Mitsubishi Electric Research Laboratories (MERL)

Annual Report

April 2015 through March 2016

TR2016-00

(Published May 2016)

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.

201 Broadway, Cambridge, Massachusetts 02139
617.621.7500

Production:

Marissa Deegan, Karen Dickie, Richard C. Waters

Table of Contents

Mitsubishi Electric Research Laboratories 1
Awards and Commendations 7
Technical Staff 9
Publications 23
Research 39
- Electronics & Communications 41
- Multimedia 49
- Data Analytics 57
- Spatial Analysis 65
- Mechatronics 73
- Algorithms 81

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 optimization, control and signal processing.

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 universities.

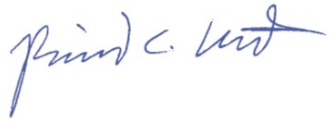
MERL focuses on five principal technology sectors:

Electronics & Communications - featuring wireless & optical signal processing technology.
Multimedia – featuring speech interfaces, video (de)coding & compressive sensing.
Data Analytics – featuring simulation, planning and optimization.
Computer Vision – featuring 3D imaging processing algorithms.
Mechatronics – featuring advanced control of electro-mechanical systems.

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

A Business Innovation group focuses on changes in Mitsubishi Electrics approach to business.

This annual report is a snapshot of MERL's web site. For additional and updated information please visit "www.merl.com".



Richard C. Waters
President, MERL

MERL Organization

MERL is organized as seven 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 six members of the top management team work closely together, guiding all aspects of MERL's operation.

- Dr. Richard C. (Dick) Waters (President & CEO)
  - Dr. Takuji Magara (EVP & CFO) —— Finance & Liaisons
  - Administration, Human Resources, & Information Technology
  - Dr. Jinyun Zhang, IEEE Fellow (VP & Director)
    - BI: Business Innovation Group - Dr. Jinyun Zhang
    - EC: Electronics & Communications Group - Dr. Phil Orlik
    - MM: Multimedia Group - Dr. Anthony Vetro, IEEE Fellow
    - DA: Data Analytics Group - Dr. Daniel Nikovski
  - Dr. Joseph Katz, IEEE & OSA Fellow (VP & Director)
    - CV: Computer Vision Group - Dr. Alan Sullivan
    - ME: Mechatronics Group - Dr. Jay Thornton
    - AL: Algorithm Group - Dr. Joseph Katz, IEEE & OSA Fellow
  - Dr. Anthony Vetro, IEEE Fellow (Deputy Director) —— Patents

Richard C. (Dick) Waters *Ph.D., MIT, 1978*
President, CEO & MERL Fellow, ACM Distinguished Scientist

Dick Waters received his Ph.D. in artificial intelligence (AI). For 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. At MERL, his research centered on multi-user interactive environments for work, learning, and play. In 1999, he became CEO of MERL as a whole.

Takuji Magara *Ph.D., Tokyo Institute of Technology, 1992*
Executive Vice President & CFO

Takuji Magara joined Mitsubishi Electric's Nagoya Works in 1982 where he developed Electric Discharge Machine (EDM) systems, eventually becoming the Senior Manager of EDM Systems Department. In 2008, he then moved to the Advanced Technology Research Center (ATC) as Senior Manager of the Laser and Electric Machining Department. He rose to General Manager of the Electro-Mechanical Technology Laboratory at ATC, before coming to MERL in 2015.

Joseph Katz *Ph.D., California Institute of Technology, 1981*
Vice President & Director, IEEE Fellow, OSA Fellow

After leading research in optical communications and optoelectronic devices & materials at Caltech's Jet Propulsion Laboratory for a number of years, Joseph 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, Director & MERL Fellow, IEEE Fellow

Before joining MERL in 2001, Jinyun 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. She joined MERL's management in 2001. In recognition of her contributions to broadband wireless transmission and networking technology she became an IEEE Fellow in 2008.

Anthony Vetro *Ph.D., Polytechnic University, 2001*
Deputy Director IP & Multimedia Group Manager, IEEE Fellow

Anthony 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. He joined MERL top management in 2014.

Elizabeth Phillips *B.A., University of Massachusetts Amherst, 1988*
Manager, Human Resources & Administration

Elizabeth has over 25 years of human resources experience. For 12 years before joining MERL in 2014 she was the principal of a boutique human resources consulting firm in New England, which supported small to mid-size companies with all aspects of their employee related needs. Engagements included: on-site HR leadership, development of talent management programs, management of total rewards programs, facilitation of employee development programs, and HR compliance and administration.

Mitsubishi Electric

One of the world's largest companies, Mitsubishi Electric Corporation has $41 billion in annual sales, $2.8 billion in operating profits (in the year ending in March 2016) and more than 130,000 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 it was founded 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 MI & Mason OH)
Alternators, Ignition Coils, Automotive Electronics

Mitsubishi Electric Power Products, Inc. (Pittsburgh PA & Memphis TN)
Power Transmission Products, Rail Transportation Systems

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

Mitsubishi Electric Automation, Inc. (Chicago IL)
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 MA)
  Communications, Multimedia, Data Analytics, Imaging and Mechatronics Technologies
- **Mitsubishi Electric R&D Centre Europe, B.V.** (Rennes, France & Edinburgh, Scotland)
  Communications, Energy & Environmental Technologies
- **Mitsubishi Electric (China) Co, Ltd.** (Shanghai, China)
  Materials Science

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 who are Fellows of technical societies. The second is best paper and other 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. Andrew Knyazev - Fellow, Society for Industrial and Applied Mathematics
Dr. Keisuke Kojima - 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

Zhu, L.; Teo, K.H.; Gao, Q., "Dynamic On-Resistance and Tunneling Based De-Trapping in GaN HEMT", IEEE International Conference on Electron Devices and Solid-State Circuits (EDSSC) June 2015 received the "Best Student Poster Award" at the conference.

MERL achieved the world's best results in the benchmark scene labelling competition sponsored by Daimler, see Liu, M.-Y.; Lin, A.; Ramalingam, S.; Tuzel, C.O., "Layered Interpretation of Street View Images", Robotics: Science and Systems Conference (RSS), July 2015.

MERL's Speech and Audio Team, in collaboration with SRI, ranked 2nd out of 26 teams in the third 'CHiME' Speech Separation and Recognition Challenge.

MERL's researcher Petros Boufounos was a recipient of the 2015 IEEE Signal Processing Society Best Paper Award for the paper that he co-authored with Mark A. Davenport, Michael B. Wakin and Richard G. Baraniuk on "Signal Processing with Compressive Measurements" which was published in the April 2010 issue of IEEE Journal of Selected Topics in Signal Processing.

It is also worthy of note that MERL had a large number of papers in some of the most selective and prestigious conferences related to MERL's areas of research: 12 in the IEEE International Conference on Acoustics, Speech & Signal Processing (ICASSP), 10 in the American Control Conference (ACC), and 5 in the Optical Fiber Communication (OFC) Conference including one "top scored" paper. These results make MERL one of the most highly represented research labs in the world at these conferences, with output greater than labs that are much larger.

Technical Staff

By providing a highly productive, collaborative environment, MERL believes that it is more than the sum of its parts; however, there is no question that its only important parts 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 later in this report.

Valeria Arlunno *Ph.D., Technical University of Denmark (DTU), 2013*
Visiting Member Research Staff

Valeria's interests are in applications of digital signal processing for coherent optical communications. She is particularly interested in advanced modulation formats, equalization schemes and demodulation-decoding cooperation. Her PhD focused on advance equalization techniques for digital coherent optical receivers.

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 Manager and in various System/Network Support roles.

Mouhacine Benosman *Ph.D., Ecole Centrale de Nantes, 2002*
Senior 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.

Karl Berntorp *Ph.D., Lund University, 2014*
Visiting Member Research Staff

Karl's doctoral research addressed development of particle-filtering methods, and sensor fusion and optimal control applied to vehicles and robots. His research interests are in nonlinear estimation and control, path planning, motion control, and their applications to automotive, robotics, and aerospace systems.

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*
Senior Principal Member Research Staff

After completing his doctoral studies, Petros joined Rice University as a Postdoctoral associate until Jan. 2009, when he joined MERL. Since joining MERL, Petros has contributed in areas such as high-speed video acquisition, ultrasonic imaging, and privacy-preserving secure embeddings. His interests include signal acquisition and processing, signal representations and compressive sensing. He is also a visiting scholar at Rice University and an Associate Editor of IEEE Signal Processing Letters.

Matthew E. Brand *Ph.D., Northwestern University, 1994*
MERL Fellow

Matt develops and analyzes optimization algorithms for problems in logistics, control, perception, data-mining, and learning. Notable results include methods for parallel solution of quadratic programs, recomposing photos by re-arranging pixels, nonlinear dimensionality reduction, online singular value decomposition, 3D shape-from-video, and learning concise models of data.

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

At MIT, Dan 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.

Esra Cansizoglu *Ph.D., Northeastern University, 2015*
Visiting Member Research Staff

Prior to joining MERL, Esra worked on biomedical image processing and machine learning at the Cognitive Systems Laboratory, Northeastern University. Her dissertation was about retinal vasculature extraction, disease classification and analysis of inter-expert variability. Her current research interests include 3D reconstruction and multi-view geometry.

Robert A. Cohen *Ph.D., Rensselaer Polytechnic Institute, 2007*
Principal Member Research Staff

Prior to getting his Ph.D., Bob 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 video coding standards.

Claus Danielson *Ph.D., University of California, Berkeley, 2008*
Member Research Staff

Claus' research interests are in model predictive control, constrained control, and networked control systems. His doctoral research was focused on exploiting symmetry in large-scale control and optimization problems.

Stefano Di Cairano *Ph.D., University of Siena, 2008*
Senior Principal Member Research Staff,
Optimization-Based Control Team Leader

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.

Amir-massoud Farahmand *Ph.D., University of Alberta, 2011*
Member Research Staff

Amir-massoud's research interests are in reinforcement learning, sequential decision-making under uncertainty, and nonparametric methods in machine learning and statistics. His focus at MERL is on developing theoretically-sound algorithms for challenging industrial problems. Before joining MERL in December 2014, he held postdoctoral fellowships at Carnegie Mellon University and McGill University.

Chen Feng *Ph.D., University of Michigan, 2015*
Visiting Member Research Staff

Chen worked on computer vision and robotics for construction automation during his Ph.D. research, including camera pose estimation and 3D scene understanding. At MERL, he has worked on SLAM using points and planes, and invented a fast plane extraction algorithm. His research interests include computer vision, photogrammetry, robotics, machine learning, and augmented reality.

Guy Gold
Systems & Network Administrator

Guy Has 12 years of experience with Computing and Networking systems, with special interest in Unix/Linux systems. Previous to working at MERL, Guy worked as a Web Farm admin at Sutra Inc (Airline ticketing systems), as an IT consultant, as Network operations tech at Presbyterian Healthcare services (NM), and for Bezeq's (Israel) core Business IP/VPN support center.

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

At WPI, Abraham researched 3D ultrasound imaging, particularly the reconstruction of 3D volumes from sequences of 2D images. At 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*
Principal 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*
Senior 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.

Akiko Hasegawa *M.Eng.,Waseda University, 2010*
Visiting Member Research Staff

In 2010 Akiko joined Mitsubishi Electric Corporation where she worked on designing antennas of airplanes and ships as a mechanical engineer for the first three years. She then worked on Electro-Optical (EO)/Infrared (IR) sensor systems for airplanes as a system engineer and a project manager.

John R. Hershey *Ph.D., University of California San Diego, 2004*
Senior Principal Member Research Staff & 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.

Chiori Hori *Ph.D., Tokyo Institute of Technology, 2002*
Visiting Member Research Staff

Prior to joining MERL in 2015, Chiori spent 8 years at Japan's National Institute of Information and Communication Technology (NICT). Prior to that, she researched at Carnegie Mellon and the NTT Communication Science Laboratories. She was the research manager of Spoken Language Communication Laboratory of NICT from 2012. Chiori's work has focused on speech summarization/translation, spoken dialog technologies, and standardization of communication protocols for speech interfaces at ITU-T and ASTAP.

Takaaki Hori *Ph.D., Yamagata University, 1999*
Senior Principal Member Research Staff

Before joining MERL in 2015, Takaaki spent 15 years doing research on speech and language technology at Nippon Telegraph, and Telephone (NTT) in Japan. His work includes studies on speech recognition algorithms using weighted finite-state transducers (WFSTs), efficient search algorithms for spoken document retrieval, spoken language understanding, and automatic meeting analysis.

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, Data Mining, ZigBee, reliable wireless protocols and web development. Prior to joining MERL Fred worked at IPL Systems.

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.

Uros Kalabic *Ph.D., Universityof Michigan, 2015*
Member Research Staff

Uros works on advancements in the theory of predictive control and constrained control, as well as its applications to the control of automotive and aerospace systems. His dissertation dealt with theoretical developments and practical applications of reference governors. Prior to joining MERL, Uros interned at MERL and at Ford Motor Company.

Ulugbek Kamilov *Ph.D., Ecole Polytechnique Federale de Lausanne, 2015*
Member Research Staff

Ulugbek's PhD research developed statistical estimation techniques for solving inverse problems in biomicroscopy. His interests include signal acquisition and processing, signal representations and resolution of inverse problems. Prior to joining to MERL, Ulugbek was an exchange student at Carnegie Mellon University in 2007, a visiting student at MIT in 2010, and a visiting student researcher at Stanford University.

Kyeong Jin Kim *Ph.D., University of California Santa Barbara, 2000*
Senior Principal Member Research Staff

Kyeong Jin's research interests include transceiver design, performance analysis of spectrum sharing systems, design of cooperative communication systems. Since joining MERL, he has contributed in areas such as reliable communcations and E-WLAN system. Currently he is an Associate Editor of IEEE Communications Letters.

Andrew Knyazev *Ph.D., Inst of Numerical Math, Soviet Acad of Sci, 1985*
Distinguished Member Research Staff, Professor Emeritus University of Colorado Denver, Society for Industrial and Applied Mathematics (SIAM) Fellow

During his 30 years in the academy, Andrew contributed to numerical analysis of partial differential equations and computational linear algebra, with emphasis on eigenvalue problems. His focus at MERL is on novel algorithms for image & video processing, data sciences, optimal control, material sciences, and numerical simulation of complex phenomena.

Toshiaki Koike-Akino *Ph.D., Kyoto University, 2005*
Senior Principal 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 in 2008 and 2009.

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&T/Lucent Bell Laboratories and other major US companies, Keisuke worked on R&D of semiconductor lasers and optical systems as a technical staff 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.

Emil Laftchiev *Ph.D., Pennsylvania State University, 2015*
Member Research Staff

Emil's research interests are in the identification of efficient storage methods using dimension reducing data features. The purpose of this research is to enable rapid continuous localization within the data. Prior to joining MERL Emil served as a Distinguished Teaching Fellow for the College of Engineering at the Pennsylvania State University.

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

Jonathan completed his B.Sc. and M.Sc. in Mathematics at the Ecole Normale Supérieure in Paris, France. Before joining MERL in 2011, he spent several years in Beijing and Tokyo. In Tokyo he 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.

Teng-Yok Lee *Ph.D., Ohio State University, 2011*
Member Research Staff

Teng-Yok's research interests cover 2 aspects: Visual (computer graphics, visualization, and image processing) and Computing (GPGPU, high performance and cloud computing). Before joining MERL in 2015, he worked at Amazon Web Service (AWS) to optimize HPC applications on AWS cloud computing environments. His PhD studies were about the visualization of scientific simulation result, especially time-varying and Computational Fluid Dynamics (CFD) data.

Chungwei Lin *Ph.D., Columbia University, 2008*
Visiting Member Research Staff

Before joining MERL as a visiting member research staff, Chungwei was a postdoctoral researcher in the Physics Department of the University of Texas at Austin. He has worked on transition metal oxides including manganites and titanates. His particular interest is the use of doping/interface to control optical, thermal, and transport properties. In addition to oxides, he has worked on the theory of self-assembly, configuration interaction quantum impurity solvers, and the theory of photoemission spectroscopy.

Dehong Liu *Ph.D., Tsinghua University, 2002*
Principal 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 *Ph.D, University of Maryland College Park, 2012*
Principal 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,*
Principal Member Research Staff

Prior to joining MERL, Rui was a Senior 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.

Hassan Mansour, *Ph.D. University of British Columbia, 2009*
Member Research Staff

Hassan's research interests are in the areas of video compression, video transmission and compressed sensing. His PhD research developed resource allocation schemes for the transmission of scalable video content over bandwidth constrained wireless networks. His postdoctoral work developed adaptive sparse recovery algorithms for correlated signals from compressive measurements.

Tim K. Marks *Ph.D., University of California San Diego, 2006*
Principal 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.

David S. Millar *Ph.D., University College London (UCL), 2011*
Principal Member Research Staff

Before joining MERL, David was a postdoctoral researcher at UCL, working on DSPs for coherent optical fiber transmission. Since then, he has been working on next generation systems and subsystems for the physical layer. He is particularly interested in advanced modulation formats, algorithms for equalization & carrier recovery, and reduced complexity transponders.

Francis Morales *B.S., Universidad APEC, 2007*
Systems & Network Administrator

Francis has been in the IT field since 2001 with experience in different IT industries with special interest in OSs, Networking and Security. Prior to joining MERL he worked 4 years in the healthcare IT field. Previous to that, he was the principal of a small Computer Service business in his home country.

Saleh Nabi *Ph.D., University of Alberta, 2014*
Visiting Member Research Staff

Saleh's research interests are analytical, numerical and similitude experimental modeling of fluid flow and heat transfer in complex systems. His ambition is to derive reduced order models for turbulent buoyancy-driven flows in confined regions to reduce the simulation run time by several orders of magnitude. Saleh's doctoral research mainly focused on environmental and architectural fluid mechanics applied to airflow modeling within the built environment with applications of novel and advanced HVAC systems.

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

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*
Electronics & Communications Group Manager

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.

Milutin Pajovic *Ph.D., Massachusetts Institute of Technology, 2014*
Member Research Staff

Milutin's doctoral thesis studied adaptive signal processing with deficient sample support using random matrix theory methods and considered adaptive sensor array processing, channel estimation and channel equalization as specific applications. His interests also include communications, statistical signal processing and machine learning.

Kieran Parsons *Ph.D., University of Bristol, UK, 1996*
Senior Principal Member Research Staff, Optical Team Leader

Kieran spent 12 years in Canada working at Nortel, BelAir Networks and AMCC on the system design of several wireless and optical technologies, including early work on electronic dispersion compensation for optical links. 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.

Hongtao Qiao *Ph.D., University of Maryland, 2014*
Visiting Member Research Staff

Prior to his PhD, Hongtao worked at Carrier Corporation developing advanced steady-state computer simulations for HVAC systems. During his PhD, he developed a comprehensive transient modeling framework for thermo-fluid systems to explore complex dynamic characteristics of vapor compression cycles.

Arvind U. Raghunathan *Ph.D., Carnegie Mellon University, 2004*
Senior 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*
Senior Principal 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.

Zafer Sahinoglu *Ph.D., New Jersey Institute of Technology, 2001*
MBA, Massachusetts Institute of Technology, 2013
Senior Principal Member Research Staff

Zafer worked at AT&T's Shannon Research Labs as a visiting researcher in 2001, and then joined Mitsubishi Electric Research Labs. He has contributed and served in officer positions in numerous international standards in the areas of smart-grid, electric vehicles, indoor localization, wireless communications and sensor networks; and written two books published by Cambridge University Press.

Alan Sullivan *Ph.D., University of California at Berkeley, 1993*
Distinguished Member Research Staff, Dynamic Systems and Computational Geometry Team Leader

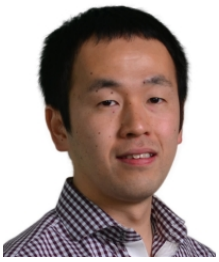
First at U.C. Berkeley, then at Lawrence Livermore National Laboratory, Alan studied interactions between ultra-high intensity femtosecond lasers and plasmas. Prior to joining MERL in 2007, he worked at a series of start-ups where he developed a novel volumetric 3D display technology. At MERL His research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

Hongbo Sun *Ph.D., Chongqing University, 1991*
Senior 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.



Yuichi Taguchi *Ph.D. The University of Tokyo, 2009*
Principal 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*
Senior Principal Member Research Staff, Power & Devices Team Leader

Koon Hoo was with Nortel for 15 years where he was actively involved in the research and implementation of 3G and 4G wireless systems. His work at MERL includes Cognitive Radio, Game Theory and Wireless Mesh for WiMAX and LTE systems. His current areas of research include Metamaterials, Power Amplifiers and Power Devices.

Jay E. Thornton *Ph.D., University of Michigan, 1982*
Spatial Analysis 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*
Senior 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.

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

Prior to his graduate studies, Oncel worked for 4 years on 3D game and simulation development. His doctoral work focused on statistical learning techniques on smooth manifolds and their applications to scene analysis. His research interests are in computer vision, machine learning, data mining, and computer graphics.

Jeroen van Baar *Ph.D., ETH Zurich, 2013*
Principal Member Research Staff

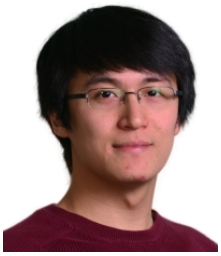
Jeroen came to MERL in 1997 as intern, and was subsequently hired as research associate. He temporarily left MERL to pursue a Ph.D. and returned early 2013. At MERL he has made contributions in the areas of computer graphics, computer vision and computational photography. His interests include 3D reconstruction, medical imaging, GP-GPU for computational photography and computer vision.

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

Gene graduated cum laude with distinction in Intellectual Property law. In addition, he 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*
Principal Member Research Staff

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



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

Prior to joining MERL, Yebin worked on process control, software development and management, and nonlinear estimation theory for over ten years. Yebin's research interests include nonlinear estimation/control theory and applications, optimal control, adaptive/learning systems, modeling and control of complex systems.

Shinji Watanabe *Ph.D., Waseda University, 2006*
Senior Principal 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.

Avishai Weiss *Ph.D., University of Michigan, 2013*
Member Research Staff

Avishai's doctoral research was on spacecraft orbital and attitude control. Prior to the University of Michigan, he studied at Stanford University, where he received a B.S. in Electrical Engineering and an M.S. in Aeronautics and Astronautics. Avishai's interests are in constrained control, model predictive control, and time-varying systems.

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

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 was voted one of the 50 most important people in computer network security by Network World magazine.

Publications

The following lists the major publications by members of the MERL staff during the period of this report. 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.

Jones, M.J.; Nikovski, D.N.; Imamura, M.; Hirata, T., **"Exemplar Learning for Extremely Efficient Anomaly Detection in Real-Valued Time Series"**, *Journal of Data Mining and Knowledge Discovery*, DOI: 10.1007/s10618-015-0449-3, ISSN: 1573-756X, pp. 1-28, March 2016 (TR2016-027)

Kamilov, U.S.; Mansour, H., **"Learning Optimal Nonlinearities for Iterative Thresholding Algorithms"**, *IEEE Signal Processing Letters*, DOI: 10.1109/LSP.2016.2548245, ISSN: 1070-9908, Vol. 23, pp. 747-751, March 2016 (TR2016-039)

Cohen, R.A.; Tian, D.; Vetro, A., **"Point Cloud Attribute Compression Using 3-D Intra Prediction and Shape-Adaptive Transforms"**, *Data Compression Conference (DCC)*, March 2016 (TR2016-023)

Mansour, H.; Saab, R., **"Recovery Analysis for Weighted '1 Minimization Using the Null Space Property"**, *Applied and Computational Harmonic Analysis*, DOI: 10.1016/j.acha.2015.10.005, March 2016 (TR2016-024)

Vesely, K.; Watanabe, S.; Zmolikova, K.; Karafiat, M.; Burget, L.; Cernocky, J.H., **"Sequence Summarizing Neural Network for Speaker Adaptation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472692, pp. 5315-5319, March 2016 (TR2016-001)

Arlunno, V.; Millar, D.S.; Koike-Akino, T.; Pajovic, M.; Kojima, K.; Parsons, K., **"Reduced-Complexity Blind Chromatic Dispersion Estimation for Digital Coherent Systems"**, *Optical Fiber Communication Conference and Exposition (OFC)*, DOI: 10.1364/OFC.2016.Th2A.38, ISBN: 978-943580-07-1, March 2016 (TR2016-017)

Koike-Akino, T.; Millar, D.S.; Kojima, K.; Parsons, K., **"GMI-Maximizing Constellation Design with Grassmann Projection for Parametric Shaping"**, *Optical Fiber Communication Conference and Exposition (OFC)*, DOI: 10.1364/OFC.2016.M2A.4, ISBN: 978-1-943580-07-1, March 2016 (TR2016-015)

Kojima, K.; Koike-Akino, T.; Millar, D.S.; Pajovic, M.; Parsons, K.; Yoshida, T., **"Investigation of Low Code Rate DP-8PSK as an Alternative to DP-QPSK"**, *Optical Fiber Communication Conference and Exposition (OFC)*, DOI: 10.1364/OFC.2016.Th1D.2, ISBN: 978-1-843580-07-1, March 2016 (TR2016-016)

Xiao, X.; Watanabe, S.; Erdogan, H.; Lu, L.; Hershey, J.R.; Seltzer, M.; Chen, G.; Zhang, Y.; Mandel, M.; Yu, D., **"Deep Beamforming Networks for Multi-Channel Speech Recognition"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472778, pp. 5745-5749, March 2016 (TR2016-002)

Hershey, J.R.; Chen, Z.; Le Roux, J.; Watanabe, S., **"Deep Clustering: Discriminative Embeddings for Segmentation and Separation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7471631, pp. 31-35, March 2016 (TR2016-003)

Zhang, Z.; Liu, D.; Aeron, S.; Vetro, A., **"An Online Tensor Robust PCA Algorithm for Sequential 2D Data"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472114, pp. 2434-2438, March 2016 (TR2016-004)

Kao, J.-Y.; Tian, D.; Mansour, H.; Ortega, A.; Vetro, A., **"Geometric-Guided Label Propagation for Moving Object Detection"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.747933, pp. 1531-1535, March 2016 (TR2016-005)

Mansour, H.; Kamilov, U.S., **"Multipath Removal by Online Blind Deconvolution in Through-the-Wall-Imaging"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472249, pp. 3106-3110, March 2016 (TR2016-006)

Kamilov, U.S., **"Parallel Proximal Methods for Total Variation Minimization"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.74772568, pp. 4697-4701, March 2016 (TR2016-007)

Wisdom, S.; Hershey, J.R.; Le Roux, J.; Watanabe, S., **"Deep Unfolding for Multichannel Source Separation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7471649, pp. 121-125, March 2016 (TR2016-008)

Castorena, J.; Kamilov, U.S.; Boufounos, P.T., **"Autocalibration of LIDAR and Optical Cameras via Edge Alignment"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472200, pp. 2862-2866, March 2016 (TR2016-009)

Valsesia, D.; Boufounos, P.T., **"Universal Encoding of Multispectral Images"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472519, pp. 4453-4457, March 2016 (TR2016-010)

Hori, T.; Hori, C.; Watanabe, S.; Hershey, J.R., **"Minimum Word Error Training of Long Short-Term Memory Recurrent Neural Network Language Models for Speech Recognition"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472827, pp. 5990-5994, March 2016 (TR2016-011)

Suryaprakash, R.T.; Pajovic, M.; Kim, K.J.; Orlik, P.V., **"Millimeter Wave Communications Channel Estimation via Bayesian Group Sparse Recovery"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7472309, pp. 3406-3410, March 2016 (TR2016-012)

Koike-Akino, T.; Kojima, K.; Millar, D.S.; Parsons, K.; Yoshida, T.; Sugihara, T., **"Pareto-Efficient Set of Modulation and Coding Based on RGMI in Nonlinear Fiber Transmissions"**, *Optical Fiber Communication Conference and Exposition (OFC)*, DOI: 10.1364/OFC.2016.Th1D.4, ISBN: 978-1-943580-07-1, March 2016 (TR2016-013)

Paskov, M.; Millar, D.S.; Parsons, K., **"A Fully-Blind Fractionally-Oversampled Frequency Domain Adaptive Equalizer"**, *Optical Fiber Communication Conference and Exposition (OFC)*, DOI: 10.1364/OFC.2016.Th2A.33, ISBN: 978-1-943580-07-1, March 2016 (TR2016-014)

Chung, S.; Ma, R.; Teo, K.H., **"Design Considerations on Wideband Envelope Termination for High Efficiency RF Power Amplifiers"**, *Electronics Letters*, DOI: 10.1049/el.2015.4328, ISSN: 0013-5194, Vol. 52, pp. 460-462, March 2016 (TR2016-026)

Millar, D.S.; Koike-Akino, T.; Kojima, K.; Pajovic, M.; Parsons, K.; Paskov, M.; Maher, R.; Lavery, D.; Alvarado, A.; Thomsen, B.C.; Savory, S.J.; Bayvel, P., **"Design of a 1 Tb/s Superchannel Coherent Receiver"**, *Journal of Lightwave Technology*, DOI: 10.1109/JLT.2016.2519260, ISSN: 0733-8724, Vol. 34, pp. 1453-1463, March 2016 (TR2016-029)

Liu, M.-Y.; Mallya, A.; Tuzel, C.O.; Chen, X., **"Unsupervised Network Pretraining via Encoding Human Design"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, DOI: 10.1109/WACV.2016.7477698, pp. 1-9, March 2016 (TR2016-022)

Farahmand, A.-M.; Nikovski, D.N.; Igarashi, Y.; Konaka, H., **"Truncated Approximate Dynamic Programming with Task-Dependent Terminal Value"**, *Association for the Advancement of Artificial Intelligence (AAAI)*, pp. 3123-3129, February 2016 (TR2016-020)

Basciftci, Y.O.; Wang, Y.; Ishwar, P., **"On Privacy-Utility Tradeoffs for Constrained Data Release Mechanisms"**, *IEEE Information Theory and Applications Workshop (ITA)*, February 2016 (TR2016-019)

Wang, B.; Long, J.; Teo, K.H., **"Multi-Channel Capacitive Sensor Arrays"**, *Sensors Journal*, DOI: 10.3390/s16020150, Vol. 16, January 2016 (TR2016-021)

Laughman, C.R.; Nabi, S.; Grover, P., **"A Numerical Study of Refrigerant Dispersion in Single and Multiple Connected Spaces"**, *ASHRAE Winter Conference*, January 2016 (TR2016-018)

Koike-Akino, T.; Millar, D.S.; Kojima, K.; Parsons, K.; Miyata, Y.; Sugihara, K.; Matsumoto, W., **"Iteration-Aware LDPC Code Design for Low-Power Optical Communications"**, *IEEE/OSA Journal of Lightwave Technology*, DOI: 10.1109/JLT.2015.2477881, ISSN: 0733-8724, Vol. 34, pp. 573-581, January 2016 (TR2016-028)

Kanagawa, H.; Tachioka, Y.; Watanabe, S.; Ishii, J., **"Feature-Space Structural MAPLR with Regression Tree-Based Multiple Transformation Matrices for DNN"**, *Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA)*, DOI: 10.1109/APSIPA.2015.7415425, pp. 86-92, December 2015 (TR2015-150)

Danielson, C.; Bauer, S., **"Numerical Decomposition of Symmetric Linear Systems"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC.2015.7502510, ISBN: 978-1-4799-7884-7, pp. 2061-2066, December 2015 (TR2015-144)

Guay, M.; Burns, D.J., **"A Proportional Integral Extremum-Seeking Control Approach for Discrete-Time Nonlinear Systems"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC.2015.7403314, ISBN: 978-1-4799-7884-7, pp. 6948-6953, December 2015 (TR2015-146)

Wang, Z.; Sun, H.; Nikovski, D.N., **"Static Voltage Stability Detection Using Local Measurement for Microgrids in a Power Distribution Network"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC.2015.7402708, ISBN: 978-1-4799-7884-7, pp. 3254-3259, December 2015 (TR2015-147)

Kvasnica, M.; Takacs, B.; Holaza, J.; Di Cairano, S., **"On Region-Free Explicit Model Predictive Control"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC.2015.7402788, ISBN: 978-1-4799-7884-7, pp. 3669-3674, December 2015 (TR2015-148)

Knyazev, A.; Zhu, P.; Di Cairano, S., **"Explicit Model Predictive Control Accuracy Analysis"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC.2015.7402565, ISBN: 978-1-4799-7884-7, pp. 2389-2394, December 2015 (TR2015-149)

Danielson, C.; Di Cairano, S., **"Reduced Complexity Control Design for Symmetric LPV Systems"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC.2015.7402088, ISBN: 978-1-4799-7884-7, pp. 72-77, December 2015 (TR2015-145)

Knyazev, A.; Malyshev, A., **"Conjugate Gradient Acceleration of Non-Linear Smoothing Filters"**, *IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, DOI: 10.1109/GlobalSIP.2015.7418194, pp. 245-249, December 2015 (TR2015-143)

Knyazev, A., **"Edge-Enhancing Filters with Negative Weights"**, *IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, DOI: 10.1109/GlobalSIP.2015.7418197, pp. 260-264, December 2015 (TR2015-142)

Gadde, A.; Knyazev, A.; Tian, D.; Mansour, H., **"Guided Signal Reconstruction with Application to Image Magnification"**, *IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, DOI: 10.1109/GlobalSIP.2015.7418335, pp. 938-942, December 2015 (TR2015-141)

Hori, T.; Chen, Z.; Erdogan, H.; Hershey, J.R.; Le Roux, J.; Mitra, V.; Watanabe, S., **"The MERL/SRI System for the 3rd CHiME Challenge Using Beamforming, Robust Feature Extraction, and Advanced Speech Recognition"**, *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, DOI: 10.1109/ASRU.2015.7404833, pp. 475-481, December 2015 (TR2015-135)

Liu, D.; Kamilov, U.S.; Boufounos, P.T., **"Sparsity-Driven Distributed Array Imaging"**, *IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP)*, DOI: 10.1109/CAMSAP.2015.7383831, pp. 441-444, December 2015 (TR2015-140)

Moriya, T.; Shinozaki, T.; Watanabe, S.; Duh, K., **"Automation of System Building for State-of-the-Art Large Vocabulary Speech Recognition Using Evolution Strategy"**, *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, DOI: 10.1109/ASRU.2015.7404852, pp. 610-616, December 2015 (TR2015-137)

Barker, J.; Marxer, R.; Vincent, E.; Watanabe, S., **"The Third 'CHiME' Speech Separation and Recognition Challenge: Dataset, Task and Baselines"**, *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, DOI: 10.1109/ASRU.2015.75404837, pp. 504-511, December 2015 (TR2015-136)

Hsiao, R.; Ma, J.; Hartmann, W.; Karafiat, M.; Grezl, F.; Burget, L.; Szoke, I.; Cernocky, J.; Watanabe, S.; Chen, Z.; Mallidi, S.H.; Hermansky, H.; Tsakalidis, S.; Schwartz, R., **"Robust Speech Recognition in Unknown Reverberant and Noisy Conditions"**, *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, DOI: 10.1109/ARSU.2015.7404841, pp. 533-538, December 2015 (TR2015-138)

Handa, H.; Mansour, H.; Liu, D.; Kamilov, U.S., **"Extended Target Localization with Total-Variation Denoising in Through-the-Wall-Imaging"**, *IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP)*, DOI: 10.1109/CAMSAP.2015.7383832, pp. 445-448, December 2015 (TR2015-139)

Hori, C..; Hori, T.; Watanabe, S.; Hershey, J.R., **"Context Sensitive Spoken Language Understanding Using Role Dependent LSTM Layers"**, *NIPS Workshop on Machine Learning for Spoken Language Understanding and Interaction*, December 2015 (TR2015-134)

Bagnell, J.A.; Farahmand, A.-M., **"Learning Positive Functions in a Hilbert Space"**, *NIPS Workshop on Optimization for Machine Learning (OPT)*, December 2015 (TR2015-133)

Ma, R., **"Recent Advances in Power Encoding and GaN Switching Technologies for Digital Transmitters"**, *Asia-Pacific Microwave Conference (APMC)*, DOI: 10.1109/APMC.2015.7413427, ISBN: 978-1-4799-8765-8, Vol. 3, pp. 1-3, December 2015 (TR2015-131)

Pajovic, M.; Orlik, P.V.; Koike-Akino, T.; Kim, K.J.; Aikawa, H.; Hori, T., **"An Unsupervised Indoor Localization Method Based on Received Signal Strength (RSS) Measurements"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOCOM.2015.7417708, pp. 1-6, December 2015 (TR2015-129)

Guo, J.; Orlik, P.V.; Parsons, K.; Ishibashi, K.; Takita, D., **"Resource Aware Routing Protocol in Heterogeneous Wireless Machine-to-Machine Networks"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOCOM.2015.7417203, pp. 1-6, December 2015 (TR2015-127)

Koike-Akino, T.; Kim, K.J.; Orlik, P.V.; Pajovic, M., **"Universal Multi-Stage Precoding with Monomial Phase Rotation for Full-Diversity M2M Transmission"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOCOM.2015.7417467, pp. 1-7, December 2015 (TR2015-130)

Yeoh, P.L.; Yang, N.; Kim, K.J., **"Secrecy Outage Probability of Selective Relaying Wiretap Channels with Collaborative Eavesdropping"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOCOM.2015.7417082, pp. 1-6, December 2015 (TR2015-128)

Fujihashi, T.; Koike-Akino, T.; Watanabe, T.; Orlik, P.V., **"Compressive Sensing for Loss-Resilient Hybrid Wireless Video Transmission"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOCOM.2015.7417536, pp. 1-7, December 2015 (TR2015-132)

Di Cairano, S.; Kalabic, U.V.; Kolmanovsky, I.V., **"Reference Governor for Network Control Systems Subject to Variable Time-Delay"**, *Automatica (Journal of IFAC)*, DOI: 10.1016/j.automatica.2015.09.006, Vol. 62, pp. 77-86, December 2015 (TR2015-154)

Kim, T.; Wang, Y.; Sahinoglu, Z.; Wada, T.; Hara, S.; Qiao, W., **"Model-Based Condition Monitoring for Lithium-Ion Batteries"**, *Journal of Power Sources*, DOI: 10.1016/j.jpowsour.2015.03.184, Vol. 295, pp. 16-27, November 2015 (TR2015-055)

Fang, H.; Wang, Y., **"Health-Aware and User-Involved Battery Charging Management for Electric Vehicles Using Linear Quadratic Control"**, *ASME Dynamic Systems and Control Conference*, DOI: 10.1115/DECC2015-9921, Vol. 1, October 2015 (TR2015-022)

Tawara, N.; Ogawa, T.; Watanabe, S.; Nakamura, A.; Kobayashi, T., **"A Sampling-Based Speaker Clustering Using Utterance-Oriented Dirichlet Process Mixture Model and Its Evaluation on Large Scale Data"**, *APSIPA Transactions on Signal and Information*: *Processing*, DOI: 10.1017/ATSIP.2015.19, ISSN: 2048-7703, October 2015 (TR2015-153)

Wittenburg, K.B.; Pekhteryev, G., **"Multi-Dimensional Comparative Visualization for Patent Landscaping"**, *BusinessVis15, IEEE VIS Workshop*, October 2015 (TR2015-123)

Tian, D.; Kao, J.-Y.; Mansour, H.; Vetro, A., **"Graph Spectral Motion Segmentation Based on Motion Vanishing Point Analysis"**, *IEEE International Workshop on Multimedia Signal Processing (MMSP)*, DOI: 10.1109/MMSP.2015.7340869, pp. 1-6, October 2015 (TR2015-122)

Di Cairano, S.; Borrelli, F., **"Reference Tracking with Guaranteed Error Bound for Constrained Linear Systems"**, *IEEE Transactions on Automatic Control*, DOI: 10.1109/TAC.2015.2491738, ISSN: 0018-9286, Vol. PP, pp. 1, October 2015 (TR2015-124)

Harsham, B.A.; Watanabe, S.; Esenther, A.; Hershey, J.R.; Le Roux, J.; Luan, Y.; Nikovski, D.N.; Potluru, V.K., **"Driver Prediction to Improve Interaction with In-Vehicle HMI"**, *Workshop on DSP for In-Vehicle Systems and Safety*, October 2015 (TR2015-120)

Jiang, Y.; Wang, Y.; Bortoff, S.A.; Jiang, Z.-P., **"An Iterative Approach to the Optimal Co-Design of Linear Control Systems"**, *International Journal of Control*, DOI: 10.1080/00207179.2015.1091510, Vol. 89, pp. 680-690, October 2015 (TR2015-117)

Knyazev, A.; Malyshev, A., **"Continuation Model Predictive Control on Smooth Manifolds"**, *IFAC Workshop on Control Applications of Optimization (CAO)*, DOI: 10.1016/j.ifacol.2015.11.071, ISSN: 2405-8963, Vol. 48, pp. 126-131, October 2015 (TR2015-118)

Knyazev, A.; Malyshev, A., **"Efficient Particle Continuation Model Predictive Control"**, *IFAC Workshop on Control Applicaiton of Optimization*, DOI: 10.1016/j.ifacol.2015.11.102, Vol. 48, pp. 287-291, October 2015 (TR2015-119)

Koike-Akino, T.; Millar, D.S.; Kojima, K.; Parsons, K., **"Laser Frequency Drift Compensation with Han-Kobayashi Coding in Superchannel Nonlinear Optical Communications"**, *European Conference on Optical Communication (ECOC)*, DOI: 10.1109/ECOC.2015.7341865, pp. 1-3, September 2015 (TR2015-110)

Tian, D.; Mansour, H.; Vetro, A., **"Depth-Weighted Group-Wise Principal Component Analysis for Video Foreground/Background Separation"**, *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2015.7351400, pp. 3230-3234, September 2015 (TR2015-111)

Millar, D.S.; Lavery, D.; Maher, R.; Pajovic, M.; Koike-Akino, T.; Paskov, M.; Savory, S.J.; Bayvel, P.; Thomsen, B.C.; Kojima, K.; Parsons, K.; Alvarado, A., **"Detection of a 1Tb/s Superchannel with a Single Coherent Receiver"**, *European Conference on Optical Communication (ECOC)*, DOI: 10.1109/ECOC.2015.7341618, pp. 1-3, September 2015 (TR2015-108)

Pajovic, M.; Millar, D.S.; Koike-Akino, T.; Parsons, K.; Savory, S.J.; Maher, R.; Lavery, D.; Bayvel, P.; Paskov, M.; Alvarado, A.; Thomsen, B.C., **"Experimental Demonstration of Multi-Pilot Aided Carrier Phase Estimation for DP-64QAM and DP-256QAM"**, *European Conference on Optical Communication (ECOC)*, DOI: 10.1109/ECOC.2015.7341655, pp. 1-3, September 2015 (TR2015-104)

Kojima, K.; Koike-Akino, T., **"Novel Multimode Interference Devices for Wavelength Beam Splitting/Combining"**, *International Conference on Photonics in Switching (PS)*, DOI: 10.1109/PS.2015.7328944, pp. 34-36, September 2015 (TR2015-114)

Kojima, K.; Koike-Akino, T.; Millar, D.S.; Parsons, K., **"BICM Capacity Analysis of 8QAM-Alternative Modulation Formats in Nonlinear Fiber Transmission"**, *Tyrrhenian International Workshop on Digital Communications (TIWDC)*, DOI: 10.1109/TIWDC.2015.7323337, pp. 57-59, September 2015 (TR2015-103)

Laughman, C.R.; Qiao, H., **"Mass Conserving Models of Vapor Compression Cycles"**, *International Modelica Conference*, DOI: 10.3384/ecp15118759, ISSN: 1650-3686, ISBN: 978-91-7685-955-1, pp. 759-767, September 2015 (TR2015-109)

Knyazev, A.; Malyshev, A., **"Preconditioning for Continuation Model Predictive Control"**, *IFAC Conference on Nonlinear Model Predictive Control*, DOI: 10.1016/j.ifacol.2015.11.282, Vol. 48, pp. 191-196, September 2015 (TR2015-112)

Knyazev, A.; Malyshev, A., **"Accelerated Graph-Based Spectral Polynomial Filters"**, *IEEE International Workshop on Machine Learning for Signal Processing (MLSP)*, DOI: 10.1109/MLSP.2015.7324315, ISSN: 1551-2541, pp. 1-6, September 2015 (TR2015-106)

Di Cairano, S.; Goldsmith, A.M.; Bortoff, S.A., **"MPC and Spatial Governor for Multistage Precision Manufacturing Machines"**, *IFAC Conference on Nonlinear Model Predictive Control Conference (NMPC)*, DOI: doi:10.1016/j.ifacol.2015.11.311, Vol. 48, pp. 398-403, September 2015 (TR2015-107)

Xu, J.; Joshi, R.; Cohen, R.A., **"Overview of the Emerging HEVC Screen Content Coding Extension"**, *IEEE Transactions on Circuits and Systems for Video Technology*, DOI: 10.1109/TCSVT.2015.2478706, ISSN: 1051-8215, Vol. 26, pp. 50-62, September 2015 (TR2015-126)

Osechas, O.; Kim, K.J.; Parsons, K., **"Seamless Handover of Satellite Tracking Using Geographic Aiding"**, *International Trachnical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+)*, pp. 2369-2379, September 2015 (TR2015-116)

Tech, G.; Chen, Y.; Mueller, K.; Ohm, J.-R.; Vetro, A.; Wang, Y.-K., **"Overview of the Multiview and 3D Extensions of High Efficiency Video Coding"**, *IEEE Transactions on Circuits and Systems for Video Technology*, DOI: 10.1109/TCSVT.2015.2477935, ISSN: 1051-8215, Vol. 26, pp. 35-49, September 2015 (TR2015-125)

Jia, N.; Sanches, V.; Li, C-T.; Mansour, H., **"On Reducing the Effect of Silhouette Quality on Individual Gait Recogniton: A Feature Fusion Approach"**, *International Conference on the Biometrics Special Interest Group (BIOSIG)*, DOI: 10.1109/BIOSIG.2015.7314613, pp. 1-5, September 2015 (TR2015-155)

Korolko, N.; Sahinoglu, Z., **"Robust Optimization of EV Charging Schedules in Unregulated Electricity Markets"**, *IEEE Transactions on Smart Grid*, DOI: 10.1109/TSG.2015.2472597, ISSN: 1949-3053, Vol. PP, pp. 1, September 2015 (TR2015-121)

Soni, N.; Namboodiri, A.; Ramalingam, S.; Jawahar, C.V., **"Semantic Classification of Boundaries from an RGBD Image"**, *British Machine Vision Conference (BMVC)*, DOI: 10.5244/C.29.114, ISBN: 1-901725.53-7, pp. 114.1-114.12, September 2015 (TR2015-102)

Tachioka, Y.; Watanabe, S., **"Uncertainty Training and Decoding Methods of Deep Neural Networks Based on Stochastic Representation of Enhanced Features"**, *Interspeech*, ISBN: 978-1-5108-1790-6, Vol. 1 or 5, pp. 3541, September 2015 (TR2015-099)

Chen, Z.; Watanabe, S.; Erdogan, H.; Hershey, J.R., **"Speech Enhancement and Recognition Using Multi-Task Learning of Long Short-Term Memory Recurrent Neural Networks"**, *Interspeech*, ISBN: 978-1-5108-1790-6, Vol. 1 of 5, pp. 1278, September 2015 (TR2015-100)

Liu, K.; Guo, J.; Orlik, P.V.; Parsons, K.; Sawa, K., **"Battery Energy Management in Heterogeneous Wireless Machine-to-Machine Networks"**, *IEEE Vehicular Technology Conference (VTC-Fall)*, DOI: 10.1109.VTCFall.2015.7390853, pp. 1-5, September 2015 (TR2015-101)

Luan, Y.; Watanabe, S.; Harsham, B.A., **"Efficient Learning for Spoken Language Understanding Tasks with Word Embedding Based Pre-Training"**, *Interspeech*, ISBN: 978-1-5108-1790-6, Vol. 1 or 5, pp. 1398-1402, September 2015 (TR2015-097)

Abdelaziz, A.H.; Watanabe, S.; Hershey, J.R.; Vincent, E.; Kolossa, D., **"Uncertainty Propagation Through Deep Neural Networks"**, *Interspeech*, ISBN: 978-1-5108-1790-6, Vol. 1 or 5, pp. 3561, September 2015 (TR2015-098)

Liu, D.; Lu, D., **"Off-the-Grid Compressive Sensing for Broken-Rotor-Bar Fault Detection in Squirrel-Cage Induction Motors"**, *IFAC Symposium on Fault Detection, Supervision and Safety for Technical Processes (SAFEPROCESS)*, DOI: 10.1016/j.ifacol.2015.09.729, Vol. 48, pp. 1451-1456, September 2015 (TR2015-096)

Ma, R., **"A Review of Recent Development on Digital Transmitters with Integrated GaN Switch-Mode Amplifiers"**, *IEEE International Symposium on Radio-Frequency Integration Technology (RFIT)*, DOI: 10.1109/RFIT.2015.7377891, pp. 73-75, August 2015 (TR2015-115)

Weninger, F.J.; Erdogan, H.; Watanabe, S.; Vincent, E.; Le Roux, J.; Hershey, J.R.; Schuller, B.W., **"Speech Enhancement with LSTM Recurrent Neural Networks and Its Application to Noise-Robust ASR"**, *Latent Variable Analysis and Signal Separation Conference (LVA)*, DOI: 10.1007/978-3-319-22482-4_11, Vol. 9237, pp. 91-99, August 2015 (TR2015-094)

Korolko, N.; Sahinoglu, Z.; Nikovski, D.N., **"Modeling and Forecasting Self-Similar Power Load Due to EV Fast Chargers"**, *IEEE Transactions on Smart Grid*, DOI: 10.1109/TSG.2015.2458852, ISSN: 1949-3053, Vol. 7, pp. 1620-1629, August 2015 (TR2015-105)

Kumar, R.; Da Silva, C.; Akalin, O.; Aravkin, A.; Mansour, H.; Recht, B.; Herrmann, F., **"Efficient Matrix Completion for Seismic Data Reconstruction"**, *Geophysics*, DOI: 10.1190/geo2014-0369.1, Vol. 20, pp. 97-114, August 2015 (TR2015-053)

Zhang, J.; Wang, Y.; Bortoff, S.A.; Satake, A.; Furutani, S.; Deng, X., **"Integrated Design of Speed Sensorless Control Algorithms for Induction Motors"**, *Chinese Control Conference (CCC)*, DOI: 10.1109/ChiCC.2015.7261011, pp. 8678-8684, July 2015 (TR2015-093)

Koike-Akino, T.; Kojima, K.; Wang, B.; Parsons, K.; Nishikawa, S.; Yagyu, E., **"An MMI-Based 4-Beam Combiner with Spline-Curved Index Step"**, *Signal Processing in Photonic Communications (SPPCom)*, DOI: 10.1364/IPRSN.2015.JM3A.16, ISBN: 978-1-55752-000-5, July 2015 (TR2015-091)

Liu, D., **"Compressive Sensing Based 3D Imaging Using a Moving MIMO Array"**, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, DOI: 10.1109/IGARSS.2015.7326449, ISSN: 2153-6996, pp. 3010-3013, July 2015 (TR2015-090)

Koike-Akino, T.; Kojima, K.; Parsons, K., **"Trellis-Coded High-Dimensional Modulation for Polarization Crosstalk Self Cancellation in Coherent Optical Communications"**, *Signal Processing in Photonic Communications (SPPCom)*, DOI: 10.1364/SPPCOM.2015.SpS3D.6, ISBN: 978-1-55752-000-5, July 2015 (TR2015-088)

Xia, T.; Koike-Akino, T.; Millar, D.S.; Kojima, K.; Parsons, K.; Miyata, Y.; Sugihara, K.; Matsumoto, W., **"Nonbinary LDPC Convolutional Codes for High-Dimensional Modulations"**, *Signal Processing in Photonic Communications (SPPCom)*, DOI: 10.1364/SPPCOM.2015.SpS3D.5, ISBN: 978-1-55752-000-5, July 2015 (TR2015-087)

Koike-Akino, T.; Kojima, K.; Millar, D.S.; Parsons, K., **"Simplified Han-Kobayashi Coding Strategy for Tb/s Optical Superchannel Transmissions"**, *Signal Processing in Photonic Communications (SPPCom)*, DOI: 10.1364/SPPCOM.2015.SpS3D.3, ISBN: 978-1-55752-000-5, July 2015 (TR2015-089)

Felicetti, M.; Kojima, K.; Koike-Akino, T.; Wang, B.; Parsons, K.; Nishikawa, S.; Yagyu, E., **"MMI-Based Polarization Beam Splitter/Combiner for InP Photonic Integrated Circuits"**, *Integrated Photonics Research, Silicon and Nano Photonics (IPR)*, DOI: 10.1364/IPRSN.2015.IM2A.5, ISBN: 978-1-55752-000-5, July 2015 (TR2015-052)

Nikovski, D.N., **"Barycentric Quantization for Planning in Continuous Domains"**, *AI Communications*, DOI: 10.3233/AIC-150675, Vol. 28, pp. 539-551, July 2015 (TR2015-151)

Benosman, M.; Xia, M., **"Extremum Seeking-Based Indirect Adaptive Control for Nonlinear Systems with State-Dependent Uncertainties"**, *SIAM Conference on Control and its Applications*, DOI: 10.1137/1.9781611974072.44, ISBN: 978-1-61197-407-2, pp. 319-326, July 2015 (TR2015-068)

Xia, M.; Benosman, M., **"Extremum Seeking-Based Indirect Adaptive Control for Nonlinear Systems with Time-Varying Uncertainties"**, *European Control Conference (ECC)*, DOI: 10.1109/ECC.2015.7330959, pp. 2780-2785, July 2015 (TR2015-042)

Weiss, A.; Di Cairano, S., **"Opportunities and Potential of Model Predictive Control for Low-Thrust Spacecraft Station-Keeping and Momentum-Management"**, *European Control Conference (ECC)*, DOI: 10.1109/ECC.2015.7330729, pp. 1370-1375, July 2015 (TR2015-083)

Holaza, J.; Takacs, B.; Kvasnica, M.; Di Cairano, S., **"Safety Verification of Implicitly Defined MPC Feedback Laws"**, *European Control Conference (ECC)*, DOI: 10.1109/ECC.2015.7330921, pp. 2547-2552, July 2015 (TR2015-086)

Lan, X.; Di Cairano, S., **"Continuous Curvature Path Planning for Semi-Autonomous Vehicle Maneuvers Using RRT"**, *European Control Conference (ECC)*, DOI: 10.1109/ECC.2015.7330891, pp. 2360-2365, July 2015 (TR2015-085)

Knyazev, A.; Fujii, Y.; Malyshev, A., **"Preconditioned Continuation Model Predictive Control"**, *SIAM Conference on Control and Its Applications*, DOI: 10.1137/1.9781611974072.15, ISBN: 978-1-61197-407-2, pp. 101-108, July 2015 (TR2015-084)

Liu, M.-Y.; Lin, A.; Ramalingam, S.; Tuzel, C.O., **"Layered Interpretation of Street View Images"**, *Robotics: Science and Systems Conference (RSS)*, DOI: 10.15607/RSS.2015.XI.025, July 2015 (TR2015-073)

Vaccaro, R.; Boufounos, P.T.; Benosman, M., **"Resolution-Directed Optimization-Based Distributed Sensing"**, *SIAM Conference on Control and its Applications*, DOI: 10.1137/1.9781611974072.24, ISBN: 978-1-61197-407-2, pp. 167-174, July 2015 (TR2015-050)

Berntorp, K., **"Feedback Particle Filter: Application and Evaluation"**, *International Conference on Information Fusion (FUSION)*, pp. 1633-1640, July 2015 (TR2015-074)

Gupta, R.; Kalabic, U.V.; Di Cairano, S.; Kolmanovsky, I.V.; Bloch, A., **"Constrained Spacecraft Attitude Control on SO(3) Using Fast Nonlinear Model Predictive Control"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7171188, ISBN: 978-1-4799-8685-9, pp. 2980-2986, July 2015 (TR2015-066)

Tang, S.; Wang, Y.; Sahinoglu, Z.; Wada, T.; Hara, S.; Krstic, M., **"State-of-Charge Estimation of Lithium-Ion Batteries via a Coupled Thermal-Electrochemical Model"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7172260, ISBN: 978-1-4799-8685-9, pp. 5871-5877, July 2015 (TR2015-065)

Kang, J.; Raghunathan, A.U.; Di Cairano, S., **"Decomposition via ADMM for Scenario-Based Model Predictive Control"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7170904, ISBN: 978-1-4799-8685-9, pp. 1246 - 1251, July 2015 (TR2015-060)

Di Cairano, S., **"Model Adjustable Predictive Control with Stability Guarantees"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7170740, ISSN: 0743-1619, ISBN: 978-1-4799-8685-9, pp. 226-231, July 2015 (TR2015-059)

Wada, T.; Takegami, T.; Wang, Y., **"Sequential Estimation of State of Charge and Equivalent Circuit Parameters for Lithium-Ion Batteries"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7171106, ISBN: 978-1-4799-8685-9, pp. 2494-2498, July 2015 (TR2015-058)

Wang, Y.-S.; Wang, Y., **"A Gradient-Based Approach for Optimal Plant Controller Co-Design"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7171833, ISBN: 978-1-4799-8685-9, pp. 3249-3254, July 2015 (TR2015-061)

Xu, J.; Nikovski, D.N., **"A Framework for Real-Time Near-Optimal Train Run-Curve Computation with Dynamic Travel Time and Speed Limits"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7170790, ISBN: 978-1-4799-8685-9, pp. 533-540, July 2015 (TR2015-063)

Burns, D.J.; Guay, M.; Weiss, W., **"Realtime Setpoint Optimization with Time-Varying Extremum Seeking for Vapor Compression Systems"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7170860, ISBN: 978-1-4799-8685-9, pp. 974-979, July 2015 (TR2015-067)

Weiss, A.; Kalabic, U.V.; Di Cairano, S., **"Model Predictive Control for Simultaneous Station Keeping and Momentum Management of Low-Thrust Spacecraft"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7171076, ISBN: 978-1-4799-8685-9, pp. 2305-2310, July 2015 (TR2015-062)

Cheng, Y.; Haghighat, S.; Di Cairano, S., **"Robust Dual Control MPC with Application to Soft-Landing Control"**, *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7171932, ISSN: 0743-1619, ISBN: 978-1-4799-8685-9, pp. 3862-3867, July 2015 (TR2015-064)

Tachioka, Y.; Narita, T.; Watanabe, S., **"Effectiveness of Dereverberation, Feature Transformation, Discriminative Training Methods, and System Combination Approach for Various Reverberant Environments"**, *EURASIP Journal on Advances in Signal Processing*, DOI: 10.1186/s13634-015-0241-y, June 2015 (TR2015-152)

Sun, H.; Wang, Y.; Nikovski, D.N.; Zhang, J., **"Flex-Grid: A Dynamic and Adaptive Configurable Power Distribution System"**, *IEEE Eindhoven PowerTech*, DOI: 10.1109/PTC.2015.7232488, pp. 1-6, June 2015 (TR2015-082)

Laughman, C.R.; Grover, P.; Nabi, S., **"A Study of Refrigerant Dispersion in Occupied Spaces Under Parametric Variation"**, *ASHRAE Annual Conference*, Vol. 121, June 2015 (TR2015-081)

Pajovic, M.; Millar, D.S.; Koike-Akino, T.; Kojima, K.; Arlunno, V.; Parsons, K., **"Multi-Pilot Aided Carrier Phase Estimation for Single Carrier Coherent Systems"**, *Signal Processing in Photonic Communications (SPPCom)*, DOI: 10.1364/SPPCOM.2015.SpT4D.4, ISBN: 978-1-55752-000-5, June 2015 (TR2015-080)

Xiao, Y.; Feng, C.; Taguchi, Y.; Kamat, V.R., **"User-Guided Dimensional Analysis of Indoor Scenes Using Depth Sensors"**, *International Symposium on Automation and Robotics in Construction and Mining (ISARC)*, June 2015 (TR2015-079)

Khan, T.; Kim, K.J.; Orlik, P.V., **"Performance Analysis of a Cooperative Wireless Networks with Unreliable Backhaul Links"**, *IEEE Communications Letters*, DOI: 10.1109/LCOMM.2015.2442991, ISSN: 1089-7798, Vol. 19, pp. 1386-1389, June 2015 (TR2015-095)

Khan, T.; Orlik, P.V.; Kim, K.J., **"A Stochastic Geometry Analysis of Cooperative Wireless Networks Powered by Energy Harvesting"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2015.7248617, ISSN: 1550-3607, pp. 1988-1993, June 2015 (TR2015-078)

Papazov, C.; Marks, T.K.; Jones, M.J., **"Real-time Head Pose and Facial Landmark Estimation from Depth Images Using Triangular Surface Patch Features"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2015.7299104, pp. 4722-4730, June 2015 (TR2015-069)

Sharma, A.; Tuzel, C.O.; Jacobs, D., **"Deep Hierarchical Parsing for Semantic Segmentation"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2015.7298651, ISSN: 1063-6919, pp. 530-538, June 2015 (TR2015-057)

Ahmed, E.; Jones, M.J.; Marks, T.K., **"An Improved Deep Learning Architecture for Person Re-Identification"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2015.7299016, pp. 3908-3916, June 2015 (TR2015-076)

Ramalingam, S.; Antunes, M.; Snow, D.; Lee, G.H.; Pillai, S., **"Line-Sweep: Cross-Ratio for Wide-Baseline Matching and 3D Reconstruction"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2015.7298728, ISSN: 1063-6919, pp. 1238-1246, June 2015 (TR2015-077)

Shirao, M.; Kojima, K.; Itamoto, H., **"53.2 Gb/s NRZ Transmission Over 10 km Using High Speed EML for 400GbE"**, *Opto-Electronics and Communications Conference (OECC)*, DOI: 10.1109/OECC.2015.7340137, pp. 1-3, June 2015 (TR2015-075)

Bouwmeester, H.; Dougherty, A.; Knyazev, A., **"Nonsymmetric Preconditioning for Conjugate Gradient and Steepest Descent Methods"**, *International Conference on Computational Science (ICCS)*, DOI: 10.1016/j.procs.2015.05.241, Vol. 51, pp. 276-285, June 2015 (TR2015-113)

Zhu, L.; Teo, K.H.; Gao, Q., **"Dynamic On-Resistance and Tunneling Based De-Trapping in GaN HEMT"**, *IEEE International Conference on Electron Devices and Solid-State Circuits (EDSSC)*, DOI: 10.1109/EDSSC.2015.7285217, ISBN: 978-1-4799-8362-9, pp. 717-720, June 2015 (TR2015-047)

Wada, T.; Takegami, T.; Wang, Y.; Sahinoglu, Z., **"Capacity Estimation for Lithium-Ion Batteries Using Adaptive Filter on Affine Space"**, *Asian Control Conference (ASCC)*, DOI: 10.1109/ASCC.2015.7244497, pp. 1-6, May 2015 (TR2015-071)

Laughman, C.R.; Qiao, H.; Aute, V.; Radermacher, R., **"A Comparison of Transient Heat Pump Cycle Simulations with Homogeneous and Heterogeneous Flow Models"**, *Science and Technology for the Built Environment*, DOI: 10.1080/23744731.2015.1040342, ISSN: 2374-4731, Vol. 21, pp. 666-680, May 2015 (TR2015-072)

Boufounos, P.T.; Mansour, H., **"Universal Embeddings for Kernel Machine Classification"**, *International Conference on Sampling Theory and Applications (SampTA)*, DOI: 10.1109/SAMPTA.2015.7148902, pp. 307-311, May 2015 (TR2015-070)

Bergman, D.; Raghunathan, A.U., **"A Benders Approach to the Minimum Chordal Completion Problem"**, *International Conference on Integration of Artificial Intelligence and Operations Research (CPAIOR)*, DOI: 10.1007/978-3-319-18008-3_4, ISBN: 978-3-319-18008-3, Vol. 9075, pp. 47-64, May 2015 (TR2015-056)

Chung, S.W; Ma, R.; Shinjo, S.; Teo, K.H., **"Inter-Band Carrier Aggregation Digital Transmitter Architecture with Concurrent Multi-Band Delta-Sigma Modulation Using Out-of-Band Noise Cancellation"**, *International Microwave Symposium (IMS)*, DOI: 10.1109/MWSYM.2015.7166934, ISSN: 0149-645X, pp. 1-4, May 2015 (TR2015-043)

Wu, J.; Wang, B.; Yerazunis, W.S.; Teo, K.H., **"Circularly Polarized Near Field for Resonant Wireless Power Transfer"**, *IEEE Wireless Power Transfer Conference (WPTC)*, DOI: 10.1109/WPT.2015.7140117, pp. 1-3, May 2015 (TR2015-037)

Wang, Y.; Wu, J.; Long, C.; Zhou, M., **"Economical Manufacturing from Optimal Control Perspective: Simplification, Methods and Analysis"**, *IFAC Symposium on Information Control in Manufacturing (INCOM)*, DOI: 10.1016/j.ifacol.2015.06.086, Vol. 48, pp. 231-237, May 2015 (TR2015-054)

Koike-Akino, T.; Millar, D.S.; Kojima, K.; Parsons, K.; Sugihara, K.; Miyata, Y.; Yoshida, T., **"LDPC-Coded 16-Dimensional Modulation Based on the Nordstrom-Robinson Nonlinear Block Code"**, *Conference on Lasers and Electro-Optics (CLEO)*, DOI: 10.1364/CLEO_AT.2015.JTh2A.59, ISBN: 978-1-55752-968-8, pp. 1-2, May 2015 (TR2015-038)

Koike-Akino, T.; Millar, D.S.; Kojima, K.; Parsons, K., **"Phase Noise-Robust LLR Calculation with Linear/Bilinear Transform for LDPC-Coded Coherent Communications"**, *Conference on Lasers and Electro-Optics (CLEO)*, DOI: 10.1364/CLEO_SI.2015.SW1M.3, ISBN: 978-1-55752-968.8, pp. 1-2, May 2015 (TR2015-039)

Kim, T.; Wang, Y.; Sahinoglu, Z.; Wada, T.; Hara, S.; Qiao, W., **"A Rayleigh Quotient-Based Recursive Total-Least-Square Online Maximum Capacity Estimation for Lithium-Ion Batteries"**, *IEEE Transactions on Energy Conversion*, DOI: 10.1109/TEC.2015.2424673, ISSN: 0885-8969, Vol. 30, pp. 842-851, May 2015 (TR2015-040)

Deng, Y.; Wang, Y.; Teo, K.H.; Harley, R.G., **"A Simplified Space Vector Modulation Scheme for Multilevel Converters"**, *IEEE Transactions on Power Electronics*, DOI: 10.1109/TPEL.2015.2429595, ISSN: 0885-8993, Vol. 31, pp. 1873-1886, May 2015 (TR2015-048)

Le Roux, J.; Vincent, E.; Hershey, J.R.; Ellis, D.P.W., **"Micbots: Collecting Large Realistic Datasets for Speech and Audio Research Using Mobile Robots"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7179050, pp. 5635-5639, April 2015 (TR2015-030)

Shinozaki, T.; Watanabe, S., **"Structure Discovery of Deep Neural Network Based on Evolutionary Algorithms"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7178918, pp. 4979-4983, April 2015 (TR2015-032)

Mansour, H.; Jiang, X., **"A Robust Online Subspace Estimation and Tracking Algorithm"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7178735, pp. 4065-4069, April 2015 (TR2015-027)

Erdogan, H.; Hershey, J.R.; Watanabe, S.; Le Roux, J., **"Phase-Sensitive and Recognition-Boosted Speech Separation Using Deep Recurrent Neural Networks"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7178061, pp. 708-712, April 2015 (TR2015-031)

Mansour, H.; Saab, R., **"Weighted One-Norm Minimization with Inaccurate Support Estimates: Sharp Analysis via the Null-Space Property"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7178585, pp. 3317-3321, April 2015 (TR2015-026)

Kadambi, A.; Boufounos, P.T., **"Coded Aperture Compressive 3-D LIDAR"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7178153, pp. 1166-1170, April 2015 (TR2015-028)

Le Roux, J.; Hershey, J.R.; Weninger, F.J., **"Deep NMF for Speech Separation"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7177933, pp. 66-70, April 2015 (TR2015-029)

Tachioka, Y.; Watanabe, S., **"Discriminative Method for Recurrent Neural Network Language Models"**, *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7179000, pp. 5386-5390, April 2015 (TR2015-033)

Ataer-Cansizoglu, E.; Taguchi, Y.; Kalpathy-Cramer, J.; Chiang, M.F.; Erdogmus, D., **"Analysis of Shape Assumptions in 3D Reconstruction of Retina from Multiple Fundus Images"**, *IEEE International Symposium on Biomedical Imaging (ISBI)*, DOI: 10.1109/ISBI.2015.7164162, pp. 1502-1505, April 2015 (TR2015-051)

Vetro, A.; Chen, Y.; Mueller, K., **"HEVC-Compatible Extensions for Advanced Coding of 3D and Multiview Video"**, *Data Compression Conference (DCC)*, DOI: 10.1109/DCC.2015.26, ISSN: 1068-0314, pp. 13-22, April 2015 (TR2015-046)

Boufounos, P.T.; Mansour, H., **"Kernel Machine Classification Using Universal Embeddings"**, *Data Compression Conference (DCC)*, DOI: 10.1109/DCC.2015.61, ISSN: 1068-0314, pp. 440, April 2015 (TR2015-044)

Research

The body and soul of any research lab is its portfolio of research projects. Therefore it is appropriate that the main body of this annual report consists of descriptions of research projects being done at MERL. The reports are grouped into six topic areas corresponding to MERL's six research groups.

Electronics & Communications - wireless and optical communications, advanced signal processing, optical and semiconductor devices, and electro-magnetics, with application to product areas such as terrestrial and trans-oceanic optical networks, train and automotive connectivity and electronics, power equipment and systems for smart grid, RF power amplifiers & front-end modules, and wireless charging, thermal and electrical conductivity manipulation.

Multimedia – Acquisition, representation, processing and security of multimedia, as well as enhanced interaction with multimedia. Core technical strengths are in various aspects of signal processing ranging from video and speech processing, to information forensics and security, as well as signal processing theory and sensing methods.

Data Analytics – Innovative high-performance algorithms that can be applied to electrical power systems, various transportation systems (trains, elevators, car navigation), heating, ventilation, and air conditioning (HVAC) systems and solutions, and factory automation. The application of these algorithms minimizes costs, increases reliability, improves energy efficiency, and reduces environmental impact of products.

Computer Vision - Processing data from across space and time to extract meaning and build representations of objects and events in the world. 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 - If it moves, we control it: Advanced control algorithms, model predictive control, nonlinear dynamical systems, system-level dynamic modeling and analysis, mechatronic co-design, thermo-fluid system dynamics, and applications to factory automation, elevators, space systems, automotive mechatronics, and HVAC.

Algorithms - Solution methods for optimization problems involving very large numbers of variables or real-time computing in the areas of control, data mining, signal processing and optics.

Electronics & Communications

The Electronics & Communications Group conducts fundamental and applied research in the areas of wireless and optical communications, advanced signal processing, optical and semiconductor devices, and electro-magnetics. Our research has application to product areas such as terrestrial and trans-oceanic optical networks, train and automotive connectivity and electronics, power equipment and systems for smart grid, RF power amplifiers and front-end modules, and wireless charging, thermal and electrical conductivity manipulation.

Wireless research focuses on the development of novel physical and network layer algorithms, combined with advanced channel modeling, to enable high reliability wireless networks for machine-to-machine networking, 5G/millimeter wave systems and vehicular networks. Our signal processing work involves detection, localization and applied optimization algorithms for applications such as IoT.

Optical research focuses on signal processing algorithms and error control coding for coherent long haul and sub-sea fiber-optic communications, and the development of novel photonic integrated circuits to support optical communications applications.

Power & RF work emphasizes highly efficient wideband power amplifier technology and semiconductor devices, as well as electro-magnetic analysis and manipulation, for applications such as wireless power transfer to static and mobile devices and material design for thermal and electrical conductivity.

Recent Research

On Probabilistic Data Association for … Near-Exponential Diversity over Fading Channels 42
Han-Kobayashi and Dirty-Paper Coding for Superchannel Optical Communications 42
Resource Aware Routing Protocol in Heterogeneous Wireless Machine-to-Machine Networks 43
Investigation of Low Code Rate DP-8PSK as an Alternative to DP-QPSK..... 43
Outphasing Multi-Level RF PWM for Inter-Band Carrier Aggregation in Digital Transmitters. 44
Millimeter Wave Communications Channel Estimation via Bayesian Group Sparse Recovery . 44
Metamaterials and Resonant Array Wireless Power Systems 45
A Metamaterial-Inspired Combined Inductive-Capacitive Sensor..... 45
MMI-Based Polarization Beam Splitter/Combiner for InP Photonic Integrated Circuits 46
Application of Numerical Optimization to the Design of InP-based Wavelength Combiners..... 46
Design of a 1 Tb/s Superchannel Coherent Receiver 47
An Unsupervised Indoor Localization Method Based on Received Signal Strength (RSS) 47
A Fully Analog Two-way Sequential GaN Power Amplifier with 40% Fractional Bandwidth .. 48

On Probabilistic Data Association for Achieving Near-Exponential Diversity over Fading Channels

Citation: Yellepeddi, A.; Kim, K.J.; Duan, C.; Orlik, P.V., "On Probabilistic Data Association for Achieving Near-Exponential Diversity over Fading Channels", *IEEE International Conference on Communications (ICC)*, DOI: 10.2209/icc.2013.6655449, ISSN: 1550-3607, pp. 5409-5414, June 2013

Contacts: Kyeong Jin Kim, Philip V. Orlik

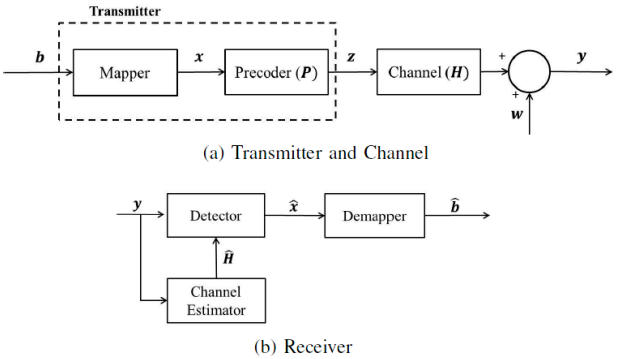


Fig. 1: Block diagram of the considered system.

Machine-to-Machine (M2M) wireless communication requires the transmission of short blocks of data with high reliability over fading channels. We discuss the use of the probabilistic data association (PDA) detector in conjunction with precoding to design high-performance systems for these links. First, the performance of the traditional PDA algorithm with precoding over ideal Rayleigh fading links is analyzed, which provides insight into its performance, and evidence of an error floor at high SNRs. Then, a novel ordering mechanism is proposed that takes advantage of the precoder characteristics. It is shown by simulation that the proposed modified algorithm can achieve near-ML performance for block sizes as small as 32 symbols.

Han-Kobayashi and Dirty-Paper Coding for Superchannel Optical Communications

Citation: Koike-Akino, T., Kojima, K., Millar, D.S., Parsons, K., Kametani, S., Sugihara, T., Yoshida, T., Ishida, K., Miyata, Y., Matsumoto, W., Mizuochi, T., "Han-Kobayashi and Dirty-Paper Coding for Superchannel Optical Communications", *Journal of Lightwave Technology*, DOI: 10.1109/JLT.2015.2397435, ISSN: 0733-8724, Vol. 33, No. 7, pp. 1292-1299, February 2015.

Contacts: Toshiaki Koike-Akino, Keisuke Kojima, David S. Millar, Kieran Parsons

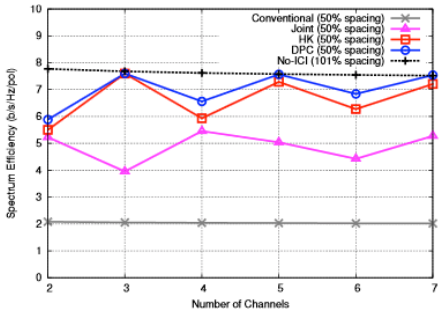


Fig. 10. Spectrum efficiency vs. number of channels N ($\delta f = 0.50$).

Superchannel transmission is a candidate to realize Tb/s-class high-speed optical communications. In order to achieve higher spectrum efficiency, the channel spacing shall be as narrow as possible. However, densely allocated channels can cause nonnegligible inter-channel interference (ICI) especially when the channel spacing is close to or below the Nyquist bandwidth. In this paper, we consider joint decoding to cancel the ICI in dense superchannel transmission. To further improve the spectrum efficiency, we propose the use of Han-Kobayashi (HK) superposition coding. In addition, for the case when neighboring subchannel transmitters can share data, we introduce dirty-paper coding (DPC) for pre-cancellation of the ICI.

Resource Aware Routing Protocol in Heterogeneous Wireless Machine-to-Machine Networks

Citation: Guo, J.; Orlik, P.V.; Parsons, K.; Ishibashi, K.; Takita, D., "Resource Aware Routing Protocol in Heterogeneous Wireless Machine-to-Machine Networks", *IEEE Global Communications Conference (GLOBECOM),* DOI: 10.1109/GLOBECOM.2015.7417208, pp. 1-6, December 2015.

Contacts: Jianlin Guo, Philip V. Orlik, Kieran Parsons

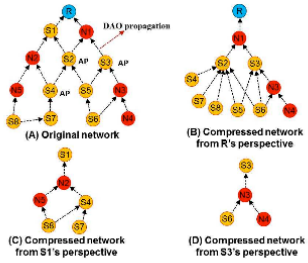


Fig. 3: Illustration of Acting Parent and Route Compression in RAM-RPL

A routing algorithm can significantly impact network performance. Routing in a network containing heterogeneous nodes differs from routing in a network with homogeneous nodes. If the routing algorithm is designed to fit less powerful nodes, the resources of more powerful nodes are wasted and network performance can be degraded. If the routing algorithm is developed to suit more powerful nodes, less powerful nodes may not have sufficient resources to run the algorithm and the network may break down. This paper proposes a resource-aware adaptive mode RPL (RAM-RPL) to achieve adaptive mode of operation in heterogeneous wireless machine-to-machine (M2M) networks. RAM-RPL not only allows routers to have mixed modes of operation in a network but also allows routers to adaptively adjust their modes of operation during network operation. Acting parent and acting root techniques are introduced to realize adaptive mode of operation and route compression. RAM-RPL exploits resource heterogeneity and shifts routing workload from less powerful nodes to more powerful nodes. Simulation results show that RAM-RPL can improve data packet delivery rate by 26% and reduce control message overhead by 53% while maintaining similar packet latency.

Investigation of Low Code Rate DP-8PSK as an Alternative to DP-QPSK

Citation: Kojima, K.; Koike-Akino, T.; Millar, D.S.; Pajovic, M.; Parsons, K.; Yoshida, T., "Investigation of Low Code Rate DP-8PSK as an Alternative to DP-QPSK", *Optical Fiber Communication Conference and Exposition (OFC),* DOI: 10.1364/OFC.2016Th1D.2, ISBN: 978-1-843580-07-1, March 2016.

Contacts: Keisuke Kojima, Toshiaki Koike-Akino, David S. Millar, Milutin Pajovic, Kieran Parsons

Low code rate DP-8PSK was studied as an alternative to DP-QPSK for long distance coherent communications. For a 4,000 km transmission with multiple link configurations, low code rate DP-8PSK is shown to have 1.6 - 1.8 dB span loss budget over DP-QPSK for the same spectral efficiency through simulations.

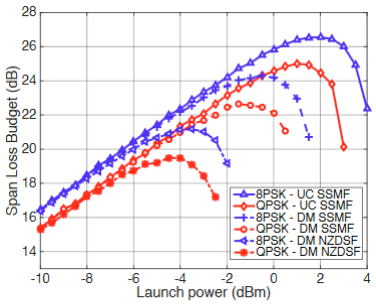


Fig. 2: Span loss budget of low code rate 8PSK and high code rate QPSK of the same information bit rate, plotted as a function of launch power for three types of links.

Outphasing Multi-Level RF PWM for Inter-Band Carrier Aggregation in Digital Transmitters

Citation: Chung, S., Ma, R., Teo, K.H., Parsons, K., "Outphasing Multi-Level RF PWM Signals for Inter-Band Carrier Aggregation in Digital Transmitters", *IEEE Radio Wireless Week (RWW),* January 2015.
Contacts: Rui Ma, Koon Hoo Teo, Kieran Parsons

A novel non-contiguous concurrent multiband digital-RF transmitter architecture is presented, which is based on outphasing the multi-level RF pulse-width modulated signals (MLRF-PWM) for digital Class-S power amplifiers. To improve the transmitter power efficiency, the outphasing modulation in the proposed architecture effectively increases the number of MLRF-PWM signal output levels. In addition, a multi-band multibit band-pass delta-sigma modulator (BPDSM) with a hard clipping technique is introduced, which further improves power coding efficiency by trading off distortion performance with coding efficiency. Experimental results with a dual-channel 25-GSPS arbitrary waveform generator (AWG) demonstrate non-contiguous carrier aggregation for 3-level Class-S PAs with inter-band LTE signals at 874 MHz and 1501 MHz for the channel bandwidth of 10-MHz and 20-MHz, respectively. The proposed outphasing MLRF-PWM technique achieves 59.5% power coding efficiency, which is significant improvement from the 8.6% coding efficiency of conventional 3-level BPDSM with the experimental dual band LTE signal transmission.

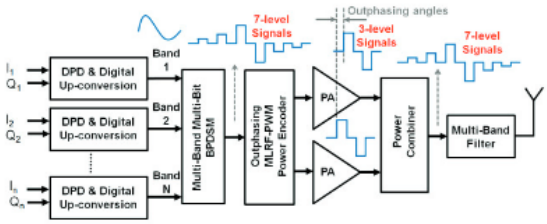


Fig. 2. Proposed outphasing multi-level RF-PWM (MLRF-PWM) transmitter architecture for inter-band CA.

Millimeter Wave Communications Channel Estimation via Bayesian Group Sparse Recovery

Citation: Suryaprakash, R.T.; Pajovic, M.; Kim, K.J.; Orlik, P.V., "Millimeter Wave Communications Channel Estimation via Bayesian Group Sparse Recovery", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP),* DOI: 10.1109/ICASSP.2016.7472309, pp. 3406-3410, March 2016.
Contacts: Milutin Pajovic, Kyeong Jin Kim, Philip V. Orlik

We consider the problem of channel estimation for millimeter wave communications (mmWave). We formulate channel estimation as a structured sparse signal recovery problem, in which the signal structure is governed by a priori knowledge of the channel characteristics. We develop a Bayesian group sparse recovery algorithm, which takes into account several features unique to mmWave channels, such as spatial (angular) spreads of received signals and power profile of rays impinging on the receiver array.

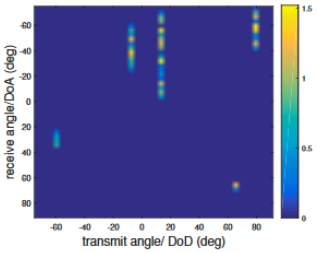


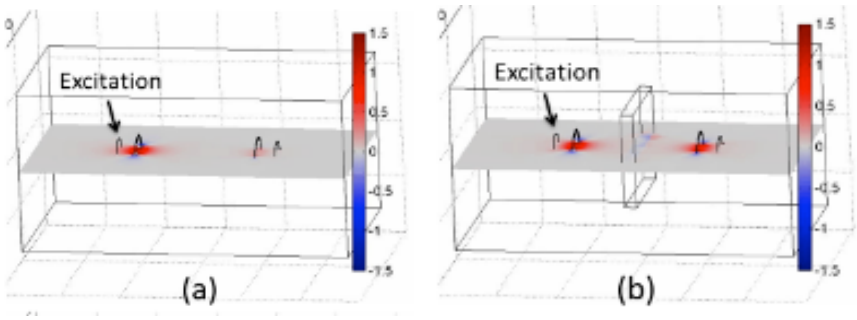
Fig. 1. Plot of $|H_s|$ (single realization). Rows correspond to DoD and columns to DoA. Rays arrive clustered spatially at the receiver, so that non-zero components are group sparse.

Metamaterials and Resonant Array Wireless Power Systems

Citation: Yerazunis, W.S., Wang, B., Teo, K.H., "Metamaterials and Resonant Array Wireless Power Systems", *IEEE Antennas and Propagation Society International Symposium (APSURSI)*, DOI: 10.1109/APS.2014.6905027, ISSN: 1522-3965, ISBN: 978-1-4799-3538-3, July 2014, pp. 1403-1404.

Contacts: William S. Yerazunis, Bingnan Wang, Koon Hoo Teo

This article discusses the use of metamaterials and resonator arrays to improve the range and efficiency of wireless power transfer, including both predicted and actual experimental results with single and multiple coupled resonators and metamaterial structures.



A Metamaterial-Inspired Combined Inductive-Capacitive Sensor

Citation: Long, J., Wang, B., "A Metamaterial-inspired Combined Inductive-capacitive Sensor", *SPIE Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications*, DOI: 10.1117/12.2053318, ISBN: 9781628410587, Vol. 9121, May 2014.

Contacts: Bingnan Wang

This paper reports a metamaterial inspired combined inductive-capacitive sensing method for detecting and distinguishing metallic and non-metallic objects. Metallic and non-metallic objects can be distinguished by measuring both of their inductive and capacitive responses based on the fact that they respond differently to inductive and capacitive sensing. The proposed method is inspired by metamaterial structures. Both inductive and capacitive sensing are simultaneously realized when the sensor is operating at off-resonant frequencies. The proposed method is demonstrated with typical printed circuit board (PCB) technology. The designed sensor can distinguish the metallic and dielectric objects with a sensing range about 10 mm, showing a competitive performance compared with commercially available proximity sensors.

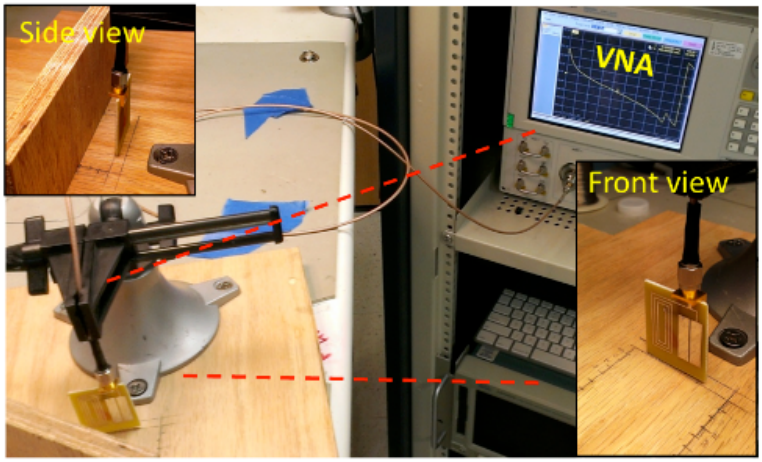


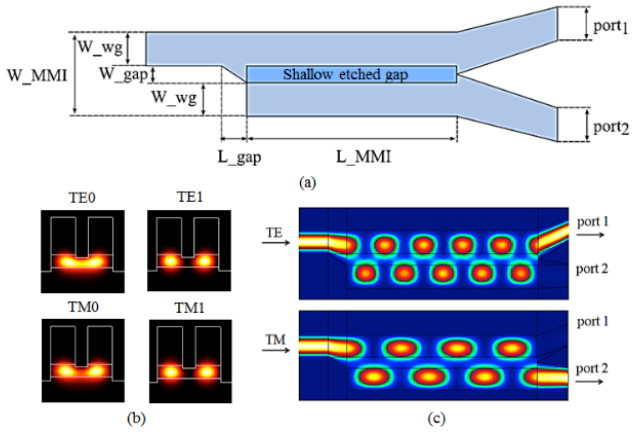
Figure 7. Experiment setup, with fabricated sensing structure shown in the inset.

MMI-Based Polarization Beam Splitter/Combiner for InP Photonic Integrated Circuits

Citation: Felicetti, M.; Kojima, K.; Koike-Akino, T.; Wang, B.; Parsons, K.; Nishikawa, S.; Yagyu, E., "MMI-Based Polarization Beam Splitter/Combiner for InP Photonic Integrated Circuits", *Integrated Photonics Research, Silicon and Nano Photonics (IPR),* DOI: 10.1364/IPRSN.2015.IM2A.5, ISBN: 978-1-55752-0005, July 2015.

Contacts: Keisuke Kojima, Toshiaki Koike-Akino, Bingnan Wang, Kieran Parsons

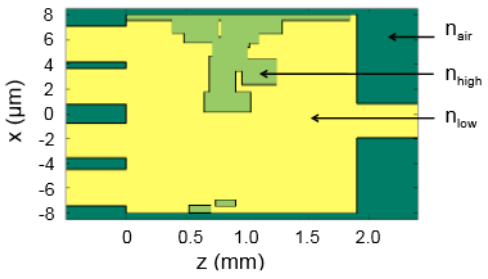
An MMI-based polarization splitter/combiner with a TE-TM splitting ratio above 15 dB over a 21 nm wavelength range is demonstrated. The compact device is integrated in a photonic circuit within an InP multi-project wafer run.



Application of Numerical Optimization to the Design of InP-based Wavelength Combiners

Citation: Ozbayat, S., Kojima, K., Koike-Akino, T., Wang, B., Parsons, K., Singh, S., Nishikawa, S., Yagyu, E., "Application of Numerical Optimization to the Design of InP-based Wavelength Combiners", *Optics Communications*, DOI: 10.1016/j.optcom.2014.02.030, ISSN: 0030-4018, Vol. 322, pp. 131-136, July 2014.

Contacts: Keisuke Kojima, Toshiaki Koike-Akino, Bingnan Wang, Kieran Parsons

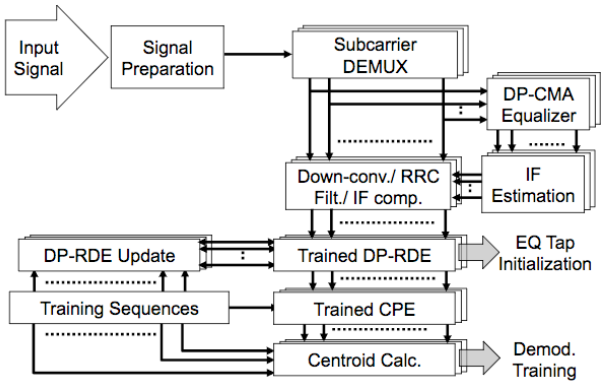


We applied a numerical device optimization scheme, where tens of parameters can be optimized simultaneously with multiple target performance criteria that are given. The key items of the design scheme are the selection of the best optimization algorithm, metric, and consideration for fabrication errors. This method was then applied to design an MMI beam combiner with rectangular effective refractive steps with up to 75 parameters, and we obtained a simulated insertion loss of 0.8 dB for a 1.4 mm-long 2x1 wavelength combiner, and a simulated insertion loss of 4.2 dB for a 1.9 mm-long 4x1 wavelength combiner, both with 20 nm wavelength spacing.

Design of a 1 Tb/s Superchannel Coherent Receiver

Citation: Millar, D.S.; Koike-Akino, T.; Kojima, K.; Pajovic, M.; Parsons, K.; Paskov, M.; Maher, R.; Lavery, D.; Alvarado, A.; Thomsen, B.C.; Savory, S.J.; Bayvel, P., " Design of a 1 Tb/s Superchannel Coherent Receiver", *Journal of Lightwave Technology,* DOI: 10.1109/JLT.w016.2519260, ISSN: 0733-8724, Vol. 34, pp. 1453-1463, March 2016

Contacts: David S. Millar, Toshiaki Koike-Akino, Keisuke Kojima, Milutin Pajovic, Kieran Parsons



We describe the design of a trained and pilot-aided digital coherent receiver, capable of detecting a 1 Tb/s superchannel with a single optical front-end. Algorithms for receiver training are described, which calculate the equalizer coefficients, subchannel SNRs, and centroids of the transmitted constellations. Algorithms for pilot-aided operation are then described in detail, providing pilot-aided constant modulus equalization and joint carrier phase estimation over several coherent subchannels. We demonstrate detection of a superchannel with net bit rate in excess of 1 Tb/s with a single coherent receiver. An 11 10 GBd DP-64QAM Nyquist superchannel is used, with 1.32 Tb/s gross bit rate.

An Unsupervised Indoor Localization Method Based on Received Signal Strength (RSS)

Citation: Pajovic, M.; Orlik, P.V.; Koike-Akino, T.; Kim, K.J.; Aikawa, H.; Hori, T., "An Unsupervised Indoor Localization Method Based on Received Signal Strength (RSS) Measurements", *IEEE Global Communications Conference (GLOBECOM),* DOI: 10.1109/GLOCOM.2015.7417708, pp.1-6, December 2015.

Contacts: Milutin Pajovic, Philip V. Orlik, Toshiaki Koike-Akino, Kyeong Jin Kim, Takaaki Hori

We propose an unsupervised, received signal strength (RSS)-based indoor localization method, which as an infrastructure uses commercial WiFi chipsets and does not require any changes in the existing hardware. The method relies on path loss model for measured RSS levels where path loss coefficient is treated as a discrete random variable which takes values from some finite alphabet. The unknown location and path loss coefficient corresponding to each access point are jointly estimated using the Expectation Maximization (EM) approach. The algorithm is experimentally tested in an office space area of dimensions 32- by- 52 m (1600 m2) with only five access points and the achieved average localization error is below 4.5 m.

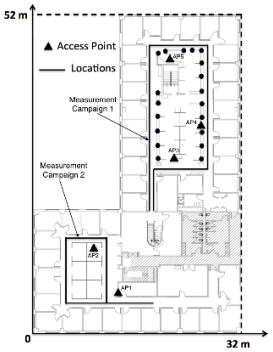


Fig. 1: Floor plan of the office space.

A Fully Analog Two-way Sequential GaN Power Amplifier with 40% Fractional Bandwidth

Citation: Shao, J., Ma, R., Teo, K.H., Shinjo, S., Yamanaka, K., "A Fully Analog Two-way Sequential GaN Power Amplifier with 40% Fractional Bandwidth", *IEEE MTT-S International Wireless Symposium (IWS)*, March 2015.

Contacts: Rui Ma, Koon Hoo Teo

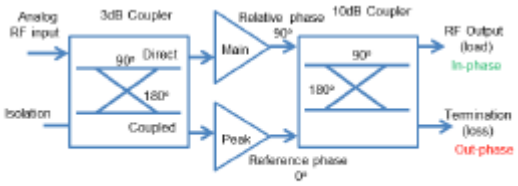


Fig. 1. Schematic of the proposed two-way SPA.

In this paper, we report a two-way sequential power amplifier (SPA) using GaN HEMTs. The proposed fully analog SPA delivers Past of approximately 40dBm over 2-3 GHz covering 40% fractional bandwidth. The design consists of a 3dB input coupler, a main amplifier, a peak amplifier, and a 10dB output coupler for power combining. After proper designing and optimizing these critical wideband couplers in terms of both phase and amplitude alignment, the measured final SPA shows 45% to 61% drain efficiency (DE) at 34dBm (5dB backoff) output from 2.1 to 2.9 GHz under CW stimulus. A complete set of SPA with analog RF input and output network is demonstrated.

Multimedia

Multimedia research at MERL addresses the acquisition, representation, processing and privacy of multiple data modalities. Core technical strengths are in various aspects of signal processing ranging from video and speech processing to information security and sensing methods.

- The current thrust of our digital video work is on advanced compression technologies for 3D point clouds and remotely sensed imagery, as well as advanced visual analysis including analysis of human activity and motion flows.

- The speech and audio team pursue a range of challenging machine-perception problems involving acoustic signals, human language and everything in between. The research covers source separation and novel deep learning methods for acoustic and language modelling, as well as natural language understanding.

- Research on computational sensing exploits widely available computational power to overhaul the signal acquisition paradigm and significantly enhance sensing capabilities. Our research aims to fundamentally understand how signals behave and propagate in the environment, and develops reconstruction algorithms to recover these signals.

- Our information security research develops technologies to perform statistical inference under constraints, providing a computationally inexpensive method for data analysis while assuring strong statistical guarantees of security via anonymization of the data.

Our research results are applied to a wide range of products including automotive electronics and home appliances; surveillance and building management systems; space/airborne systems for remote sensing; and information technology systems.

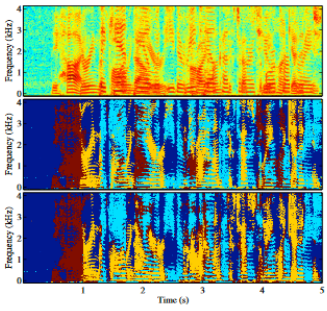
Recent Research

Deep Clustering: Discriminative Embeddings for Segmentation and Separation 50
The MERL/SRI System for the 3rd CHiME Challenge … 50
Context Sensitive Spoken Language Understanding Using Role Dependent LSTM Layers .. 51
Deep Unfolding for Multichannel Source Separation 51
Learning Optimal Nonlinearities for Iterative Thresholding Algorithms 52
Autocalibration of LIDAR and Optical Cameras via Edge Alignment 52
Coded Aperture Compressive 3-D LIDAR 53
Multipath Removal by Online Blind Deconvolution in Through-the-Wall-Imaging 53
Sparsity-Driven Distributed Array Imaging 54
Point Cloud Attribute Compression Using 3-D Intra Prediction … Transforms 54
Overview of the Emerging HEVC Screen Content Coding Extension 55
Overview of the Multiview and 3D Extensions of High Efficiency Video Coding 55
Graph Spectral Motion Segmentation Based on Motion Vanishing Point Analysis 56
On Privacy-Utility Tradeoffs for Constrained Data Release Mechanisms 56

Deep Clustering: Discriminative Embeddings for Segmentation and Separation

Citation: Hershey, J.R.; Chen, Z.; Le Roux, J.; Watanabe, S., "Deep Clustering: Discriminative Embeddings for Segmentation and Separation", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7471631, pp. 31-35, March 2016.

Contacts: John R. Hershey, Jonathan Le Roux, Shinji Watanabe

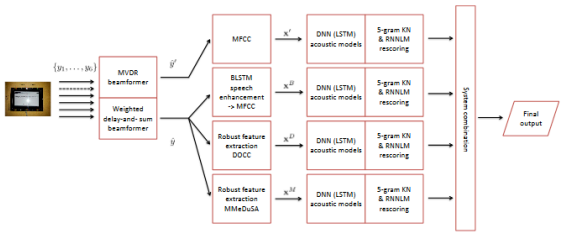


We address the problem of "cocktail-party" source separation in a deep learning framework called deep clustering. For arbitrary source classes and number, "class-based" methods are not suitable. Instead, we train a deep network to assign contrastive embedding vectors to each time-frequency region of the spectrogram in order to implicitly predict the segmentation labels of the target spectrogram from the input mixtures. At test time, the clustering step "decodes" the segmentation implicit in the embeddings by optimizing K-means with respect to the unknown assignments. Preliminary experiments on single channel mixtures from multiple speakers show that a speaker-independent model trained on two-speaker mixtures can improve signal quality for mixtures of held-out speakers by an average of 6dB.

The MERL/SRI System for the 3rd CHiME Challenge Using Beamforming, Robust Feature Extraction and Advanced Speech Recognition

Citation: Hori, T.; Chen, Z.; Erdogan, H.; Hershey, J.R.; LeRoux, J.; Mitra, C.; Watanabe, S., "The MERL/SRI System for the 3rd CHiME Challenge Using Beamforming, Robust Feature Extraction and Advanced Speech Recognition", *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, DOI: 10.1109/ASRU.2015.7404833, pp. 475-481, December 2015.

Contacts: Takaaki Hori, John R. Hershey, Jonathan Le Roux, Shinji Watanabe

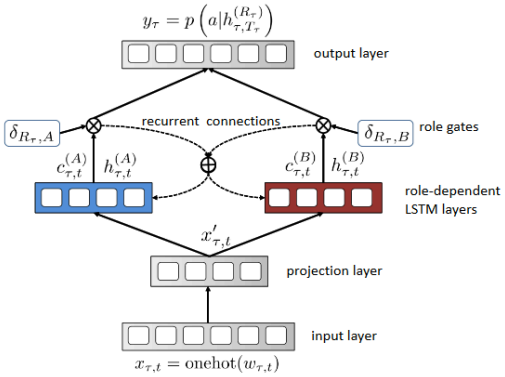


This paper introduces the MERL/SRI system designed for the 3rd CHiME speech separation and recognition challenge (CHiME-3). Our proposed system takes advantage of recurrent neural networks (RNNs) throughout the model from the front speech enhancement to the language modeling. In addition, two proposed noise-robust feature extraction methods are used with the beam formed signal. The features are used for decoding in speech recognition systems with deep neural network (DNN) based acoustic models and large-scale RNN language models to achieve high recognition accuracy in noisy environments. Results on the CHiME-3 benchmark show that the full cadre of techniques substantially reduced the word error rate (WER). Combining hypotheses from different robust-feature systems ultimately achieved 9.10% WER for the real test data, a 72.4% reduction relative to the baseline of 32.99% WER.

Context Sensitive Spoken Language Understanding Using Role Dependent LSTM Layers

Citation: Hori, C.; Hori, T.; Watanabe, S.; Hershey, J.R., "Context Sensitive Spoken Language Understanding Using Role Dependent LSTM Layers", *NIPS Workshop on Machine Learning for Spoken Language Understanding and Interaction*, December 2015

Contacts: Chiori Hori, Takaaki Hori, Shinji Watanabe, John R. Hershey

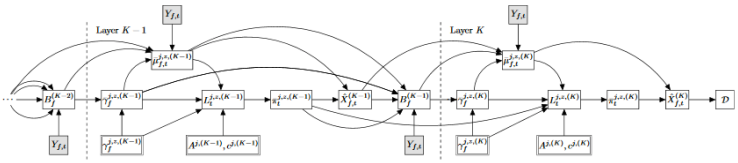


To understand speaker intentions accurately in a dialog, it is important to consider the sentence in the context of the surrounding sequence of dialog turns. In this study, we use long short-term memory (LSTM) recurrent neural networks (RNNs) to train a context sensitive model to predict sequences of dialog concepts from the spoken word sequences. In this model, words of each utterance are input one at a time, and concept tags are output at the end of each utterance. The model is trained from human-to-human dialog data annotated with concept tags representing client and agent intentions for a hotel reservation task. The LSTM layers jointly represent both the context within each utterance, and the context within the dialog. The different roles of client and agent are modeled by switching between role-dependent layers. To evaluate the performance of our models, we compared label accuracies using Logistic Regression (LR) and LSTMs. The results show 70.8% for LR, 72.4% for LR w/ word2vec, 78.8% for context sensitive LSTMs, and 84.0% for role dependent LSTMs.

Deep Unfolding for Multichannel Source Separation

Citation: Wisdom, S.; Hershey, J.R.; Le Roux, J.; Watanabe, S., "Deep Unfolding for Multichannel Source Separation", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2016.7471649, pp. 121-125, March 2016.

Contacts: John R. Hershey, Jonathan Le Roux, Shinji Watanabe

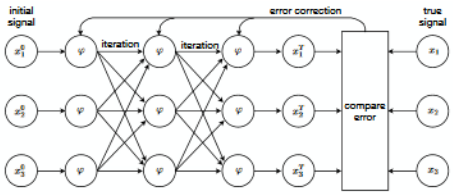


Deep unfolding has recently been proposed to derive novel deep network architectures from model-based approaches. In this paper, we consider its application to multichannel source separation. We unfold a multichannel Gaussian mixture model (MCGMM), resulting in a deep MCGMM computational network that directly processes complex-valued frequency-domain multichannel audio and has an architecture defined explicitly by a generative model, thus combining the advantages of deep networks and model-based approaches. Experiments on source separation for multichannel mixtures of two simultaneous speakers show that the deep MCGMM leads to improved performance with respect to the original MCGMM model.

Learning Optimal Nonlinearities for Iterative Thresholding Algorithms

Citation: Kamilov, U.S.; Mansour, H., "Learning Optimal Nonlinearities for Iterative Thresholding Algorithms", *IEEE Signal Processing Letters*, DOI: 10.1109/LSP.2016.2548245, ISSN: 1070-9908, Vol. 23, pp. 747-751, March 2016.

Contacts: Ulugbek S. Kamilov, Hassan Mansour

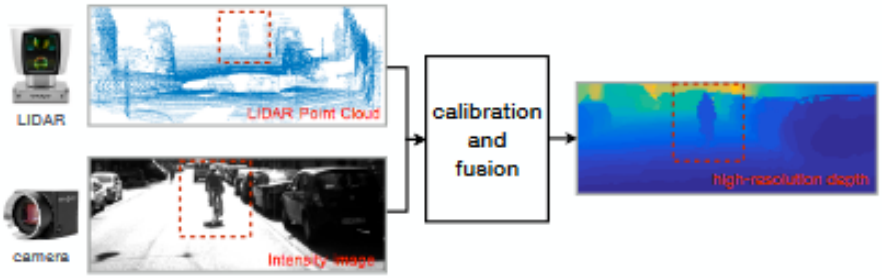


Iterative shrinkage/thresholding algorithm (ISTA) is a well-studied method for finding sparse solutions to ill posed inverse problems. In this letter, we present a data-driven scheme for learning optimal thresholding functions for ISTA. The proposed scheme is obtained by relating iterations of ISTA to layers of a simple feedforward neural network and developing a corresponding error backpropagation algorithm for fine-tuning the thresholding functions. Simulations on sparse statistical signals illustrate potential gains in estimation quality due to the proposed data adaptive ISTA.

Autocalibration of LIDAR and Optical Cameras via Edge Alignment

Citation: Castorena, J.; Kamilov, U.S.; Boufounos, P.T., "Autocalibration of LIDAR and Optical Cameras via Edge Alignment", *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP),* DOI: 10.1109/ICASSP.2016.7472200, pp. 2862-2866, March 2016.

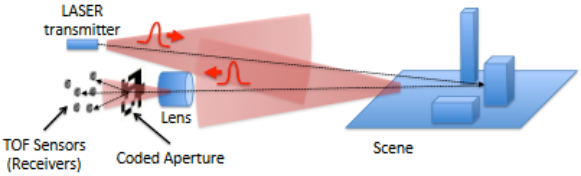
Contacts: Ulugbek S. Kamilov, Petros T. Boufounos



We present a new method for joint automatic extrinsic calibration and sensor fusion for a multimodal sensor system comprising a LIDAR and an optical camera. Our approach exploits the natural alignment of depth and intensity edges when the calibration parameters are correct. Thus, in contrast to a number of existing approaches, we do not require the presence or identification of known alignment targets. On the other hand, the characteristics of each sensor modality, such as sampling pattern and information measured, are significantly different, making direct edge alignment difficult. To overcome this difficulty, we jointly fuse the data and estimate the calibration parameters. In particular, the joint processing evaluates and optimizes both the quality of edge alignment and the performance of the fusion algorithm using a common cost function on the output. We demonstrate accurate calibration in practical configurations in which depth measurements are sparse and contain no reflectivity information. Experiments on synthetic and real data obtained with a three-dimensional LIDAR sensor demonstrate the effectiveness of our approach.

Coded Aperture Compressive 3-D LIDAR

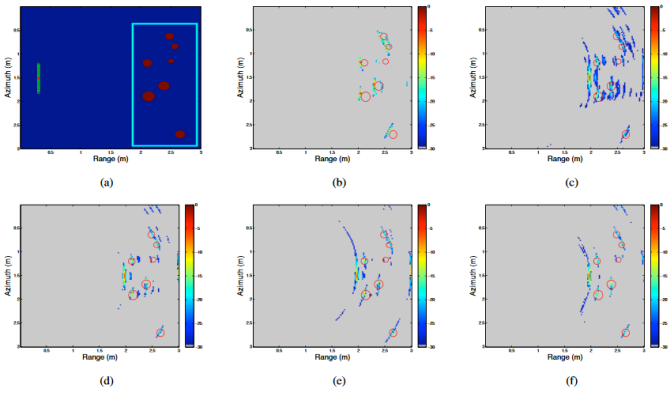
Citation: Kadambi, A.; Boufounos, P.T., "Coded Aperture Compressive 3-D LIDAR", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2015.7178153, pp. 1166-1170, April 2015.
Contacts: Petros T. Boufounos



Continuous improvement in optical sensing components, as well as recent advances in signal acquisition theory provide, a great opportunity to reduce the cost and enhance the capabilities of depth sensing systems. In this paper we propose a new depth sensing architecture that exploits a fixed coded aperture to significantly reduce the number of sensors compared to conventional systems. We further develop a modeling and reconstruction framework, based on model-based compressed sensing, which characterizes a large variety of depth sensing systems. Our experiments demonstrate that it is possible to reduce the number of sensors by more than 85%, with negligible reduction on the sensing quality.

Multipath Removal by Online Blind Deconvolution in Through-the-Wall-Imaging

Citation: Mansour, H.; Kamilov, U.S., "Multipath Removal by Online Blind Deconvolution in Through-the-Wall-Imaging", *IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP),* DOI: 10.1109/ICASSP.2016.7472249, pp. 3106-3110, March 2016.
Contacts: Hassan Mansour, Ulugbek S. Kamilov

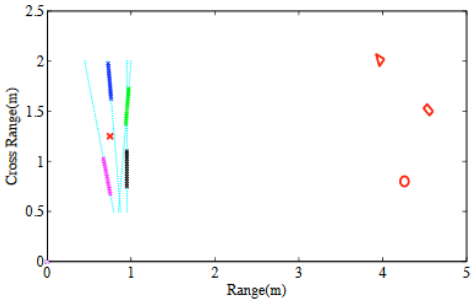


In this paper, we propose an online radar imaging scheme that recovers a sparse scene and removes the multipath ringing induced by the front wall in a Through-the-Wall-Imaging (TWI) system without prior knowledge of the wall parameters. Our approach uses online measurements obtained from individual transmitter-receiver pairs to incrementally build the primary response of targets behind the front wall and find a corresponding delay convolution operator that generates the multi-path reflections available in the received signal. In order to perform online sparse imaging while removing wall clutter reflections, we developed a deconvolution extension of the Sparse Randomized Kaczmarz (SRK) algorithm that finds sparse solutions to under- and over-determined linear systems of equations. Our scheme allows for imaging with nonuniformly spaced antennas by building an explicit delay-and-sum imaging operator for each new measurement. We test our approach on a simple FDTD simulated room with internal targets and demonstrate that our method successfully eliminates multipath reflections while correctly locating the targets.

Sparsity-Driven Distributed Array Imaging

Citation: Liu, D.; Kamilov, U.S.; Boufounos, P.T., "Sparsity-Driven Distributed Array Imaging", *IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP),* DOI: 10.1109/CAMSAP.2015.7383831, pp. 441-444, December 2015

Contacts: Dehong Liu, Ulugbek S. Kamilov, Petros T. Boufounos

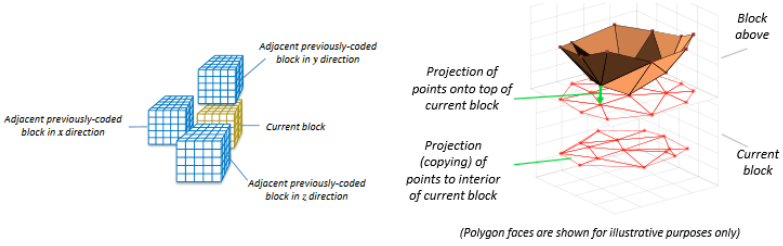


We consider multi-static radar with a single transmitter and multiple, spatially distributed, linear sensor arrays, imaging an area with several targets. Assuming that the location and orientation of all the sensor arrays is known and that all measurements are synchronized, we develop compressive sensing based methods to improve imaging performance.
Our approach imposes sparsity on the complex-valued reconstruction of the region of interest, with the non-zero coefficients corresponding to the imaged targets. Compared to conventional delay-and-sum approaches, which typically exhibit aliasing and ghosting artifacts due to the distributed small-aperture arrays, our sparsity-driven methods improve the imaging performance and provide high resolution. We validate our methods through numerical experiments on simulated data.

Point Cloud Attribute Compression Using 3-D Intra Prediction and Shape-Adaptive Transforms

Citation: Cohen, R.A.; Tian, D.; Vetro, A., "Point Cloud Attribute Compression Using 3-D Intra Prediction and Shape-Adaptive Transforms", *Data Compression Conference (DCC)*, March 2016.

Contacts: Robert A. Cohen, Dong Tian, Anthony Vetro



With the increased proliferation of applications using 3-D capture technologies for applications such as virtual reality, mobile mapping, scanning of historical artifacts, and 3-D printing, representing these kinds of data as 3-D point clouds has become a popular method for storing and conveying the data independently of how it was captured. A point cloud consists of a set of coordinates indicating the location of each point, along with one or more attributes such as color associated with each point. Because the size of point cloud data can be quite large, compression is needed to efficiently store or transmit this data. This paper, motivated by techniques currently being used for image and video coding, proposes methods using 3-D block-based prediction and transform coding to compress point cloud attributes. Experimental results using a modified shape-adaptive DCT tailored for use in 3-D point clouds and a benchmark using 3-D graph transforms are shown.

Overview of the Emerging HEVC Screen Content Coding Extension

Citation: Xu, J.; Joshi, R.; Cohen, R.A., "Overview of the Energing HEVC Screen Content Coding Extension", *IEEE Transactions on Circuits and Systems for Video Technology,* DOI: 10.1109/TCSVT.2015.2478706, ISSN: 1051-8215, Vol. 26, pp. 50-62, September 2015.

Contacts: Robert A. Cohen

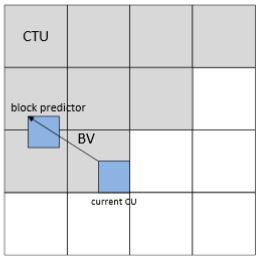


Fig. 2. Search area for IBC (shown in gray).

A Screen Content coding (SCC) extension to High Efficiency Video Coding (HEVC) is currently under development by the Joint Collaborative Team on Video Coding (JCT-VC), which is a joint effort from the ITU-T Video Coding Experts Group and the ISO/IEC Moving Picture Experts Group. The main goal of the HEVC screen content coding standardization effort is to enable significantly improved compression performance for videos containing a substantial amount of still or moving rendered graphics, text, and animation rather than, or in addition to, camera-captured content. This paper provides an overview of the technical features and characteristics of the current HEVCSCC test model and related coding tools, including intra block copy, palette mode, adaptive color transform, and adaptive motion vector resolution.

Overview of the Multiview and 3D Extensions of High Efficiency Video Coding

Citation: Tech, G.; Chen, Y.; Mueller, K.; Ohm, J.-R.; Vetro, A.; Wang, Y.-K., "Overview of the Multiview and 3D Extensions of High Efficiency Video Coding", *IEEE Transactions on Circuits and Systems for Video Technology*, DOI: 10.1109/TCSVT.2015.2477935, ISSN: 1051-8215, Vol.26, pp. 35-49, September 2015.

Contacts: Anthony Vetro

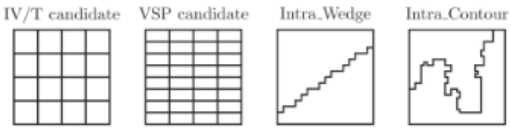


Fig. 3. Examples of possible sub-block partitions (SBPs) of a 32×32 PB.

The High Efficiency Video Coding standard has recently been extended to support efficient representation of multiview video and depth-based 3D video formats. The multiview extension, MV-HEVC, allows efficient coding of multiple camera views and associated auxiliary pictures, and can be implemented by reusing single-layer decoders without changing the block-level processing modules since block-level syntax and decoding processes remain unchanged. Bit rate savings compared to HEVC simulcast are achieved by enabling the use of inter-view references in motion-compensated prediction. The more advanced 3D video extension, 3D-HEVC, targets a coded representation consisting of multiple views and associated depth maps, as required for generating additional intermediate views in advanced 3D displays. Additional bit rate reduction compared to MV-HEVC is achieved by specifying new block-level video coding tools, which explicitly exploit statistical dependencies between video texture and depth, and specifically adapt to the properties of depth maps. The technical concepts and features of both extensions are presented in this paper.

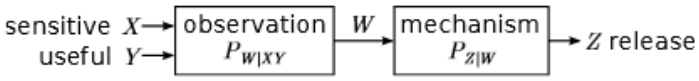
Graph Spectral Motion Segmentation Based on Motion Vanishing Point Analysis

Citation: Tian, D.; Kao, J.-Y.; Mansour, H.; Vetro, A., "Graph Spectral Motion Segmentation Based on Motion Vanishing Point Analysis", *IEEE International Workshop on Multimedia Signal Processing (MMSP)*, DOI: 10.1109/MMSP.2015.7340869, pp. 1-6, October 2015.
Contacts: Dong Tian, Hassan Mansour, Antony Vetro

Motion segmentation relies on identifying coherent relationships between image pixels that are associated with motion vectors. However, perspective differences can often deteriorate the performance of conventional techniques. In this paper, we develop a motion segmentation scheme that utilizes the motion map of a single frame to identify motion representations based on motion vanishing points. Segmentation is achieved using graph spectral clustering where a novel graph is constructed using the motion representation distances in the motion vanishing point image associated with the image pixels. Experimental results show that the proposed graph spectral motion segmentation algorithm outperforms state-of-the-art methods for dense segmentation on image sequences with strong perspective effects using motion vectors between only two images.

On Privacy-Utility Tradeoffs for Constrained Data Release Mechanisms

Citation: Basciftci, Y.O.; Wang, Y.; Ishwar, P., "On Privacy-Utility Tradeoffs for Constrained Data Release Mechanisms", *IEEE Information Theory and Applications Workshop (ITA),* February 2016.
Contacts: Ye Wang



Privacy-preserving data release mechanisms aim to simultaneously minimize information-leakage with respect to sensitive data and distortion with respect to useful data. Dependencies between sensitive and useful data results in a privacy-utility tradeoff that has strong connections to generalized rate-distortion problems. In this work, we study how the optimal privacy-utility tradeoff region is affected by constraints on the data that is directly available as input to the release mechanism. In particular, we consider the availability of only sensitive data, only useful data, and both (full data). We show that a general hierarchy holds, that is, the tradeoff region given only the sensitive data is no larger than the region given only the useful data, which in turn is clearly no larger than the region given both sensitive and useful data. In addition, we determine conditions under which the tradeoff region given only the useful data coincides with that given full data. This is based on the common information between the sensitive and useful data.

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, various transportation systems (trains, elevators, cars), heating, ventilation, and air conditioning (HVAC) systems and solutions, and factory automation. 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 fields of statistical machine learning and data management aims to create accurate data-driven models of electromechanical and thermo dynamical systems, as well as models of complex natural and man-made phenomena such as road traffic and demand for electrical power. The rapidly increasing amount of available sensor data, popularly known as Big Data, necessitates the development of very scalable learning algorithms with computational complexity that is close to linear in the number of data records and measured variables.

Decision optimization research emphasizes numerical methods for fast solution of continuous and discrete optimization problems, and finds 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. Many problems in transportation systems such as train operation optimization, group elevator scheduling, and route guidance for car navigation, can be reduced to planning and optimization problems. Energy consumption in buildings can be minimized by solving sequential decision and optimization problems, both at the level of individual air conditioning devices, as well as at the level of entire buildings.

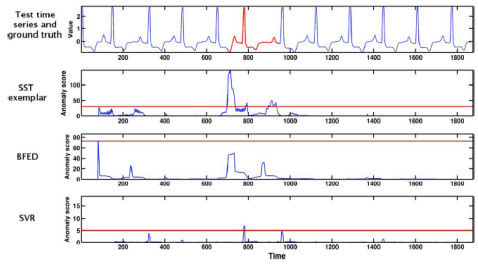
Recent Research

Exemplar Learning for Extremely Efficient Anomaly Detection in Real-Valued Time Series ... 58
Truncated Approximate Dynamic Programming with Task-Dependent Terminal Value 58
A Numerical Study of Refrigerant Dispersion in Single and Multiple Connected Spaces 59
Static Voltage Stability Detection Using Local Measurement for Microgrids in a … Network .. 59
Learning Positive Functions in a Hilbert Space 60
Multi-Dimensional Comparative Visualization for Patent Landscaping 60
Driver Prediction to Improve Interaction with In-Vehicle HMI 61
Mass Conserving Models of Vapor Compression Cycles 61
Modeling and Forecasting Self-Similar Power Load Due to EV Fast Chargers 62
Barycentric Quantization for Planning in Continuous Domains 62
Decomposition via ADMM for Scenario-Based Model Predictive Control 63
A Framework for Real-Time Near-Optimal Train Run-Curve Computation with … Limits 63
Flex-Grid: A Dynamic and Adaptive Configurable Power Distribution System 64
A Study of Refrigerant Dispersion in Occupied Spaces Under Parametric Variation 64

Exemplar Learning for Extremely Efficient Anomaly Detection in Real-Valued Time Series

Citation: Jones, M.J.; Nikovski, D.N.; Imamura, M.; Hirata, T., "Exemplar Learning for Extremely Efficient Anomaly Detection in Real-Valued Time Series", *Journal of Data Mining and Knowledge Discovery,* DOI: 10.1007/S10618-015-0449-3, ISSN: 1573-756X, pp. 1-28, March 2016

Contacts: Michael J. Jones, Daniel N. Nikovski

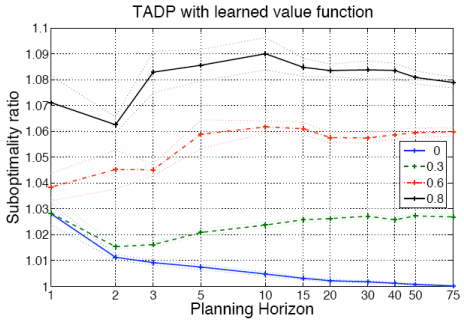


We investigate algorithms for efficiently detecting anomalies in real-valued one-dimensional time series. Past work has shown that a simple brute force algorithm that uses as an anomaly score the Euclidean distance between nearest neighbors of subsequences from a testing time series and a training time series is an effective anomaly detector. We present a new method based on summarizing the training time series with a small set of exemplars. The exemplars we use are feature vectors that capture both the high frequency and low frequency information in sets of similar subsequences of the time series. We show that this exemplar-based method is both much faster than even a very efficient implementation of the brute force method as well as a prediction-based method and also handles a wider range of anomalies. Our exemplar-based algorithm is able to process time series in minutes that would take other methods days to process.

Truncated Approximate Dynamic Programming with Task-Dependent Terminal Value

Citation: Farahmand, A.-M.; Nikovski, D.N.; Igarashi, Y.; Konaka, H., "Truncated Approximate Dynamic Programming with Task-Dependent Terminal Value", Association for the Advancement of Artificial Intelligence (AAAI) pp. 3123-3129, February 2016

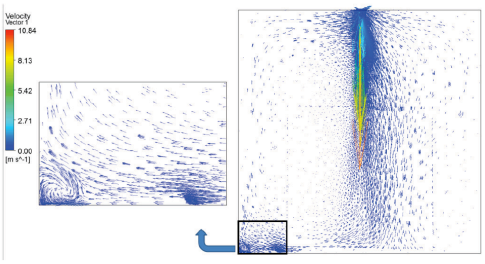
Contacts: Amir-massoud Farahmand, Daniel N. Nikovski



We propose a new class of computationally fast algorithms to find close to optimal policies for Markov Decision Processes (MDP) with large finite horizon T. The main idea is that instead of planning until the time horizon T, we plan only up to a truncated horizon H << T and use an estimate of the true optimal value function as the terminal value. Our approach of finding the terminal value function is to learn a mapping from an MDP to its value function by solving many similar MDPs during a training phase and fit a regression estimator. We analyze the method by providing an error propagation theorem that shows the effect of various sources of errors to the quality of the solution.

A Numerical Study of Refrigerant Dispersion in Single and Multiple Connected Spaces

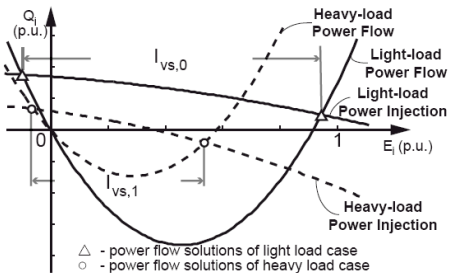
Citation: Laughman, C.R.; Nabi, S.; Grover, P., "A Numerical Study of Refrigerant Dispersion in Single and Multiple Connected Spaces", *ASHRAE Winter Conference*, January 2016
Contacts: Christopher R. Laughman, Saleh Nabi, Piyush Grover



While the possible impact of refrigerant leaks and subsequent dispersion in an occupied space pertains to a wide variety of applications, dynamic models that accurately describe dispersion phenomena in the built environment have not been extensively explored in the literature. This paper builds on work published in (Laughman, Nabi and Grover 2015) by assessing the performance of well-mixed models via a comparison to computational fluid dynamics simulations and studying the behavior of refrigerant dispersion in multiple connected spaces. Results indicate that the well-mixed models are not able to capture variation in the geometric parameters very accurately, and should be used cautiously, while the studies of the dynamics in multiple spaces highlights the importance of the location of ventilation sources and sinks.

Static Voltage Stability Detection Using Local Measurement for Microgrids in a Power Distriubiton Network

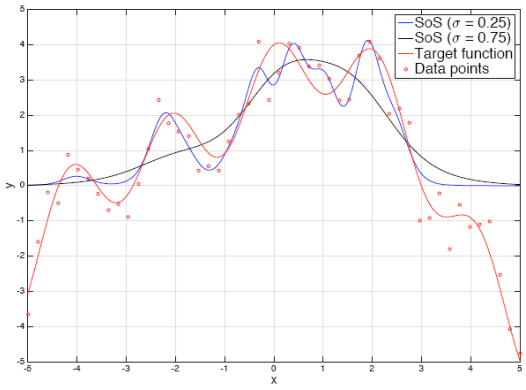
Citation: Wang, Z.; Sun, H.; Nikovski, D.N., "Static Voltage Stability Detection Using Local Measurement for Microgrids in a Power Distribution Network". IEEE conference on Decision and Control (CDC), DOI: 10.1109/CDC.2015,7402708, ISBN: 978-1-4799-7884-7, pp. 3254-3259, December 2015.
Contacts: Hongbo Sun, Daniel N. Nikovski



Microgrid, integrated with generation, storage, and load, either produces or consumes power. When power consumption increases at a microgrid's point of common coupling (PCC), the entire power distribution network is at risk of voltage collapse. Critical load impedance and continuation power flow are currently used to assess static voltage stability in power systems. Critical load impedance is derived based on a Thevenin equivalent circuit model, but information used to derive the equivalent circuit is usually not available and accurate parameter estimation takes time. Because continuation power flow uses approximation, this method is not accurate unless close to voltage collapse. To predict impending voltage collapse for a microgrid, this paper introduces a static voltage stability detector that only uses local measurements available at the microgrid's PCC. A voltage stability index depicts the distance of microgrid's power consumption from voltage collapse.

Learning Positive Functions in a Hilbert Space

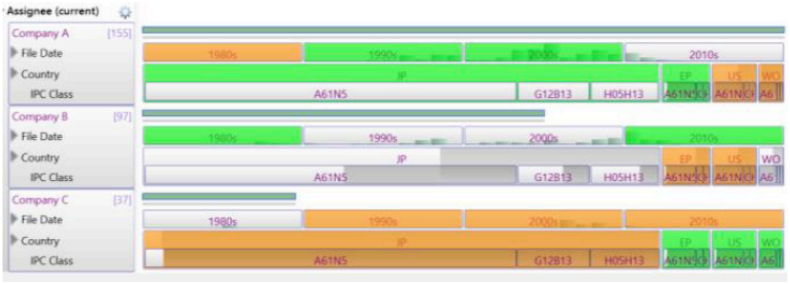
Citation: Bagnell, J.A.; Farahmand, A.-M., "Learning Positive Functions in a Hilbert Space", NIPS Workshop on Optimization for Machine Learning (OPT), December 2015
Contacts: Amir-massoud Farahmand



We develop a method for learning positive functions by optimizing over SoSK, a reproducing kernel Hilbert space subject to a Sum-of-Squares (SoS) constraint. This constraint ensures that only nonnegative functions are learned. We establish a new representor theorem that demonstrates that the regularized convex loss minimization subject to the SoS constraint has a unique solution and moreover, its solution lies on a finite dimensional subspace of an RKHS that is defined by data. Furthermore, we show how this optimization problem can be formulated as a semidefinite program. We conclude with an example of learning such functions

Multi-Dimensional Comparative Visualization for Patent Landscaping

Citation: Wittenburg, K.B.; Pekhteryev, G., "Multi-Dimensional Comparative Visualization for Patent Landscaping", BusinessVis15, IEEE VIS Workshop, October 2015
Contacts: Kent B. Wittenburg

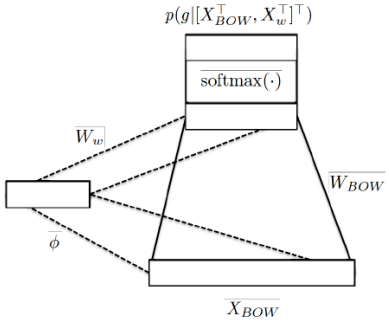


Patent landscaping is a significant activity for modern businesses. Understanding and taking action on information gleaned from analyses of intellectual property (IP) in specific product or technology domains is necessary for many business decisions. Examples include decisions about future product development, about how to guard against litigation threats from competitors, about how to set R&D priorities, about how to value IP for sale or licensing, and about how to target companies for mergers and acquisitions. This paper proposes a novel method for visualizing patent landscapes that supports the complex hierarchical, multi-dimensional, multi-typed data found in this domain. Our solution directly addresses the problem of how to provide high-level overviews of such a complex domain while at the same time providing enough detail to draw attention to the most significant areas of difference for further drill-down leading to actionable intelligence.

Driver Prediction to Improve Interaction with In-Vehicle HMI

Citation: Harsham, B.A.; Watanabe, S.; Esenther, A.; Hershey, J.R.; Le Roux, J.; Luan, Y.; Nikovski, D.N.; Potluru, V.K., "Driver Prediction to Improve Interaction with In-Vehicle HMI", *Workshop on DSP for In-Vehicle Systems and Safety,* October 2015.

Contacts: Bret A. Harsham, Shinji Watanabe, John R. Hershey, Jonathan Le Roux



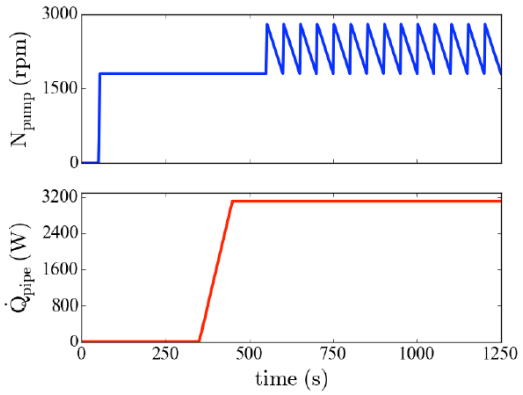
Recently there has been a trend toward increasing the capability of the in-vehicle interface in terms of access to information and complex controls. This has been accompanied by an increase in the complexity of the car Human Machine Interface [HMI]. At the same time, studies have shown that driver distraction can contribute to accidents. This paper provides some possible ways to reduce driver cognitive load by augmenting the interface. We use prediction of the driver's next action or intention in order to provide UI affordances for more quickly selecting actions. Two examples of this are presented: prediction of driver interaction with the car HMI based on the driving history, and prediction of driver intention from the driver speech. In the first example, we used signal processing techniques to extract meaningful features from vehicle CAN and history data, and then we used machine learning techniques to predict the driver's next action. In the second example, we used ASR and natural language processing to extract text features from driver speech, and predict user intention using a neural network and word embedding.

Mass Conserving Models of Vapor Compression Cycles

Citation: Laughman, C.R.; Qiao, H., "Mass Conserving Models of Vapor compression Cycles", International Modelica Conference, DOI: 10.3384/ecp15118759, ISSN: 1650-3686, ISBN: 978-91-7685-955-1, pp. 759-767, September 2015.

Contacts: Christopher R. Laughman, Hongtao Qiao

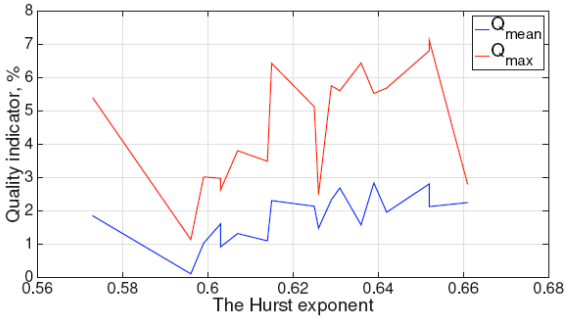
Many dynamic models of vapor compression systems experience nonphysical variations in the total refrigerant mass contained in the system when common modeling approaches are used. Rather than use the traditional state variables of pressure and specific enthalpy, the use of density as a state variable can eliminate these variations. A set of test models is developed in Modelica to study the effect of the state variable selection on the overall system charge, and results indicate that this alternative approach has significant benefits for maintaining a specified mass of refrigerant in the cycle.



Modeling and Forecasting Self-Similar Power Load Due to EV Fast Chargers

Citation: Korolko, N.; Sahinoglu, Z.; Nikovski, D.N., "Modeling and Forecasting Self-Similar Power Load Due to EV Fast Chargers", IEEE Transactions on Smart Grid, DOI: 10.1109/TSG.2015.2458852, ISSN: 1949-3053, Vol. 7, pp. 1620-1629, August 2015.

Contacts: Zafer Sahinoglu, Daniel N. Nikovski

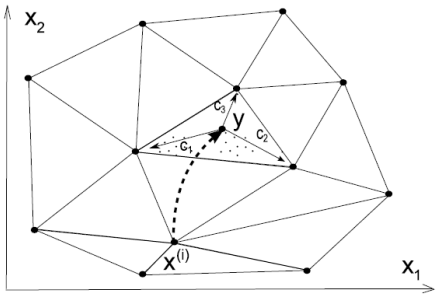


We consider modeling and prediction of power loads due to fast charging stations for plug-in electric vehicles. The first part of the project is to simulate work of a fast charger activity by exploiting empirical data that characterize EV user behavior. The second part describes the time series obtained by this simulator and its properties. We show that the power load aggregated over a number of fast chargers (after de-seasonalizing and elimination of the linear trend) is a self-similar process with the Hurst parameter $0.57 < H < 0.67$, where H varies depending on the multiplexing level. The main contribution of the paper is empirical evidence that a fitted fractional autoregressive integrated moving average (fARIMA) model taking into account self-similarity of the load time series can yield high quality short-term forecasts when H is large enough. Namely, the fitted fARIMA model uniformly outperforms regular ARIMA algorithms in terms of root-mean-square error for predictions with time horizon up to 120 minutes for H greater than or equal to 0.639. Moreover, we show that the fARIMA advantage on average grows as a function of the Hurst exponent H.

Barycentric Quantization for Planning in Continuous Domains

Citation: Nikovski, D.N., "Barycentric Quantization for Planning in Continuous Domains", AI Communications, DOI: 10.3233/AIC-150675, Vol. 28, pp. 539-551, July 2015

Contacts: Daniel N. Niknovski

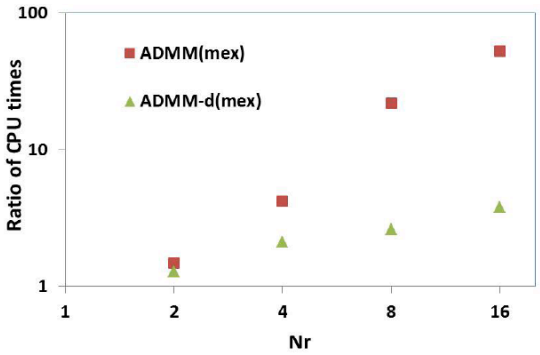


We consider the class of planning and sequential decision making problems where the state space has continuous components, but the available actions come from a discrete set, and argue that a suitable approach for solving them could involve an appropriate quantization scheme for the continuous state variables, followed by approximate dynamic programming. We propose one such scheme based on barycentric approximations that effectively converts the continuous dynamics into a Markov decision process, and demonstrate that it can be viewed both as an approximation to the continuous dynamics, as well as a value function approximator over the continuous domain.

Decomposition via ADMM for Scenario-Based Model Predictive Control

Citation: Kang, J.; Raghunathan, A.U.; Di Cairano, S., "Decomposition via ADMM for Scenario-Based Model Predictive Control", American Control Conference (ACC), DOI: 10.1109/ACC.2015.7170904, ISBN: 978-1-4799-8685-9, pp. 1246-1251, July 2015

Contacts: Arvind U. Raghunathan, Stefano Di Cairano

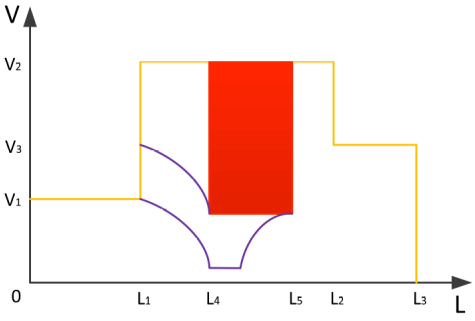


We present a scenario-decomposition based Alternating Direction Method of Multipliers (ADMM) algorithm for the efficient solution of scenario-based Model Predictive Control (MPC) problems which arise for instance in the control of stochastic systems. We duplicate the variables involved in the non-anticipativity constraints, which allows developing an ADMM algorithm in which the computations scale linearly in the number of scenarios. Further, the decomposition allows for using different values of the ADMM step size parameter for each scenario. We provide convergence analysis and derive the optimal selection of the parameter for each scenario.

A Framework for Real-Time Near-Optimal Train Run-Curve Computation with Dynamic Travel Time and Speed Limits

Citation: Xu, J.; Nikovski, D.N., "A Framework for Real-Time Near-Optimal Train Run-Curve Computation with Dynamic Travel Time and Speed Limits", American Control Conference (ACC), DOI: 10.1109/ACC.2015.7170790, ISBN: 978-1-4799-9-8685-9, pp. 533-540, July 2015

Contacts: Daniel N. Nikovski

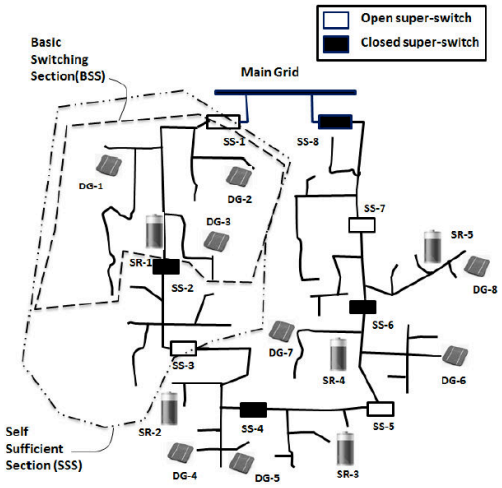


This paper studies the problem of generating the most energy efficient run-curves subject to given travel time requirements. The target is to provide a train with the ability to quickly adjust its run curve according to different travel time requirements and speed limits along the track before departing a terminal. Using a train model considering train length, varying track gradient and speed limit profile, the optimal run-curve problem is formulated as a bi-criteria optimization problem that minimizes weighted energy consumption and weighted travel time. By selecting appropriate weight values, the optimization problem generates a run-curve with near-optimal energy consumption. We propose a two-stage procedure framework, which includes an off-line stage and a real-time stage. A series of geometric relations between weight in the objective function and travel time are derived. The actual run-curves are generated in the real-time stage using approximate dynamic programming.

Flex-Grid: A Dynamic and Adaptive Configurable Power Distribution System

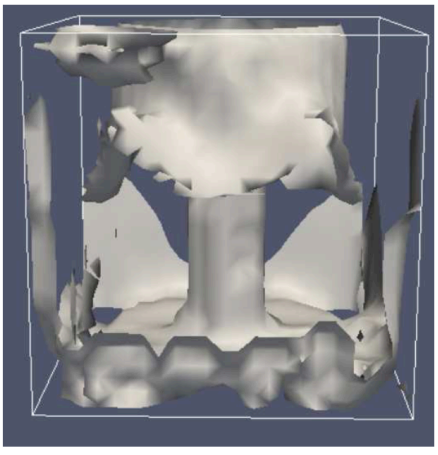
Citation: Sun, H.; Wang, Y.; Nikovski, D.N.; Zhang, J., "Flex-Grid: A Dynamic and Adaptive Configurable Power Distribution System", IEEE Eindhoven PowerTech, DOI: 10.1109/PTC.2015.7232488, pp. 1-6, June 2015
Contacts: Hongbo Sun, Daniel N. Nikovski, Jinyun Zhang

This paper proposes a new configuration of distribution system, Flex-Grid that dynamically and adaptively re-configures in real-time to maximally utilize the renewables, improve energy efficiency, reliability and power quality, particularly if the system includes distributed generations and energy storages. A multi-objective optimal scheduling method is provided to partition the system into self-sufficient sections through optimally combination of adjacent basic switching sections. The method uses two storage based transient security indices, storage compensation power margin and storage compensation energy margin to evaluate the transient stability margin of distribution system when subject to large unexpected load deviations.



A Study of Refrigerant Dispersion in Occupied Spaces Under Parametric Variation

Citation: Laughman, C.R.; Grover, P.; Nabi, S., "A Study of Refrigerant Dispersion in Occupied Spaces Under Parametric Variation", ASHRAE Annual Conference, Vol. 121, June 2015
Contacts: Christopher R. Laughman, Piyush Grover, Saleh Nabi



While an understanding of the dispersion of refrigerant in occupied spaces is important to ASHRAE Standard 15-2010's objective of ensuring the safety of occupants for spaces in which HVAC&R systems are installed, only simplified models are generally used to describe refrigerant leakage phenomena because of their complexity. This paper describes some studies of the transient refrigerant dispersion behavior from variations in the leakage rate, the exhaust ventilation rate, and the height of a wall undercut that could be used to develop improved models of the dynamics of refrigerant leaks. The results indicate that well-mixed models do not accurately describe the refrigerant distribution in many cases because of stratification, and that this stratification may be used in tandem with vent placement to ensure that refrigerant concentration levels do not exceed safety limits.

Computer Vision

The research in the Computer Vision 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.

For many years, MERL has applied machine-learning methods to imaging problems of detection, classification, segmentation and understanding. A decade ago, the Viola-Jones algorithm for face detection was a good example. More recently we have been applying deep learning for semantic scene labeling and people detection/re-identification. We have freely blended our research in 3D and machine learning to enable learning of the most effective features to use in 3D detection and estimation tasks.

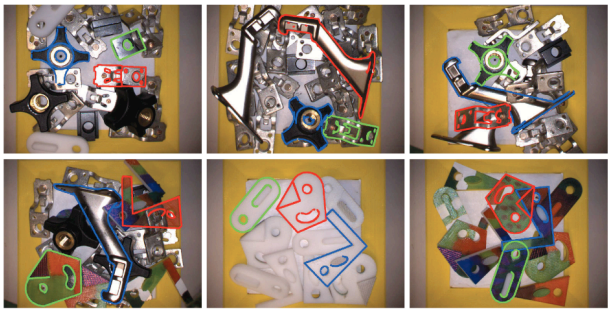
Recent Research

Fast Object Localization and Pose Estimation in Heavy Clutter for Robotic Bin Picking..... 66
Monocular Visual Odometry and Dense 3D Reconstruction for On-Road Vehicles 66
Unsupervised Network Pretraining via Encoding Human Design 67
Point-Plane SLAM for Hand-Held 3D Sensors 67
Semantic Classification of Boundaries from an RGBD Image 68
Layered Interpretation of Street View Images 68
User-Guided Dimensional Analysis of Indoor Scenes Using Depth Sensors..... 69
Deep Hierarchical Parsing for Semantic Segmentation..... 69
An Improved Deep Learning Architecture for Person Re-Identification 70
High Accuracy NC Milling Simulation Using Composite Adaptively Sampled Distance Fields 70
Real-time Head Pose and Facial Landmark Estimation from Depth Images Using …..... 71
Line-Sweep: Cross-Ratio For Wide-Baseline Matching and 3D Reconstruction 71
Analysis of Shape Assumptions in 3D Reconstruction of Retina from Multiple Fundus Images 72
Fast Plane Extraction in Organized Point Clouds Using Agglomerative Hierarchical Clustering72

Fast Object Localization and Pose Estimation in Heavy Clutter for Robotic Bin Picking

Citation: Liu, M.-Y.; Tuzel, O.; Veeraraghavan, A.; Taguchi, Y.; Marks, T.K.; Chellappa, R., "Fast Object Localization and Pose Estimation in Heavy Clutter for Robotic Bing Picking", *The International Journal of Robotics Research*, May 2012

Contacts: Ming-Yu Liu, Tim K. Marks, Yuichi Taguchi, C. Oncel Tuzel

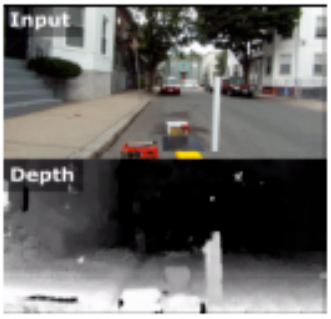


We present a practical vision-based robotic bin-picking system that performs detection and 3D pose estimation of objects in an unstructured bin using a novel camera design, picks up parts from the bin, and performs error detection and pose correction while the part is in the gripper. Two main innovations enable our system to achieve real-time robust and accurate operation. First, we use a multi-flash camera that extracts robust depth edges. Second, we introduce an efficient shape-matching algorithm called fast directional chamfer matching (FDCM), which is used to reliably detect objects and estimate their poses. FDCM improves the accuracy of chamfer matching by including edge orientation. It also achieves massive improvements in matching speed using line-segment approximations of edges, a 3D distance transform, and directional integral images. FDCM is up to two orders of magnitude faster than the previous methods.

Monocular Visual Odometry and Dense 3D Reconstruction for On-Road Vehicles

Citation: Zhu, M.; Ramalingam, S.; Taguchi, Y.; Garaas, T.W., "Monocular Visual Odometry and Dense 3D Reconstruction for On-Road Vehicles", *European Conference on Computer Vision (ECCV)*, Vol. 7584, 2012, pp. 596-606, October 2012

Contacts: Srikumar Ramalingam, Yuichi Taguchi



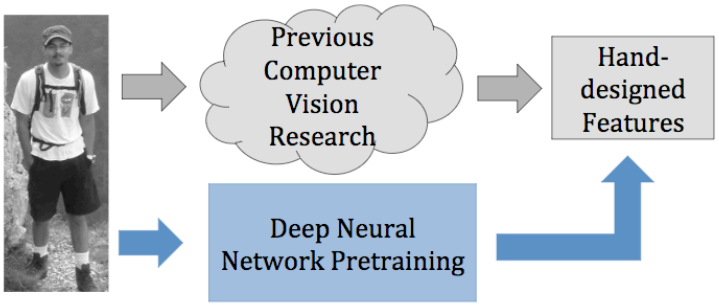
(c)

More and more on-road vehicles are equipped with cameras each day. This paper presents a novel method for estimating the relative motion of a vehicle from a sequence of images obtained using a single vehicle-mounted camera. In this paper, we show that the planar 2-point motion estimation can be solved analytically using a single quadratic equation. Although 2-point motion estimation generates visually accurate on-road vehicle-trajectory, the motion is not precise enough to perform dense 3D reconstruction due to the non-planarity of roads. Thus we use a 2-point relative motion algorithm for the initial images followed by 3-point 2D-to-3D camera pose estimation for the subsequent images. Using this hybrid approach, we generate accurate motion estimates for a plane-sweeping algorithm that produces dense depth maps for obstacle detection applications.

Unsupervised Network Pretraining via Encoding Human Design

Citation: Liu, M.-Y.; Mallya, A.; Tuzel, C.O.; Chen, X., "Unsupervised Network Pretraining via Encoding Human Design", *IEEE Winter Conference on Applications of Computer Vision (WACV)*, DOI: 10.1109/WACV.2016.7477698, pp. 1-9, March 2016

Contact: Ming-Yu Liu



Over the years, computer vision researchers have spent an immense amount of effort on designing image features for the visual object recognition task. We propose to incorporate this valuable experience to guide the task of training deep neural networks. Our idea is to pretrain the network through the task of replicating the process of hand-designed feature extraction. By learning to replicate the process, the neural network integrates previous research knowledge and learns to model visual objects in a way similar to the hand-designed features. In a succeeding finetuning step, it further learns object-specific representations from labeled data and this boosts its classification power.

Point-Plane SLAM for Hand-Held 3D Sensors

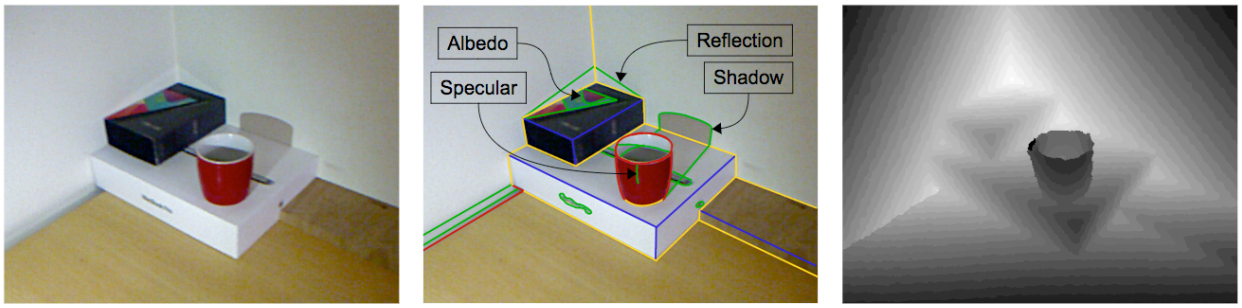
Citation: Taguchi, Y.; Jian, Y-D; Ramalingam, S.; Feng, C., "Point-Plane SLAM for Hand-Held 3D Sensors", *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA.2013.6631318, ISSN: 1050-4729, ISBN: 978-1-4673-5641-1, pp. 5182-5189, May 2013

Contacts: Yuichi Taguchi, Chen Feng, Srikumar Ramalingam

We present a simultaneous localization and mapping (SLAM) algorithm for a hand-held 3D sensor that uses both points and planes as primitives. We show that it is possible to register 3D data in two different coordinate systems using any combination of three point/plane primitives (3 planes, 2 planes and 1 point, 1 plane and 2 points, and 3 points). In contrast to existing approaches that mainly use points for registration, our algorithm has the following advantages: (1) it enables faster correspondence search and registration due to the smaller number of plane primitives; (2) it produces plane-based 3D models that are more compact than point-based ones; and (3) being a global registration algorithm, our approach does not suffer from local minima or any initialization problems. Our experiments demonstrate real-time, interactive 3D reconstruction of indoor spaces using a hand-held Kinect sensor.

Semantic Classification of Boundaries from an RGBD Image

Citation: Soni, N.; Namboodiri, A.; Ramalingam, S.; Jawahar, C.V., "Semantic Classification of Boundaries from an RGBD Image", *British Machine Vision Conference (BMVC)*, DOI: 10.5244/C.29.114, ISBN: 1-901725.53-7, pp. 114.1-114.12, September 2015
Contact: Srikumar Ramalingam

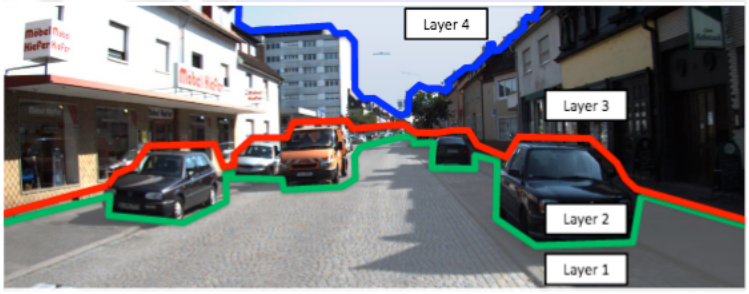


(a) RGB Image (b) Edge Types (c) Depth Map

The problem of labeling the edges present in a single color image as convex, concave, and occluding entities is one of the fundamental problems in computer vision. Recently, it has been shown that this classification is not straightforward even using RGBD data. In this paper, we propose a novel algorithm using random forest for classifying edges into convex, concave and occluding entities. We release a data set with more than 500 RGBD images with pixel-wise ground labels. Our method produces promising results and achieves an F-score of 0.84.

Layered Interpretation of Street View Images

Citation: Liu, M.-Y.; Lin, A.; Ramalingam, S.; Tuzel, C.O., "Layered Interpretation of Street View Images", *Robotics: Science and Systems Conference (RSS)*, DOI: 10.15607/RSS.2015.XI.025, July 2015
Contacts: Ming-Yu Liu, Srikumar Ramalingam



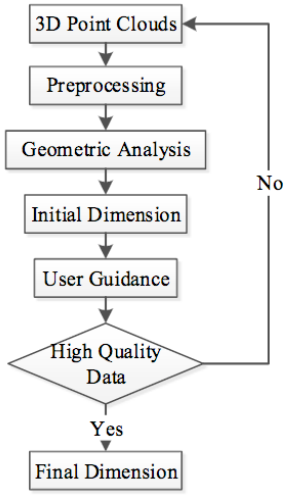
We propose a layered street view model to encode both depth and semantic information on street view images for autonomous driving. Recently, stixels, stix-mantics, and tiered scene labeling methods have been proposed to model street view images. We propose a 4-layer street view model, a compact representation over the recently proposed stix-mantics model. Our layers encode semantic classes like ground, pedestrians, vehicles, buildings, and sky in addition to the depths. The only input to our algorithm is a pair of stereo images. We use a deep neural network to extract the appearance features for semantic classes. We use a simple and an efficient inference algorithm to jointly estimate both semantic classes and layered depth values. Our method outperforms other competing approaches in Daimler urban scene segmentation dataset. Our algorithm is massively parallelizable, allowing a GPU implementation with a processing speed about 9 fps.

User-Guided Dimensional Analysis of Indoor Scenes Using Depth Sensors

Citation: Xiao, Y.; Feng, C.; Taguchi, Y.; Kamat, V.R., "User-Guided Dimensional Analysis of Indoor Scenes Using Depth Sensors", *International Symposium on Automation and Robotics in Construction and Mining (ISARC)*, June 2015

Contacts: Yuichi Taguchi, Chen Feng

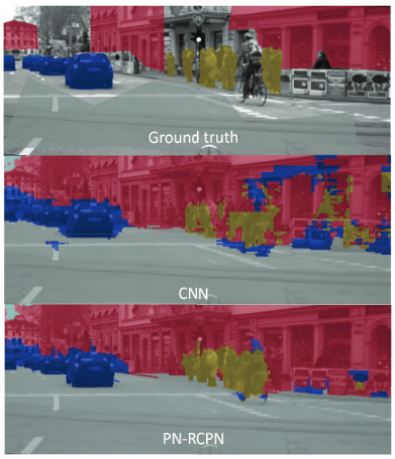
In many civil engineering tasks, dimensional analysis of environmental objects is significant for spatial analysis and decision-making. Tasks such as as-built geometry generation need to efficiently interpret the critical dimensions of specific objects (e.g., diameter of a pipe, width of an opening) in a potentially cluttered environment based on data gathered from different positions. This paper presents a user-guided dimensional analysis approach to automatically acquire geometric information from a single frame of a depth sensor. Firstly a depth sensor is used to capture three-dimensional (3D) point clouds of indoor scenes. Then by extracting planes and performing geometric analysis, the dimensional information of objects of interest is obtained from a single frame. Our user guidance system evaluates the quality of the current data and measurement provides interactive guidance for moving the sensor to acquire higher quality data, from which more accurate geometric measurements can be obtained.



Deep Hierarchical Parsing for Semantic Segmentation

Citation: Sharma, A.; Tuzel, C.O.; Jacobs, D., "Deep Hierarchical Parsing for Semantic Segmentation", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 1503.02725v2, June 2015

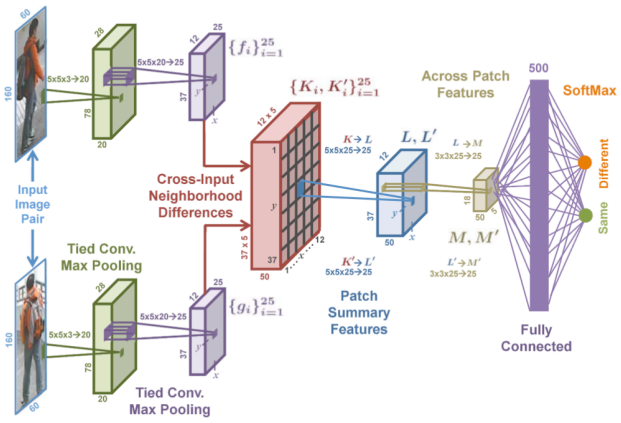
This paper proposes a learning-based approach to scene parsing inspired by the deep Recursive Context Propagation Network (RCPN). RCPN is a deep feed-forward neural network that utilizes the contextual information from the entire image, through bottom-up followed by top-down context propagation via random binary parse trees. This improves the feature representation of every super-pixel in the image for better classification into semantic categories. We analyze RCPN and propose two novel contributions to further improve the model. We first analyze the learning of RCPN parameters and discover the presence of bypass error paths in the computation graph of RCPN that can hinder contextual propagation. We propose to tackle this problem by including the classification loss of the internal nodes of the random parse trees in the original RCPN loss function. Secondly, we use an MRF on the parse tree nodes to model the hierarchical dependency present in the output. Both modifications provide performance boosts over the original RCPN and the new system achieves state-of-the-art performance on Stanford Background, SIFT-Flow and Daimler urban datasets.



An Improved Deep Learning Architecture for Person Re-Identification

Citation: Ahmed, E.; Jones, M.J.; Marks, T.K., "An Improved Deep Learning Architecture for Person Re-Identification", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2015.7299016, pp. 3908-3916, June 2015

Contacts: Michael J. Jones, Tim K. Marks

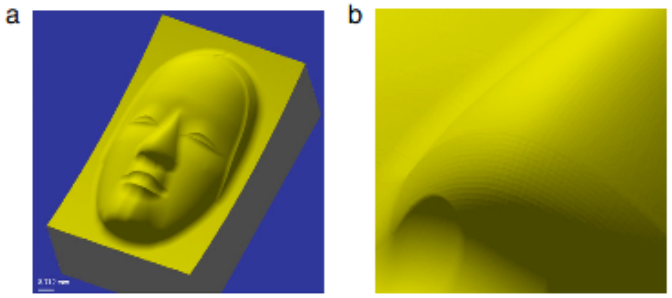


We propose a method for simultaneously learning features and a corresponding similarity metric for person re-identification. Given a pair of images as input, our network outputs a similarity value indicating whether the two input images depict the same person. Novel elements of our architecture include a layer that computes cross-input neighborhood differences, which capture local relationships between the two input images based on midlevel features from each input image. A high-level summary of he outputs of this layer is computed by a layer of patch summary features, which are then spatially integrated in subsequent layers. Our method significantly outperforms the state of the art on both a large data set (CUHK03) and a medium- sized data set (CUHK01).

High Accuracy NC Milling Simulation Using Composite Adaptively Sampled Distance Fields

Citation: Sullivan, A.; Erdim, H.; Perry, R.N.; Frisken, S.F., "High Accuracy NC Milling Simulation Using Composite Adaptively Sampled Distance Fields", Computer-Aided Design, Vol. 44, Issue 6, pp. 522-536, June 2012

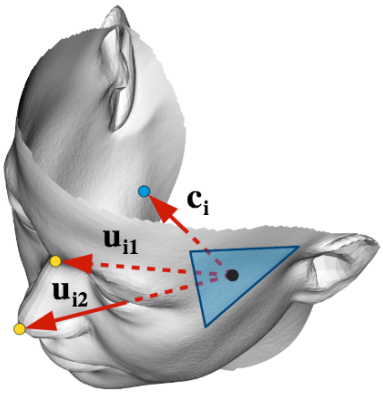
Contacts: Alan Sullivan, Ronald N. Perry



We describe a new approach to shape representation called a composite adaptively sampled distance field (composite ADF) and describe its application to NC milling simulation. In a composite ADF each shape is represented by an analytic or procedural signed Euclidean distance field and the milled workpiece is given as the Boolean difference between distance fields representing the original workpiece volume and distance fields representing the volumes of the milling tool swept along the prescribed milling path. The computation of distance field of the swept volume of a milling tool is handled by an inverted trajectory approach where the problem is solved in tool coordinate frame instead of a world coordinate frame.

Real-time Head Pose and Facial Landmark Estimation from Depth Images Using Triangular Surface Patch Features

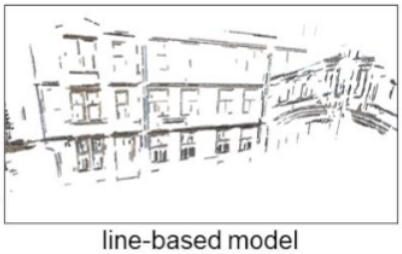
Citation: Papazov, C.; Marks, T.K.; Jones, M.J., "Real-time Head Pose and Facial Landmark Estimation from Depth Images Using Triangular Surface Patch Features", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2015.7299104, June 2015, pp. 4722-4730.
Contacts: Michael J. Jones, Tim K. Marks

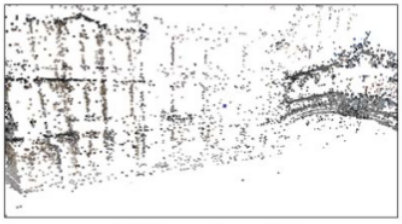


We present a real-time system for 3D head pose estimation and facial landmark localization using a commodity depth sensor. We introduce a novel triangular surface patch (TSP) descriptor, which encodes the shape of the 3D surface of the face within a triangular area. The proposed descriptor is viewpoint invariant, and it is robust to noise and to variations in the data resolution. Using a fast nearest neighbor lookup, TSP descriptors from an input depth map are matched to the most similar ones that were computed from synthetic head models in a training phase. The matched triangular surface patches in the training set are used to compute estimates of the 3D head pose and facial landmark positions in the input depth map. By sampling many TSP descriptors, many votes for pose and landmark positions are generated which together yield robust final estimates. We evaluate our approach on the publicly available Biwi Kinect Head Pose Database to compare it against state-of-the-art methods. Our results show a significant improvement in the accuracy of both pose and landmark location estimates while maintaining real-time speed.

Line-Sweep: Cross-Ratio For Wide-Baseline Matching and 3D Reconstruction

Citation: Ramalingam, S.; Antunes, M.; Snow, D.; Lee, G.H.; Pillai, S., "Line-Sweep: Cross-Ratio for Wide-Baseline Matching and 3D Reconstruction", *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR.2015.7298728, ISSN: 1063-6919, pp. 1238-1246, June 2015
Contacts: Srikumar Ramalingam


line-based model

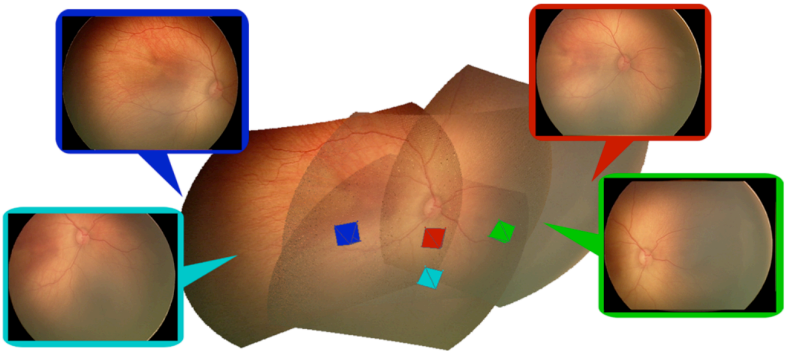

point-based model

We propose a simple and useful idea based on cross-ratio constraint for wide-baseline matching and 3D reconstruction. Most existing methods exploit feature points and planes from images. Lines have always been considered notorious for both matching and reconstruction due to the lack of good line descriptors. We propose a method to generate and match new points using virtual lines constructed using pairs of key points, which are obtained using standard feature point detectors. We use cross-ratio constraints to obtain an initial set of new point matches, which are subsequently used to obtain line correspondences. We develop a method that works for both calibrated and un-calibrated camera configurations.

Analysis of Shape Assumptions in 3D Reconstruction of Retina from Multiple Fundus Images

Citation: Ataer-Cansizoglu, E.; Taguchi, Y.; Kalpathy-Cramer, J.; Chiang, M.F.; Erdogmus, D., "Analysis of Shape Assumptions in 3D Reconstruction of Retina from Multiple Fundus Images", *IEEE International Symposium on Biomedical Imaging (ISBI)*, DOI: 10.1109/ISBI.2015.7164162, pp. 1502-1505, April 2015

Contacts: Yuichi Taguchi, Esra Ataer-Caniszoglu



Utilizing priors about the shape of retinal surface is important for accurate reconstruction. We present a detailed analysis of geometrical shape priors in the 3D reconstruction of retina. We first approximate the retinal surface either as a sphere inspired by the actual shape of the eyeball, or as a plane inspired by the 2D mosaicing approaches. Based on this approximation, we perform an initial camera localization with a 2D-to-3D registration procedure. Then, parameters of the surface and the camera poses are refined through a nonlinear least squares optimization using different shape priors. The resulting 3D model and camera poses can be used for intuitively visualizing the retinal images with a model-guided browsing interface.

Fast Plane Extraction in Organized Point Clouds Using Agglomerative Hierarchical Clustering

Citation: Feng, C., Taguchi, Y., Kamat, V., "Fast Plane Extraction in Organized Point Clouds Using Agglomerative Hierarchical Clustering", *IEEE International Conference on Robotics and Automation (ICRA),* DOI: 10.1109/ICRA.2014.6907776, May 2014, pp. 6218-6225.

Contacts: Chen Feng, Yuichi Taguchi

We present a novel algorithm for reliably detecting multiple planes in real time in organized point clouds obtained from devices such as Kinect sensors. By uniformly dividing such a point cloud into non-overlapping groups of points in the image space, we first construct a graph whose node and edge represent a group of points and their neighborhood respectively. We then perform an agglomerative hierarchical clustering on this graph to systematically merge nodes belonging to the same plane until the plane fitting mean squared error exceeds a threshold. Finally we refine the extracted planes using pixel-wise region growing. Our experiments demonstrate that the proposed algorithm can reliably detect all major planes in the scene at a frame rate of more than 35Hz for 640x480 point clouds, which to the best of our knowledge is much faster than state-of-the-art algorithms.

Mechatronics

Mechatronics (mechanics + electronics) is a multidisciplinary field of engineering science combines mechanical engineering, electrical engineering, control engineering, dynamical systems and embedded computer systems.
The Mechatronics Group has expertise in multivariable, nonlinear, optimal & model predictive control theory, nonlinear estimation, nonlinear dynamical systems, mechanical design, thermofluid system dynamics, laser processing and sensing, and rapid prototyping. The business drivers for this R&D program are twofold. First, control of mechatronic systems is central to many areas of Mitsubishi Electric's business. Second, with the increasing power and decreasing cost of embedded computation and sensing technologies, there is the opportunity for innovation and synergy among researchers in the Mechatronics Group and other researchers in MERL's other research groups whose strengths include signal processing, computer and information technology.

Automatic control systems take real-time measurements of a system under control, process the information with a control algorithm, and apply the results of the calculation back to the system under control via actuators. Feedback is the central concept. MERL's research focuses on development of new control algorithms that provide higher performance than the state-of-the-art. Recent results include more energy efficient air conditioners and servomotors, more precise laser processing systems, smoother riding elevators, and low-fuel mission plans for space probes. MERL also conducts fundamental research to develop new control theory for general-purpose use, with a strong focus on model predictive control and nonlinear state and parameter estimation.

A dynamical system is one described by differential or difference equations. MERL's interest is to improve the performance of MELCO products and technology through the application of nonlinear dynamical systems theory. Applied research interests include mixing in fluids and thermofluid systems dynamics, and the design of minimum-fuel trajectories for space probes, both of which exploit nonlinearity and chaos in highly creative and deeply mathematical ways.

Recent Research

Numerical Decomposition of Symmetric Linear Systems 74
Reduced Complexity Control Design for Symmetric LPV Systems 74
Station-keeping and Momentum-management on Halo Orbits Around L2: … 75
Reference Governor for Network Control Systems Subject to Variable Time-Delay 75
Governor-Based Control for Rack-Wheel Coordination in Mechanically … Steering Systems.. 76
Model-Based Condition Monitoring for Lithium-Ion Batteries 76
Feedback Particle Filter: Application and Evaluation 77
A Real-Time Energy-Optimal Trajectory Generation Method for a Servomotor System 77
A Gradient-Based Approach for Optimal Plant Controller Co-Design 78
Model Predictive Control of Vapor Compression Systems 78
Design of Low Fuel Trajectory in Interior Realm as a Backup Trajectory for Lunar … 79
Realtime Setpoint Optimization with … Extremum Seeking for Vapor Compression Systems.. 79
Model Predictive Control for Simultaneous Station Keeping and … of Low-Thrust Spacecraft 80
Reference Tracking with Guaranteed Error Bound for Constrained Linear Systems 80

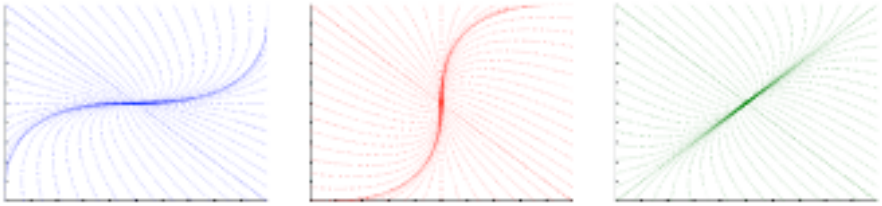
Numerical Decomposition of Symmetric Linear Systems

Citation: Danielson, C.; Bauer, S., "Numerical Decomposition of Symmetric Linear Systems", *IEEE Conference on Decision and Control (CDC),* DOI: 10.1109/CDC.2015.7502510, ISBN: 978-1-4799-7884-7, pp. 2061-2066, December 2015.
Contacts: Claus Danielson

This paper proposes a method for numerically decomposing symmetric linear systems. We define system symmetries as transformations of the inputs, outputs, and states that do not change the system behavior. We show that symmetric systems can be decomposed into decoupled subsystems. We provide an algorithm for performing this decomposition that uses the input-output symmetries and minimal realizations to calculate the decomposition.

Reduced Complexity Control Design for Symmetric LPV Systems

Citation: Danielson, C.; Di Cairano, S., "Reduced Complexity Control Design for Symmetric LPV Systems", *IEEE Conference on Decision and Control (CDC),* DOI: 10.1109/CDC.2015.7402088, ISBN: 978-1-4799-7884-7, pp. 72-77, December 2015.
Contacts: Claus Danielson, Stefano Di Cairano



(a) $f_1(x) = A_1 x$ (b) $f_2(x) = A_2 x$ (c) $f_3(x) = A_3 x$

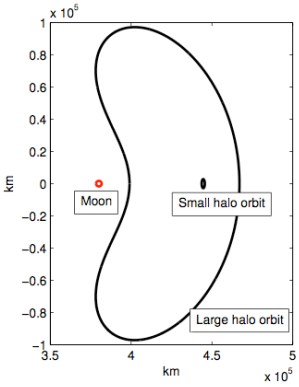
We use symmetry to reduce the computational complexity of designing parameter-dependent controllers and Lyapunov functions. We propose three complementary methods for exploiting symmetry to reduce the complexity. The first method uses symmetry to reduce the number of design variables. The second method uses symmetry to reduce the dimension of the design variables. And the third method reduces the number of linear matrix inequalities that the design variables must satisfy. We apply our reduced complexity control design to a building control problem. We show that, for this example, our method leads to an exponential decrease in the number of design variables and linear matrix inequalities.

Station-keeping and Momentum-management on Halo Orbits Around L2: Linear-quadratic Feedback and Model Predictive Control Approaches

Citation: Kalabic, U.V., Weiss, A., Di Cairano, S., Kolmanovsky, I.V., "Station-keeping and momentum-management on halo orbits around L2: Linear-quadratic feedback and model predictive control approaches", *AAS/AIAA Space Flight Mechanics Meeting,* January 2015.

Contacts: Uros V. Kalabic, Avishai Weiss, Stefano Di Cairano

The control of station-keeping and momentum-management is considered while tracking a halo orbit centered at the second Earth-Moon Lagrangian point. Multiple schemes based on linear-quadratic feedback control and model predictive control (MPC) is considered and it is shown that the method based on periodic MPC performs best for position tracking. The scheme is then extended to incorporate attitude control requirements and numerical simulations are presented demonstrating that the scheme is able to achieve simultaneous tracking of a halo orbit and dumping of momentum while enforcing tight constraints on pointing error.

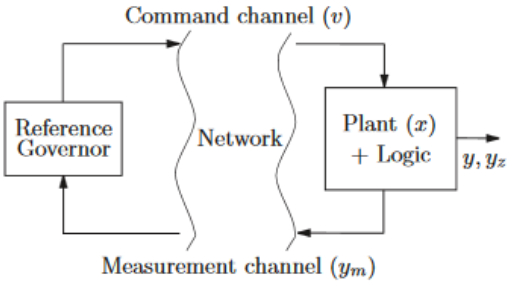


Reference Governor for Network Control Systems Subject to Variable Time-Delay

Citation: Di Cairano, S.; Kalabic, U.V.: Kolmanovsky, I.V., "Reference Governor for Network Control Systems Subject to Variable Time-Delay", *Automatica (Journal of IFAC),* DOI: 10.1016/j.automatica.2015.09.006, Vol. 62, pp. 77-86, December 2015

Contacts: Stefano Di Cairano, Uros V. Kalabic

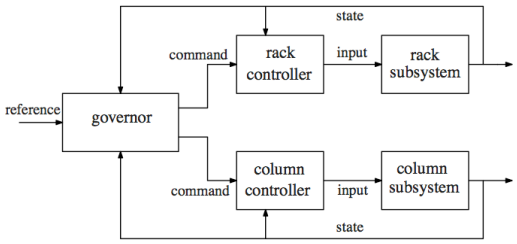
The handling of constraints in systems subject to variable time-delay is a challenging problem. It is particularly relevant to Network Control Systems (NCSs) in which a control system is remotely located with respect to the plant to be controlled. In this paper, we develop reference governors for controlling constrained systems subject to variable delays with a particular focus on the application to NCSs. In the proposed approach, which neither exploits nor depends on any explicit synchronization between the plant and the governor, the closed-loop dynamics are modeled by a sampled data system, for which input delays result in additive disturbances with magnitude proportional to the input rate of change. We first develop a network reference governor (netRG) that guarantees constraint enforcement and finite-time convergence for variable time-delay shorter than the sampling period. Then, we extend the network reference governor to the case of output feedback. Finally, we consider the case of long and potentially unbounded delay. The netRGs is evaluated in a case study of orientation control of a spacecraft with a flexible appendage.



Governor-Based Control for Rack-Wheel Coordination in Mechanically Decoupled Steering Systems

Citation: Zafeiropoulos, S., Di Cairano, S., "Governor-Based Control for Rack-wheel Coordination in Mechanically Decoupled Steering Systems", *IEEE Conference on Decision and Control (CDC),* DOI: 10.1109/CDC.2014.7040025, ISBN: 978-1-4799-7746-8, December 2014, pp. 4089-4094.

Contacts: Stefano Di Cairano

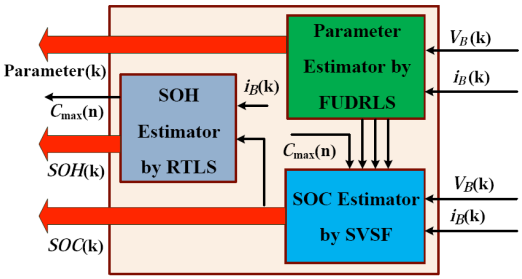


A mechanically decoupled steering system enables autonomous or semi-autonomous vehicle steering by independently actuating the vehicle wheels and the steering wheel. In semi-autonomous operation the steering system should be controlled such that the vehicle wheel angles track a reference signal provided by the trajectory planner rapidly and safely, while guaranteeing that a certain alignment is maintained between the steering wheel and the vehicle wheels to avoid loss of driver feel. We develop a controller for a mechanically decoupled steering system that can achieve this by coordinating the steering column and the steering rack actuators, while enforcing constraints on the motion of the vehicle wheels, on the interaction between the steering wheel with the driver, and on the relative motion between steering wheel and vehicle wheels.

Model-Based Condition Monitoring for Lithium-Ion Batteries

Citation: Kim, T.; Wang, Y.; Sahinoglu, Z.; Wada, T.; Hara, S.; Qiao, W., "Model-Based Condition Monitoring for Lithium-Ion Batteries", *Journal of Power Sources*, DOI: 10:1016/j.jpowsour.2015.03.184, Vol. 295, pp. 16-27, November 2015

Contacts: Yebin Wang, Zafer Sahinoglu

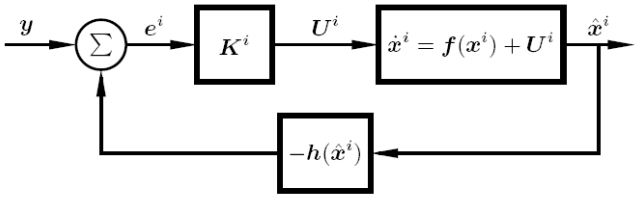


Condition monitoring for batteries involves tracking changes in physical parameters and operational states such as state of health (SOH) and state of charge (SOC), and is fundamentally important for building high-performance and safety-critical battery systems. A model-based condition monitoring strategy is developed in this paper for Lithium-ion batteries on the basis of an electrical circuit model incorporating hysteresis effect. It systematically integrates 1) a fast upper-triangular and diagonal recursive least squares algorithm for parameter identification of the battery model, 2) a smooth variable structure filter for the SOC estimation, and 3) a recursive total least squares algorithm for estimating the maximum capacity, which indicates the SOH. The proposed solution enjoys advantages including high accuracy, low computational cost, and simple implementation, and therefore is suitable for deployment and use in real-time embedded battery management systems (BMSs). Simulations and experiments validate effectiveness of the proposed strategy.

Feedback Particle Filter: Application and Evaluation

Citation: Berntorp, K., "Feedback Particle filter: Application and Evaluation", International Conference on Information Fusion (FUSION), pp. 1633-1640, July 2015.

Contacts: Karl Berntorp

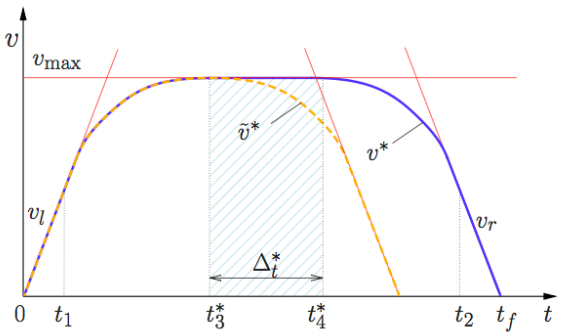


Recent research has provided several new methods for avoiding degeneracy in particle filters. These methods implement Bayes rule using a continuous transition between prior and posterior. The feedback particle filter (FPF) is one of them. The FPF uses feedback gains to adjust each particle according to the measurement, which is in contrast to conventional particle filters based on importance sampling. The gains are found as solutions to partial differential equations. This paper contains an evaluation of the FPF on two highly nonlinear estimation problems. The FPF is compared with conventional particle filters and the unscented Kalman filter. Sensitivity to the choice of the gains is discussed and illustrated. We demonstrate that with a sensible approximation of the exact gain, the FPF can decrease tracking errors with more than one magnitude while significantly improving the quality of the particle distribution.

A Real-Time Energy-Optimal Trajectory Generation Method for a Servomotor System

Citation: Wang, Y, Zhao, Y., Bortoff, S.A., Ueda, K., "A Real-Time Energy-Optimal Trajectory Generation Method for a Servomotor System", *IEEE Transactions on Industrial Electronics*, DOI: 10.1109/TIE.2014.2360077, ISSN: 0278-0046, Vol. 62, No. 2, pp. 1175-1188, September 2014

Contacts: Yebin Wang, Scott A. Bortoff



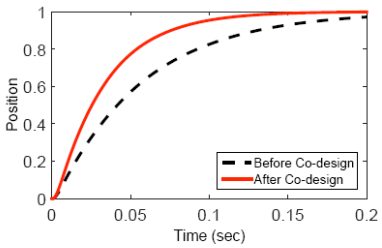
This paper considers real-time energy-optimal trajectory generation for a servomotor system, which performs a single-axis point-to-point positioning task for a fixed time interval. The trajectory generation is formulated as a linear constrained optimal control problem (LCOCP), and the Pontryaginas Maximum Principle is applied to derive necessary optimality conditions. Instead of solving multi-point boundary value problems directly, this paper proposes a novel real-time algorithm based on two realizations: solving the LCOCP is equivalent to determine an optimal time interval of the speed constrained arc and solve a specific acceleration constrained optimal control problem (ACOCP); solving an ACOCP is equivalent to determine optimal switch times of acceleration constrained arcs and solve a specific two-point boundary value problem (TBVP).

A Gradient-Based Approach for Optimal Plant Controller Co-Design

Citation: Wang, Y.-S.; Wang, Y., "A Gradient-Based Approach for Optimal Plant Controller Co-Design", *American Control Conference (ACC),* DOI: 10.1109/ACC.2015.7171833, ISBN: 978-1-4799-8685-9, pp. 3249-3254, July 2015

Contacts: Yebin Wang

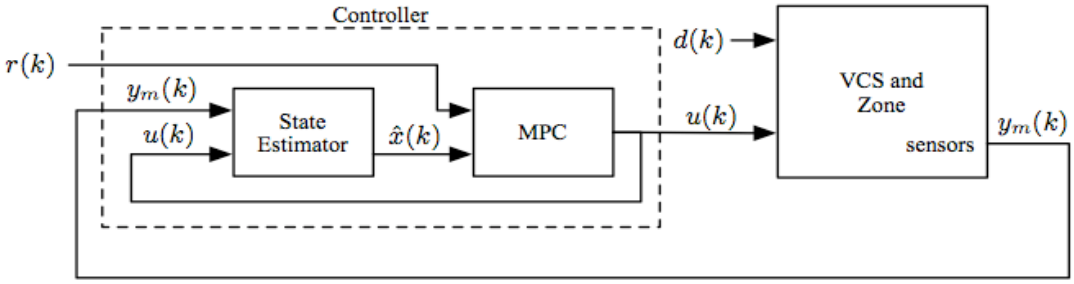
This paper proposes a gradient-based iterative algorithm for optimal co-design of a linear physical plant and a controller. The proposed algorithm does not rely on the common linear parameterization assumption, and thus is applicable to a broader class of problems. The convergence of the algorithm and the verification procedure for a local minimum are given. Numerical examples show that our algorithm is comparable to other complicated algorithms in terms of the performance, but can deal with a more general class of problems.



Model Predictive Control of Vapor Compression Systems

Citation: Jain, N., Burns, D.J., Di Cairano, S., Laughman, C.R., Bortoff, S.A., "Model Predictive Control of Vapor Compression Systems", *International Refrigeration and Air Conditioning Conference at Purdue*, pp. 1-10, July 2014.

Contacts: Daniel J. Burns, Stefano Di Cairano, Christopher R. Laughman, Scott A. Bortoff

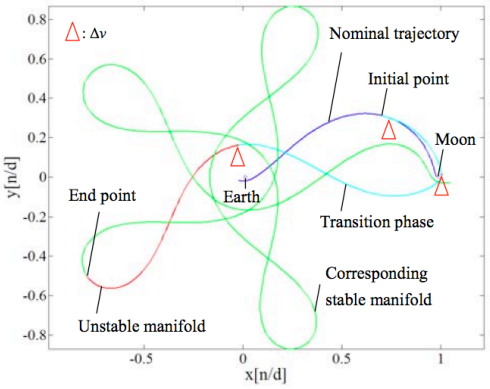


Model Predictive Control (MPC) of vapor compression systems (VCSs) offers several advantages over conventional control methods (such as multivariable process control with selector logic) in terms of 1) the resulting closed-loop performance and 2) the control engineering design process. VCSs are multivariable systems and feature constraints on system variables and actuators that must be enforced during steady-state and transient operation. We present the design and validation of an MPC for a split ductless VCS. The design regulates room temperature with zero steady state error for unknown changes in the thermal load and enforces constraints on system variables such as compressor discharge temperature and actuator ranges and rates. We show how the MPC design can evolve during the engineering process by adding and modifying constraints and process variables. The design methodology provides guarantees in terms of closed loop stability and convergence. In contrast to other published results on MPC for VCSs, our design makes use of only available temperature measurements and does not require pressure or mass flow measurements, which are typically not available in production VCSs.

Design of Low Fuel Trajectory in Interior Realm as a Backup Trajectory for Lunar Exploration

Citation: Sato, Y., Grover, P., Yoshikawa, S., "Design of Low Fuel Trajectory in Interior Realm as a Backup Trajectory for Lunar Exploration", *Transactions of the Japan Society for Aaeronautical and Space Sciences, Aerosplace Technology Japan*, DOI: 10.2322/tastj.12.Pd_47, Vol. 12, pp. 47-52, June 2014.

Contacts: Piyush Grover

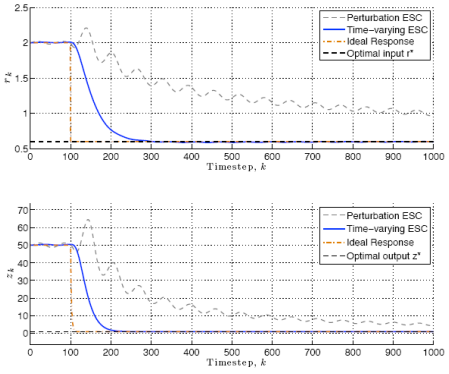


In case of a failure on a Hohmann-base translunar trajectory, a reconfiguration of the trajectory that utilizes the three body dynamics of the interior realm of Earth-moon system is proposed. The stable and unstable manifold of a periodic orbit around the L1 point extended toward the Earth side have homoclinic intersections. In the proposed method, after detection of a failure on the nominal trajectory, the trajectory is modified by small maneuvers so that the spacecraft can be kicked back by the moon and transferred to the unstable manifold. Then the spacecraft is returned back to the moon side through the intersection with the corresponding stable manifold on the Earth side. The periodic orbit is again used as a parking orbit so that the amount of delta-v at the moon orbit insertion can be reduced.

Realtime Setpoint Optimization with Time-Varying Extremum Seeking for Vapor Compression Systems

Citation: Burns, D.J.; Guay, M.; Weiss, W., "Realtime Setpoint Optimization with Time-Varying Extremum Seeking for Vapor Compression Systems", *American Control Conference (ACC),* DOI: 10.1109/ACC.2015.7470860, ISBN: 978-1-4799-8685-9, pp. 974-979, July 2015.

Contacts: Daniel J. Burns

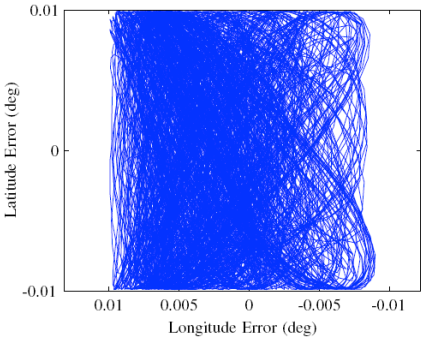


In this paper, we consider a model-free extremum seeking algorithm that adjusts compressor discharge temperature setpoints in order to optimize energy efficiency. While perturbation-based extremum seeking methods have been known for some time, they suffer from slow convergence rates — a problem emphasized in application by the long time constants associated with thermal systems. Our method uses a new algorithm (time-varying extremum seeking), which has dramatically faster and more reliable convergence properties. In particular, we regulate the compressor discharge temperature using set points selected from a model-free time-varying extremum seeking algorithm. We show that the relationship between compressor discharge temperature and power consumption is convex (a requirement for this class of real-time optimization), and use time-varying extremum seeking to drive these set points to values that minimize power.

Model Predictive Control for Simultaneous Station Keeping and Momentum Management of Low-Thrust Spacecraft

Citation: Weiss, A.; Kalabic, U.V.; Di Cairano, S., "Model Predictive Control for Simultaneous Station Keeping and Momentum Management of Low-Thrust Spacecraft", *American Control Conference (ACC)*, DOI: 10.1109/ACC.2015.7171076, ISBN: 978-1-4799-8685-9, pp.2305-2310, July 2015.

Contacts: Avishai Weiss, Uros V. Kalabic, Stefano Di Cairano

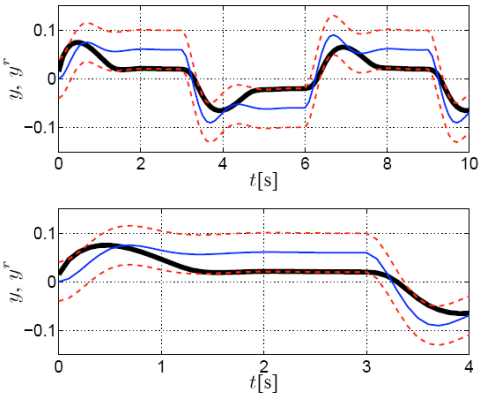


We propose a Model Predictive Control (MPC) policy for simultaneous station keeping and momentum management of a low-thrust nadir-pointing satellite in geostationary orbit around the Earth. The satellite is equipped with six electrically powered thrusters and three axisymmetric reaction wheels, which must be coordinated to control the satellite's orbital position and, concurrently, unload the wheels' stored angular momentum. The MPC policy enforces constraints that maintain the satellite in a tight latitude and longitude window and in a tight nadir-pointing attitude configuration, while minimizing the delta-v provided by the thrusters. The MPC policy exploits a prediction model of the environmental disturbance forces in order to significantly reduce the delta-v required for station keeping, and enforces constraints determined by the thruster configuration to select control forces and torques that can be generated by the propulsion system.

Reference Tracking with Guaranteed Error Bound for Constrained Linear Systems

Citation: Di Cairano, S.; Borrelli, F., "Reference Tracking with Guaranteed Error Bound for Constrained Linear Systems", *IEEE Transactions on Automatic Control*, DOI: 10.1109/TAC.2015.2491738, ISSN: 0018-9286, Vol. PP, pp. 1, October 2015.

Contacts: Stefano Di Cairano



We propose a control design for a constrained linear system to track reference signals within a given bounded error. The admissible reference signals are generated as output trajectories of a reference generator, which is a linear system driven by unknown bounded inputs. The controller has to track the reference signals and to never violate a given tracking error bound, while satisfying state and input constraints, for any admissible reference. The design is based on a model predictive controller (MPC) enforcing a polyhedral robust control invariant set defined by the system and reference generator models and constraints. We describe an algorithm to compute the robust control invariant set and how to design the tracking MPC law that guarantees satisfaction of the tracking error bound and of the system constraints, and achieves persistent feasibility.

Algorithms

Researchers in the Algorithms group at MERL develop solution methods for optimization problems involving very large numbers of variables or real-time computing, particularly in settings where classical methods are not viable. Our results can open new business opportunities where there are no competitive technologies. Much of the group's work involves graph-based optimizations, where the graph is a representation of the problem and associated computational constraints such as the dataflow of a parallel computer. This meshes with and helps build MERL's expertise in fields and technologies such as machine learning, computer vision, dynamic programming, convex optimization, computational mathematics, control, and signal processing. Another main research theme involves adaptively-sampled distance fields (ADFs), an efficient representation for shapes of any dimension. ADFs have distinct advantages over alternative forms, including superior font and graphical rendering for digital displays.

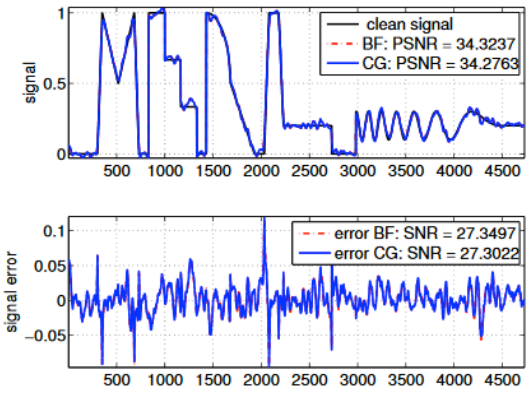
Recent Research

Conjugate Gradient Acceleration of Non-Linear Smoothing Filters 82
Edge-Enhancing Filters with Negative Weights 82
Preconditioning for Continuation Model Predictive Control 83
Projection-free Parallel Quadratic Programming for Linear Model Predictive Control 83
Parallel Quadratic Programming for Image Processing 84
Lifting 3D Manhattan Lines from a Single Image 84

Conjugate Gradient Acceleration of Non-Linear Smoothing Filters

Citation: Knyazev, A.; Malyshev, A., "Conjugate Gradient Acceleration of Non-Linear Smoothing Filters", *IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, DOI: 10.1109/GlobalSIP.2015.7418194, pp. 245-249, December 2015

Contacts: Andrew Knyazev

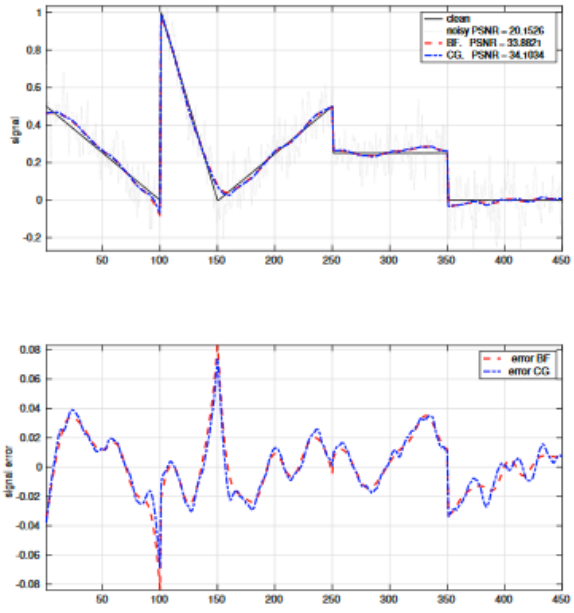


The most efficient signal edge-preserving smoothing filters, e.g., for denoising, are non-linear. Thus, their acceleration is challenging and is often performed in practice by tuning filter parameters, such as by increasing the width of the local smoothing neighborhood, resulting in more aggressive smoothing of a single sweep at the cost of increased edge blurring. We propose an alternative technology, accelerating the original filters without tuning, by running them through a special conjugate gradient method, not affecting their quality. The filter nonlinearity is dealt with by careful freezing and restarting. Our initial numerical experiments on toy one-dimensional signals demonstrate 20x acceleration of the classical bilateral filter and 3-5x acceleration of the recently developed guided filter.

Edge-Enhancing Filters with Negative Weights

Citation: Knyazev, A., "Edge-Enhancing filters with Negative Weights", *IEEE Global Conference on Signal and Information Processing (GlobalSIP),* DOI: 10.1109/GlobalSIP.2015.7518197, pp. 260-264, December 2015

Contacts: Andrew Knyazev



In [doi:10.1109/ICMEW.2014.6890711], a graph-based denoising is performed by projecting the noisy image to a lower dimensional Krylov subspace of the graph Laplacian, constructed using non-negative weights determined by distances between image data corresponding to image pixels. We extend the construction of the graph Laplacian to the case, where some graph weights can be negative. Removing the positivity constraint provides a more accurate inference of a graph model behind the data, and thus can improve quality of filters for graphbased signal processing, e.g., denoising, compared to the standard construction, without affecting the computational costs.

Preconditioning for Continuation Model Predictive Control

Citation: Knyazev, A.; Malyshev, A., "Preconditioning for Continuation Model Predictive Control", IFAC Conference o nNonlinear Model Predictive Contol, DOI: 10.1016/j.ifacol.2015.11.282,Vol. 48, pp.191-196, September 2015

Contacts: Andrew Knyazev

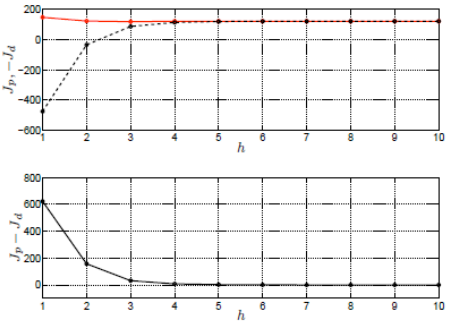
Model predictive control (MPC) anticipates future events to take appropriate control actions. Nonlinear MPC (NMPC) deals with nonlinear models and/or constraints. A Continuation/GMRES Method for NMPC, suggested by T. Ohtsuka in 2004, uses the GMRES iterative algorithm to solve a forward difference approximation Ax = b of the original NMPC equations on every time step. We have previously proposed accelerating the GMRES and MINRES convergence by preconditioning the coefficient matrix A. We now suggest simplifying the construction of the preconditioner, by approximately solving a forward recursion for the state and a backward recursion for the costate, or simply reusing previously computed solutions.

$$F[U,x,t] = \begin{bmatrix} \frac{\partial H^T}{\partial u}(\tau_0, x_0, \lambda_1, u_0, \mu_0, p)\Delta\tau \\ \vdots \\ \frac{\partial H^T}{\partial u}(\tau_i, x_i, \lambda_{i+1}, u_i, \mu_i, p)\Delta\tau \\ \vdots \\ \frac{\partial H^T}{\partial u}(\tau_{N-1}, x_{N-1}, \lambda_N, u_{N-1}, \mu_{N-1}, p)\Delta\tau \\ C(\tau_0, x_0, u_0, p)\Delta\tau \\ \vdots \\ C(\tau_i, x_i, u_i, p)\Delta\tau \\ \vdots \\ C(\tau_{N-1}, x_{N-1}, u_{N-1}, p)\Delta\tau \\ \psi(x_N, p) \\ \frac{\partial \phi^T}{\partial p}(x_N, p) + \frac{\partial \psi^T}{\partial p}(x_N, p)\nu \\ + \sum_{i=0}^{N-1} \frac{\partial H^T}{\partial p}(\tau_i, x_i, \lambda_{i+1}, u_i, \mu_i, p)\Delta\tau \end{bmatrix}.$$

Projection-free Parallel Quadratic Programming for Linear Model Predictive Control

Citation: Di Cairano, S.; Brand. M.E.; Bortoff, S.A., "Projection-free Parallel Quadratic Programming for Linear Model predictive Control", *International Journal of Control*, DOI: 10.1080/00207179.2013.801080, Vol. 86, Issue 8, pp. 1367-1385, July 2013

Contacts: Stefano Di Cairano, Matthew Brand, Scott Bortoff



A key component in enabling the application of model predictive control (MPC) in fields such as automotive, aerospace and factory automation is the availability of low-complexity fast optimization algorithms to solve the MPC finite horizon optimal control problem in architectures with reduced computational capabilities. In this paper we introduce a projection-free iterative optimization algorithm and discuss its application to linear MPC. The algorithm, originally developed by Brand for non-negative quadratic programs, is based on a multiplicative update rule and it is shown to converge to a fixed point which is the optimum. An acceleration technique based on a projection-free line search is also introduced, to speed-up the convergence to the optimum. The algorithm is applied to MPC through the dual of the quadratic program (QP) formulated from the MPC finite time optimal control problem. We discuss how termination conditions with guaranteed degree of suboptimality can be enforced, and how the algorithm performance can be optimized by pre-computing the matrices in a parametric form. We show computational results of the algorithm in three common case studies.

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, pp. 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

Lifting 3D Manhattan Lines from a Single Image

Citation: Ramalingam, S.; Brand. M.E., "Lifting 3D Manhattan Lines from a Single Image", *IEEE International Conference on Computer Vision (ICCV)*, DOI: 10.1109/ICCV.2013.67, ISSN: 1550-5499, pp. 497-504, December 2013

Contacts: Srikumar Ramalingam, Matthew Brand

We propose a novel and an efficient method for reconstructing the 3D arrangement of lines extracted from a single image, using vanishing points, orthogonal structure, and an optimization procedure that considers all plausible connectivity constraints between lines. Line detection identifies a large number of salient lines that intersect or nearly intersect in an image, but relatively few of these apparent junctions correspond to real intersections in the 3D scene. We use linear programming (LP) to identify a minimal set of least-violated connectivity constraints that are sufficient to unambiguously reconstruct the 3D lines. In contrast to prior solutions that primarily focused on well-behaved synthetic line drawings with severely restricting assumptions, we develop an algorithm that can work on real images.