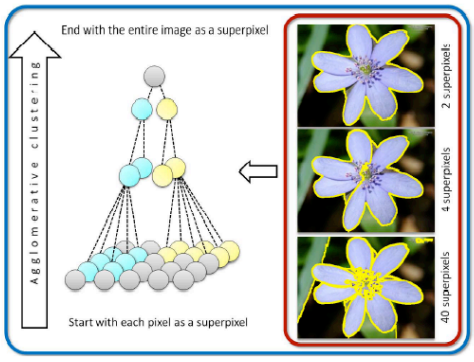


This paper identifies and fills the probably last two missing items in minimal pose estimation algorithms using points and lines. Pose estimation refers to the problem of recovering the pose of a calibrated camera given known features (points or lines) in the world and their projections on the image. There are four minimal configurations using point and line features: 3 points, 2 points and 1 line, 1 point and 2 lines, 3 lines. The first and the last scenarios that depend solely on either points or lines have been studied a few decades earlier. However the mixed scenarios, which are more common in practice, have not been solved yet. In this paper we show that it is indeed possible to develop a general technique that can solve all four scenarios. The centerpiece of our method is a simple and generic method that uses collinearity and coplanarity constraints for solving the pose. In addition to validating the performance of these algorithms in simulations, we also show a compelling application for geo-localization using image sequences and coarse (plane-based) 3D models of GPSchallenged urban canyons.

Entropy Rate Superpixel Segmentation

Citation: Liu, M-Y, Tuzel, O.; Ramalingam, S.; Chellappa, "Entropy Rate Superpixel Segmentation", *IEEE Computer Vision & Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2011.5995323, pp. 2097-2104, June 2011

Contacts: O. Oncel Tuzel, Srikumar Ramalingam



We propose a new objective function for super-pixel segmentation. This objective function consists of two components: entropy rate of a random walk on a graph and a balancing term. The entropy rate favors formation of compact and homogeneous clusters, while the balancing function encourages clusters with similar sizes. We present a novel graph construction for images and show that this construction induces a matroid—a combinatorial structure that generalizes the concept of linear independence in vector spaces. The segmentation is then given by the graph topology that maximizes the objective function under the matroid constraint. By exploiting sub-modular and monotonic properties of the objective function, we develop an efficient greedy algorithm. Furthermore, we prove an approximation bound of 1/2 for the optimality of the solution.

Mechatronics

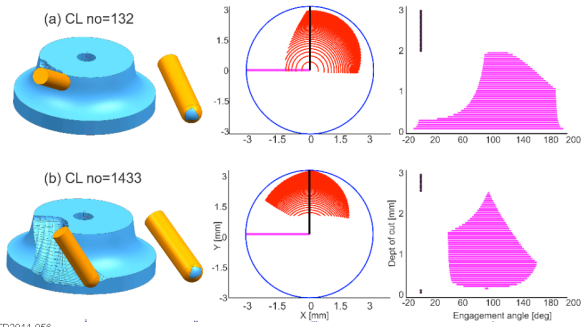
The Mechatronics group conducts fundamental and applied research and develops advanced technology in the areas of mechatronic systems and control, merging advanced control theory, dynamical systems theory, physics, computer science, mechanical engineering, optics, embedded systems, and power electronics, all with the intent to expand the performance envelope of Mitsubishi Electric products. The Mechatronics Group has expertise in multivariable, nonlinear, optimal & model-predictive control theory, nonlinear estimation, nonlinear dynamical systems, mechanical design, laser processing & sensing, 3D CAD and rapid prototyping. The group 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 systems is central to many areas of Mitsubishi Electric's 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 Current Forces for 5-Axis Machining of Sculputured 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

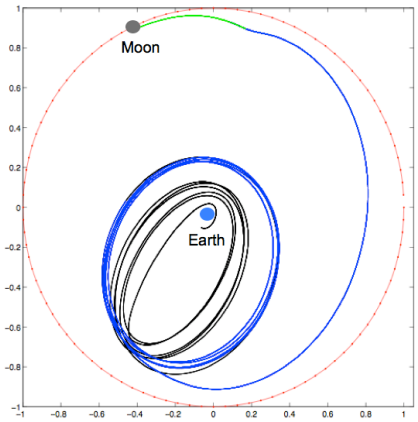


5-axis milling processes are used widely in various industries such as aerospace, die-mold and biomedical industries where surface quality and integrity is important and the production tolerances are very tight. Therefore, improving surface quality and integrity without sacrificing productivity is crucial 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, or 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. Validation tests demonstrate that presented model is computationally efficient and force predictions are in good agreement with the experimental data.

End to End Optimization of Low-Energy Lunar Missions

Citation: Grover, P.; Andersson, C., "End to End Optimization of Low-Energy Lunar Missions", *American Astronautical Society (AAS) American Institute of Aeronautics and Astronautics (AIAA)*, January 2012

Contacts: Piyush Grover



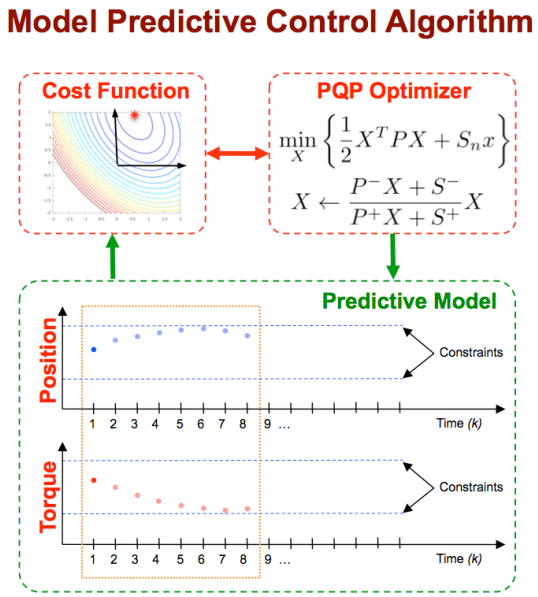
We describe a modular optimization framework for GTO-to-moon mission design using the planar circular restricted three-body problem (PCR3BP) model .The three-body resonant gravity assists and invariant manifolds in the planar restricted three-body problem are used as basic building blocks of this mission design. The mission is optimized by appropriately timed delta-Vs, which are obtained by a shooting method and a Gauss-Pseudospectral collocation method for different phases of the mission. Depending upon the initial and final orbits, the optimized missions consume between 10-15 % less fuel compared to a Hohmann transfer, while taking around 4 to 5 months of travel time.

A Parallel Quadratic Programming Algorithm for Model Predictive Control

Citation: Brand, M.; Shilpiekandula, V.; Bortoff, S.A., "A Parallel Quadratic Programming Algorithm for Model Predictive Control", *International Federation of Automatic Control (IFAC)*, Vol. 18, Part 1, August 2011

Contacts: Matthew E. Brand, Scott A. Bortoff

In this paper, an iterative multiplicative algorithm is proposed for the fast solution of quadratic programming (QP) problems that arise in the real-time implementation of Model Predictive Control (MPC). The proposed algorithm--Parallel Quadratic Programming (PQP)--is amenable to fine-grained parallelization. Conditions on the convergence of the PQP algorithm are given and proved. Due to its extreme simplicity, even serial implementations offer considerable speed advantages. To demonstrate, PQP is applied to several simulation examples, including a stand-alone QP problem and two MPC examples. When implemented in MATLAB using single-thread computations, numerical simulations of PQP demonstrate a 5 - 10x speed-up compared to the MATLAB active-set based QP solver quadprog. A parallel implementation would offer a further speed-up, linear in the number of parallel processors.

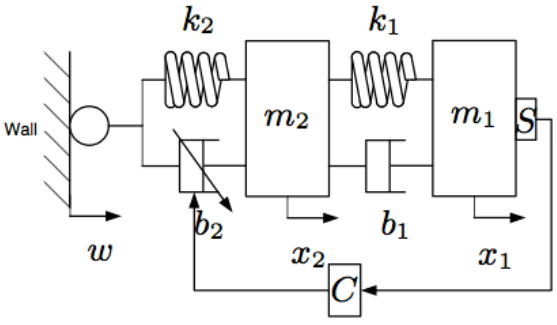


Nonlinear Control Design for Semi-Active Vibration Reduction System

Citation: Wang, Y.; Utsunomiya, K.; Bortoff, S.A,, "Nonlinear Control Design for a Semi-active Vibration Reduction System", *Chinese Control Conference (CCC)*, pp. 5833-5837, July 2011

Contacts: Yebin Wang, Scott A. Bortoff

This paper considers the control design for a vibration reduction system using semi-active actuators to improve the ride quality. The main challenges come from the nonlinear dynamics, limited control authority, and lack of performance-oriented nonlinear control design results. Two nonlinear controllers are proposed and compared to a conventional semi-active control. Simulation shows the proposed controls provide a good balance of metrics.



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.

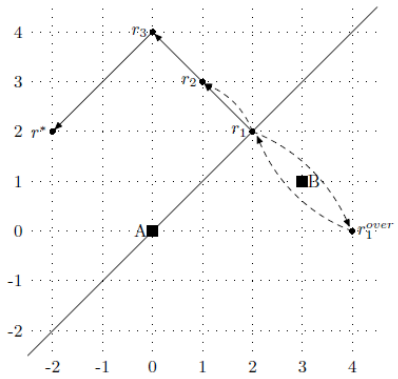
Recent Research

Divide & Concur and Difference-Map BP Decoders for LDPC Codes

Citation: Yedidia, J.S.; Wang, Y.; Draper, S.C., "Divide & Concur and Difference - Map BP Decoders for LDPC Codes", *Physics of Algorithms* , arXiv:1001.1730, August 2009

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.



t	r_t	$P_D(r_t)$	r_t^{over}	r_t^{conc}
1	$(2,2)$	$(3,1)$	$(4,0)$	$(2,2)$
2	$(1,3)$	$(3,1)$	$(5,-1)$	$(2,2)$
3	$(0,4)$	$(0,0)$	$(0,-4)$	$(-2,-2)$
4	$(-2,2)$	$(0,0)$	$(2,-2)$	$(0,0)$
5	$(-2,2)$			

Cooperative Routing for Wireless Networks Using Mutual-Information Accumulation

Citation: Draper, S.C.; Liu, L.; Molisch, A.F.; Yedidia, J.S., "Cooperative Routing for Wireless Networks using Mutual-Information Accumulation", *The Smithsonian/NASA Astrophysics Data System*, eprint arXiv:0908.3886, August 2009

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.

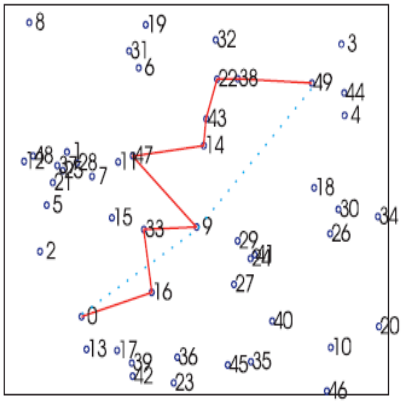


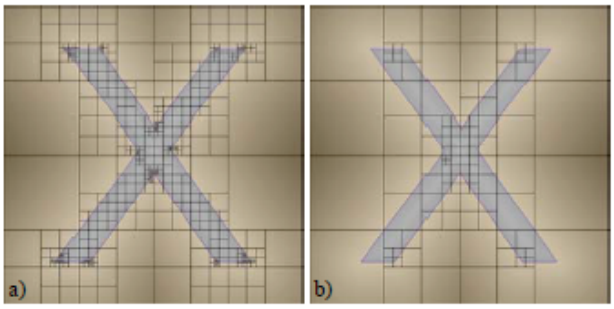
Image and Video Retargeting by Darting

Citation: Brand, M., "Image and Video Retargetting by Darting", *Image Analysis and Recognition*, ISBN: 978 3 642 02610 2, Vol. 5627/2009, pp. 33-42, July 2009
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.

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



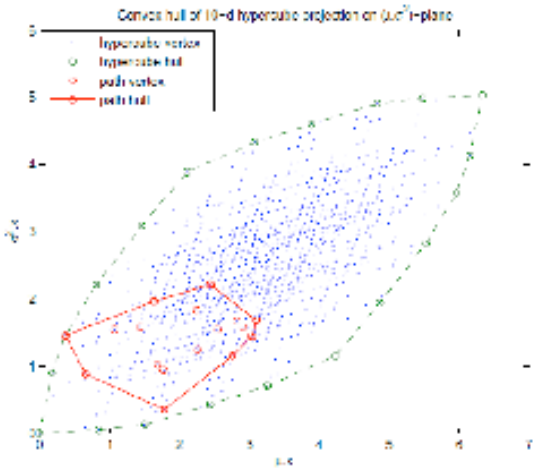
Distance fields provide an implicit representation of shape that has advantages in many application areas; in this overview, we focus on their use in digital design. Distance fields have been used in Computer Aided Design since the 1970's (e.g. for computing offset surfaces and for generating rounds 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.

Stochastic Shortest Paths Via Quasi-convex Maximization

Citation: Nikolova, E.; Kelner, J.; Brand, M.; Mitzenmacher,M., "Stochastic Shortest Paths Via Quasi-convex Maximization", *ESA 2006*, ISBN:3-540-38875-3, Pp 552 - 563 , September 2006

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.



Parallel Quadratic Programming for Image Processing

Citation: Brand, M.; Chen, D., "Parallel Quadratic Programming for Image Processing", *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2011.6116089, pps. 2261-2264, September 2011

Contacts: Matthew E. Brand

Many image processing and computer vision problems can be solved as quadratic programs in the non-negative cone. This paper develops a provably convergent multiplicative update that has a simple form and is amenable to fine-grained data parallelism. Classic algorithms for deblurring, matrix factorization, and tomography are recovered as special cases. This paper also demonstrates applications to super-resolution, labeling and segmentation.

(a) 4 of 30 low-res images (b) reconstructed high-res image

Fig. 1. Super-resolution example: a) 4 of 30 low-res images; b) the reconstruction high-res image obtained by solving SR model (6) with the multiplicative update.