Mitsubishi Electric Research Laboratories (MERL)

Annual Report

April 2019 through March 2020

TR2020-000

(Published June 2020)

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, Colleen Shields, Richard C. Waters

Table of Contents

Mitsubishi Electric Research Laboratories

Mitsubishi Electric Research Laboratories (MERL) is the US subsidiary of the corporate research and development organization of Mitsubishi Electric Corporation. MERL conducts application-motivated basic research and advanced development in: Physical Modelling & Simulation, Signal Processing, Control, Optimization, and Artificial Intelligence. The main body of this report presents our recent research in these areas.

MERL's mission—our assignment from Mitsubishi Electric:

- Generating new technology and intellectual property in areas of importance to Mitsubishi Electric.
- Impacting Mitsubishi Electric's business significantly: 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 a premiere research laboratory, 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:

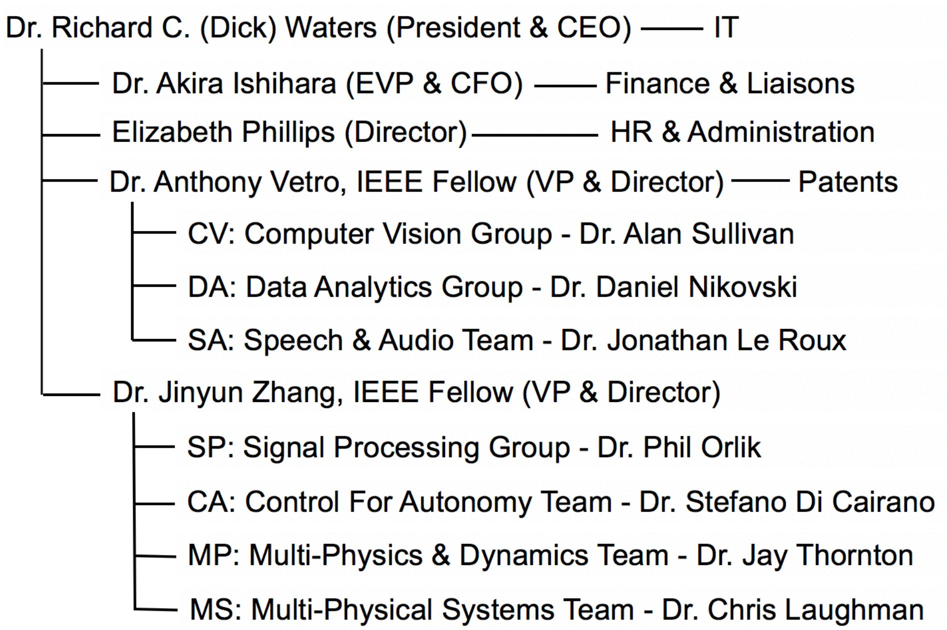
- Recruiting the highest-quality researchers and developing them into leaders in their fields, encouraging everyone to be a principal investigator and pursue their passions.
- Fostering interdisciplinary teamwork inside MERL with our colleagues at Mitsubishi Electric, and with interns and universities.
- Participating in the world research community, publishing our work while maintaining the confidentiality of business information.
- Combining nimble bottom-up research direction setting with stable long-term support from our large parent organization.
- Enabling researchers to both extend the frontier of science and make real products happen through the large and capable engineering workforce of Mitsubishi Electric.
- Providing excellent benefits and a flexible work environment.

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



Richard C. (Dick) Waters *Ph.D., MIT, 1978*
President, 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.

Akira Ishihara *Ph.D., University of Osaka, 2010*
Executive Vice President & CFO

Akira joined Mitsubishi Electric in 1993 and did research on software platforms for computer supported cooperative work, supervisory control and data acquisition systems, and manufacturing execution systems. He has also done research on software engineering technology and is interested in applying it to designing large-scale industrial systems. Before joining MERL in 2018, he was the manager of the Strategic Planning Department in Mitsubishi Electric's Advanced Technology Center.

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 U. (now part of NYU), 2001*
Vice President & Director, IEEE Fellow

Anthony joined MERL in 1996 and conducted 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 has also served in various leadership roles for conferences, technical committees and editorial boards. He joined MERL's top management in 2014.

Elizabeth Phillips *B.A., University of Massachusetts Amherst, 1988*
Director, 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 $42 billion in annual sales, $2.4 billion in operating profits (in the year ending in March 2019) and more than 145,000 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.

- **Business Innovation Group**
  Initiation of innovative new products and services across the company
- **Information Systems & Network Services**
  IT Systems, Information Security/Encryption Systems, Business Solutions
- **Public Utility Systems**
  Government Systems, Transportation Systems
- **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
- **Living Environment & Digital Media Equipment**
  Air Conditioners, Home Appliances
- **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 separated for many years and Mitsubishi Electric has been separate from all of them since its founding in 1921.

Mitsubishi Electric's US Operations

A significant part of Mitsubishi Electric's sales are in North America and many of Mitsubishi Electric's business units have North American subsidiaries. The largest US operations are listed below (see www.mitsubishielectric-usa.com).

Mitsubishi Electric Automotive America, Inc. (Detroit 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, 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 and is the second largest filer of international patents in the world. 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)
  Physical Modeling & Simulation, Signal Processing, Optimization, Control and AI
- **Mitsubishi Electric R&D Centre Europe, B.V.** (Rennes, France & Edinburgh, Scotland)
  Communications, Energy and 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. 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

In January 2019, MERL researcher Siheng Chen received an IEEE Young Author Best Paper award based on his paper: S. Chen, R. Varma, A. Sandryhaila and J. Kovačević, **"Discrete Signal Processing on Graphs: Sampling Theory,"** in IEEE Transactions on Signal Processing, vol. 63, no. 24, December 2015.

The conference's Best Visualization Note Award was given to MERL's paper: Lee, T.-Y., Wittenburg, K.B., **"Space-Time Slicing: Visualizing Object Detector Performance in Driving Video Sequences"**, *IEEE Pacific Visualization Symposium (PacificVis)*, April 2019.

In April 2019, the president of the laser society of Japan issued an award to MELCO on "Vehicle Laser Detection Technology for ETC System". This award is for outstanding products that can contribute to the development of the laser-related industry in Japan. Key underlying technology fir this system was provided by MERL.

The conference's best paper award was given to MERL's paper: Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., **"GPS Spoofing Detection and Mitigation in PMUs Using Distributed Multiple Directional Antennas"**, IEEE International Conference on Communications (ICC), June 2019.

The conference's Smart Grid Symposium's Best Paper Award was given to MERL's paper: Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., **"Wide-Area GPS Time Monitoring Against Spoofing Using Belief Propagation"**, *IEEE International Conference on Sensing, Communication and Networking (SECON)*, June 2019.

In October 2019, the workshop's Best Oral Presentation award was given to MERL's paper: Marks, T., Kumar, A., Mou, W., Feng, C., Liu, X., **"UGLLI Face Alignment: Estimating Uncertainty with Gaussian Log-Likelihood Loss"**, IEEE International Conference on Computer Vision (ICCV) Workshop on Statistical Deep Learning for Computer Vision (SDL-CV), October 2019.

In October 2019, MERL researcher Devesh Jha received the 2019 Rudolf Kalman Best Paper Award for the paper: Nurali Virani, Devesh K. Jha, Zhenyuan Yuan, Ishana Shekhawat, Asok Ray **"Imitation of Demonstrations Using Bayesian Filtering With Non-Parametric Data-Driven Models"**, Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME, March 2018, which was written prior to his coming to MERL.

In December 2019, the workshop's best paper award was given to MERL's paper: Chang, X., Zhang, W., Qian, Y., Le Roux, J., Watanabe, S., **"MIMO-Speech: End-to-End Multi-Channel Multi-Speaker Speech Recognition"**, IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU), December 2019, pp. 237-144.

It is 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: 16 papers in the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 11 papers in the IEEE Global Communications Conference (GLOBECOM), 8 papers in the American Control Conference (ACC), 8 papers in the European Control Conference (ECC), and 7 papers in the Interspeech conference.

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 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 descriptions later in this report.

Jose Amaya *Northern Essex Community College*
Systems & Network Administrator

Jose has over 15 years' experience in various IT support roles in system administration and technical training. His primary interests are working with different open source technologies and research computing services. Northern Essex Community College graduate, certified in computer networking.

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

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 Research Scientist

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*
Principal Research Scientist

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.

Daniel Birch *Ph.D., University of California, San Diego, 2007*
Visiting Research Scientist

Daniel earned his Ph.D. and did postdoctoral work in oceanography, where he studied mathematical models for plankton distributions and mixing in the ocean. After taking a few years to teach high school physics, Daniel returned to research and currently works on developing innovative lighting technologies at MERL.

Scott A. Bortoff *Ph.D., University of Illinois Urbana-Champaign, 1992*
Distinguished Research Scientist, Strategic Project Leader

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 Research Scientist, Team Leader

Petros was a Postdoctoral associate at Rice 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.

Ankush Chakrabarty *Ph.D., Purdue University, 2016*
Research Scientist

At Purdue, Ankush's research focused on developing scalable, data-driven methods for simplifying computationally intensive operations encountered in controlling and observing complex, nonlinear systems. Prior to joining MERL, Ankush was a postdoctoral Fellow at Harvard where he designed embedded model predictive controllers and deep learning-assisted control strategies for treating people with type 1 diabetes.

Siheng Chen *Ph.D., Carnegie Mellon University, 2016*
Research Scientist

Before coming to MERL, Siheng worked postdoctoral research associate at CMU and on perception and prediction systems for self-driving cars at Uber Advanced Technologies Group. He is the recipient of the 2018 IEEE Signal Processing Society Young Author Best Paper Award. His research interests include graph signal processing, graph neural networks, 3D point cloud processing, and graph mining.

Anoop Cherian *Ph.D., University of Minnesota, 2013*
Principal Research Scientist

Anoop was a postdoctoral researcher in the LEAR group at Inria 2012-2015 where his research was on the estimation and tracking of human poses in videos. 2015-2017, he was a Research Fellow at the Australian National University, where he worked on recognizing human activities in video. Currently, his research focus is on modeling the semantics of video data.

Radu Corcodel *Ph.D., University of Connecticut, 2017*
Research Scientist

Radu's PhD focused on workspace analysis and motion synthesis for arbitrary kinematic chains, with particular emphasis on robotic 3D printing and Fusion Deposition Modeling. Currently his research focuses on motion planning and workspace analysis for over-actuated kinematic linkages and collaborative robots.

Claus Danielson *Ph.D., University of California, Berkeley, 2008*
Principal Research Scientist

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

Marissa Deegan *M.B.A., Southern New Hampshire University, 2018*
HR Generalist, Administrator

Marissa joined MERL in 2015. She has experience in various fields as coordinators of customer service and administration departments. Previously, she worked as a Coordinator of Customer Service and Administration in a soccer company for children. Her interests are in human resource management.

Stefano Di Cairano *Ph.D., University of Siena, 2008*
Senior Principal Research Scientist, Senior 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.

Abraham M. Goldsmith *M.S., Worcester Polytechnic Institute, 2008*
Principal Research Scientist

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 of electro-mechanical systems. In addition, Abraham provides electrical and mechanical engineering support to the entire laboratory.

Jianlin Guo *Ph.D., University of Windsor, 1995*
Senior Principal Research Scientist

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 Research Scientist

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.

Hiroyuki Hashimoto *Ph.D., University of Tokyo, 2015*
Liaison Manager

Hiroyuki joined Mitsubishi Electric Corporation in 1995 where he had been engaged in research on electric power grid analysis, stability control, thermal/hydro generation scheduling, power liberalization support system, and smart grid system. He has also researched optimization technology and is interested in applying it to an industrial system. Before joining MERL, he was a Group Manager of power system technology group in the Advanced Technology Research Center.

Chiori Hori *Ph.D., Tokyo Institute of Technology, 2002*
Senior Principal Research Scientist

Prior to joining MERL in 2015, Chiori spent 8 years at Japan's National Institute of Information and Communication Technology (NICT), rising to research manager of the Spoken Language Communication Lab. Chiori's work has focused on speech summarization/translation, spoken dialog technology, and standardization of speech interface communication protocols.

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

Before joining MERL in 2015, Takaaki spent 15 years doing research on speech and language technology at Nippon Telegraph, and Telephone in Japan. His work includes 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.

Siddarth Jain *Ph.D., Northwestern University, 2019*
Visiting Research Scientist

Siddarth's research lies at the intersection of robotics, computer vision, and machine learning. Prior to joining MERL in 2019, he was affiliated with the Shirley Ryan Abilitylab, Chicago (nation's top ranked physical medicine and rehabilitation research hospital). Currently, Siddarth's research focuses on the core challenges in active perception, robotic manipulation, autonomy, and human-robot interaction.

Devesh Jha *Ph.D., Pennsylvania State University, 2016*
Principal Research Scientist

Devesh's PhD Thesis was on decision & control of autonomous systems. He also got a Master's degree in Mathematics from Penn State. His research interests are in the areas of Machine Learning, Time Series Analytics and Robotics. He was a recipient of the best student paper award at the 1st ACM SIGKDD workshop on Machine Learning for Prognostics and Health Management at KDD 2016, San Francisco.

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

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

Uros Kalabic *Ph.D., University of Michigan, 2015*
Principal Research Scientist

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.

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

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 communications and E-WLAN system. Currently he is an Associate Editor of IEEE Communications Letters.

Toshiaki Koike-Akino *Ph.D., Kyoto University, 2005*
Senior Principal Research Scientist

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*
Distinguished Research Scientist

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*
Principal Research Scientist

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*
Senior Principal Research Scientist, Senior Team Leader

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*
Senior Principal Research Scientist, Senior Team Leader

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.

Chungwei Lin *Ph.D., Columbia University, 2008*
Principal Research Scientist

Before joining MERL, Chungwei was a postdoctoral researcher in the Physics Department of the University of Texas at Austin. His particular interest is the use of doping/interface to control optical, thermal, and transport properties. He has worked on the theory of self-assembly, configuration interaction quantum impurity solvers, and photoemission spectroscopy.

Dehong Liu *Ph.D., Tsinghua University, 2002*
Senior Principal Research Scientist

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.

Suhas Lohit *Ph.D., Arizona State University, 2019*
Visiting Research Scientist

Before coming to MERL, Suhas worked as an intern at MERL (summer 2018), SRI International (summer 2017) and Nvidia (summer 2016). His research interests include computer vision, computational imaging and deep learning. Recently, his research focus has been on creating hybrid model- and data-driven neural architectures for various applications in imaging and vision.

Rui Ma *Ph.D., University of Kassel, 2009*
Senior Principal Research Scientist

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.

Yanting Ma *Ph.D., North Carolina State University, 2017*
Research Scientist

Yanting's research interests are mainly in algorithm design and analysis for inverse problems arising in computational sensing using statistical inference and optimization techniques. Her PhD research focused on algorithmic and theoretical studies of approximate message passing, as well as provably convergent optimization algorithms for nonlinear diffractive imaging. Her postdoctoral work developed principled methods for dead time compensation for single-photon detectors based on Markov chain modeling.

Hassan Mansour, *Ph.D. University of British Columbia, 2009*
Senior Principal Research Scientist

Hassan's research interests are in 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. Subsequent work developed adaptive sparse recovery algorithms for correlated signals from compressive measurements.

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

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.

James McAleenan *J.D., Hamline University Law School, 1999*
Patent Counsel

Jim is a registered patent attorney and former U.S. Patent Examiner with more than 16 years of experience in patent and Intellectual Property law. Jim has held in-house legal roles at significant U.S. and multinational companies, having served as Senior Patent Counsel and Senior Intellectual Property Attorney.

Kathleen McCarthy *B.A., Boston College, 1992*
Controller

Kathleen has worked for over 30 years in the Accounting field with experience in general accounting, payroll and property management. Prior to joining MERL in 1993, she worked in manufacturing, financial and service industries.

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

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 (Dominican Republic), 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.

Niko Moritz *Ph.D., University of Oldenburg, 2016*
Visiting Research Scientist

Niko's research interests are in automatic speech recognition and machine learning with application to acoustic events and speech. Prior to joining MERL in 2018, Niko spent 9 years at the Hearing, Speech and Audio (HSA) Technology branch of the Fraunhofer IDMT in Oldenburg (Germany) doing R&D to build automatic speech recognition systems.

Saleh Nabi *Ph.D., University of Alberta, 2014*
Principal Research Scientist

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.

Yukimasa (Yuki) Nagai *M.S., University of Electro-Communications, 2000*
Liaison Manager

Yuki joined Mitsubishi Electric Corporation in 2000 where he has been engaged in research on wireless communication, connected cars, V2X and Vehicle IoT. Before joining MERL, he was an active participant in the IEEE 802.11, 15 & 19 standardization efforts, the Wi-Fi Alliance and JasPar. He has been the vice chair of the Automotive Market Segment Task Group and the DSRC Marketing Task Group in the Wi-Fi Alliance since 2013.

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*
Signal Processing 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.

Kieran Parsons *Ph.D., University of Bristol, UK, 1996*
Senior Principal Research Scientist, Senior 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.

Kuan-Chuan Peng *Ph.D., Cornell University, 2016*
Principal Research Scientist

Before joining MERL, Kuan-Chuan was a Research Scientist (2016-2018) and Staff Scientist (2019) at Siemens Corporate Technology. In addition to his PhD, he received Bachelor's and Master's degrees from National Taiwan University in 2009 and 2012 respectively. His research interests include incremental learning, developing practical solutions given biased or scarce data, and fundamental computer vision and machine learning problems.

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

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.

Kristin Peterson *B.S., Towson University, 2007*
Patent Paralegal

Kristin joined MERL in 2012 as a Patent assistant. Prior to working at MERL she attended Boston University's Paralegal program to support a career change. She previously held a position in hospital finance and was a Realtor in the Maryland metropolitan area. She has a Bachelor of Science degree in Psychology.

Hongtao Qiao *Ph.D., University of Maryland, 2014*
Principal Research Scientist

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.

Rien Quirynen *Ph.D., KU Leuven and University of Freiburg, 2017*
Principal Research Scientist

Rien's research interests are in model predictive control and moving horizon estimation, numerical algorithms for (nonlinear) dynamic optimization and real-time control applications. His doctoral research was focused on numerical simulation methods with efficient sensitivity propagation for real-time optimal control algorithms.

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

Arvind's research focuses on optimization algorithms large-scale 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, and energy systems.

Diego Romeres *Ph.D., University of Padova, 2017*
Principal Research Scientist

Diego's research interests are in machine learning, system identification and robotic applications. At MERL he is currently working on applying nonparametric machine learning techniques for the control of robotic platforms. His Ph.D. thesis is about the combination of nonparametric data-driven models and physics-based models in gaussian processes for robot dynamics learning.

Koji Sakai *M.S., Kobe University, 2008*
Liaison Manager

Koji joined Mitsubishi Electric Corporation in 2016 and has been working in the area of Intellectual Property. Prior to joining Mitsubishi Electric in 2016, he worked at Toshiba in the same area.

Alan Sullivan *Ph.D., University of California at Berkeley, 1993*
Computer Vision Group Manager

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 Research Scientist

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 with more than 20 years' experience in technical consulting, product development and research on electrical transmission and distribution system planning, analysis, 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.

Koon Hoo Teo *Ph.D., University of Alberta 1990*
Senior Principal Research Scientist, Strategic Projects 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*
Multi-Physical Devices 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.

Hironori Tsukamoto *Ph.D., Tokyo Institute of Technology, 1999*
Patent Agent

Tsukamoto worked as a research scientist in the area of silicon and compound semiconductor materials/devices at Sony Research Center and Yale University for more than 15 years. Prior to joining MERL, he worked at a Japanese Patent Firm to support US patent practice of Japanese client companies for more than 5 years.

Jeroen van Baar *Ph.D., ETH Zurich, 2013*
Senior Principal Research Scientist, Team leader

Jeroen came to MERL in 1997 as an 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*
Senior Patent Counsel

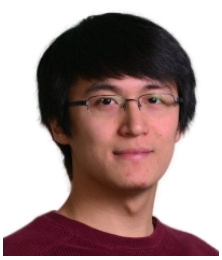
Gene graduated cum laude with distinction in Intellectual Property law. In addition, he holds advanced degrees in Mechanical Engineering and Computer Science. He is a member of Massachusetts Bar and has been a licensed patent practitioner since 2003.

Bingnan Wang *Ph.D., Iowa State University 2009*
Senior Principal Research Scientist

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.

Pu Wang *Ph.D., Stevens Institute of Technology, 2011*
Principal Research Scientist

Before coming to MERL, Pu was a Research Scientist in the Mathematics and Modeling Department of Schlumberger-Doll Research, contributing to development of logging-while-drilling Acoustic/NMR products. His current research interests include statistical signal processing, Bayesian inference, sparse signal recovery, and their applications to sensing, wireless communications, and networks.



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

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*
Senior Principal Research Scientist

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.

Avishai Weiss *Ph.D., University of Michigan, 2013*
Principal Research Scientist

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.

Gordon Wichern *Ph.D., Arizona State University, 2010*
Principal Research Scientist

Gordon's research interests are at the intersection of signal processing and machine learning applied to speech, music, and environmental sounds. Prior to joining MERL, Gordon worked at iZotope inc. developing audio signal processing software, and at MIT Lincoln Laboratory where he worked in radar target tracking.

Victoria Wong *B.S. Bentley College, 2008*
Principal Staff Accountant

Victoria has over 10 years' experience primarily focusing on accounts payable and payroll. She joined MERL in June, 2008. Prior to joining MERL, she was an intern with Federal Reserve Bank of Boston and EF Education. Her B.S. degree is in Accounting Information Systems.

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

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.

Jing Zhang *Ph.D., Boston University, 2017*
Research Scientist

Jing's PhD dissertation was on detection and optimization problems with applications in transportation systems. His research interests include anomaly detection, optimization, machine learning, and time series analysis. He was a recipient of the Boston Area Research Initiative (BARI) Research Seed Grant Award (Spring 2017).

Lei Zhou *Ph.D., Massachusetts Institute of Technology, 2019*
Visiting Research Scientist

Lei's research is in precision mechatronics, with an emphasis on electromagnetic modeling and design, actuators and sensors, control, magnetic suspension, and manufacturing systems. Lei received her B.E. degree in Control and Instrumentation Engineering from Tsinghua University in 2012.

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.

Wang, P., Millar, D.S., Parsons, K., Ma, R., Orlik, P.V., **"Range Accuracy Analysis for FMCW Systems with Source Nonlinearity"**, *IEEE International Conference on Microwaves for Intelligent Mobility (ICMIM)*, DOI: 10.1109/ICMIM.2019.8726679, April 2019, pp. 1-5. (TR2019-018)

Brand, M.E., Birch, D.A., **"Freeform irradiance tailoring for light fields"**, *Optics Express*, DOI: 10.1364/OE.27.00A611, Vol. 27, No. 12, pp. A611-A619, May 2019. (TR2019-019)

TaherSima, M., Kojima, K., Koike-Akino, T., Jha, D., Wang, B., Lin, C., Parsons, K., **"Nanostructured Photonic Power Splitter Design via Convolutional Neural Networks"**, *Conference on Lasers and Electro-Optics (CLEO)*, DOI: 10.1364/CLEO_SI.2019.SW4J.6, May 2019. (TR2019-027)

Moritz, N., Hori, T., Le Roux, J., **"Triggered Attention for End-to-End Speech Recognition"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683510, May 2019. (TR2019-015)

Wang, P., Koike-Akino, T., Pajovic, M., Orlik, P.V., Tsujita, W., Gini, F., **"Misspecified CRB Parameter Estimation for a Coupled Mixture of Polynomial Phase and Sinusoidal FM Signals"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682703, May 2019. (TR2019-011)

Le Roux, J., Wichern, G., Watanabe, S., Sarroff, A., Hershey, J., **"The Phasebook: Building Complex Masks via Discrete Representations for Source Separation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682587, May 2019. (TR2019-008)

Seetharaman, P., Wichern, G., Le Roux, J., Pardo, B., **"Bootstrapping Single-Channel Source Separation via Unsupervised Spatial Clustering on Stereo Mixtures"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683198, May 2019. (TR2019-014)

Lodhi, M.A., Mansour, H., Boufounos, P.T., **"Coherent Radar Imaging Using Unsynchronized Distributed Antennas"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682782, May 2019. (TR2019-001)

Aihara, R., Hanazawa, T., Okato, Y., Wichern, G., Le Roux, J., **"Teacher-Student Deep Clustering For Low-Delay Channel Speech Separation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682695, May 2019. (TR2019-003)

Hori, C., Alamri, H., Wang, J., Wichern, G., Hori, T., Cherian, A., Marks, T.K., Cartillier, V., Lopes, R., Das, A., Essa, I., Batra, D., Parikh, D., **"End-to-End Audio Visual Scene-Aware Dialog Using Multimodal Attention-Based Video Features"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682583, May 2019. (TR2019-016)

Baskar, M.K., Burget, L., Watanabe, S., Karafiat, M., Hori, T., Cernocky, J.H., **"Promising Accurate Prefix Boosting for Sequence-to-Sequence ASR"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682782, ISSN: 2379-190X, ISBN: 978-1-4799-8131-1, May 2019, pp. 5646-5650. (TR2019-006)

Hori, T., Astudillo, R., Hayashi, T., Zhang, Y., Watanabe, S., Le Roux, J., **"Cycle-Consistency Training for End-to-End Speech Recognition"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683307, May 2019. (TR2019-002)

Cho, J., Watanabe, S., Hori, T., Baskar, M.K., Inaguma, H., Villalba, J., Dehak, N., **"Language Model Integration Based on Memory Control for Sequence to Sequence Speech Recognition"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683380, May 2019. (TR2019-007)

Seetharaman, P., Wichern, G., Venkataramani, S., Le Roux, J., **"Class-Conditional Embeddings for Music Source Separation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683007, May 2019. (TR2019-004)

Lohit, S., Liu, D., Mansour, H., Boufounos, P.T., **"Unrolled Projected Gradient Descent for Multi-Spectral Image Fusion"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683124, May 2019. (TR2019-010)

Das, P., Kao, J.-Y., Ortega, A., Mansour, H., Vetro, A., Sawada, T., Minezawa, A., **"Hand Graph Representations for Unsupervised Segmentation of Complex Activities"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683643, May 2019. (TR2019-009)

Zhang, S., Wang, B., Kanemaru, M., Lin, C., Liu, D., Habetler, T., **"Quantification of Rolling-Element Bearing Fault Severity of Induction Machines"**, *International Electric Machine & Drives Conference (IEMDC)*, DOI: 10.1109/IEMDC.2019.8785225, May 2019, pp. 44-50. (TR2019-033)

Kadu, A., Mansour, H., Boufounos, P.T., Liu, D., **"Reflection Tomographic Imaging of Highly Scattering Objects Using Incremental Frequency Inversion"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682393, May 2019. (TR2019-012)

Le Roux, J., Wisdom, S., Erdogan, H., Hershey, J., **"SDR -- Half-Baked or Well Done?"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8683855, May 2019. (TR2019-013)

Wang, X., Li, R., Mallidi, S.H., Hori, T., Watanabe, S., Hermansky, H., **"Stream Attention-Based Multi-Array End-to-End Speech Recognition"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2019.8682650, May 2019. (TR2019-005)

Wang, Y., **"Improved A-search guided tree construction for kinodynamic planning"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA.2019.8793705, May 2019, pp. 5530-5536. (TR2019-029)

van Baar, J., Sullivan, A., Corcodel, R., Jha, D., Romeres, D., Nikovski, D.N., **"Sim-to-Real Transfer Learning using Robustified Controllers in Robotic Tasks involving Complex Dynamics"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA.2019.8793561, May 2019, pp. 6001-6007. (TR2018-202)

Romeres, D., Jha, D., Dalla Libera, A., Yerazunis, W.S., Nikovski, D.N., **"Semiparametrical Gaussian Processes Learning of Forward Dynamical Models for Navigating in a Circular Maze"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA.2019.8794229, ISSN: 2577-087X, ISBN: 978-1-5386-6027-0, May 2019, pp. 3195-3202. (TR2019-028)

Minot, A., Sun, H., Nikovski, D.N., Zhang, J., **"Distributed Estimation and Detection of Cyber-Physical Attacks in Power Systems"**, *IEEE International Conference on Communications Workshops (ICC)*, DOI: 10.1109/ICCW.2019.8756653, ISSN: 2474-9133, May 2019, pp. 1-6. (TR2019-035)

Kim, K.J., Liu, H., Di Renzo, M., Tsiftsis, T.A., Orlik, P.V., Poor, H.V., **"Outage Analysis of Distributed CDD Systems with Mixture Interference"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2019.8761114, May 2019. (TR2019-034)

Hu, B., Wang, Y., Orlik, P.V., Koike-Akino, T., Guo, J., **"Co-design of Safe and Efficient Networked Control Systems in Factory Automation with State-dependent Wireless Fading Channels"**, *Automatica*, DOI: 10.1016/j.automatica.2019.04.009, Vol. 105, pp. 334-346, May 2019. (TR2019-021)

Ma, Y., Guo, J., Wang, Y., Chakrabarty, A., Ahn, H., Orlik, P.V., Lu, C., **"Optimal Dynamic Scheduling of Wireless Networked Control Systems"**, *ACM/IEEE International Conference on Cyber-Physical Systems (ICCPS)*, DOI: 10.1145/3302509.3311040, May 2019, pp. 77-86. (TR2019-022)

Huang, M., Gao, W., Wang, Y., Jiang, Z.-P., **"Data-Driven Shared Steering Control of Semi-Autonomous Vehicles"**, *IEEE Transactions on Human-Machine Systems*, DOI: 10.1109/THMS.2019.2900409, May 2019. (TR2019-020)

Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., Zhang, J., **"Joint BP and RNN for Resilient GPS Timing Against Spoofing Attacks"**, *EAI International Conference on Artificial Intelligence for Communications and Networks*, May 2019, pp. 190-209. (TR2019-036)

Komatsuszaki, Y., Sakata, S., Nakatani, K., Shinjo, S., Ma, R., Benosman, M., Nagai, Y., **"A Novel 1.4-4.8 GHz Ultra-Wideband, over 45% High Efficiency Digitally Assisted Frequency-Periodic Load Modulated Amplifier"**, *IEEE International Microwave Symposium (IMS)*, DOI: 10.1109/MWSYM.2019.8700930, ISSN: 2576-7216, ISBN: 978-1-7281-1309-8, June 2019, pp. 706-709. (TR2019-041)

Ploskas, N., Laughman, C.R., Raghunathan, A., Sahinidis, N.V., **"Heat Exchanger Circuitry Design by Decision Diagrams"**, *International Conference on the Integration of Constraint Programming, Artificial Intelligence, and Operations Research*, DOI: 10.1007/978-3-030-19212-9_30, June 2019, vol. 11494, pp. 467-471. (TR2019-038)

Serra, T., Raghunathan, A., Bergman, D., Hooker, J., Kobori, S., **"Last-Mile Scheduling Under Uncertainty"**, *International Conference on the Integration of Constraint Programming, Artificial Intelligence, and Operations Research*, DOI: 10.1007/978-3-030-19212-9_34, June 2019, vol. 11494, pp. 519-528. (TR2019-040)

Lee, T.-Y., Wittenburg, K.B., **"Space-Time Slicing: Visualizing Object Detector Performance in Driving Video Sequences"**, *IEEE Pacific Visualization Symposium (PacificVis)*, June 2019. (TR2019-024)

Fujihashi, T., Koike-Akino, T., Watanabe, T., Orlik, P.V., **"HoloCast: Graph Signal Processing for Graceful Point Cloud Delivery"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2019.8761819, ISSN: 1938-1883, ISBN: 978-1-5386-8088-9, June 2019. (TR2019-026)

Matsumine, T., Koike-Akino, T., Wang, Y., **"Deep Learning-Based Constellation Optimization for Physical Network Coding in Two-Way Relay Networks"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC.2019.8761963, ISSN: 1938-1883, ISBN: 978-1-5386-8088-9, June 2019. (TR2019-025)

Duan, C., Chen, S., Tian, D., Moura, J., Kovacevic, J., **"Deep Graph Topology Learning for 3D Point Cloud Reconstruction"**, *Graph Signal Processing Workshop*, June 2019. (TR2019-046)

Chen, S., **"Large-Scale 3D Point Cloud Representations via Graph Inception Networks with Applications to Autonomous Driving"**, *Graph Signal Processing Workshop*, DOI: 10.1109/ICIP.2019.8803525, June 2019, pp. 4395-4399. (TR2019-039)

Kim, K.J., Di Renzo, M., Liu, H., Tsiftsis, T.A., Orlik, P.V., Poor, H.V., **"Distributed Cyclic Delay Diversity Systems with Spatially Distributed Interferers"**, *IEEE Transactions on Wireless Communications*, Vol. 18, No. 4, pp. 2066-2079, June 2019. (TR2019-162)

Ye, F., Guo, J., Kim, K.J., Orlik, P.V., Ahn, H., Di Cairano, S., **"Bi-level Optimal Edge Computing Model for On-ramp Merging in Connected Vehicle Environment"**, *IEEE Intelligent Vehicle Symposium*, DOI: 10.1109/IVS.2019.8814096, June 2019, pp. 2005-2011.

Brand, M.E., Birch, D.A., **"Data-driven freeform irradiance tailoring"**, *OSA Optical Design and Fabrication Congress*, ISSN: 978-1-943580-60-6, June 2019. (TR2019-043)

Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., **"Wide-Area GPS Time Monitoring Against Spoofing Using Belief Propagation"**, *IEEE International Conference on Sensing, Communication and Networking (SECON)*, June 2019, pp. 1-8. (TR2019-044)

Raghunathan, A., Cherian, A., Jha, D., **"Game Theoretic Optimization via Gradient-based Nikaido-Isoda Function"**, *International Conference on Machine Learning (ICML)*, Lawrence, N. and Reid, M., Eds., ISSN: 2640-3498, June 2019, pp. 5291-5300. (TR2019-045)

Alamri, H., Cartillier, V., Das, A., Wang, J., Lee, S., Anderson, P., Essa, I., Parikh, D., Batra, D., Cherian, A., Marks, T.K., Hori, C., **"Audio-Visual Scene-Aware Dialog"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, Long Beach, CA, USA, June 2019, pp. 7550-7559. doi: 10.1109/CVPR.2019.00774. (TR2019-048)

Lee, T.-Y., van Baar, J., Wittenburg, K.B., Sullivan, A., **"Analysis of the contribution and temporal dependency of LSTM layers for reinforcement learning tasks"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR) Explanable AI Workshop*, June 2019, pp.99-102. (TR2019-049)

Zhang, J., Nikovski, D.N., Lee, T.-Y., Fujino, T., **"Fault Detection and Classification of Time Series Using Localized Matrix Profiles"**, *IEEE International Conference on Prognostics and Health Management*, DOI: 10.1109/ICPHM.2019.8819389, June 2019. (TR2019-057)

Sangwan, A., Ma, R., Wang, B., Kim, K.J., Parsons, K., Koike-Akino, T., Wang, P., Orlik, P.V., Teo, K.H., Tasuku, K., Kazunari, K., Fukasawa, T., **"CDM-based 4-Channel Digital Beamforming Transmitter Using a Single DAC"**, *IEEE International New Circuits and Systems Conference*, DOI: 10.1109/NEWCAS44328.2019.8961250, ISBN: 978-1-7281-1031-8, June 2019, pp. 1-4. (TR2019-058)

Chakrabarty, A., Quirynen, R., Danielson, C., Gao, W., **"Approximate Dynamic Programming For Linear Systems with State and Input Constraints"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8795815, June 2019. (TR2019-059)

Bortoff, S.A., Schwerdtner, P., Danielson, C., Di Cairano, S., **"H Infinity Loop-Shaped Model Predictive Control with Heat Pump Application"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8796158, June 2019, pp. 2386-2393. (TR2019-052)

Hespanhol, P., Quirynen, R., Di Cairano, S., **"A Structure Exploiting Branch-and-Bound Algorithm for Mixed-Integer Model Predictive Control"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8796242, June 2019, pp. 2763-2768. (TR2019-050)

Berntorp, K., **"Recursive Bayesian Inference and Learning of Gaussian-Process State-Space Models"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8796120, June 2019, pp. 1866-1871. (TR2019-053)

Schwerdtner, P., Bortoff, S.A., Danielson, C., Di Cairano, S., **"Projection-Based Anti-Windup for Multivariable Control with Heat Pump Application"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8795876, June 2019, pp. 1281-1287. (TR2019-054)

Krupa, P., Danielson, C., Laughman, C.R., Bortoff, S.A., Burns, D.J., Di Cairano, S., Limon, D., **"Modelica Implementation of Centralized MPC Controller for a Multi-Zone Heat Pump"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8795616, June 2019, pp. 1784-1789. (TR2019-056)

Romeres, D., Jha, D., Dau, H., Yerazunis, W.S., Nikovski, D.N., **"Anomaly Detection for Insertion Tasks in Robotic Assembly Using Gaussian Process Models"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8795698, ISBN: 978-3-907144-00-8, June 2019, pp. 1017-1022. (TR2019-055)

Berntorp, K., **"Bayesian Tire-Friction Learning by Gaussian-Process State-Space Models"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC.2019.8796193, June 2019, pp. 231-236. (TR2019-051)

Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., **"GPS Spoofing Detection and Mitigation in PMUs Using Distributed Multiple Directional Antennas"**, *IEEE International Conference on Communications (ICC)*, Shanghai, China, doi: 10.1109/ICC.2019.8761208, June 2019, pp. 1-7. (TR2019-023)

Pajovic, M., Wang, P., Koike-Akino, T., Orlik, P.V., **"Sparse Bayesian Estimation of Millimeter-Wave Channel Correlation Matrix"**, *IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, DOI: 10.1109/SPAWC.2019.8815397, ISSN: 1948-3252, ISBN: 978-1-5386-6528-2, July 2019. (TR2019-042)

Berntorp, K., Di Cairano, S., **"Particle Filtering for Automotive: A survey"**, *International Conference on Information Fusion (FUSION)*, ISBN: 978-0-9964527-8-6, July 2019, pp. 1-8. (TR2019-069)

Koike-Akino, T., Wang, Y., Cayci, S., Millar, D.S., Kojima, K., Parsons, K., **"Hardware-Efficient Quantized Polar Decoding with Optimized Lookup Table"**, *OptoElectronics and Communications Conference and International Conference on Photonics in Switching (OECC/PS)*, DOI: 10.23919/PS.2019.8817861, ISBN: 978-4-88552-321-2, July 2019. (TR2019-070)

Malladi, B., Di Cairano, S., Weiss, A., **"Nonlinear Model Predictive Control of Coupled Rotational-Translational Spacecraft Relative Motion"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC.2019.8814345, ISSN: 2378-5861, ISBN: 978-1-5386-7926-5, July 2019, pp. 3581-3586. (TR2019-064)

Berntorp, K., Inani, P., Quirynen, R., Di Cairano, S., **"Motion Planning of Autonomous Road Vehicles by Particle Filtering: Implementation and Validation"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC.2019.8815309, July 2019, pp. 1382-1387. (TR2019-062)

Qiao, H., Nabi, S., Laughman, C.R., **"Performance Evaluation of HVAC Systems via Coupled Simulation between Modelica and OpenFOAM"**, *International Conference on Compressor and Refrigeration*, July 2019. (TR2019-073)

Chakrabarty, A., Jha, D., Wang, Y., **"Data-Driven Control Policies for Partially Known Systems via Kernelized Lipschitz Learning"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC.2019.8815325, July 2019, pp. 4192-4197. (TR2019-047)

Matsumine, T., Koike-Akino, T., Wang, Y., **"Channel Decoding with Quantum Approximate Optimization Algorithm"**, *IEEE International Symposium on Information Theory (ISIT)*, DOI: 10.1109/ISIT.2019.8849710, ISSN: 2157-8117, ISBN: 978-1-5386-9291-2, July 2019. (TR2019-071)

Ahn, H., Danielson, C., **"Moving Horizon Sensor Selection for Reducing Communication Costs with Applications to Internet of Vehicles"**, *American Control Conference (ACC)*, July 2019, pp.1464-1469. (TR2019-066)

Berntorp, K., Quirynen, R., Di Cairano, S., **"Steering of Autonomous Vehicles Based on Friction-Adaptive Nonlinear Model-Predictive Control"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC.2019.8814448, July 2019, pp. 965-970. (TR2019-063)

Koga, S., Benosman, M., Borggaard, J., **"Learning-Based Robust Observer Design for Coupled Thermal and Fluid Systems"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC.2019.8815123, July 2019, pp. 941-946. (TR2019-067)

Tian, N., Fang, H., Wang, Y., **"Parameter Identification of the Nonlinear Double-Capacitor Model for Lithium-Ion Batteries: From the Wiener Perspective"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC.2019.8814957, July 2019, pp. 897-902. (TR2019-065)

Greiff, M., Robertsson, A., Berntorp, K., **"Performance Bounds in Positioning with the VIVE Lighthouse System"**, *International Conference on Information Fusion (FUSION)*, Ottawa, ON, Canada, July 2019, pp. 1-8. (TR2019-068)

Di Cairano, S., **"Modular Design for Constrained Control of Actuator-Plant Cascades"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC.2019.8814744, July 2019, pp. 1755-1760. (TR2019-061)

Takahashi, T., Sun, H., Tian, D., Wang, Y., **"Learning Heuristic Functions for Mobile Robot Path Planning Using Deep Neural Networks"**, *International Conference on Automated Planning and Scheduling (ICAPS)*, July 2019, pp. 764-772. (TR2019-072)

Huang, M., Zhao, M., Parikh, P., Wang, Y., Ozbay, K., Jiang, Z.-P., **"Reinforcement Learning for Vision-Based Lateral Control of a Self-Driving Car"**, *IEEE International Conference on Control and Automation (ICCA)*, DOI: 10.1109/JAS.2019.19117678, July 2019, pp. 1126-1131. (TR2019-074)

Pajovic, M., Orlik, P.V., Wada, T., Takegami, T., **"A Data-Driven Method for Predicting Capacity Degradation of Rechargeable Batteries"**, *IEEE International Conference on Industrial Informatics (INDIN)*, DOI: 10.1109/INDIN41052.2019.8972129, ISSN: 2378-363X, ISBN: 978-1-7281-2927-3, July 2019, pp. 1259-1265. (TR2019-076)

Benosman, M., Borggaard, J., **"Robust Nonlinear State Estimation for a Class of Infinite-Dimensional Systems Using Reduced-Order Models"**, *International Journal of Control*, DOI: 10.1080/00207179.2019.1645359, pp. 1-12, July 2019. (TR2019-111)

Liu, D., Mansour, H., Boufounos, P.T., **"Robust Mutual Information-Based Multi-Image Registration"**, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Yokohama, Japan, July 2019, pp. 915-918. (TR2019-079)

Kojima, K., Gotoda, M., Koike-Akino, T., TaherSima, M., Parsons, K., Meissner, T., Song, B., Klamkin, J., **"Shallow Angle Grating Coupler"**, *Integrated Photonics Research, Silicon and Nano Photonics (IPR)*, DOI: 10.1364/IPRSN.2019.IM3A.6, July 2019. (TR2019-075)

Odekunle, A., Gao, W., Wang, Y., **"Data-Driven Global Robust Optimal Output Regulation of Uncertain Partially Linear Systems"**, *IEEE/CAA Journal of Automatica Sinica*, DOI: 10.1109/JAS.2019.19117678, Vol. 6, No. 5, pp. 1108-1115, July 2019. (TR2019-080)

Zhu, Y., Imamura, M., Nikovski, D.N., Keogh, E., **"Introducing Time Series Chains: A New Primitive for Time Series Data Mining"**, *Knowledge and Information Systems*, DOI: 10.1007/s10115-018-1224-8, Vol. 60, No. 2, pp. 1135-1161, August 2019. (TR2019-077)

Poudel, S., Sun, H., Nikovski, D.N., Zhang, J., **"Resilient Restoration of Power Distribution System Based on Minimum Spanning Forest"**, *IEEE PES General Meeting*, DOI: 10.1109/PESGM40551.2019.8973730, ISSN: 1944-9925, August 2019, pp. 1-5. (TR2019-081)

Li, Z., Chu, T., Kalabić, U., **"Dynamics-Enabled Safe Deep Reinforcement Learning: Case Study on Active Suspension Control"**, *IEEE Conference on Control Technology and Applications (CCTA)*, DOI: 10.1109/CCTA.2019.8920696, August 2019, pp. 585-591. (TR2019-082)

Kalabić, U., Di Cairano, S., **"Smooth Transitions in Shared Control Using Constraint-Admissible Sets"**, *IEEE Conference on Control Technology and Applications (CCTA)*, DOI: 10.1109/CCTA.2019.8920574, August 2019, pp. 21-26. (TR2019-083)

Wei, C., Benosman, M., Kim, T., **"Online Parameter Identification for State of Power Prediction of Lithiumion Batteries in Electric Vehicles Using Extremum Seeking"**, *International Journal of Control, Automation and Systems*, August 2019, pp. 2906-2916. (TR2019-085)

Lin, C., Wang, Y., Kolesov, G., Kalabić, U., **"Application of Pontryagin's Minimum Principle to Grover's Quantum Search Problem"**, *Physical Review*, DOI: 10.1103/PhysRevA.100.022327, Vol. 100, No. 2, August 2019. (TR2019-087)

Wang, J., Cherian, A., **"Discriminative Video Representation Learning Using Support Vector Classifiers"**, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, DOI: 10.1109/TPAMI.2019.2937292, August 2019. (TR2019-107)

Zhang, S., Zhang, S., Wang, B., Habetler, T., **"Deep Learning Algorithms for Bearing Fault Diagnostics – A Review"**, *Symposium on Diagnostics for Electric Machines, Power Electronic and Drives (SDEMPED)*, DOI: 10.1109/DEMPED.2019.8864915, August 2019, pp. 257-263. (TR2019-084)

Berntorp, K., Danielson, C., Weiss, A., Di Cairano, S., Erliksson, K., Bai, R., **"Positive Invariant Sets for Safe Integrated Vehicle Motion Planning and Control"**, *Transactions on intelligent vehicles*, DOI: 10.1109/TIV.2019.2955371, Vol. 5, No. 1, pp. 112-126, August 2019. (TR2019-086)

Wang, P., Koike-Akino, T., Bose, A., Ma, R., Orlik, P.V., Tsujita, W., Sadamoto, K., Tsutada, H., Soltanalian, M., **"Learning-Based Shadow Mitigation for Terahertz Multi-Layer Imaging"**, *International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, DOI: 10.1109/IRMMW-THz.2019.8874429, ISSN: 2162-2035, ISBN: 978-1-5386-8285-2, September 2019. (TR2019-090)

Matsumine, T., Koike-Akino, T., Millar, D.S., Kojima, K., Parsons, K., **"Short Lattice-Based Shaping Approach Exploiting Non-Binary Coded Modulation"**, *European Conference on Optical Communication (ECOC)*, September 2019. (TR2019-092)

Bose, A., Kadu, A., Mansour, H., Wang, P., Boufounos, P.T., Orlik, P.V., Soltanalian, M., **"THz Multi-Layer Imaging via Nonlinear Inverse Scattering"**, *International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, DOI: 10.1109/IRMMW-THz.2019.8874118, ISSN: 2162-2027, September 2019, pp. 1-2. (TR2019-091)

Yamashita, G., Tsujita, W., Tsutada, H., Ma, R., Wang, P., Orlik, P.V., Suzuki, S., Dobroiu, A., Asada, M., **"Terahertz Polarimetric Sensing for Linear Encoder Based on a Resonant-Tunneling-Diode and CFRP polarizing plates"**, *International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, DOI: 10.1109/IRMMW-THz.2019.8873859, ISSN: 2162-2027, September 2019, pp. 1-2. (TR2019-089)

Laughman, C.R., Mackey, C., Bortoff, S.A., Qiao, H., **"Modeling and Control of Radiant, Convective, and Ventilation Systems for Multizone Residences"**, *Building Simulation*, September 2019. (TR2019-093)

Yalta, N., Watanabe, S., Hori, T., Nakadai, K., Ogata, T., **"CNN-based Multichannel End-to-End Speech Recognition for Everyday Home Environments"**, *European Signal Processing Conference (EUSIPCO)*, A Coruna, Spain, doi: 10.23919/EUSIPCO.2019.8902524 September 2019. Pp.1-5. (TR2019-094)

Poveda, J., Vamvoudakis, K., Benosman, M., **"DEES: A Class of Data-Enabled Robust Feedback Algorithms for Real-Time Optimization"**, *IFAC Nonlinear Control Systems (NOLCOS)*, September 2019, pp.670-675. (TR2019-095)

Jones, M.J., Rambhatla, S., **"Body Part Alignment and Temporal Attention for Video-Based Person Re-Identification"**, *British Machine Vision Conference (BMVC)*, September 2019. (TR2019-108)

Wichern, G., McQuinn, E., Antognini, J., Flynn, M., Zhu, R., Crow, D., Manilow, E., Le Roux, J., **"WHAM!: Extending Speech Separation to Noisy Environments"**, *Interspeech*, DOI: 10.21437/Interspeech.2019-2821, September 2019, pp. 1368-1372. (TR2019-099)

Hori, C., Cherian, A., Marks, T., Hori, T., **"Joint Student-Teacher Learning for Audio-Visual Scene-Aware Dialog"**, *Interspeech*, September 2019, pp. 1886-1890. (TR2019-097)

Moritz, N., Hori, T., Le Roux, J., **"Unidirectional Neural Network Architectures for End-to-End Automatic Speech Recognition"**, *Interspeech*, DOI: 10.21437/Interspeech.2019-2837, September 2019, pp. 76-80. (TR2019-098)

Karafiat, M., Baskar, M.K., Watanabe, S., Hori, T., Wiesner, M., Cernocky, J.H., **"Analysis of Multilingual Sequence-to-Sequence Speech Recognition Systems"**, *Interspeech*, DOI: 10.21437/Interspeech.2019-2355// Interspeech. 2019-2355, September 2019. (TR2019-103)

Seki, H., Hori, T., Watanabe, S., Le Roux, J., Hershey, J., **"End-to-End Multilingual Multi-Speaker Speech Recognition"**, *Interspeech*, DOI: 10.21437/Interspeech.2019-3038, September 2019, pp. 3755-3759. (TR2019-101)

Baskar, M.K., Watanabe, S., Astudillo, R., Hori, T., Burget, L., Cernocky, J.H., **"Semi-supervised Sequence-to-sequence ASR using Unpaired Speech and Text"**, *Interspeech*, September 2019, pp. 3790- 3794 (TR2019-100)

Seki, H., Hori, T., Watanabe, S., Moritz, N., Le Roux, J., **"Vectorized Beam Search for CTC-Attention-based Speech Recognition"**, *Interspeech*, DOI: 10.21437/Interspeech.2019-2860, September 2019, pp. 3825-3829. (TR2019-102)

Millar, D.S., Fehenberger, T., Yoshida, T., Suzuki, N., Koike-Akino, T., Kojima, K., Parsons, K., **"Huffman Coded Sphere Shaping with Short Length Reduced Complexity"**, *European Conference on Optical Communication (ECOC)*, September 2019. (TR2019-105)

Fehenberger, T., Millar, D.S., Koike-Akino, T., Kojima, K., Parsons, K., **"Mapping Strategies for Short-Length Probabilistic Shaping"**, *European Conference on Optical Communication (ECOC)*, September 2019. (TR2019-106)

Kao, J.-Y., Ortega, A., Tian, D., Mansour, H., Vetro, A., **"Graph Based Skeleton Modeling for Human Activity Analysis"**, *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP.2019.8803186, ISSN: 2381-8549, ISBN: 978-1-5386-6249-6, September 2019. (TR2019-037)

Koike-Akino, T., Wang, Y., Millar, D.S., Kojima, K., Parsons, K., **"Neural Turbo Equalization to Mitigate Fiber Nonlinearity"**, *European Conference on Optical Communication (ECOC)*, September 2019. (TR2019-088)

Zhang, W., Jha, D., Laftchiev, E., Nikovski, D.N., **"Multi-label Prediction in Time Series Data using Deep Neural Networks"**, *International Journal for Prognostics and Health Management Special Issue on Applications of Deep Learning and Emerging Analytics*, ISSN: 2153-2648, Vol. 10, pp. 0-12, September 2019. (TR2019-110)

Tripathy, A., Wang, Y., Ishwar, P., **"Privacy-Preserving Adversarial Networks"**, *Allerton Conference on Communication, Control, and Computing*, DOI: 10.1109/ALLERTON.2019.8919758, ISBN: 978-1-7281-3151-1, September 2019. (TR2019-113)

Wen, M., Beixiong, Z., Kim, K.J., Di Renzo, M., Tsiftsis, T.A., Chen, K.-C., Al-Dhahir, N., **"A Survey on Spatial Modulation in Emerging Wireless Systems: Research Progresses and Applications"**, *IEEE Journal on Selected Areas in Communications*, DOI: 10.1109/JSAC.2019.2929453, Vol. 37, No. 9, pp. 1949-1972, September 2019. (TR2019-112)

Wang, Y., Chakrabarty, A., Zhou, M., Zhang, J., **"Near-optimal control of motor drives via approximate dynamic programming"**, *IEEE International Conference on Systems, Man, and Cybernetics*, DOI: 10.1109/SMC.2019.8914595, October 2019, pp. 3679-3686. (TR2019-116)

Vinokur, G., **"Introduction to Patent Drafting to Both Protect and Promote Scientific Research"**, *Innovate Magazine: American Intellectual Property Law Association (AIPLA)*, October 2019. (TR2019-114)

Nabi, S., Grover, P., **"Improving LiDAR performance on a complex terrain using CFD-based correction and direct-adjoint-loop optimization"**, *NAWEA/WindTech Conference*, DOI: 10.1088/1742-6596/1452/1/012082, October 2019. (TR2019-130)

Ma, T., Komatsu, T., Wang, B., Wang, Y., Lin, C., **"Observer Designs for Simultaneous Temperature and Loss Estimation for Electric Motors: A Comparative Study"**, *Annual Conference of the IEEE Industrial Electronics Society (IES)*, DOI: 10.1109/IECON.2019.8927182, ISSN: 1553-572X, October 2019, pp. 1234-1241. (TR2019-122)

Almeida, D., Ataer-Cansizoglu, E., Corcodel, R., **"Detection, Tracking and 3D Modeling of Objects with Sparse RGB-D SLAM and Interactive Perception"**, *IEEE-RAS International Conference on Humanoid Robots*, DOI: 10.1109/Humanoids43949.2019.9035001, October 2019, pp. 1-8 (TR2019-119)

Manilow, E., Wichern, G., Seetharaman, P., Le Roux, J., **"Cutting Music Source Separation Some Slakh: A Dataset to Study the Impact of Training Data Quality and Quantity"**, *IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA)*, DOI: 10.1109/WASPAA.2019.8937170, ISSN: 1947-1629, ISBN: 978-1-7281-1123-0, October 2019, pp. 45-49. (TR2019-124)

Kavalerov, I., Wisdom, S., Erdogan, H., Patton, B., Wilson, K., Le Roux, J., Hershey, J., **"Universal Sound Separation"**, *IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA)*, DOI: 10.1109/WASPAA.2019.8937253, ISSN: 1947-1629, ISBN: 978-1-7281-1123-0, October 2019, pp. 170-174. (TR2019-123)

Weiss, A., Yerazunis, W.S., Radyjowski, P., Cottrell, R., **"On-Orbit Additive Manufacturing of Parabolic Reflector via Solar Photopolymerization"**, *International Astronautical Congress (IAC)*, October 2019. (TR2019-125)

Kalabić, U., Chakrabarty, A., Quirynen, R., Di Cairano, S., **"Learning autonomous vehicle passengers' preferred driving styles using g-g plots and haptic feedback"**, *IEEE Intelligent Transportation Systems Conference (ITSC)*, DOI: 10.1109/ITSC.2019.8917328, October 2019, pp. 4012-4017. (TR2019-115)

Marks, T., Kumar, A., Mou, W., Feng, C., Liu, X., **"UGLLI Face Alignment: Estimating Uncertainty with Gaussian Log-Likelihood Loss"**, *IEEE International Conference on Computer Vision (ICCV) Workshop on Statistical Deep Learning for Computer Vision (SDL-CV)*, October 2019. (TR2019-117)

Wang, J., Cherian, A., **"GODS: Generalized One-class Discriminative Subspaces for Anomaly Detection"**, *IEEE International Conference on Computer Vision (ICCV)*, DOI: 10.1109/ICCV.2019.00829 October 2019, pp. 8200-8210. (TR2019-121)

Paul, S., van Baar, J., Roy-Chowdhury, A.K., **"Learning from Trajectories via Subgoal Discovery"**, *Advances in Neural Information Processing Systems (NeurIPS)*, pp. 8409-8419, October 2019. (TR2019-128)

Maske, H., Chu, T., Kalabić, U., **"Large-scale traffic control using autonomous vehicles and decentralized deep reinforcement learning"**, *IEEE Intelligent Transportation Systems Conference (ITSC)*, DOI: 10.1109/ITSC.2019.8916776, October 2019, pp. 3816-3821. (TR2019-126)

Wu, Y., Marks, T., Cherian, A., Chen, S., Feng, C., Wang, G., Sullivan, A., **"Unsupervised Joint 3D Object Model Learning and 6D Pose Estimation for Depth-Based Instance Segmentation"**, *IEEE ICCV Workshop on Recovering 6D Object Pose*, DOI: 10.1109/ICCVW.2019.00339, October 2019, 2777-2786. (TR2019-118)

Zhang, Z., Wu, Y., Wang, G., **"Unsupervised Deep Feature Transfer for Low Resolution Image Classification"**, *IEEE International Conference on Computer Vision Workshops (ICCV)*, DOI: 10.1109/ICCVW.2019.00136, October 2019, pp. 1065-1069. (TR2019-127)

Jha, D., Raghunathan, A., Romeres, D., **"Quasi-Newton Trust Region Policy Optimization"**, *Conference on Robot Learning (CoRL)*, October 2019. (TR2019-120)

Imamura, M., Inoue, M., Terada, M., Nikovski, D.N., **"Time Series Segmentation with Leg Analysis for Human Motion Analysis"**, *International Workshop on Informatics*, October 2019. (TR2019-150)

Ota, K., Jha, D.K., Oiki, T., Miura, M., Nammoto, T., Nikovski, D., Mariyama, T., **"Trajectory Optimization for Unknown Constrained Systems using Reinforcement Learning"**, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, DOI: 10.1109/IROS40897.2019.8968010, ISSN: 2153-0866, ISBN: 978-1-7281-4004-9, November 2019, pp. 3487-3494. (TR2019-129)

Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., Zhang, J., **"Joint BP and RNN for Resilient GPS Timing Against Spoofing Attacks"** in Social Informatics and Telecommunications Engineering, Han S., Ye L., Meng W., Eds., DOI: 10.1007/978-3-030-22971-9_17, vol. 287 of Lecture Notes of the Institute for Computer Sciences, Springer, Cham, November 2019. (TR2019-131)

Nabi, S., Nishio, N., Grover, P., Matai, R., Kajiyama, Y., Kotake, N., Kameyama, S., Yoshiki, W., Iida, M., **"Improving LiDAR performance on complex terrain using CFD-based correction and direct-adjoint-loop optimization"**, *Journal of physics*, DOI: 10.1088/1742-6596/1452/1/012082, Vol. 1452, November 2019. (TR2019-152)

Pei, X., Wen, M., Kim, K.J., Zheng, B., Yu, H., **"NOMA Based Coordinated Direct and Relay Transmission: Secure Design and Performance Analysis"**, *IEEE Global Communications Conference (GLOBECOM)*, December 2019, pp. 1-6. (TR2019-155)

Wang, P., Koike-Akino, T., Orlik, P.V., Pajovic, M., Kim, K.J., **"Variational Bayesian Symbol Detection for Massive MIMO Systems with Symbol-Dependent Transmit Impairments"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9013363, ISSN: 2576-6813, ISBN: 978-1-7281-0962-6, December 2019. (TR2019-139)

Jha, D., Raghunathan, A., Romeres, D., **"QNTRPO: Including Curvature in TRPO"**, *Optimization Foundations for Reinforcement Learning Workshop at NeurIPS*, December 2019. (TR2019-154)

Liu, B., Wei, Z., Yuan, J., Pajovic, M., **"Deep Learning Assisted User Identification in Massive Machine-Type Communications"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9014177, December 2019, pp.1-6 (TR2019-134)

Fujihashi, T., Koike-Akino, T., Watanabe, T., Orlik, P.V., **"DNN-based Overhead Reduction for High-Quality Soft Delivery"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9014124, ISSN: 2576-6813, ISBN: 978-1-7281-0962-6, December 2019. (TR2019-133)

Jespersen, M.H., Pajovic, M., Koike-Akino, T., Wang, Y., Popovski, P., Orlik, P.V., **"Deep Learning for Synchronization and Channel Estimation in NB-IoT Random Access Channel"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9013510, ISSN: 2576-6813, ISBN: 978-1-7281-0962-6, December 2019. (TR2019-140)

Wang, P., Pajovic, M., Koike-Akino, T., Sun, H., Orlik, P.V., **"Fingerprinting-Based Indoor Localization with Commercial MMWave WiFi - Part II: Spatial Beam SNRs"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9014103, ISSN: 2576-6813, ISBN: 978-1-7281-0962-6, December 2019. (TR2019-138)

Tanovic, O., Ma, R., Orlik, P.V., Megretski, A., **"Optimal Power Encoding of OFDM Signals in All-Digital Transmitters"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9014289, ISSN: 2576-6813, ISBN: 978-1-7281-0962-6, December 2019, pp. 1-6. (TR2019-137)

Pajovic, M., Wang, P., Koike-Akino, T., Sun, H., Orlik, P.V., **"Fingerprinting-Based Indoor Localization with Commercial MMWave WiFi – Part I: RSS and Beam Indices"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9013466, ISSN: 2576-6813, ISBN: 978-1-7281-0962-6, December 2019. (TR2019-141)

Kim, K.J., Guo, J., Tang, J., Orlik, P.V., **"Distributed Cyclic Delay Diversity for Cooperative Infrastructure-to-Vehicle Systems"**, *IEEE Global Communications Conference (GLOBECOM)*, December 2019, pp. 1-6. (TR2019-135)

Fujihashi, T., Koike-Akino, T., Watanabe, T., Orlik, P.V., **"DNN-based Simultaneous Screen-to-Camera and Screen-to-Eye Communications"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM38437.2019.9013967, ISSN: 2576-6813, ISBN: 978-1-7281-0962-6, December 2019. (TR2019-132)

Kim, K.J., Liu, H., Wen, M., Orlik, P.V., Poor, H.V., **"Distributed Asynchronous Cyclic Delay Diversity-Based Cooperative Systems with a Passive Eavesdropper"**, *IEEE Global Communications Conference (GLOBECOM)*, December 2019, pp. 1-6. (TR2019-136)

Nabi, S., Grover, P., Caulfield, C., **"Nonlinear Optimal Control Strategies for Buoyancy-Driven Flows in the Built Environment"**, *Journal of Computers and Fluids*, DOI: 10.1016/j.compfluid.2019.104313, Vol. 194, No. 104313, December 2019. (TR2019-151)

Wollenstein, S., Sun, C., Zhang, J., Paschalidis, I., **"Joint Estimation of OD Demands and Cost Functions in Transportation Networks from Data"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC40024.2019.9029445 December 2019, pp.5113-5118. (TR2019-144)

Chu, T., Kalabić, U., **"Model-based deep reinforcement learning for CACC in mixed-autonomy vehicle platoons"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC40024.2019.9030110, December 2019, pp. 4079-4084. (TR2019-142)

Garcia, J., Danielson, C., Limon, D., Bortoff, S.A., Di Cairano, S., **"Steady-State Analysis of HVAC Performance using Indoor Fans in Control Design"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC40024.2019.9029730, December 2019, pp. 2952-2957. (TR2019-143)

Menner, M., Berntorp, K., Di Cairano, S., **"Inverse Learning for Human-Adaptive Motion Planning"**, *IEEE Conference on Decision and Control (CDC)*, December 2019. (TR2019-146)

Chakrabarty, A., Zemouche, A., Rajamani, R., Benosman, M., **"Robust Data-Driven Neuro-Adaptive Observers With Lipschitz Activation Functions"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC40024.2019.9029394, December 2019, pp. 2862-2867. (TR2019-149)

Poveda, J., Vamvoudakis, K., Benosman, M., **"CODES: Cooperative Data-Enabled Extremum Seeking for Multi-Agent Systems"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC40024.2019.9029908, December 2019, pp. 2988-2993 (TR2019-148)

Benosman, M., Borggaard, J., **"Robust Nonlinear State Estimation for Thermal-Fluid Models Using Reduced-Order Models: The Case of the Boussinesq Equations"**, *IEEE Conference on Decision and Control (CDC)*, December 2019, DOI: 10.1109/CDC40024.2019.9029593 pp. 2157-2162. (TR2019-147)

Berntorp, K., Hiroaki, K., **"Bayesian Learning of Tire Friction with Automotive-Grade Sensors by Gaussian-Process State-Space Models"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC40024.2019.9029732, December 2019, pp. 6681-6686. (TR2019-145)

Karita, S., Chen, N., Hayashi, T., Hori, T., Inaguma, H., Jiang, Z., Someki, M., Enrique Yalta Soplin, N., Yamamoto, R., Wang, X., Watanabe, S., Yoshimura, T., Zhang, W., **"A Comparative Study on Transformer Vs RNN in Speech Applications"**, *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, DOI: 10.1109/ASRU46091.2019.9003750, December 2019, pp. 449-456 (TR2019-158)

Moritz, N., Hori, T., Le Roux, J., **"Streaming End-to-End Speech Recognition with Joint CTC-Attention Based Models"**, *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, ISBN: 978-1-7281-0305-1, December 2019, pp. 936-943. (TR2019-159)

Jha, D., Kolaric, P., Romeres, D., Raghunathan, A., Benosman, M., Nikovski, D.N., **"Robust Optimization for Trajectory-Centric Model-based Reinforcement Learning"**, *NeurIPS Workshop on Safety and Robustness in Decision Making*, December 2019. (TR2019-156)

Chang, X., Zhang, W., Qian, Y., Le Roux, J., Watanabe, S., **"MIMO-Speech: End-to-End Multi-Channel Multi-Speaker Speech Recognition"**, *IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU)*, ISBN: 978-1-7281-0305-1, December 2019, pp. 237-144. (TR2019-157)

DeRousseau, M.A., Laftchiev, E., Kasprzyk, J.R., Balaji, R., Srubar III, W.V., **"Machine Learning Methods for Predicting the Field Compressive Strength of Concrete"**, *Construction And Building Materials*, DOI: 10.1016/j.conbuildmat.2019.08.042, Vol. 228, December 2019. (TR2019-096)

Ma, Y., Lu, C., Wang, Y., **"Efficient Holistic Control: Self-Awareness across Controllers and Wireless Networks"**, *ACM Transactions on Cyber-Physical Systems*, Vol. 1, No. 1, Article 1, January 2020, pp. 1-25. (TR2020-002)

Romero, O., Benosman, M., **"Finite-Time Convergence of Continuous-Time Optimization Algorithms via Differential Inclusions"**, *Advances in Neural Information Processing Systems (NIPS)- Workshop*, January 2020. (TR2020-001)

Berntorp, K., Quirynen, R., Uno, T., Di Cairano, S., **"Trajectory Tracking for Autonomous Vehicles on Varying Road Surfaces by Friction-Adaptive Nonlinear Model Predictive Control"**, *Journal of Vehicle Systems Dynamics*, DOI: 10.1080/00423114.2019.1697456, January 2020. (TR2020-005)

Xu, H., Sun, H., Nikovski, D.N., Kitamura, S., Mori, K., Hashimoto, H., **"Deep Reinforcement Learning for Joint Bidding and Pricing of Load Serving Entity"**, *IEEE Transactions on smart grids*, DOI: 10.1109/TSG.2019.2903756, ISSN: 1949-3061, Vol. 10, No. 6, pp. 6366-6375, January 2020. (TR2020-003)

Chen, S., Duan, C., Yang, Y., Feng, C., Li, D., Tian, D., **"Deep Unsupervised Learning of 3D Point Clouds via Graph Topology Inference and Filtering"**, *IEEE Transactions on Image Processing*, DOI: 10.1109/TIP.2019.2957935, January 2020, pp. 3183-3198. (TR2020-004)

Muralidharan, V., Weiss, A., Kalabic, U., **"Control Strategy for Long-Term Station-Keeping on Near-Rectilinear Halo Orbits"**, *AAS/AIAA Space Flight Mechanics Meeting*, DOI: 10.2514/6.2020-1459, January 2020. (TR2020-006)

Caverly, R., Di Cairano, S., Weiss, A., **"Control Allocation and Quantization of a GEO Satellite with 4DOF Gimbaled Thruster Booms"**, *AAS/AIAA Space Flight Mechanics Meeting*, DOI: 10.2514/6.2020-1687, January 2020. (TR2020-008)

Wang, P., Li, H., **"Target Detection with Imperfect Waveform Separation in Distributed MIMO Radar"**, *IEEE Transactions on Signal Processing*, DOI: 10.1109/TSP.2020.2964227, ISSN: 1053-587X, Vol. 68, No. 1, pp. 793-807, January 2020. (TR2020-007)

Teng, M., Safian, R., Alahmadi, Y., Zhuang, L., Kojima, K., **"Miniaturized silicon photonics devices for integrated optical signal processors"**, *JLT (Invited Review Paper)*, DOI: 10.1109/JLT.2019.2943251, Vol. 38, No. 1, pp. 6-17, January 2020. (TR2020-010)

He, W., Lee, T.-Y., van Baar, J., Wittenburg, K.B., Shen, H.-W., **"DynamicsExplorer: Visual Analytics for Robot Control Tasks involving Dynamics and LSTM-based Control Policies"**, *IEEE Pacific Visualization Symposium (PacificVis)*, January 2020. (TR2020-011)

Liu, F., Zhu, H., Li, C., Li, J., Wang, P., Orlik, P.V., **"Angular-Domain Channel Estimation for One-Bit Massive MIMO Systems: Performance Bounds and Algorithms"**, *IEEE Transactions on Vehicular Technology*, DOI: 10.1109/TVT.2020.2966003, ISSN: 0018-9545, Vol. 69, No. 3, January 2020. (TR2020-009)

Tang, Y., Kojima, K., Gotoda, M., Nishikawa, S., Hayashi, S., Koike-Akino, T., Parsons, K., Meissner, T., Song, B., Sang, F., Yi, X., Klamkin, J., **"Design and Optimization of Shallow-Angle Grating Coupler for Vertical Emission from Indium Phosphide Devices"**, *SPIE Photonics West*, DOI: 10.1117/12.2545082, February 2020. (TR2020-024)

Cherian, A., Wang, J., Hori, C., Marks, T., **"Spatio-Temporal Ranked-Attention Networks for Video Captioning"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, February 2020. (TR2020-016)

Huang, R., Xu, W., Lee, T.-Y., Cherian, A., Wang, Y., Marks, T., **"FX-GAN: Self-Supervised GAN Learning via Feature Exchange"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, February 2020, pp. 3194-3202. (TR2020-014)

Poudel, S., Sun, H., Nikovski, D.N., Zhang, J., **"Distributed Average Consensus Algorithm for Damage Assessment of Power Distribution system"**, *IEEE Innovative Smart Grid Technologies Conference (ISGT)*, February 2020. (TR2020-013)

Ramachandra, B., Jones, M.J., **"Street Scene: A new dataset and evaluation protocol for video anomaly detection"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, February 2020, pp. 2569- 2578. (TR2020-017)

Ramachandra, B., Jones, M.J., Vatsavai, R., **"Learning a distance function with a Siamese network to localize anomalies in videos"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, February 2020, pp. 2598- 2607. (TR2020-015)

Fehenberger, T., Millar, D.S., Koike-Akino, T., Kojima, K., Parsons, K., Griesser, H., **"Analysis of Nonlinear Fiber Interactions for Finite-Length Constant-Composition Sequences"**, *IEEE Journal of Lightwave Technology*, DOI: 10.1109/JLT.2019. 2937926, ISSN: 0733-8724, Vol. 38, No. 2, pp. 457-465, February 2020. (TR2020-021)

Lin, C., Sels, D., Wang, Y., **"Time-optimal Control of a Dissipative Qubit"**, *Physical Review*, February 2020. (TR2020-023)

Berntorp, K., Weiss, A., Di Cairano, S., **"Integer Ambiguity Resolution by Mixture Kalman Filter for Improved GNSS Precision"**, *IEEE Transactions on Aerospace and Electronic Systems*, DOI: 10.1109/TAES.2020.2965715, February 2020. (TR2020-022)

Tang, Y., Kojima, K., Koike-Akino, T., Wang, Y., Wu, P., TaherSima, M., Jha, D., Parsons, K., Qi, M., **"Generative Deep Learning Model for a Multi-level NanoOptic Broadband Power Splitter"**, *Optical Fiber Communication Conference and Exposition (OFC)*, DOI: 10.1364/OFC.2020.Th1A.1, ISBN: 978-1-943580-71-2, March 2020, pp. Th1A.1. (TR2020-025)

Koike-Akino, T., Millar, D.S., Kojima, K., Parsons, K., **"Stochastic EXIT Design for Low-Latency Short-Block LDPC Codes"**, *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC)*, DOI: 10.1364/OFC.2020.W2A.54, ISBN: 978-1-943580-71-2, March 2020, pp. W2A.54. (TR2020-027)

Koike-Akino, T., Matsumine, T., Wang, Y., Millar, D.S., Kojima, K., Parsons, K., **"Variational Quantum Demodulation for Coherent Optical Multi-Dimensional QAM"**, *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC)*, DOI: 10.1364/OFC.2020.T3D.6, ISBN: 978-1-943580-71-2, March 2020, pp. T3D.6. (TR2020-028)

D'Haro, L.F., Yoshino, K., Hori, C., Marks, T., Polymenakos, L., Kummerfeld, J.K., Galley, M., Gao, X., **"Overview of the seventh Dialog System Technology Challenge: DSTC7"**, *Computer Speech and Language*, March 2020. (TR2020-029)

Li, R., Wang, X., Mallidi, H., Watanabe, S., Hori, T., Hermansky, H., **"Multi-Stream End-to-End Speech Recognition"**, *IEEE/ACM Transactions on Audio, Speech and Language Processing*, DOI: 10.1109/TASLP.2019.2959721, Vol. 28, pp. 646-655, March 2020. (TR2020-030)

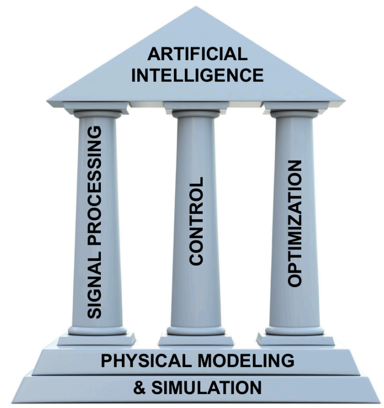
Laughman, C.R., Bortoff, S.A., **"Nonlinear State Estimation with FMI: Tutorial and Applications"**, *American Modelica Conference 2020*, March 2020. (TR2020-031)

Bortoff, S.A., **"Modeling Contact and Collisions for Robotic Assembly Control"**, *American Modelica Conference 2020*, March 2020. (TR2020-032)

Zhang, S., Zhang, S., Wang, B., Habetler, T., **"Deep Learning Algorithms for Bearing Fault Diagnostics – A Comprehensive Review"**, *IEEE Access*, March 2020. (TR2020-034)

Koike-Akino, T., Wang, Y., Millar, D.S., Kojima, K., Parsons, K., **"Neural Turbo Equalization: Deep Learning for Fiber-Optic Nonlinearity Compensation"**, *Journal of Lightwave Technology*, DOI: 10.1109/JLT.2020.2976479, March 2020. (TR2020-033)

Research



The body and soul of any research lab is its portfolio of research projects. The main body of this annual report consists of descriptions of research recently done at MERL. The reports are grouped into the five areas MERL's research is focused on.

Multi-Physical Modeling & Simulation – Research on multi-physical modeling & simulations as a basis for producing model-based design for devices, systems and controls to achieve optimized performance with high efficiency. Target applications include HVAC systems, factory automation, robotics, electrical motors, power amplifier devices, superconductors, and nanoparticles for future magnetic particle imaging. Development of simulators to enable training of machine learning for vision and robot system, and in data-poor industrial applications.

Signal Processing – Acquisition, representation, and processing of signals with an emphasis on wireless/optical communications and associated devices, computational sensing, radar processing and statistical inference. Application areas include: terrestrial and trans-oceanic optical networks, train and automotive connectivity and electronics, energy storage systems, RF power amplifiers, RF sensing systems for security, infrastructure and building monitoring.

Control – Developing new control and estimation algorithms with improved performance and robustness, and reduced computational footprint. Special focus areas include model predictive control, statistical estimation, nonlinear dynamical systems, constrained control, motion planning, integration of learning and control, and real-time optimization for control. The main application areas are driver assistance and automated driving systems, factory automation, electric vehicles, space systems, electric motors, and HVAC.

Optimization – Highly scalable continuous and discrete optimization and scheduling algorithms that can be applied to 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, increases reliability, improves energy efficiency, and reduces environmental impact of products.

Artificial Intelligence – Enabling computers and robots to see, hear, understand, and interact with the world, by extracting meaning and building representations of scenes, objects, and events. Developing machine learning algorithms to perform a wide range of inference tasks including detection, classification, recognition, and reconstruction, and applying these algorithms to problems in computer vision, speech and audio processing, as well as time-series data analysis.

Physical Modeling & Simulation

This area covers researches on modeling, simulation, and model-based design of dynamic systems, advanced machines and devices. This research serves as a foundation for other technologies, such as signal processing, control, optimization, and artificial intelligence. We investigate modeling fundamentals including mathematical formulations of multi-physical dynamics, accurate models of complex systems via state-of-the-art modeling tools, fundamental principles and applied physics research, rapid simulations via model reduction and parallel solvers, and model-based design process for optimization of architecture, control and performance.

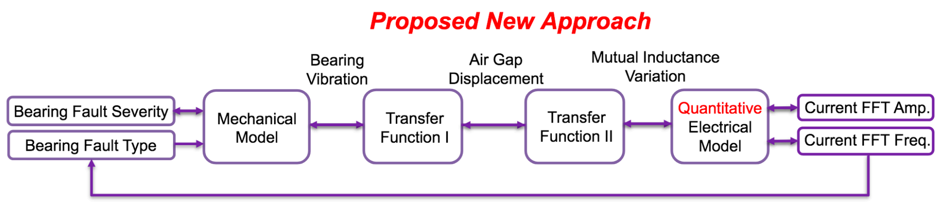
Much of this research focuses on application of a system analysis in the following areas: the development and application of new tools to model and simulate complex, heterogeneous systems; the creation of new multi-physical system designs (architectures) and performance metrics; the invention of new optimal control, coordinating control, and estimation algorithms; and the use of collaborative design tools and processes for future products. Target applications include model-based design, control and optimization of HVAC, motion control, traffic, and energy systems; advanced assembly lines in factories; and digital twin systems for zero-energy buildings.

Recent Research

Quantification of Rolling-Element Bearing Fault Severity of Induction Machines

Citation: Zhang, S., Wang, B., Kanemaru, M., Lin, C., Liu, D., Habetler, T., "Quantification of Rolling-Element Bearing Fault Severity of Induction Machines", International Electric Machine & Drives Conference (IEMDC), DOI: 10.1109/IEMDC.2019.8785225, May 2019, pp. 44-50.

Contacts: Bingnam Wang

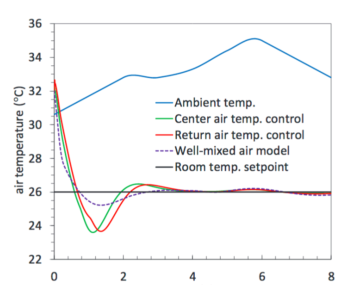


The characteristic frequencies of different types of bearing faults can be calculated by a well-defined frequency-based model that depends on the motor speed, the bearing geometry and the specific location of a defect inside a bearing. Therefore, the existence of a bearing fault as well as its specific fault type can be readily determined by performing frequency spectral analyses on the monitored signals. However, this traditional approach, despite being simple and intuitive, is not able to identify the severity of a bearing fault in a quantitatively manner. This paper proposes a quantitative approach to estimating a bearing fault severity based on the air gap displacement profile, which is reconstructed from the mutual inductance variation profile estimated from a novel electrical model that only takes the stator current as input. In addition, the accuracy of the electrical model and the estimated bearing fault severity are validated by simulation results.

Performance Evaluation of HVAC Systems via Coupled Simulation between Modelica and OpenFOAM

Citation: Qiao, H., Nabi, S., Laughman, C.R., "Performance Evaluation of HVAC Systems via Coupled Simulation between Modelica and OpenFOAM", International Conference on Compressor and Refrigeration, July 2019.

Contacts: Hongtao Qiao, Saleh Nabi

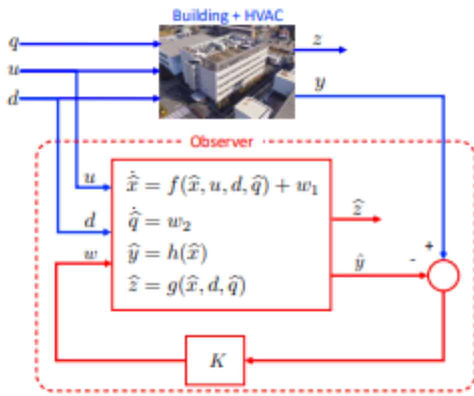


High-performance building design heavily relies on computational models that can predict the dynamic interactions between HVAC equipment, air flow and building envelope. This paper presents a coupled simulation of Modelica and OpenFOAM to evaluate the system performance of a room air-conditioner operating in buildings. The dynamic models of the air-conditioner are constructed in Modelica, whereas the indoor airflow is simulated in OpenFOAM. Dynamic system characteristics are analyzed and compared against those obtained with the well-mixed air model. The effects of thermal stratification and thermostat placement on the system energy efficiency are also discussed.

An Extended Luenberger Observer for HVAC Application using FMI

Citation: Bortoff, S.A.; Laughman, C.R., "An Extended Luenberger Observer for HVAC Application using FMI", *International Modelica Conference*, March 2019

Contacts: Scott A. Bortoff, Christopher R. Laughman

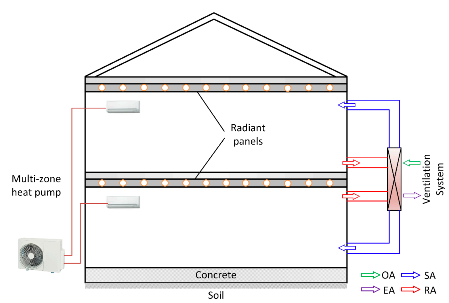


In this paper we show how a Functional Mockup Unit (FMU) may be used for the realization of an Extended Luenberger Observer (ELO), which may be considered the deterministic version of an Extended Kalman Filter (EKF). The ELO has advantages over an EKF in some situations, such as lower computational burden and improved convergence. Nonlinear observers, such as those that make use of changes of coordinates to linearize, or approximately linearize the estimate error, are continuous-time dynamical systems that use so-called output injection to modify the dynamics of a model. Output injection provides a similar feedback effect as the correction step of an EKF. However, nonlinear output injection is a slightly different use case because the ELO is a continuous time object. It is realized by feedback around a model-sharing type of continuous time FMU, in contrast with the algorithmic realization of a discrete-time EKF, which uses the co-simulation form of FMU. We illustrate the design and realization of an ELO for a building HVAC example, in which we estimate unmeasured heat flows and unmeasured boundary conditions for use in a building "digital twin." We also make some remarks about model reduction and the challenges in realizing a conventional EKF for these types of models.

Modeling and Control of Radiant, Convective, and Ventilation Systems for Multizone Residences

Citation: Laughman, C.R., Mackey, C., Bortoff, S.A., Qiao, H., "Modeling and Control of Radiant, Convective, and Ventilation Systems for Multizone Residences", Building Simulation, DOI: 10.26868/25222708.2019.210847, September 2019.

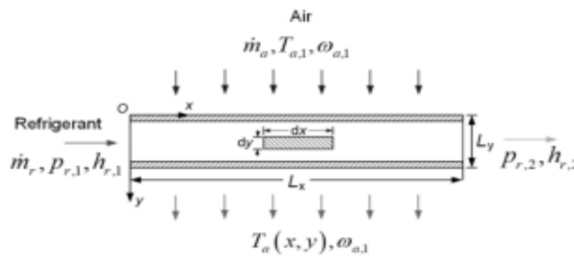
Contacts: Chris Laughman, Scott Bortoff



The variety of ventilation requirements, thermal comfort specifications, and lower cooling loads for high-performance buildings can motivate the use of multiple HVAC systems whose dynamic interactions can strongly affect performance. We develop a Modelica energy model of a multi-zone residential building, based on an prototype EnergyPlus model distributed by the U.S. DOE, to quantify these interactions and design new controls to improve comfort. Fully dynamic radiant, convective, and ventilation subsystems are all integrated into a heterogeneous cooling system that has better performance than is achievable by a smaller collection of systems.

Numerical Modeling of Fin-and-Tube Condenser with Wet-wall De-superheating

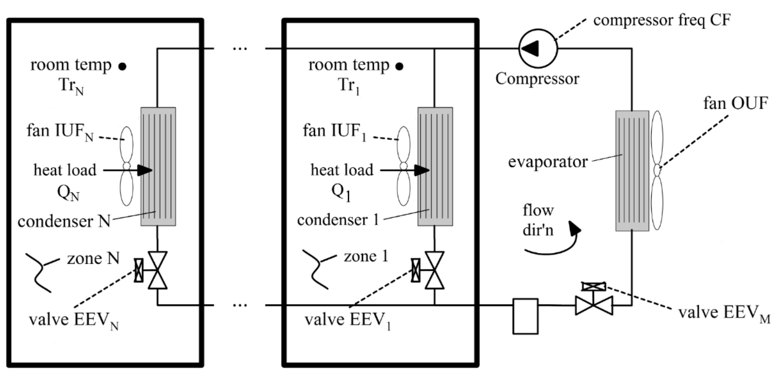
Citation: Qiao, H..; Laughman, C.R., “Numerical Modeling of Fin-and-Tube Condenser with Wet-wall De-superheating”, *International Refrigeration and Air Conditioning Conference at Purdue*, August 2018.
Contacts: Hongtao Qiao, Christopher R. Laughman



Current heat exchanger simulation models typically divide the condenser into three regimes (desuperheating, twophase and subcooled) and assume that condensation does not start until the bulk refrigerant flow reaches a state of saturated vapor. This paper proposes a new fin-and-tube condenser heat exchanger model in which the heat exchanger is divided into four regimes: dry-wall desuperheating, wet-wall desuperheating, two-phase condensation and subcooled. A tube-by-tube analysis is adopted to allow for the simulation of complex tube circuitries. Results show that wet-wall desuperheating always exists in the condenser with refrigerant vapor entering at the inlet, and neglecting the phenomenon can lead to significant prediction errors for heat exchanger performance.

Steady-State Analysis of HVAC Performance using Indoor Fans in Control Design

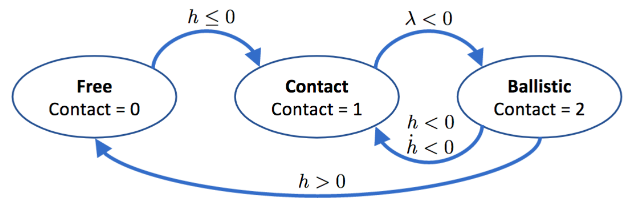
Citation: Garcia, J., Danielson, C., Limon, D., Bortoff, S.A., Di Cairano, S., "Steady-State Analysis of HVAC Performance using Indoor Fans in Control Design", IEEE Conference on Decision and Control (CDC), DOI: 10.1109/CDC40024.2019.9029730, December 2019, pp. 2952-2957.
Contacts: Scott Bortoff, Stefano Di Cairano



Indoor fans are high-authority actuators in heating, ventilation, and air conditioning (HVAC) systems since they facilitate the transfer of heat between refrigerant and room air. In some variable refrigerant flow (VRF) systems, the indoor fan speeds are under the control of the occupants, rather than the HVAC control system. This paper studies the benefits of transferring control of the indoor fans to the HVAC controller. Simulation results indicate that with this change, the maximum steady-state difference in room temperatures is tripled, and the maximum rejected heating and cooling loads are doubled. Furthermore, power consumption is significantly reduced.

Modeling Contact and Collisions for Robotic Assembly Control

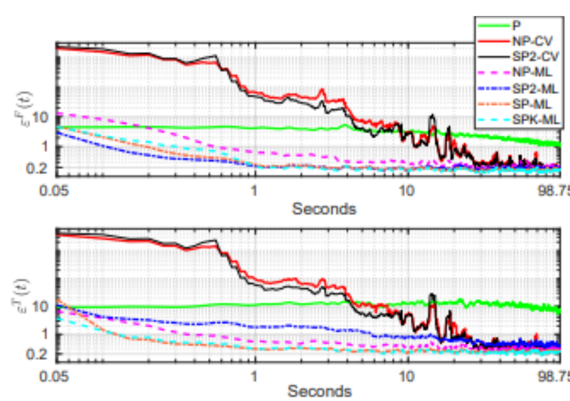
Citation: Bortoff, S.A., "Modeling Contact and Collisions for Robotic Assembly Control", American Modelica Conference 2020, March 2020.
Contacts: Scott Bortoff



We propose an implicit, event-driven, penalty-based method for modeling rigid body contact and collision that is useful for design and analysis of control algorithms for precision robotic assembly tasks. The method is based on Baumgarte's method of differential algebraic equation index reduction in which we modify the conventional constraint stabilization to model object collision, define a finite state machine to model transition between contact and non-contact states, and represent the robot and task object dynamics as a single set of differential algebraic inequalities. The method, which is realized natively in Modelica, has some advantages over conventional penalty-based methods: The resulting system is not numerically stiff after the collision transient, it enforces constraints for object penetration, and it allows for dynamic analysis of the Modelica model beyond time-domain simulation. We provide three examples: A bouncing ball, a ball maze, and a delta robot controlled to achieve soft collision and maintain soft contact with an object in its environment.

Derivative-Free Online Learning of Inverse Dynamics Models

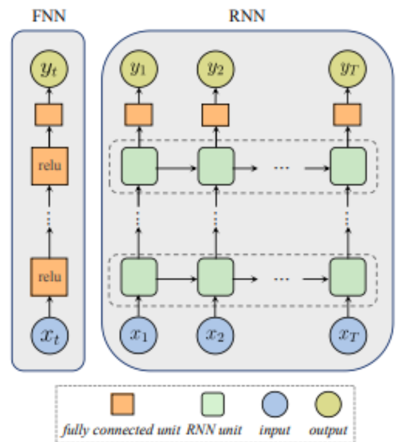
Citation: Romeres, D.; Zorzi, M.; Camoriano, R.; Traversaro, S.; Chiuso, A., "Derivative-Free Online Learning of Inverse Dynamics Models", *IEEE Transactions on Control Systems Technology*, DOI: 10.1109/TCST.2019.2891222, March 2019.
Contacts: Diego Romeres



This paper discusses online algorithms for inverse dynamics modelling in robotics. Several model classes including rigid body dynamics (RBD) models, data-driven models and semiparametric models (which are a combination of the previous two classes) are placed in a common framework. While model classes used in the literature typically exploit joint velocities and accelerations, which need to be approximated resorting to numerical differentiation schemes, in this paper a new "derivative-free" framework is proposed that does not require this preprocessing step. An extensive experimental study with real data from the right arm of the iCub robot is presented, comparing different model classes and estimation procedures, showing that our "derivative-free" methods outperform existing methodologies.

Learning Dynamical Demand Response Model in Real-Time Pricing Program

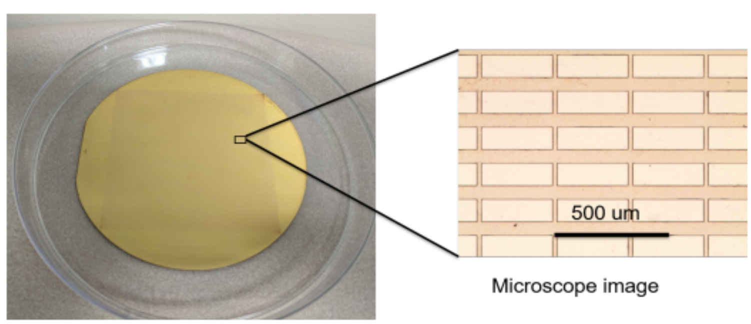
Citation: Xu, H.; Sun, H.; Nikovski, D.N.; Shoichi, K.; Mori, K., “Learning Dynamical Demand Response Model in Real-Time Pricing Program”, IEEE ISGT, February 2019.
Contacts: Hongbo Sun, Daniel N. Nikovski



Price responsiveness is a major feature of end use customers (EUCs) that participate in demand response (DR) programs, and has been conventionally modeled with static demand functions, which take the electricity price as the input and the aggregate energy consumption as the output. This, however, neglects the inherent temporal correlation of the EUC behaviors, and may result in large errors when predicting the actual responses of EUCs in real-time pricing (RTP) programs. In this paper, we propose a dynamical DR model so as to capture the temporal behavior of the EUCs. The states in the proposed dynamical DR model can be explicitly chosen, in which case the model can be represented by a linear function or a multi-layer feedforward neural network, or implicitly chosen, in which case the model can be represented by a recurrent neural network or a long short-term memory unit network. In both cases, the dynamical DR model can be learned from historical price and energy consumption data. Numerical simulation illustrated how the states are chosen and also showed the proposed dynamical DR model significantly outperforms static ones.

Metamaterial Absorber for THz Polarimetric Sensing

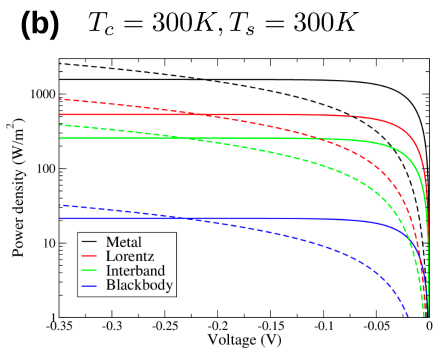
Citation: Wang, B., Sadeqi, A., Ma, R., Wang, P., Tsujita, W., Sadamoto, K., Sawa, Y., Rezaei Nejad, H., Sonkusale, S., Wang, C., Kim, M., Han, R., "Metamaterial Absorber for THz Polarimetric Sensing", *SPIE Photonics West*, DOI: 10.1117/12.2293122, February 2018.
Contacts: Bingnan Wang, Rui Ma, Pu (Perry) Wang



THz encoders have distinct advantages for position sensing compared with other types of encoders, such as those based on optical and inductive sensors. A polarization-dependent metamaterial absorber reflects one polarization while absorbs the other, which makes it an ideal building block for the barcode of a THz encoder system. In this paper, we present the design, fabrication, and experiments of a THz polarization-dependent metamaterial absorber, and its application to a polarimetric sensing system.

A coherent description of thermal radiative devices and its application on the near-field negative electroluminescent cooling

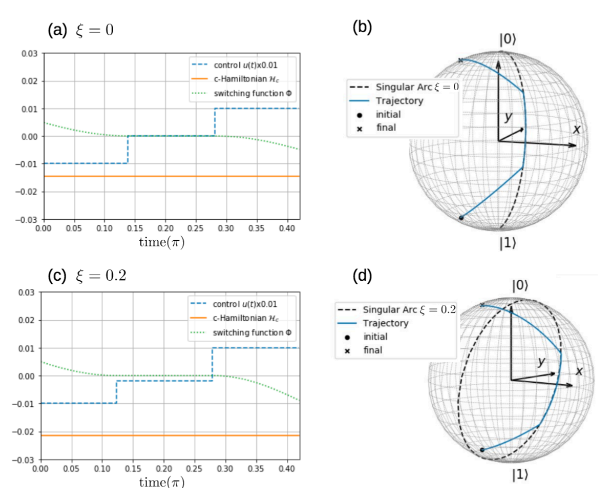
Citation: Lin, C., Wang, B., Teo, K.H., Zhang, Z., "A coherent description of thermal radiative devices and its application on the near-field negative electroluminescent cooling", *Energy - Journal*, DOI: 10.1016/j.energy.2018.01.005, January 2018
Contacts: Chungwei Lin, Bingnan Wang, Koon Hoo Teo, Ziming Zhang



Using the transimissivity between two thermal reservoirs and the generalized Planck distributions, we describe devices that use radiative energy transfer between thermal reservoirs in a unified formalism. Four types of devices are distinguished. For power generators that use the temperature difference between reservoirs, photovoltaic (PV) and thermos-radiative (TR) devices respectively use the low-temperature photovoltaic cell and high-temperature thermos-radiative cell to generate electricity. For active cooling, the electroluminescent (EL) cooling devices apply a forward bias voltage on the object we want to cool, whereas the negative EL cooling devices apply a reverse-bias voltage to the heat sink. The relationship among these four devices is explicated. One advantageous feature of the negative EL cooling is that it does not apply the voltage to the target object which we want to cool, and the nearfield enhancement can apply to various target materials that support surface resonant modes.

Time-optimal Control of a Dissipative Qubit

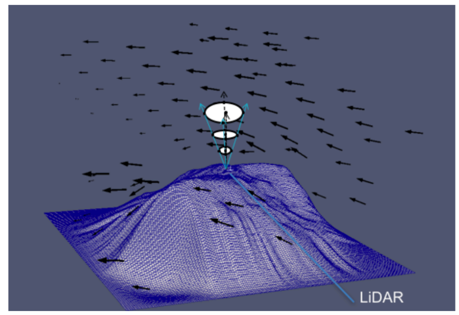
Citation: Lin, C., Sels, D., Wang, Y., "Time-optimal Control of a Dissipative Qubit", Physical Review, DOI: 10.1103/PhysRevA.101.022320, Vol. 101, No. 2, pp. 022320, February 2020.
Contacts: Chungwei Lin, Yebin Wang



A formalism based on Pontryagin's maximum principle is applied to determine the time-optimal protocol that drives a general initial state to a target state by a Hamiltonian with limited control, i.e., there is a single control field with bounded amplitude. The coupling between the bath and the qubit is modeled by a Lindblad master equation. Dissipation typically drives the system to the maximally mixed state, consequently there generally exists an optimal evolution time beyond which the decoherence prevents the system from getting closer to the target state. The formalism adopted here can efficiently evaluate the time-varying singular control which turns out to be crucial for controlling either an isolated or a dissipative qubit.

Improving LiDAR performance on complex terrain using CFD-based correction and direct-adjoint-loop optimization

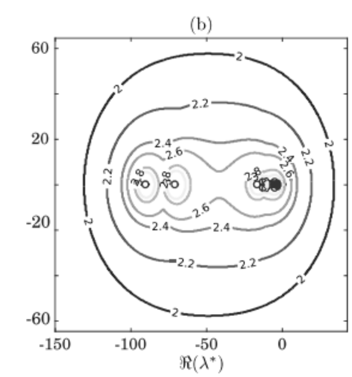
Citation: Nabi, S., Nishio, N., Grover, P., Matai, R., Kajiyama, Y., Kotake, N., Kameyama, S., Yoshiki, W., Iida, M., "Improving LiDAR performance on complex terrain using CFD-based correction and direct-adjoint-loop optimization", Journal of physics, DOI: 10.1088/1742-6596/1452/1/012082, Vol. 1452, November 2019.
Contacts: Saleh Nabi



Naive estimation of horizontal wind velocity over complex terrain using measurements from a single wind-LiDAR introduces a bias due to the assumption of uniform velocity in any horizontal plane. While Computational Fluid Dynamics (CFD)-based methods have been proposed for bias removal, several issues exist in the implantation. For instance, the upstream atmospheric boundary layer thickness or direction are unknown. We propose a direct-adjoint-loop (DAL) optimization based framework to estimate such unknown parameters in a systematic way. For the validation of the method, we performed an experimental study using DIABREZZA LiDAR on a complex terrain for two wind directions of northwesterly (NW) and southeasterly (SE).

Reduced-order modeling of fully turbulent buoyancy-driven flows using the Green's function method

Citation: Khodkar, A., Hassanzadeh, P., Nabi, S., Grover, P., "Reduced-order modeling of fully turbulent buoyancy-driven flows using the Green's function method", Physical Review Fluids, DOI: 10.1103/PhysRevFluids.4.013801, Vol. 4, No. 1, December 2018.
Contacts: Saleh Nabi



A One-Dimensional (1D) Reduced-Order Model (ROM) has been developed for a 3D Rayleigh Benard convection system in the turbulent regime with Rayleigh number Ra = 106. The state vector of the 1D ROM is horizontally averaged temperature. Using the Green's Function (GRF) method, which involves applying many localized, weak forcings to the system one at a time and calculating the responses using long-time averaged Direct Numerical Simulations (DNS), the system's Linear Response Function (LRF) has been computed. Another matrix, called the Eddy Flux Matrix (EFM), that relates changes in the divergence of vertical eddy heat fluxes to changes in the state vector, has also been calculated. Using various tests, it is shown that the LRF and EFM can accurately predict the time-mean responses of temperature and eddy heat flux to external forcings, and that the LRF can well predict the forcing needed to change the mean flow in a specified way (inverse problem).

Signal Processing

Signal processing activity focuses on fundamental and applied research in the areas of computational sensing, wireless and optical transmission systems, networking, radar, imaging and optical semiconductor device design. Our research has application to product areas such as IoT devices and applications, autonomous vehicles, terrestrial and trans-oceanic optical networks, train and automotive connectivity, GPS, automotive radars, non-contact sensing and radar imaging.

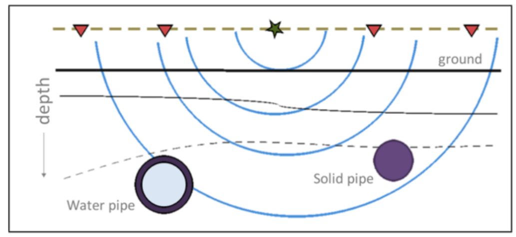
We explore novel architectures for signal acquisition and sensing, methods to acquire and filter signals in the presence of noise and other degrading factors, techniques that fuse signals from multiple sensing modalities, and approaches to infer meaning from processed signals.

Research topics focus on exploiting widely available computational power to overhaul the signal acquisition and significantly enhance sensing capabilities, improve inference systems that seek to understand signal propagation and behavior, and develop novel communications/networking/IoT algorithms for both wireless and coherent optical systems. We also seek to apply signal advanced processing methods with machine learning to explore error control coding, device design, millimeter wave and THz systems and vehicular networks, cooperative robotics, radio-based localization, smart grid, inference.

Recent Research

Reflection Tomographic Imaging of Highly Scattering Objects Using Incremental Frequency Inversion

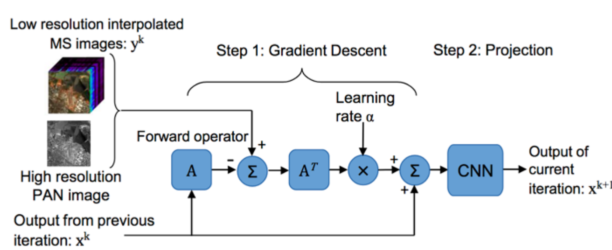
Citation: Kadu, A., Mansour, H., Boufounos, P.T., Liu, D., "Reflection Tomographic Imaging of Highly Scattering Objects Using Incremental Frequency Inversion", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP.2019.8682393, May 2019.
Contacts: Hassan Mansour, Petros Boufounos, Dehong Liu



Reflection tomography is an inverse scattering technique that estimates the spatial distribution of an object's permittivity by illuminating it with a probing pulse and measuring the scattered wavefields by receivers located on the same side as the transmitter. Unlike conventional transmission tomography, the reflection regime is severely ill-posed since the measured wavefields contain far less spatial frequency information about the object. We propose an incremental frequency inversion framework that requires no initial target model, and that leverages spatial regularization to reconstruct the permittivity distribution of highly scattering objects. Our framework solves a wave-equation constrained, total-variation (TV) regularized nonlinear least squares problem that solves a sequence of subproblems that incrementally enhance the resolution of the estimated object model. With each subproblem, higher frequency wavefield components are incorporated in the inversion to improve the recovered model resolution.

Unrolled Projected Gradient Descent for Multi-Spectral Image Fusion

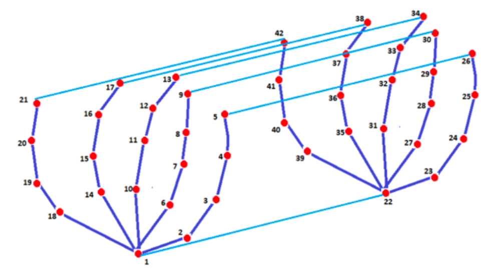
Citation: Lohit, S., Liu, D., Mansour, H., Boufounos, P.T., "Unrolled Projected Gradient Descent for Multi-Spectral Image Fusion", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP.2019.8683124, May 2019.
Contacts: Dehong Liu, Hassan Mansour, Petros Boufounos



We consider the problem of fusing low spatial resolution multi-spectral (MS) aerial images with their associated high spatial resolution panchromatic image. To solve this problem, various methods have been proposed, using either model-based or model-agnostic algorithms such as deep learning techniques. We utilize more interpretable architectures to solve the MS fusion problem by integrating existing ideas from image processing with deep learning. In particular, we develop a signal processing-inspired learning solution, where we unroll the iterations of the projected gradient descent (PGD) algorithm, and each iteration contains a projection operation carried out by a deep convolutional neural network. Our extensive experimental results show significant improvements of the proposed approach over several baselines.

Hand Graph Representations for Unsupervised Segmentation of Complex Activities

Citation: Das, P., Kao, J.-Y., Ortega, A., Mansour, H., Vetro, A., Sawada, T., Minezawa, A., "Hand Graph Representations for Unsupervised Segmentation of Complex Activities", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP.2019.8683643, May 2019.
Contacts: Hassan Mansour, Anthony Vetro



Analysis of hand skeleton data can be used to understand patterns in manipulation and assembly tasks. This paper introduces a graph-based representation of hand skeleton data and proposes a method to perform unsupervised temporal segmentation of a sequence of subtasks in order to evaluate the efficiency of an assembly task. We explore the properties of different choices of hand graphs and their spectral decomposition. A comparative performance of these graphs is presented in the context of complex activity segmentation. We show that the spectral graph features extracted from 2D hand motion data outperform the direct use of motion vectors as features.

Fingerprinting-Based Indoor Localization with Commercial MMWave WiFi - Part II: Spatial Beam SNRs

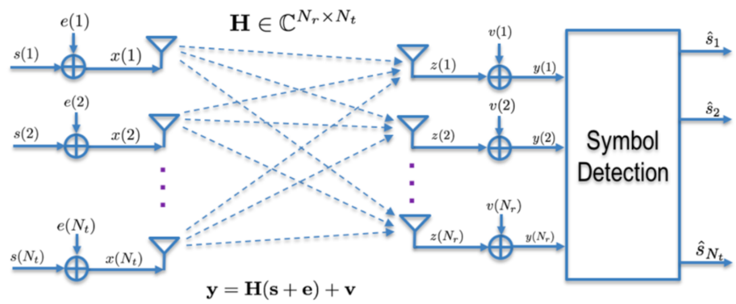
Citation: Wang, P., Pajovic, M., Koike-Akino, T., Sun, H., Orlik, P.V., "Fingerprinting-Based Indoor Localization with Commercial MMWave WiFi - Part II: Spatial Beam SNRs", IEEE Global Communications Conference (GLOBECOM), DOI: 10.1109/GLOBECOM38437.2019.9014103, December 2019.
Contacts: Pu Wang, Toshi Koike-Akino

Existing fingerprint-based indoor localization uses either fine-grained channel state information (CSI) from the physical layer or coarse-grained received signal strength indicator (RSSI) measurements from the MAC layer. We propose to use an intermediate channel measurement (spatial beam signal-to-noise ratios that are inherently available during the beam training phase as defined in the IEEE 802.11ad standard) to construct the feature space for a location- and orientation-dependent fingerprinting database. Comprehensive performance evaluation using real-world beam SNRs demonstrates that the classification accuracy in a set of spaces is 99.8%. Direct coordinate estimation gives an average root-mean-square error of 18 cm

Variational Bayesian Symbol Detection for Massive MIMO Systems with Symbol-Dependent Transmit Impairments

Citation: Wang, P., Koike-Akino, T., Orlik, P.V., Pajovic, M., Kim, K.J., "Variational Bayesian Symbol Detection for Massive MIMO Systems with Symbol-Dependent Transmit Impairments", IEEE Global Communications Conference (GLOBECOM), DOI: 10.1109/GLOBECOM38437.2019.9013363, December 2019.

Contacts: Pu Wang, Toshi Koike-Akino



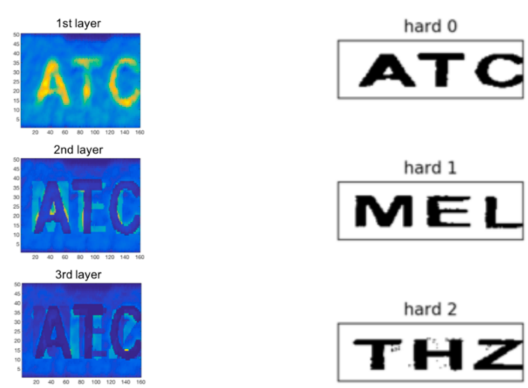
We propose a variational Bayesian inference approach for a low-complexity symbol detection for massive MIMO systems with symbol-dependent transmit-side impairments. This study is motivated by observations that real-world communication transceivers are often affected by the hardware impairments, such as non-linearities of power amplifiers, I/Q imbalance, phase drifts due to non-ideal oscillators, and carrier frequency offsets. Particularly, symbol-dependent perturbations are fully accounted into the designed hierarchical signal model as unknown model parameters. The developed variational Bayesian symbol detector is able to learn the unknown perturbations in an iterative fashion. Numerical evaluation confirms the effectiveness of the proposed approach.

Learning-Based Shadow Mitigation for Terahertz Multi-Layer Imaging

Citation: Wang, P., Koike-Akino, T., Bose, A., Ma, R., Orlik, P.V., Tsujita, W., Sadamoto, K., Tsutada, H., Soltanalian, M., "Learning-Based Shadow Mitigation for Terahertz Multi-Layer Imaging", International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), DOI: 10.1109/IRMMW-THz.2019.8874429, September 2019.

Contacts: Pu Wang, Toshi Koike-Akino, Rui Ma

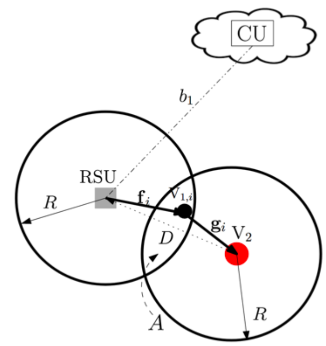
This paper proposes a learning-based approach to mitigate the shadow effect in the pixel domain for Terahertz Time-Domain Spectroscopy (THz-TDS) multi-layer imaging. Compared with model-based approaches, this learning-based approach requires no prior knowledge of material properties of the sample. Preliminary simulations confirm the effectiveness of the proposed method.



Distributed Cyclic Delay Diversity for Cooperative Infrastructure-to-Vehicle Systems

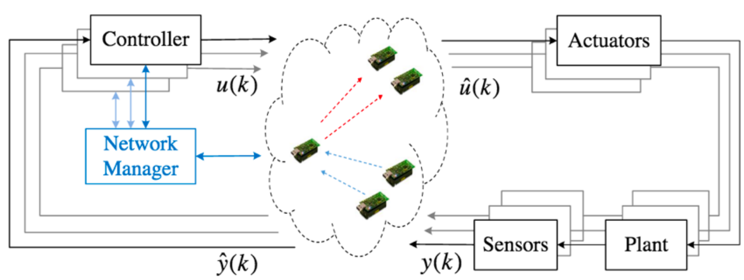
Citation: Kim, K.J., Guo, J., Tang, J., Orlik, P.V., "Distributed Cyclic Delay Diversity for Cooperative Infrastructure-to-Vehicle Systems", IEEE Global Communications Conference (GLOBECOM), December 2019, pp. 1-6.
Contacts: K.J. Kim, Jianlin Guo

A distributed cyclic delay diversity (dCDD) is proposed for a cooperative infrastructure-to-vehicle (I2V) system comprising one road side unit (RSU). At a particular time, to connect an RSU and a target vehicle outside each other's transmission range, several vehicles located within the transmission ranges of both the RSU and the target vehicle are configured to operate as dCDD based decode-and-forward (DF) cooperative relays. By using dCDD in the I2V system, the transmission range of the RSU is extended without the need of full channel state information of the vehicles at the RSU, and the transmit diversity gain can also be achieved.



Optimal Dynamic Scheduling of Wireless Networked Control Systems

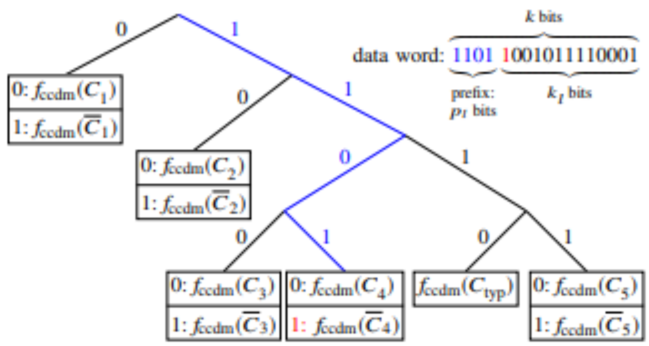
Citation: Ma, Y., Guo, J., Wang, Y., Chakrabarty, A., Ahn, H., Orlik, P.V., Lu, C., "Optimal Dynamic Scheduling of Wireless Networked Control Systems", ACM/IEEE International Conference on Cyber-Physical Systems (ICCPS), DOI: 10.1145/3302509.3311040, May 2019, pp. 77-86.
Contacts: Jianlin Guo, Yebin Wang



Wireless networked control system is gaining momentum in industrial cyber-physical systems, e.g., smart factory. Suffering from limited bandwidth and nondeterministic link quality, a critical challenge in its deployment is how to optimize the closed-loop control system performance as well as maintain stability. In order to bridge the gap between network design and control system performance, we propose an optimal dynamic scheduling strategy that optimizes performance of multi-loop control systems by allocating network resources based on predictions of both link quality and control performance at run-time. The optimal dynamic scheduling strategy boils down to solving a nonlinear integer programming problem, which is further relaxed to a linear programming problem. The proposed strategy provably renders the closed-loop system mean-square stable under mild assumptions. Its efficacy is demonstrated by simulating a four-loop control system over an IEEE 802.15.4 wireless network simulator – TOSSIM. Simulation results show that the optimal dynamic scheduling can enhance control system performance and adapt to both constant and variable network background noises as well as physical disturbance.

Multiset-Partition Distribution Matching

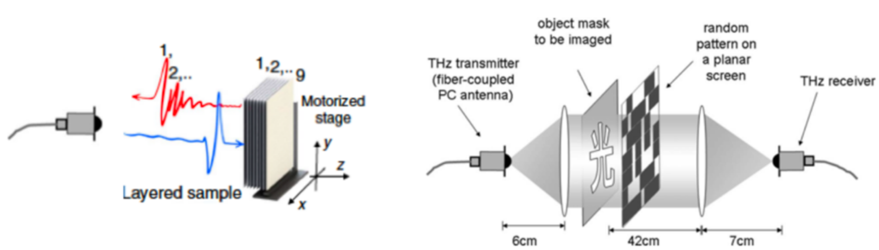
Citation: Fehenberger, T., Millar, D.S., Koike-Akino, T., Kojima, K., Parsons, K., "Multiset-Partition Distribution Matching", *IEEE Transactions on Communications*, DOI: 10.1109/TCOMM.2018.2881091, December 2018.
Contacts: David Millar, Toshiaki Koike-Akino, Keisuke Kojima, Kieran Parsons



Distribution matching is a fixed-length invertible mapping from a uniformly distributed bit sequence to shaped amplitudes and plays an important role in the probabilistic amplitude shaping framework. With conventional constant composition distribution matching (CCDM), all output sequences have identical composition. In this paper, we propose multiset partition distribution matching (MPDM) where the composition is constant overall output sequences. When considering the desired distribution as a multiset, MPDM corresponds to partitioning this multiset into equal-size subsets. Simulations of 64-ary quadrature amplitude modulation over the additive white Gaussian noise channel demonstrate that the block-length saving of MPDM over CCDM for a fixed gap to capacity is approximately a factor of 2.5 to 5 at medium to high signal-to-noise ratios (SNRs).

Terahertz Imaging of Binary Reflectance with Variational Bayesian Inference

Citation: Fu, H., Wang, P., Koike-Akino, T., Orlik, P.V., Chi, Y., "Terahertz Imaging of Binary Reflectance with Variational Bayesian Inference", *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP.2018.8461987, pp. 3394-3398, April 2018.
Contacts: Pu Wang, Toshiaki Koike-Akino, Philip Orlik



(a) (b)

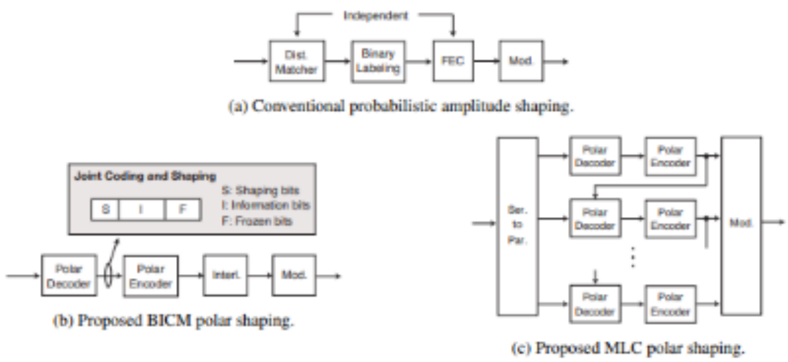
In this paper, we propose a Bayesian inference approach to extract the binary reflectance pattern of samples from compressed measurements in the terahertz (THz) frequency band. Compared with existing compressed THz imaging methods relying on the sparsity of the reflectance pattern, the proposed Bayesian approach exploits the non-negative binary nature of the reflectance without any assumption on its spatial pattern information and enables a pixel-wise iterative inference approach for fast signal recovery. Numerical evaluation confirms the effectiveness of the proposed approach.

Polar-Coded Modulation for Joint Channel Coding and Probabilistic Shaping

Citation: Matsumine, T., Koike-Akino, T., Millar, D.S., Kojima, K., Parsons, K., "Polar-Coded Modulation for Joint Channel Coding and Probabilistic Shaping", *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC),* DOI: 10.1364/OFC.2019.M4B.2, March 2019.

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

We propose joint channel coding and constellation shaping based on polar-coded modulation. The proposed shaping method offers greater than 0.6 dB gain without the need of an external distribution matcher and the increase of decoding complexity.



(a) Conventional probabilistic amplitude shaping.

(b) Proposed BICM polar shaping.

(c) Proposed MLC polar shaping.

Sparse Blind Deconvolution for Distributed Radar Autofocus Imaging

Citation: Mansour, H., Liu, D., Kamilov, U., Boufounos, P.T., "Sparse Blind Deconvolution for Distributed Radar Autofocus Imaging", *IEEE Transactions on Image Processing*, DOI: 10.1109/TCI.2018.2875375, Vol. 4, No. 4, pp. 537-551, December 2018.

Contacts: Hassan Mansour, Dehong Liu, Petros T. Boufounos

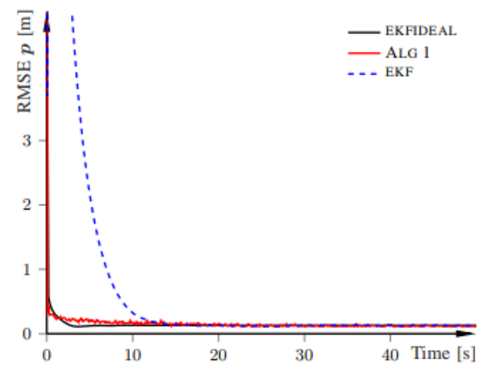
A common problem that arises in radar imaging systems, especially those mounted on mobile platforms, is antenna position ambiguity. Approaches to resolve this ambiguity and correct position errors are generally known as radar autofocus. Common techniques that attempt

to resolve the antenna ambiguity general by assume an unknown gain and phase error afflicting the radar measurements. However, ensuring identifiability and tractability of the unknown error imposes strict restrictions on the allowable antenna perturbations. Furthermore, these techniques are often not applicable in near-field imaging, where mapping the position ambiguity to phase errors breaks down.

GNSS Ambiguity Resolution by Adaptive Mixture Kalman Filter

Citation: Berntorp, K.; Weiss, A.; Di Cairano, S., "GNSS Ambiguity Resolution by Adaptive Mixture Kalman Filter", *International Conference on Information Fusion (FUSION)*, DOI: 10.23919/ICIF.2018.8455617, July 2018.

Contacts: Karl Berntorp, Avishai Weiss, Stefano Di Cairano

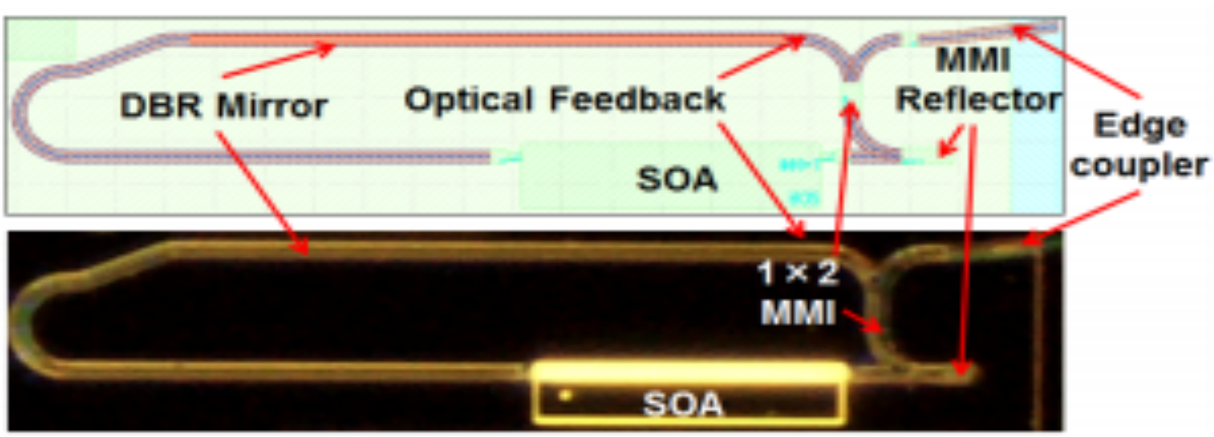


The precision of global navigation satellite systems (GNSSs) relies heavily on accurate carrier phase ambiguity resolution. The ambiguities are known to take integer values, but the set of ambiguity values is unbounded. We propose a mixture Kalman filter solution to GNSS ambiguity resolution. By marginalizing out the set of ambiguities and exploiting a likelihood proposal for generating the ambiguities, we can bound the possible values to a tight and dense set of integers, which allows for extracting the integer solution as a maximum likelihood estimate from a mixture Kalman filter. We verify the efficacy of the approach in simulation including a comparison with a well-known integer least-squares based method. The results indicate that our proposed switched mixture Kalman filter repeatedly finds the correct integers in cases where the other method fails.

Frequency Noise Reduction of Integrated Laser Source with On-Chip Optical Feedback

Citation: Song, B.; Kojima, K.; Pina, S.; Koike-Akino, T.; Wang, B.; Klamkin, J., "Frequency Noise Reduction of Integrated Laser Source with On-Chip Optical Feedback", *Integrated Photonics Research, Silicon and Nano Photonics (IPR)*, DOI: 10.1364/IPRSN.2017.ITu1A.4, July 2017.

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



Integrated indium phosphide distributed-Bragg-reflector lasers with and without on-chip optical feedback are reported. The measured linewidth for the laser with coherent optical feedback is approximately 800 kHz, demonstrating an order of magnitude reduction.

Control

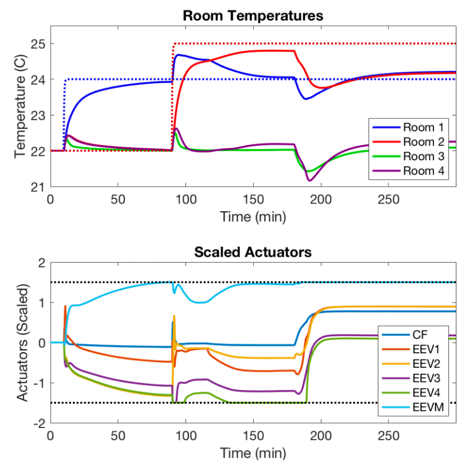
At the core of modern control systems there are advanced control algorithms that estimate information on the dynamic process under control from measurements, determine feedforward actions based on the desired behavior, and apply feedback corrections from the difference between the desired behavior and actual process condition. MERL's research focuses on developing such advanced control algorithms to constantly increase the performance and robustness with respect state-of-the-art in academia and industry, while requiring limited resources in terms of computations and memory, to be viable for production. Recent results of MERL control algorithms in applications include more energy efficient air conditioners and servomotors, faster and fault-free motion planning and steering control for autonomous vehicles, higher throughput laser processing, more precise GNSS positioning, statistical estimation of vehicle driving conditions, and more fuel-efficient satellite station keeping. MERL fundamental research in control theory with general applicability has a strong focus on model predictive control, statistical estimation, nonlinear dynamical systems, constrained control, motion planning, integration of learning and control, and real-time optimization for control.

Recent Research

H Infinity Loop-Shaped Model Predictive Control with Heat Pump Application

Citation: Bortoff, S.A., Schwerdtner, P., Danielson, C., Di Cairano, S., "H Infinity Loop-Shaped Model Predictive Control with Heat Pump Application", European Control Conference (ECC), DOI: 10.23919/ECC.2019.8796158, June 2019, pp. 2386-2393.

Contacts: Scott Bortoff, Stefano Di Cairano

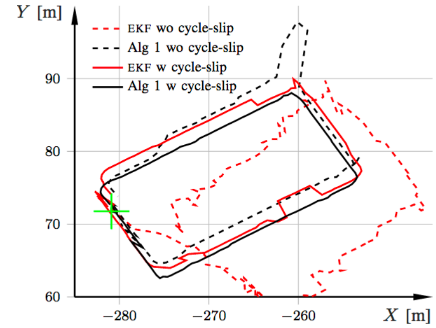


We derive a formulation for Model Predictive Control (MPC) of linear time-invariant systems based on H infinity loop-shaping. The design provides an optimized stability margin for problems that require state estimation. Input and output weights are designed in the frequency domain to satisfy steady-state and transient performance requirements, in lieu of conventional MPC plant model augmentations. The H infinity loop-shaping synthesis results in an observer-based state feedback structure. We apply the methodology to a multi-zone heat pump system in simulation. The design rejects constant unmeasured disturbances and tracks constant references with zero steady-state error, has good transient performance, provides an excellent stability margin, and enforces input and output constraints.

Integer Ambiguity Resolution by Mixture Kalman Filter for Improved GNSS Precision

Citation: Berntorp, K., Weiss, A., Di Cairano, S., "Integer Ambiguity Resolution by Mixture Kalman Filter for Improved GNSS Precision", IEEE Transactions on Aerospace and Electronic Systems, DOI: 10.1109/TAES.2020.2965715, February 2020.

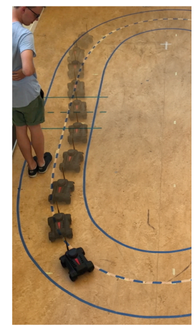
Contacts: Karl Berntorp, Avishai Weiss, Stefano Di Cairano



Accurate carrier-phase integer ambiguity resolution is fundamental for high precision global navigation satellite systems (GNSSs). Real-time GNSSs typically resolve the ambiguities by a combination of recursive estimators and integer least squares solvers, which need to be reset when satellites are added or cycle slip occurs. We propose a mixture Kalman filter solution to integer ambiguity resolution. By marginalizing out the set of ambiguities and exploiting a likelihood proposal for generating the ambiguities, we can bound the possible values to a tight and dense set of integers. A numerical analysis and experimental results indicate that the proposed method achieves reliable position estimates, repeatedly finds the correct integers in cases when other methods may fail, and is more robust to cycle slip.

Positive Invariant Sets for Safe Integrated Vehicle Motion Planning and Control

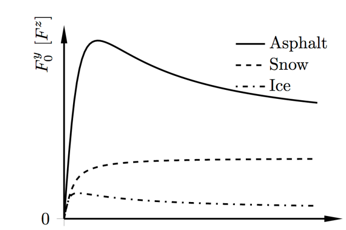
Citation: Berntorp, K., Danielson, C., Weiss, A., Di Cairano, S., Erliksson, K., Bai, R., "Positive Invariant Sets for Safe Integrated Vehicle Motion Planning and Control", Transactions on Intelligent Vehicles, DOI: 10.1109/TIV.2019.2955371, Vol. 5, No. 1, pp. 112-126, August 2019.
Contacts: Karl Berntorp, Avishai Weiss, Stefano Di Cairano



This paper describes a method for real-time integrated motion planning and control aimed at autonomous vehicles. Our method leverages feedback control, positive invariant sets, and equilibrium trajectories of the closed-loop system to produce and track trajectories that are collision-free with guarantees according to the vehicle model. Our method jointly steers the vehicle to a target region and controls the velocity while satisfying constraints associated with future motion of surrounding obstacles. We develop a receding-horizon implementation of the control policy and verify the method in both a simulated road scenario and an experimental validation using a scaled mobile robot with car-like dynamics using only onboard sensing. The results show that our method generates dynamically feasible and safe (i.e., collision-free) trajectories in real time, and indicates that the proposed planner is robust to sensing and mapping errors.

Trajectory Tracking for Autonomous Vehicles on Varying Road Surfaces by Friction-Adaptive Nonlinear Model Predictive Control

Citation: Berntorp, K., Quirynen, R., Uno, T., Di Cairano, S., "Trajectory Tracking for Autonomous Vehicles on Varying Road Surfaces by Friction-Adaptive Nonlinear Model Predictive Control", Journal of Vehicle Systems Dynamics, DOI: 10.1080/00423114.2019.1697456, January 2020.
Contacts: Karl Berntorp, Rien Quirynen, Stefano Di Cairano

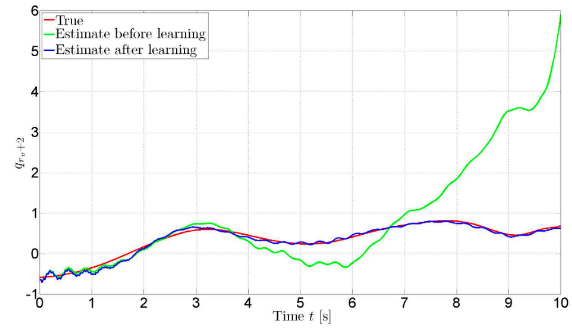


We propose an adaptive nonlinear model predictive control (NMPC) for vehicle tracking control. The controller learns in real time a tire force model to adapt to a varying road surface that is only indirectly observed from the effects of the tire forces determining the vehicle dynamics. Learning the entire tire model from data would require driving in the unstable region of the vehicle dynamics with a prediction model that has not yet converged. Instead, our approach combines NMPC with a noise-adaptive particle filter for vehicle state and tire stiffness estimation and a pre-determined library of tire models. The stiffness estimator determines the linear component of the tire model during normal vehicle driving, and the control strategy exploits the relation between the tire stiffness and the nonlinear part of the tire force to select the appropriate full tire model from the library, which is then used in the NMPC prediction model. We validate the approach in simulation using real vehicle parameters, demonstrate the real-time feasibility in automotive-grade processors using a rapid prototyping unit, and report preliminary results of experimental validation on a snow-covered test track.

Learning-Based Robust Observer Design for Coupled Thermal and Fluid Systems

Citation: Koga, S., Benosman, M., Borggaard, J., "Learning-Based Robust Observer Design for Coupled Thermal and Fluid Systems", American Control Conference (ACC), DOI: 10.23919/ACC.2019.8815123, July 2019, pp. 941-946.

Contacts: Mouhacine Benosman

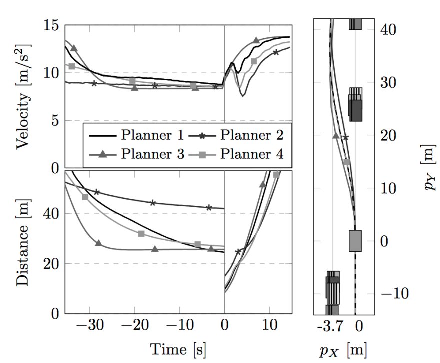


We present a learning-based robust observer design for thermal-fluid systems, pursuing an application to efficient energy management in buildings. The model is originally described by Boussinesq equations which is given by a system of two coupled partial differential equations (PDEs) for the velocity field and temperature profile constrained to incompressible flow. Using proper orthogonal decomposition (POD), the PDEs are reduced to a set of nonlinear ordinary differential equations (ODEs). Given a set of temperature and velocity point measurements, a nonlinear state observer is designed to reconstruct the entire state under the error of initial states, and model parametric uncertainties. We prove that the closed loop system for the observer error state satisfies an estimate of L2 norm in a sense of locally input-to-state stability (LISS) with respect to parameter uncertainties. Moreover, the uncertain parameters estimate used in the designed observer are optimized through iterations of a data-driven extremum seeking (ES) algorithm.

Inverse Learning for Human-Adaptive Motion Planning

Citation: Menner, M., Berntorp, K., Di Cairano, S., "Inverse Learning for Human-Adaptive Motion Planning", IEEE Conference on Decision and Control (CDC), DOI: 10.1109/CDC40024.2019.9030020, December 2019.

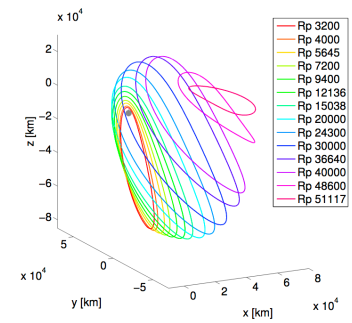
Contacts: Karl Berntorp, Stefano Di Cairano



We present a method for inverse learning of a control objective defined in terms of requirements and their probability distribution. The probability distribution characterizes tolerated deviations from the deterministic requirements, is modeled as Gaussian, and learned from data using likelihood maximization. Further, this paper introduces both parametrized requirements for motion planning in autonomous driving applications and methods for their estimation from demonstrations. Human-in-the-loop simulations with four drivers suggest that human motion planning can be modeled with the considered probabilistic control objective and our inverse learning methods enable more natural and personalized automated driving.

Control Strategy for Long-Term Station-Keeping on Near-Rectilinear Halo Orbits

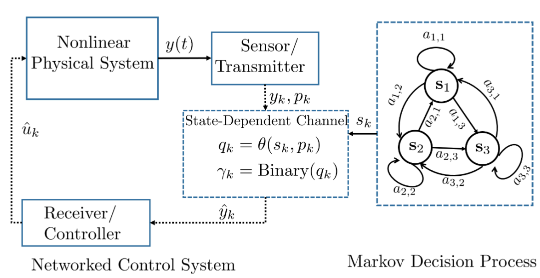
Citation: Muralidharan, V., Weiss, A., Kalabic, U., "Control Strategy for Long-Term Station-Keeping on Near-Rectilinear Halo Orbits", AAS/AIAA Space Flight Mechanics Meeting, DOI: 10.2514/6.2020-1459, January 2020.
Contacts: Avishai Weiss, Uros Kalabic



This work considers the control of a spacecraft in indefinite near-rectilinear halo orbit (NRHO) about the Earth-Moon L2. For indefinite station-keeping, it is important to minimize fuel consumption, while allowing for occasional transfer to a new orbit. The control scheme therefore consists of two components: the first component is the tracking of the nominal NRHO and the second component is an orbit correction maneuver between NRHO trajectories. The nominal NRHO is computed using a multiple-shooting technique that takes into account all forces on the spacecraft whose magnitude is larger than the dominant disturbance forces caused by navigational error. The tracking component is a linear-quadratic regulation scheme that rejects disturbances caused by orbit determination error, using a Lyapunov sublevel set that models the state covariance generated using sequential Kalman filter.

Co-design of Safe and Efficient Networked Control Systems in Factory Automation with State-dependent Wireless Fading Channels

Citation: Hu, B., Wang, Y., Orlik, P.V., Koike-Akino, T., Guo, J., "Co-design of Safe and Efficient Networked Control Systems in Factory Automation with State-dependent Wireless Fading Channels", Automatica, DOI: 10.1016/j.automatica.2019.04.009, Vol. 105, pp. 334-346, May 2019.
Contacts: Yebin Wang, Jianlin Guo

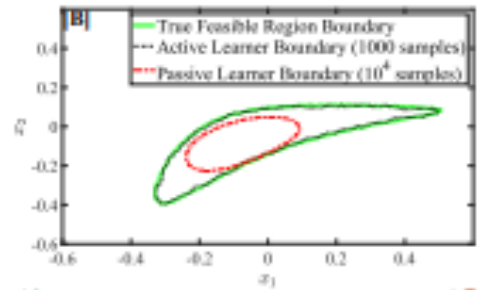


In factory automation, heterogeneous manufacturing processes need to be coordinated over wireless networks to achieve safety and efficiency. Wireless networks, however, are inherently unreliable due to shadow fading induced by the physical motion of the machinery. To assure both safety and efficiency, this paper proposes a state-dependent channel model that captures the interaction between the physical and communication systems. By adopting this channel model, sufficient conditions on the maximum allowable transmission interval are derived to ensure stochastic safety for a nonlinear physical system controlled over a state-dependent wireless fading channel. The safety and efficiency co-design problem is formulated as a constrained cooperative game, whose equilibria represent optimal control and transmission power policies. It is shown that the equilibria of the constrained game are solutions to a non-convex generalized geometric program, which are approximated by solving two convex programs.

Data-Driven Estimation of Reachable and Invariant Sets for Unmodeled Systems via Active Learning

Citation: Chakrabarty, A.; Raghunathan, A.U.; Di Cairano, S.; Danielson, C., "Data-Driven Estimation of Reachable and Invariant Sets for Unmodeled Systems via Active Learning", *IEEE Conference on Decision and Control (CDC),* DOI: 10.1109/CDC.2018.8619646, December 2018.

Contacts: Ankush Chakrabarty, Arvind U. Raghunathan, Stefano Di Cairano

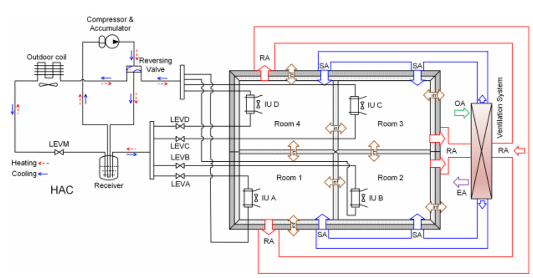


Ensuring control performance with state and input constraints is facilitated by the understanding of reachable and invariant sets. While exploiting dynamical models has provided many set-based algorithms for constructing these sets, set-based methods typically do not scale well, or rely heavily on model accuracy or structure. In contrast, it is relatively simple to generate state trajectories in a data-driven manner by numerically simulating complex systems from initial conditions sampled from within an admissible state space, even if the underlying dynamics are completely unknown. These samples can then be leveraged for reachable/invariant set estimation via machine learning, although the learning performance is strongly linked to the sampling pattern. In this paper, selective sampling reduces the number of numerical simulations required for constructing the invariant set estimator, thereby enhancing scalability to higher-dimensional state spaces.

Integrated Control of Multi-Zone Buildings with Ventilation and VRF systems in Cooling Mode

Citation: Laughman, C.R.; Bortoff, S.A.; Qiao, H., "Integrated Control of Multi-Zone Buildings with Ventilation and VRF systems in Cooling Mode", *Purdue High-Performance Buildings Conference*, July 2018.

Contacts: Christopher R. Laughman, Scott A. Bortoff, Hongtao Qiao

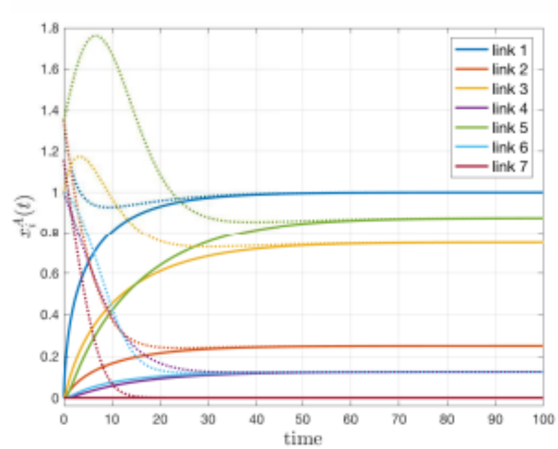


One common strategy for achieving reduced energy consumption and improved comfort in modern high-performance buildings involves the use of multiple interacting heating, cooling, and ventilation systems. Because tighter and more insulating building envelopes are often accompanied by a reduction in the capacity of the space conditioning systems, the limited control authority of these smaller systems raises the importance of understanding dynamics and control in this built environment. We explore the use of model-based strategies for analyzing and controlling the behavior of a representative building incorporating both a multi-zone VRF system and a ventilation system. Analysis of the integrated system indicates that the subsystems interact dynamically, and that these dynamics must be considered during the design process.

Assignment and Control of Two-Tiered Vehicle Traffic

Citation: Nilsson, G.; Grover, P.; Kalabic, U., "Assignment and Control of Two-Tiered Vehicle Traffic", *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC.2018.8619411, December 2018.

Contacts: Piyush Grover, Uros Kalabic

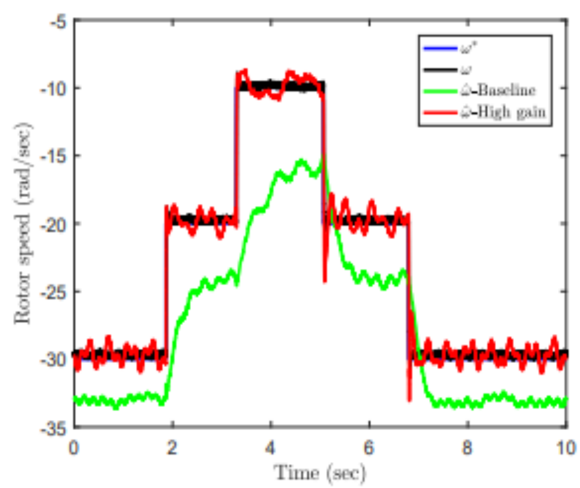


This work considers the assignment of vehicle traffic consisting of both individual, opportunistic vehicles and a cooperative fleet of vehicles. The first set of vehicles seek a user-optimal policy and the second set seeks a fleet-optimal policy. We provide explicit sufficient conditions for the existence and uniqueness of a Nash equilibrium at which both policies are satisfied. We also propose two different algorithms to determine the equilibrium, one centralized and one decentralized. Furthermore, we present a control scheme to attain such an equilibrium in a dynamical network flow. An example is considered showing the workings of our scheme and numerical results are presented.

An approximate high gain observer for speed-sensorless estimation of induction motors

Citation: Wang, Y.; Zhou, L.; Bortoff, S.A.; Satake, A.; Furutani, S., "An approximate high gain observer for speed-sensorless estimation of induction motors", *IEEE/CAA Journal of Automatica Sinica*, DOI: 10.1109/JAS.2018.7511252, vol. 6, pp. 53-63, December 2018

Contacts: Yebin Wang, Scott Bortoff



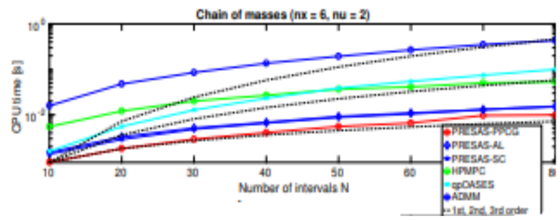
(a) Overall

Rotor speed estimation for induction motors is a key problem in speed-sensorless motor drives. This paper performs nonlinear high gain observer design based on the full-order model of the induction motor. Such an effort appears nontrivial due to the fact that the fullmodel at best admits locally a non-triangular observable form (NTOF), and its analytical representation in the NTOF can not be obtained. This paper proposes an approximate high gain estimation algorithm, which enjoys a constructive design, ease of tuning, and improved speed estimation and tracking performance. Experiments demonstrate the effectiveness of the proposed algorithm.

Projected Preconditioning within a Block-Sparse Active-Set Method for MPC

Citation: Quirynen, R.; Knyazev, A.; Di Cairano, S., “Projected Preconditioning within a Block-Sparse Active-Set Method for MPC”, *IFAC Conference on Nonlinear Model Predictive Control (NMPC)*, DOI: 10.1016/j.ifacol.2018.10.170, vol. 51, pp. 28-34, August 2018.

Contacts: Rien Quirynen, Stefano Di Cairano

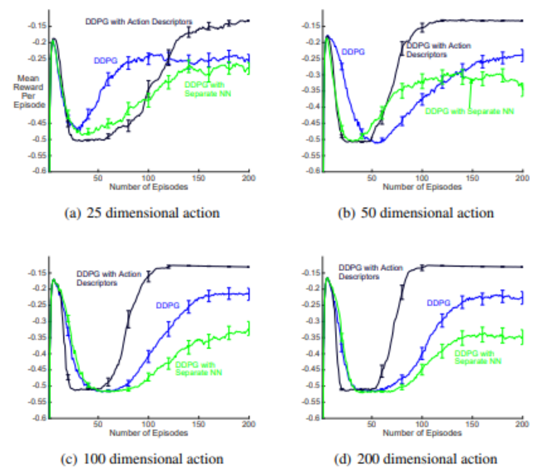


Model predictive control (MPC) often requires solving an optimal control structuredquadratic program (QP), possibly based on an online linearization at each sampling instant. Block-tridiagonal preconditioners have been proposed, combined with the minimal residual (MINRES) method, to result in a simple but efficient implementation of a sparse activeset strategy for fast MPC. This paper presents an improved variant of this PRESAS algorithm, by using a projected preconditioned conjugate gradient (PPCG) method. Based on a standalone C code implementation and using an ARM Cortex-A7 processor, we illustrate the performance of the proposed solver against the current state of the art for embedded predictive control.

Reinforcement Learning with Function-Valued Action Spaces for Partial Differential Equation Control

Citation: Pan, Y.; Farahmand, A.-M.; White, M.; Nabi, S.; Grover, P.; Nikovski, D.N., “Reinforcement Learning with Function-Valued Action Spaces for Partial Differential Equation Control”, *International Conference on Machine Learning (ICML)*, July 2018.

Contacts: Saleh Nabi, Piyush Grover, Daniel N. Nikovski



Recent work has shown that reinforcement learning (RL) is a promising approach to control dynamical systems described by partial differential equations (PDEs). This paper shows how to use RL to tackle more general PDE control problems that have continuous high-dimensional action spaces with spatial relationship among action dimensions. In particular, we propose the concept of action descriptors, which encode regularities among spatially-extended action dimensions and enable the agent to control high-dimensional action PDEs. We provide theoretical evidence suggesting that this approach can be more sample efficient compared to a conventional approach that treats each action dimension separately and does not explicitly exploit the spatial regularity of the action space. Experiments on two PDE control problems, with up to 256-dimensional continuous actions, show the advantage of the proposed approach over conventional ones.

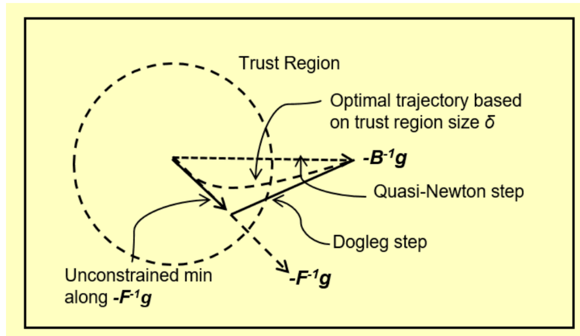
Optimization

Decision optimization research emphasizes numerical methods for fast solution of continuous and discrete optimization problems that can be scaled up to problems of industrial size and complexity. Optimization methods find application in many application domains, including the analysis of electrical power systems and Smart Grids comprising renewable power sources with intermittent output as well as highly variable loads such as electrical vehicles. Furthermore, many problems in transportation systems, such as train operation optimization, group elevator scheduling, car navigation and fully autonomous driving, as well as energy optimization in buildings, can be solved by planning and optimization algorithms. Similarly, a number of problems in robotics, factory automation, and production planning and scheduling can be addressed successfully by means of decision-theoretic planning, sequential optimization, and reinforcement learning methods. Fast and reliable optimization algorithms are also the foundation of optimizing control. We have leveraged novel representation formalisms such as decision diagrams to achieve unprecedented scalability in solving difficult combinatorial optimization problems across multiple domains. Current research actively explores similar advances in solving mixed-integer non-linear programming problems.

Recent Research

Quasi-Newton Trust Region Policy Optimization

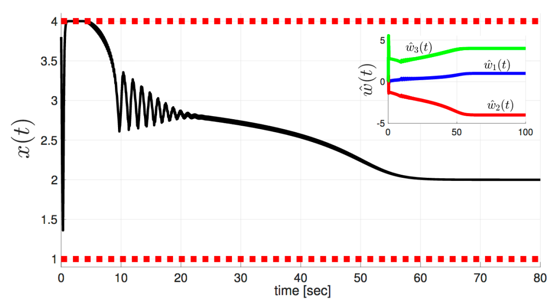
Citation: Jha, D., Raghunathan, A., Romeres, D., "Quasi-Newton Trust Region Policy Optimization", Conference on Robot Learning (CoRL), Leslie Pack Kaelbling, Danica Kragic, Komei Sugiura, Eds., October 2019, pp. 945-954.
Contacts: Devesh Jha, Arvind Raghunathan, Diego Romeres



We propose a trust region method for policy optimization that employs Quasi-Newton approximation for the Hessian, called Quasi-Newton Trust Region Policy Optimization (QNTRPO). Gradient descent is the de facto algorithm for reinforcement learning tasks with continuous controls. The algorithm has achieved state-of-the-art performance when used in reinforcement learning across a wide range of tasks. However, the algorithm suffers from a number of drawbacks including: lack of step size selection criterion, and slow convergence. We investigate the use of a trust region method using dogleg steps and a Quasi-Newton approximation for the Hessian for policy optimization. We demonstrate through numerical experiments over a wide range of challenging continuous control tasks that our particular choice is efficient in terms of the number of samples and improves performance.

DEES: A Class of Data-Enabled Robust Feedback Algorithms for Real-Time Optimization

Citation: Poveda, J., Vamvoudakis, K., Benosman, M., "DEES: A Class of Data-Enabled Robust Feedback Algorithms for Real-Time Optimization", IFAC Nonlinear Control Systems (NOLCOS), September 2019, pp. 670-675.
Contacts: Mouhacine Benosman

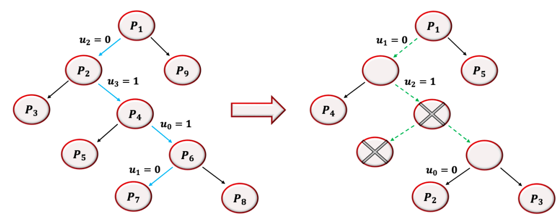


The increasing availability of information-rich data sets offers an invaluable opportunity to complement and improve the performance of existing model-based feedback algorithms. Following this principle, we present a novel class of Data-Enabled Extremum Seeking (DEES) algorithms for static maps, which make use of current and recorded data in order to solve a convex optimization problem characterized by a variational inequality. The optimization dynamics synergistically combine ideas from concurrent learning and classic neuroadaptive extremum seeking in order to dispense with the assumption of requiring a persistence of excitation condition in the closed-loop system. Using analytical tools for nonlinear systems we show that for a general class of optimization dynamics it is possible to tune the parameters of the controller to guarantee convergence in finite time to an arbitrarily small neighborhood of the set of optimizers. The results are illustrated in a scalar constrained minimization problem.

A Structure Exploiting Branch-and-Bound Algorithm for Mixed-Integer Model Predictive Control

Citation: Hespanhol, P., Quirynen, R., Di Cairano, S., "A Structure Exploiting Branch-and-Bound Algorithm for Mixed-Integer Model Predictive Control", European Control Conference (ECC), DOI: 10.23919/ECC.2019.8796242, June 2019, pp. 2763-2768.

Contacts: Rien Quirynen, Stefano Di Cairano

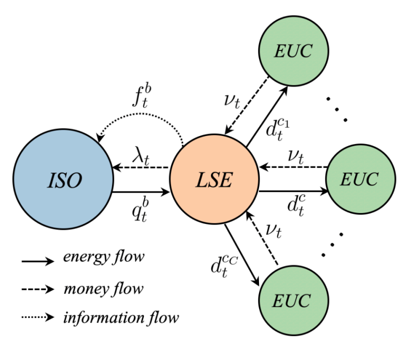


Mixed-integer model predictive control (MI-MPC) requires the solution of a mixed-integer quadratic program (MIQP) at each sampling instant under strict timing constraints, where part of the state and control variables can only assume a discrete set of values. We utilize the sequential nature and the problem structure of MI-MPC to provide a branch-and-bound algorithm that can exploit not only the block-sparse optimal control structure of the problem but that can also be warm started by propagating information from branch-and-bound trees and solution paths at previous time steps. We illustrate the computational performance of the proposed algorithm and compare against current state-of-the-art solvers for a standard hybrid MPC case study.

Deep Reinforcement Learning for Joint Bidding and Pricing of Load Serving Entity

Citation: Xu, H., Sun, H., Nikovski, D.N., Kitamura, S., Mori, K., Hashimoto, H., "Deep Reinforcement Learning for Joint Bidding and Pricing of Load Serving Entity", IEEE Transactions on smart grids, DOI: 10.1109/TSG.2019.2903756, Vol. 10, No. 6, pp. 6366-6375, January 2020.

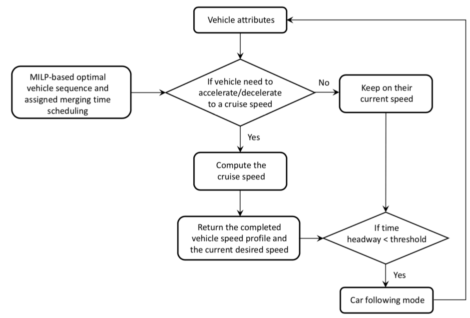
Contacts: Hongbo Sun, Dan Nikovski



We address the problem of jointly determining the energy bid submitted to the wholesale electricity market (WEM) and the energy price charged in the retailed electricity market (REM) for a load serving entity (LSE). The joint bidding and pricing problem is formulated as a Markov decision process (MDP) with continuous state and action spaces, in which the energy bid and the energy price are two actions that share a common objective. We apply the deep deterministic policy gradient (DDPG) algorithm to solve this MDP for the optimal bidding and pricing policies. Yet, the DDPG algorithm typically requires a significant number of state transition samples, which is costly in this application. To this end, we apply neural networks to learn dynamical bid and price response functions from historical data to model the WEM and the collective behavior of the EUCs, respectively. These response functions explicitly capture the inter-temporal correlations of the WEM clearing results and the EUC responses, and can be utilized to generate state transition samples without any cost. More importantly, the response functions also inform the choice of states in the MDP formulation.

CODES: Cooperative Data-Enabled Extremum Seeking for Multi-Agent Systems

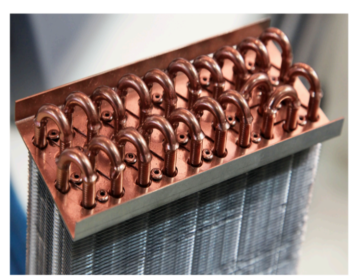
Citation: Poveda, J., Vamvoudakis, K., Benosman, M., "CODES: Cooperative Data-Enabled Extremum Seeking for Multi-Agent Systems", IEEE Conference on Decision and Control (CDC), DOI: 10.1109/CDC40024.2019.9029908, December 2019, pp. 2988-2993.
Contacts: Mouhacine Benosman



We study the problem of model-free cooperative real-time optimization in multi-agent network systems (MAS). Unlike existing adaptive extremum seeking approaches that presume the satisfaction of a persistence of excitation condition on the agents of the network, we propose a novel approach that leverages the presence of cooperation and information-rich data sets in the system. This approach is based on the idea that in MAS with sufficient communication and information resources, agents can efficiently learn a common cost function under mild individual excitation requirements by leveraging cooperation. Therefore, our main result can be seen as a spatio-temporal condition that guarantees model-free optimization in MAS with agents having homogeneous but unknown cost functions. To solve this model-free optimization problem, we characterize a class of robust dynamics that can be safely interconnected with the data-enabled learning mechanism in order to achieve a stable closed-loop system.

Heat Exchanger Circuitry Design by Decision Diagrams

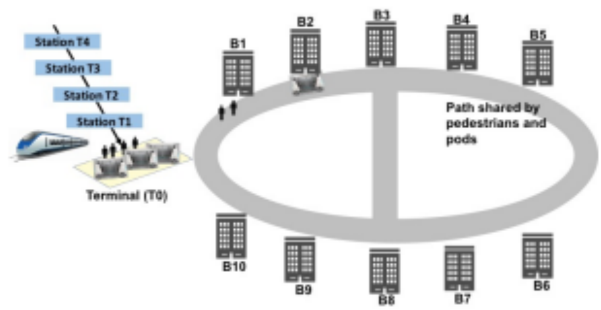
Citation: Ploskas, N., Laughman, C.R., Raghunathan, A., Sahinidis, N.V., "Heat Exchanger Circuitry Design by Decision Diagrams", International Conference on the Integration of Constraint Programming, Artificial Intelligence, and Operations Research, DOI: 10.1007/978-3-030-19212-9_30, June 2019, vol. 11494, pp. 467-471.
Contacts: Chris Laughman, Arvind Raghunathan



The interconnection pattern between the tubes of a tube-fin heat exchanger, also referred to as its circuitry, has a significant impact on its performance. We can improve the performance of a heat exchanger by identifying optimized circuitry designs. This task is difficult because the number of possible circuitries is very large, and because the dependence of the heat exchanger performance on the input (i.e., a given circuitry) is highly discontinuous and nonlinear. In this paper, we propose a novel decision diagram formulation and present computational results using the mixed integer programming solver CPLEX. The results show that the proposed approach has a favorable scaling with respect to number of tubes in the heat exchanger size and produces configurations with 9% higher heat capacity, on average, than the baseline configuration.

Last-Mile Scheduling Under Uncertainty

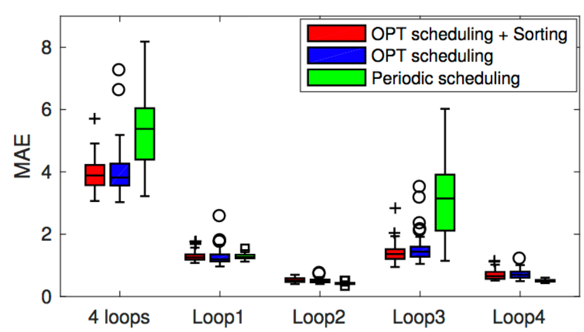
Citation: Serra, T., Raghunathan, A., Bergman, D., Hooker, J., Kobori, S., "Last-Mile Scheduling Under Uncertainty", International Conference on the Integration of Constraint Programming, Artificial Intelligence, and Operations Research, DOI: 10.1007/978-3-030-19212-9_34, June 2019, vol. 11494, pp. 519-528.
Contacts: Arvind Raghunathan



Shared mobility is revolutionizing urban transportation and has sparked interest in optimizing the joint schedule of passengers using public transit and last-mile services. Scheduling systems must anticipate future requests and provision flexibility in order to be adopted in practice. In this work, we consider a two-stage stochastic programming formulation for scheduling a set of known passengers and uncertain passengers that are realized from a finite set of scenarios. We present an optimization approach based on decision diagrams. We obtain, in minutes, schedules for 1,000 known passengers that are robust and optimized with respect to scenarios involving up to 100 additional uncertain passengers.

Optimal Dynamic Scheduling of Wireless Networked Control Systems

Citation: Ma, Y., Guo, J., Wang, Y., Chakrabarty, A., Ahn, H., Orlik, P.V., Lu, C., "Optimal Dynamic Scheduling of Wireless Networked Control Systems", ACM/IEEE International Conference on Cyber-Physical Systems (ICCPS), DOI: 10.1145/3302509.3311040, May 2019, pp. 77-86.
Contacts: Jianlin Guo, Yebin Wang, Ankush Chakrabarty

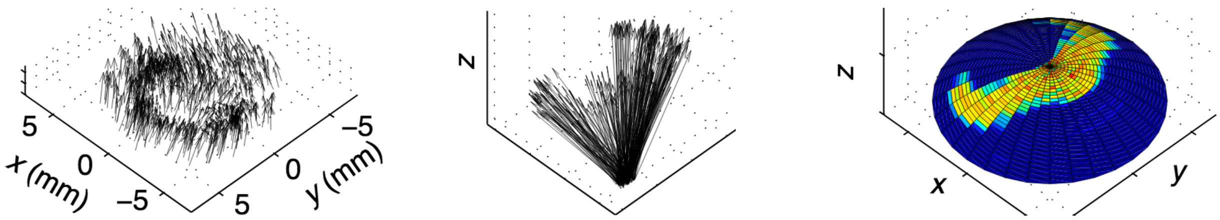


Wireless networked control systems are gaining momentum in industrial cyber-physical systems, e.g., smart factories. Suffering from limited bandwidth and nondeterministic link quality, a critical challenge in their deployment is how to optimize the closed-loop control system performance as well as maintain stability. To bridge the gap between network design and control system performance, we propose an optimal dynamic scheduling strategy that optimizes performance of multi-loop control systems by allocating network resources based on predictions of both link quality and control performance at run-time. The optimal dynamic scheduling strategy boils down to solving a nonlinear integer programming problem, which is further relaxed to a linear programming problem. The proposed strategy provably renders the closed-loop system mean-square stable under mild assumptions. Its efficacy is demonstrated by simulating a four-loop control system over an IEEE 802.15.4 wireless network.

Data-driven freeform irradiance tailoring

Citation: Brand, M.E., Birch, D.A., "Data-driven freeform irradiance tailoring", OSA Optical Design and Fabrication Congress, June 2019.

Contacts: Matt Brand

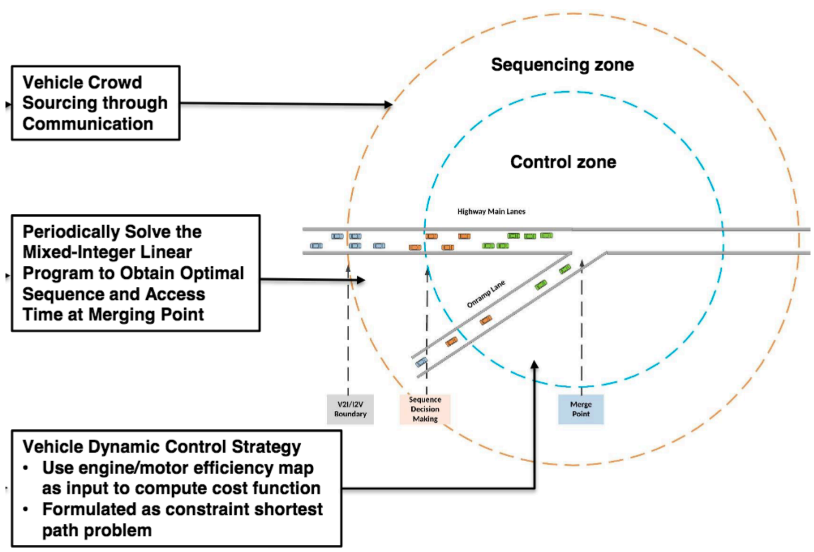


We develop data-driven high-etendue freeform irradiance tailoring for design problems where the incident light is known only through a sampling of its rays, and the transport from freeform to projection is nontrivial.

Bi-level Optimal Edge Computing Model for On-ramp Merging in Connected Vehicle Environment

Citation: Ye, F., Guo, J., Kim, K.J., Orlik, P.V., Ahn, H., Di Cairano, S., "Bi-level Optimal Edge Computing Model for On-ramp Merging in Connected Vehicle Environment", IEEE Intelligent Vehicle Symposium, DOI: 10.1109/IVS.2019.8814096, June 2019, pp. 2005-2011.

Contacts: Jianlin Guo, K.J. Kim

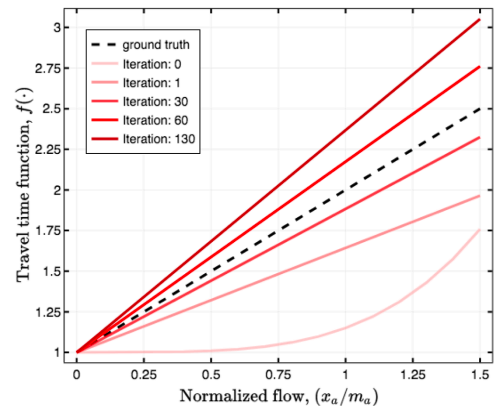


The coordinated on-ramp merging is one of the most common but critical vehicular applications that require complex data transmission and low-latency communication in the Connected and Automated Vehicles (CAVs) environment. An effective way to address on-ramp merging is to leverage the edge computing to optimize the coordination among vehicles to achieve overall minimum vehicle travel time and energy consumption. In this study, we propose a Bi-level Optimal Edge Computing (BOEC) model for on-ramp merging in the CAVs environment to optimize both merge time and vehicle trajectory. The simulation results show that the proposed BOEC model achieves great benefits in vehicle mobility, energy saving and air pollutant emission reduction by providing an energy-efficient trajectory following the optimal merge time without compromising safety.

Joint Estimation of OD Demands and Cost Functions in Transportation Networks from Data

Citation: Wollenstein, S., Sun, C., Zhang, J., Paschalidis, I., "Joint Estimation of OD Demands and Cost Functions in Transportation Networks from Data", IEEE Conference on Decision and Control (CDC), DOI: 10.1109/CDC40024.2019.9029445, December 2019, pp. 5113-5118.

Contacts: Jing Zhang

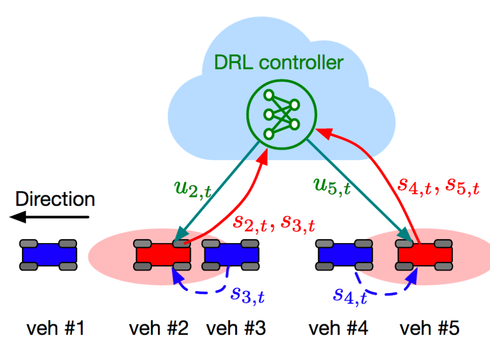


Existing work has tackled the problem of estimating Origin-Destination (OD) demands and recovering travel latency functions in transportation networks under the Wardropian assumption. The ultimate objective is to derive an accurate predictive model of the network to enable optimization and control. However, these two problems are typically treated separately and estimation is based on parametric models. In this paper, we propose a method to jointly recover nonparametric travel latency cost functions and estimate OD demands using traffic flow data. We formulate the problem as a bilevel optimization problem and develop an iterative first-order optimization algorithm to solve it. A numerical example using the Braess Network is presented to demonstrate the effectiveness of our method.

Model-based deep reinforcement learning for CACC in mixed-autonomy vehicle platoons

Citation: Chu, T., Kalabić, U., "Model-based deep reinforcement learning for CACC in mixed-autonomy vehicle platoons", IEEE Conference on Decision and Control (CDC), DOI: 10.1109/CDC40024.2019.9030110, December 2019, pp. 4079-4084.

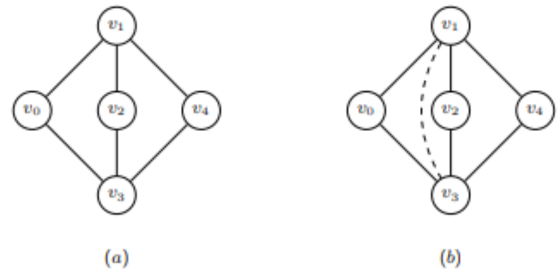
Contacts: Uroš Kalabić



This paper proposes a model-based deep reinforcement learning (DRL) algorithm for cooperative adaptive cruise control (CACC) of connected vehicles. We consider a platoon consisting of both human-driven and autonomous vehicles. The human-driven vehicles are heterogeneous and connected via vehicle-to-vehicle (V2V) communication and the autonomous vehicles are controlled by a cloud-based centralized DRL controller via vehicle-to-cloud (V2C) communication. The algorithm informs lower-level controllers of desired headway signals instead of directly controlling vehicle accelerations. Numerical experiments show that the model-based DRL algorithm outperforms its model-free version in both safety and stability of CACC.

On the Minimum Chordal Completion Polytope

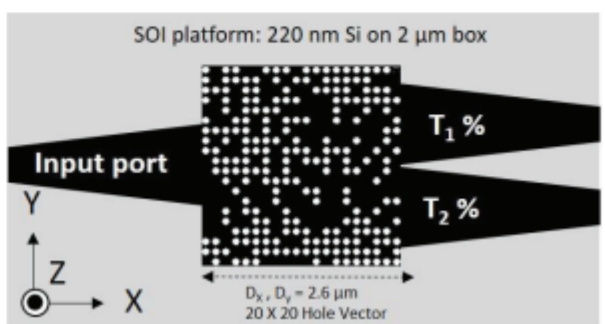
Citation: Bergman, D.; Cardonha, C.; Cire, A.; Raghunathan, A.U., “On the Minimum Chordal Completion Polytope”, Operations Research, DOI: 10.1287/opre.2018.1783, vol. 67, pp. 295-597, March 2019.
Contacts: Arvind Raghunathan



A graph is chordal if every cycle of length at least four contains a chord, that is, an edge connecting two nonconsecutive vertices of the cycle. Several classical applications in sparse linear systems, database management, computer vision, and semidefinite programming can be reduced to finding the minimum number of edges to add to a graph so that it becomes chordal, known as the minimum chordal completion problem (MCCP). We propose a new formulation for the MCCP that does not rely on finding perfect elimination orderings of the graph, as has been considered in previous work. We introduce several families of facet-defining inequalities for cycle subgraphs and investigate the underlying separation problems, showing that some key inequalities are NP-Hard to separate. We also identify conditions through which facets and inequalities associated with the polytope of a certain graph can be adapted to become facet defining for some of its subgraphs or super-graphs.

Deep Neural Network Inverse Design of Integrated Photonic Power Splitters

Citation: TaherSima, M., Kojima, K., Koike-Akino, T., Jha, D., Wang, B., Lin, C., Parsons, K., "Deep Neural Network Inverse Design of Integrated Photonic Power Splitters", *Nature Scientific Reports*, December 2018.
Contacts: Keisuke Kojima, Toshiaki Koike-Akino, Devesh Jha, Bingnan Wang, Chungwei Lin



Predicting physical response of an artificially structured material is of particular interest for scientific and engineering applications. Here we use deep learning to predict optical response of artificially engineered nanophotonic devices. In addition to predicting forward approximation of transmission response for any given topology, this approach allows us to inversely approximate designs for a targeted optical response. Our Deep Neural Network (DNN) could design compact (2.6x2.6 um 2) silicon-on-insulator (SOI)-based 1x2 power splitters with various target splitting ratios in a fraction of a second. This model is trained to minimize the reflection (to smaller than -20 dB) while achieving maximum transmission efficiency above 90% and target splitting specifications. This approach paves the way for rapid design of integrated photonic components relying on complex nanostructures.

Artificial Intelligence

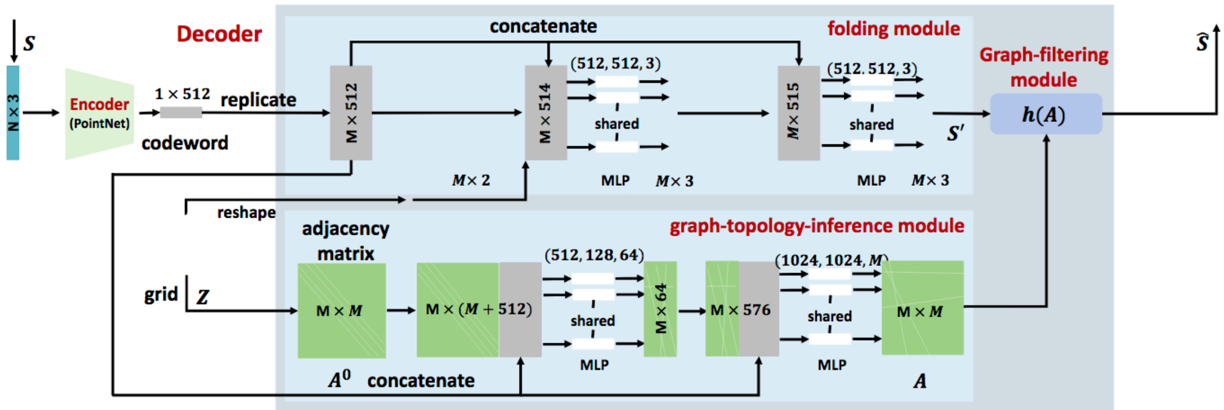
AI research at MERL aims to make machines smarter for improved safety, efficiency and comfort. Our work encompasses advances in computer vision, speech and audio processing, as well as data analytics. Key research themes include improved perception based on machine learning techniques, learning control policies through model-based reinforcement learning, as well as cognition and reasoning based on learned semantic representations. We apply our work to a broad range of automotive and robotics applications, as well as building and home systems.

Recent Research

Deep Unsupervised Learning of 3D Point Clouds via Graph Topology Inference and Filtering

Citation: Chen, S., Duan, C., Yang, Y., Feng, C., Li, D., Tian, D., "Deep Unsupervised Learning of 3D Point Clouds via Graph Topology Inference and Filtering", IEEE Transactions on Image Processing, DOI: 10.1109/TIP.2019.2957935, pp. 3183-3198, January 2020.

Contacts: Siheng Chen

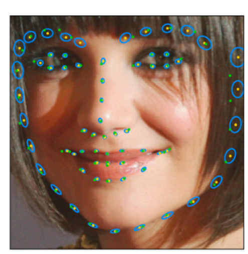


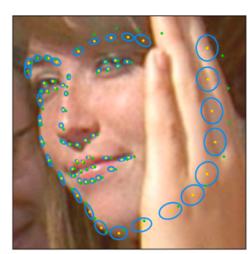
We propose a deep autoencoder with graph topology inference and filtering to achieve compact representations of unorganized 3D point clouds in an unsupervised manner. Many previous works discretize 3D points to voxels and then use lattice-based methods to process and learn 3D spatial information; however, this leads to discretization errors. We directly handle 3D points without such compromise. Experiments validate the proposed approach in three tasks: 3D point cloud reconstruction, visualization, and transfer classification.

UGLLI Face Alignment: Estimating Uncertainty with Gaussian Log-Likelihood Loss

Citation: Marks, T., Kumar, A., Mou, W., Feng, C., Liu, X., "UGLLI Face Alignment: Estimating Uncertainty with Gaussian Log-Likelihood Loss", IEEE International Conference on Computer Vision (ICCV) Workshop on Statistical Deep Learning for Computer Vision (SDL-CV), October 2019.

Contacts: Tim Marks





Modern face alignment methods have become quite accurate at predicting the locations of facial landmarks, but they do not typically estimate the uncertainty of their predicted locations. We present a novel framework for jointly predicting facial landmark locations and the associated uncertainties, modeled as 2D Gaussian distributions, using Gaussian log-likelihood loss. Our joint estimation of uncertainty and landmark locations yield state-of-the-art estimates of both landmark locations and their uncertainty.

Learning a distance function with a Siamese network to localize anomalies in videos

Citation: Ramachandra, B., Jones, M.J., Vatsavai, R., "Learning a distance function with a Siamese network to localize anomalies in videos", IEEE Winter Conference on Applications of Computer Vision (WACV), February 2020, pp. 2598-2607.

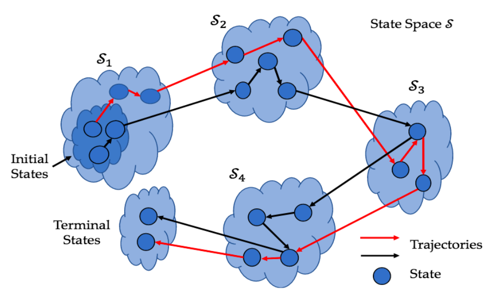
Contacts: Mike Jones

This work introduces a new approach to localize anomalies in surveillance video. The main novelty is the idea of using a Siamese convolutional neural network (CNN) to learn a distance function between a pair of video patches (spatiotemporal regions of video). The learned distance function, which is not specific to the target video, is used to measure the distance between each video patch in the testing video and the video patches found in normal training video. If a testing video patch is not similar to any normal video patch then it is considered anomalous. We compare our approach to previously published algorithms using 4 evaluation measures and 3 challenging target benchmark datasets. Experiments show that our approach at least as good and often better than current state-of-the-art methods.

Learning from Trajectories via Subgoal Discovery

Citation: Paul, S., van Baar, J., Roy-Chowdhury, A.K., "Learning from Trajectories via Subgoal Discovery", Advances in Neural Information Processing Systems (NeurIPS), pp. 8409-8419, October 2019.

Contacts: Jeroen van Baar

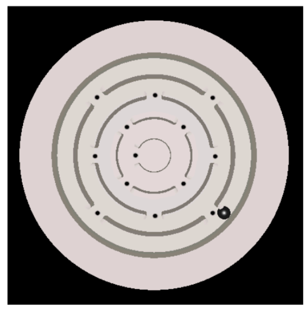


Learning to solve complex goal-oriented tasks with sparse terminal-only rewards often requires an enormous number of samples. In such cases, using a set of expert trajectories could help to learn faster. However, Imitation Learning (IL) via supervised pre-training with these trajectories may not perform as well and generally requires additional finetuning with an expert in the loop. zwe propose an approach that uses expert trajectories and learns to decompose the complex main task into smaller sub-goals. We learn a function which partitions the state-space into sub-goals, which can then be used to design an extrinsic reward function. We follow a strategy where the agent first learns from the trajectories using IL and then switches to Reinforcement Learning (RL) using the identified sub-goals, to alleviate the errors in the IL step. To deal with states that are underrepresented by the trajectory set, we also learn a function to modulate the sub-goal predictions. We show that our method is able to solve complex goal-oriented tasks, which other RL, IL or their combinations in literature are not able to solve.

Sim-to-Real Transfer Learning using Robustified Controllers in Robotic Tasks involving Complex Dynamics

Citation: van Baar, J., Sullivan, A., Corcodel, R., Jha, D., Romeres, D., Nikovski, D.N., "Sim-to-Real Transfer Learning using Robustified Controllers in Robotic Tasks involving Complex Dynamics", IEEE International Conference on Robotics and Automation (ICRA), DOI: 10.1109/ICRA.2019.8793561, May 2019, pp. 6001-6007.

Contacts: Jeroen van Baar, Alan Sullivan

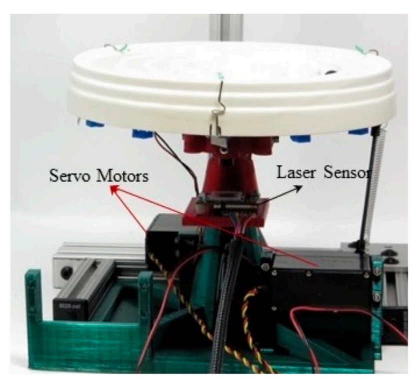


Learning robot tasks or controllers using deep reinforcement learning has been proven effective in simulations. Learning in simulation has several advantages. Transfer learning requires some amount of fine-tuning on the real robot. To reduce the amount of fine-tuning needed we learn robustified controllers in simulation by exploiting simulations ability to change parameters (both appearance and dynamics) for successive training episodes. We demonstrate our approach on a real setup in which a robot aims to solve a maze game, which involves complex dynamics due to static friction and potentially large accelerations. We show that the amount of fine-tuning in transfer learning for a robustified controller is substantially reduced compared to a non-robustified controller.

Semiparametrical Gaussian Processes Learning of Forward Dynamical Models for Navigating in a Circular Maze

Citation: Romeres, D., Jha, D., Dalla Libera, A., Yerazunis, W.S., Nikovski, D.N., "Semiparametrical Gaussian Processes Learning of Forward Dynamical Models for Navigating in a Circular Maze", IEEE International Conference on Robotics and Automation (ICRA), DOI: 10.1109/ICRA.2019.8794229, May 2019,

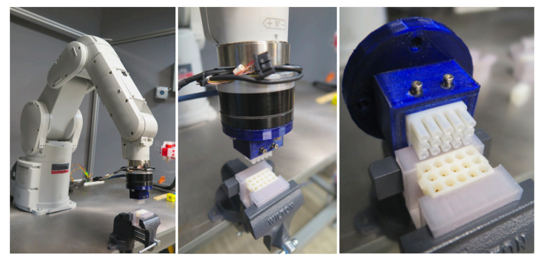
Contacts: Diego Romeres, Devesh Jha



We propose the system presented in this paper as a benchmark problem for reinforcement and robot learning, because of its interesting and challenging dynamics and its relative ease of reproducibility. The motion of the ball in the maze environment is influenced by several non-linear effects such as dry friction and contacts, that are difficult to model physically. We propose a semiparametric model to estimate the motion dynamics of the ball based on Gaussian Process Regression equipped with basis functions obtained from physics first principles. The accuracy of this semiparametric model is shown not only in estimation but also in prediction at n-steps ahead and in compared with standard algorithms for model learning.

Anomaly Detection for Insertion Tasks in Robotic Assembly Using Gaussian Process Models

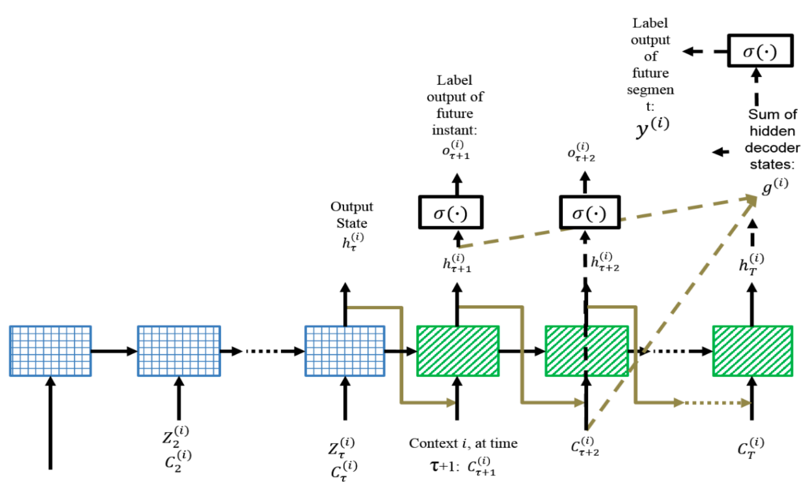
Citation: Romeres, D., Jha, D., Dau, H., Yerazunis, W.S., Nikovski, D.N., "Anomaly Detection for Insertion Tasks in Robotic Assembly Using Gaussian Process Models", European Control Conference (ECC), DOI: 10.23919/ECC.2019.8795698, June 2019, pp. 1017-1022.
Contacts: Diego Romeres, Devesh Jha



Component insertion is a common task in robotic assembly and is generally characterized by low tolerances, thus requiring high precision. Early detection of a errors in mating during insertion enables quality control of the end products, as well as safeguards the robotic equipment. We use Gaussian Process Regression-based methods to learn the force profile during successful insertions, as well as quantify permissible deviations from this profile. We report an accuracy of 100% in differentiating between normal and faulty insertions. The modeling and detection results indicate that our approach is accurate and robust to uncertainties and measurement noise.

Multi-label Prediction in Time Series Data using Deep Neural Networks

Citation: Zhang, W., Jha, D., Laftchiev, E., Nikovski, D.N., "Multi-label Prediction in Time Series Data using Deep Neural Networks", International Journal for Prognostics and Health Management Special Issue on Applications of Deep Learning and Emerging Analytics, Vol. 10, pp. 0-12, September 2019.
Contacts: Devesh Jha, Emil Laftchiev

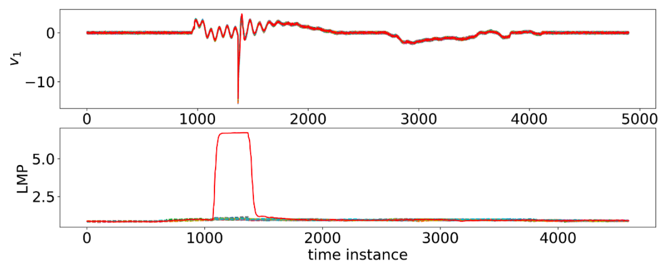


While fault (event) detection in multidimensional time-series data have been thoroughly studied in the literature, most of the state-of-the-art techniques can't reliably predict faults (events) over a desired future horizon. A key reason is that available data usually has strong class imbalances where some classes are represented by only a few samples. In many applications such as fault prediction and predictive maintenance, it is exactly these rare classes that are of most interest. To address data imbalance, this paper proposes a general approach that utilizes a multi-label recurrent neural network with a cost function that accentuates learning in the imbalanced classes.

Fault Detection and Classification of Time Series Using Localized Matrix Profiles

Citation: Zhang, J., Nikovski, D.N., Lee, T.-Y., Fujino, T., "Fault Detection and Classification of Time Series Using Localized Matrix Profiles", IEEE International Conference on Prognostics and Health Management, DOI: 10.1109/ICPHM.2019.8819389, June 2019.

Contacts: Jing Zhang

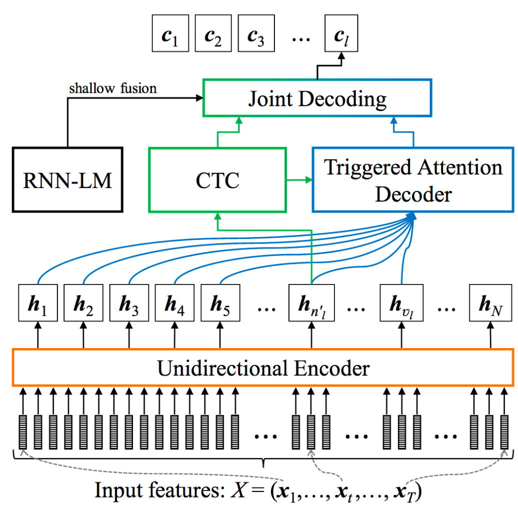


We introduce a new primitive, called the Localized Matrix Profile (LMP), for time series data mining. We devise fast algorithms for LMP computation, and propose a fault detector and a fault classifier based on LMP. A case study using synthetic sensor data generated from a physical model of an electrical motor is provided to demonstrate the effectiveness and efficiency of our approach.

Streaming End-to-End Speech Recognition with Joint CTC-Attention Based Models

Citation: Moritz, N., Hori, T., Le Roux, J., "Streaming End-to-End Speech Recognition with Joint CTC-Attention Based Models", IEEE Workshop on Automatic Speech Recognition and Understanding (ASRU), December 2019, pp. 936-943.

Contacts: Niko Moritz, Takaaki Hori, Jonathan Le Roux

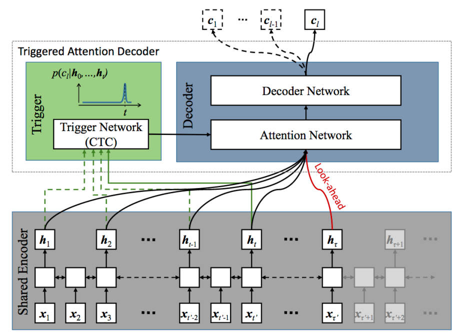


We present a one-pass decoding algorithm for streaming recognition with joint connectionist temporal classification (CTC) and attention-based end-to-end automatic speech recognition (ASR) models. The decoding scheme is based on a frame-synchronous CTC prefix beam search algorithm and the recently proposed triggered attention concept. To achieve a fully streaming end-to-end ASR system, the CTC-triggered attention decoder is combined with a unidirectional encoder neural network based on parallel time-delayed long short-term memory (PTDLSTM) streams, which has demonstrated superior performance compared to various other streaming encoder architectures in earlier work. A new type of pre-training method is studied to further improve our streaming ASR models by adding residual connections to the encoder neural network. The proposed joint CTC-triggered attention decoding algorithm, which enables streaming recognition of attention-based ASR systems, achieves similar ASR results compared to offline CTC-attention decoding and significantly better results compared to CTC prefix beam search decoding alone.

Triggered Attention for End-to-End Speech Recognition

Citation: Moritz, N., Hori, T., Le Roux, J., "Triggered Attention for End-to-End Speech Recognition", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP.2019.8683510, May 2019.

Contacts: Niko Moritz, Takaaki Hori, Jonathan Le Roux

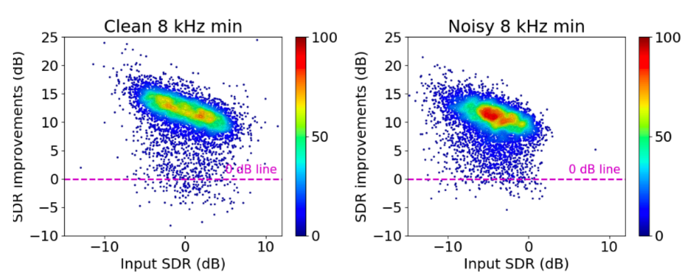


A new system architecture for end-to-end automatic speech recognition (ASR) is proposed that combines the alignment capabilities of the connectionist temporal classification (CTC) approach and the modeling strength of the attention mechanism. The proposed system architecture, named triggered attention (TA), uses a CTC-based classifier to control the activation of an attention-based decoder neural network. This allows for a frame-synchronous decoding scheme with an adjustable look-ahead parameter to control the induced delay and opens the door to streaming recognition with attention-based end-to-end ASR systems. The proposed triggered attention (TA) decoder concept achieves similar or better ASR results in all experiments compared to the full-sequence attention model, while also limiting the decoding delay to two look-ahead frames, which in our setup corresponds to an output delay of 80 ms.

WHAM!: Extending Speech Separation to Noisy Environments

Citation: Wichern, G., McQuinn, E., Antognini, J., Flynn, M., Zhu, R., Crow, D., Manilow, E., Le Roux, J., "WHAM!: Extending Speech Separation to Noisy Environments", Interspeech, DOI: 10.21437/Interspeech.2019-2821, September 2019, pp. 1368-1372.

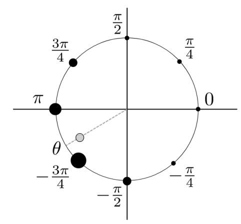
Contacts: Gordon Wichern, Jonathan Le Roux



Recent progress in separating the speech signals from multiple overlapping speakers using a single audio channel has brought us closer to solving the cocktail party problem. However, most studies in this area use a constrained problem setup, comparing performance when speakers overlap almost completely, at artificially low sampling rates, and with no external background noise. In this paper, we strive to move the field towards more realistic and challenging scenarios. To that end, we created the WSJ0 Hipster Ambient Mixtures (WHAM!) dataset, consisting of two speaker mixtures from the wsj0-2mix dataset combined with real ambient noise samples. The samples were collected in coffee shops, restaurants, and bars in the San Francisco Bay Area, and are made publicly available. We benchmark various speech separation architectures and objective functions to evaluate their robustness to noise. While separation performance decreases as a result of noise, we still observe substantial gains relative to the noisy signals for most approaches.

The Phasebook: Building Complex Masks via Discrete Representations for Source Separation

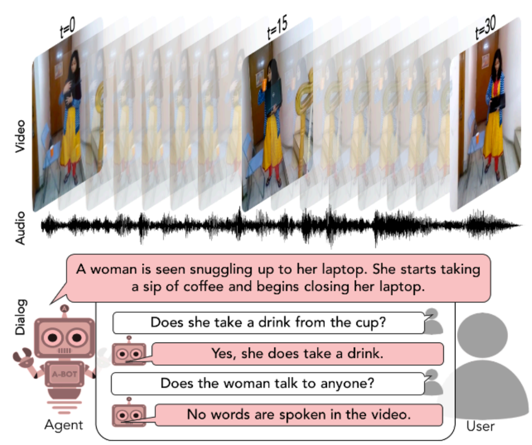
Citation: Le Roux, J., Wichern, G., Watanabe, S., Sarroff, A., Hershey, J., "The Phasebook: Building Complex Masks via Discrete Representations for Source Separation", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP.2019.8682587, May 2019.
Contacts: Jonathan Le Roux, Gordon Wichern



Deep-learning-based speech enhancement and source separation systems have recently reached unprecedented levels of quality, to the point that performance is reaching a new ceiling. Most systems rely on estimating the magnitude of a target source, either directly or by computing a real-valued mask to be applied to a time-frequency representation of the mixture signal. A limiting factor in such approaches is a lack of phase estimation: the phase of the mixture is most often used when,reconstructing the estimated time-domain signal. We propose to estimate phase using “phasebook”, a new type of layer based on a discrete representation of the phase difference between the mixture and the target. We also introduce “combook”, a similar type of layer that directly estimates a complex mask. We evaluate the proposed methods on the wsj0-2mix dataset, matching the performance of state-of-the-art mask-based approaches without requiring additional phase reconstruction steps.

Audio-Visual Scene-Aware Dialog

Citation: Alamri, H., Cartillier, V., Das, A., Wang, J., Lee, S., Anderson, P., Essa, I., Parikh, D., Batra, D., Cherian, A., Marks, T.K., Hori, C., "Audio-Visual Scene-Aware Dialog", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), DOI: 10.1109/CVPR.2019.00774, June 2019, pp. 7550-7559.
Contacts: Chiori Hori, Tim Marks



We introduce the task of scene-aware dialog. Given a follow-up question in an ongoing dialog about a video, our goal is to generate a complete and natural response to a question given (a) an input video, and (b) the history of previous turns in the dialog. To succeed, agents must ground the semantics in the video and leverage contextual cues from the history of the dialog to answer the question. To benchmark this task, we introduce the Audio-Visual Scene-Aware Dialog (AVSD) dataset. For each of more than 11,000 videos of human actions for the Charades dataset. Our dataset contains a dialog about the video, plus a final summary of the video by one of the dialog participants. We trained several baseline systems for this task and evaluated the performance of the trained models. Our results indicate that the models must comprehend all the available inputs (video, audio, question and dialog history) to perform well on this dataset.