**Mitsubishi Electric Research Laboratories (MERL)**

# Annual Report

**April 2020 through March 2021**

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


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# Mitsubishi Electric Research Laboratories

Mitsubishi Electric Research Laboratories (MERL) is the 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.

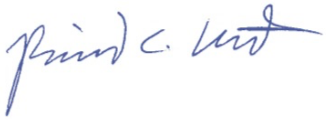
MERL's vision—our goal for ourselves:

- 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.

- Dr. Richard C. (Dick) Waters (President & CEO) —— IT
  - Shinsuke Azuma (EVP & CFO) —— Finance & Liaisons
  - Elizabeth Phillips (VP & Director) —— HR & Administration
  - Dr. Anthony Vetro, IEEE Fellow (VP & Director) —— Patents
    - CV: Computer Vision Group - Dr. Alan Sullivan
    - DA: Data Analytics Group - Dr. Daniel Nikovski
    - SA: Speech & Audio Team - Dr. Jonathan Le Roux
  - Dr. Jinyun Zhang, IEEE Fellow (VP & Director)
    - SP: Signal Processing Group - Dr. Phil Orlik
    - CA: Control For Autonomy Team - Dr. Stefano Di Cairano
    - MP: Multi-Physics & Dynamics Team - Dr. Jay Thornton
    - MS: Multi-Physical Systems Team - Dr. Chris Laughman

**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.

**Shinsuke Azuma** *M.Eng., The University of Tokyo, 1989*
Executive Vice President & CFO

Shinsuke (Shin) Azuma joined Mitsubishi Electric in 1989 and worked on the development of small business computers and database processors. In 2000, the DIAPRISM database processor he helped develop set a world record in the sort benchmark contest. Before joining MERL in 2021, he was the general manager of the Information Technology Laboratory in Mitsubishi Electric's Information Technology R&D 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*
Vice President & 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.

**Philip V. Orlik** *Ph.D., State University of NY at Stony Brook, 1999*
Deputy Director & 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. He has been an active participant in communication standards

# Mitsubishi Electric

One of the world's largest companies, Mitsubishi Electric Corporation has $38 billion in annual sales, $2.1 billion in operating profits (in the year ending in March 2021) 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

**Iconics, Inc**. (Boston MA)
Real-time visualization, HMI/SCADA, energy management and fault detection software

# 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, Optica (formerly 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 June 2020, a Best Paper Award was given for MERL's the paper: Huang, T., Sun, H., Kim, K.J., Nikovski, D.N., Xie, L., "A Holistic Framework for Parameter Coordination of Interconnected Microgrids against Disasters", IEEE Power & Energy Society General Meeting (PES), June 2020.

In August 2020, a Best Paper Student Award was given for MERL's the paper: Greiff, M., Robertsson, A., Berntorp, K., "MSE-optimal measurement dimension reduction in Gaussian filtering", Conference on Control Technology and Applications (CCTA), DOI: 10.1109/CCTA41146.2020.9206162, August 2020.

In September 2020, a Best Paper Award was given for MERL's the paper: Nagai, Y., Sumi, T., Guo, J., Orlik, P.V., Mineno, H., "Hybrid CSMA/CA for Sub-1 GHz Frequency Band Coexistence of IEEE 802.11ah and IEEE 802.15.4g", Consumer Device System 28th Research Presentation, September 2020.

In January 2020, a Best Paper Honourable Mention Award was given for MERL's the paper: Anirudh, R., Lohit, S., Turaga, P., "Generative Patch Priors for Practical Compressive Image Recovery", IEEE Winter Conference on Applications of Computer Vision (WACV), January 2021.

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: 13 papers in the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 10 papers in the American Control Conference (ACC), 7 papers in the World Congress of the International Federation of Automatic Control (IFAC), 4 papers in the IEEE Global Communications Conference (GLOBECOM), and 4 papers in IEEE Conference on Computer Vision and Pattern Recognition (CVPR).

# 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.

**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.

**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.

**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.

**Varun Haritsa** M.S., North Carolina State University, 2020
Visiting Associate Research Scientist

Varun has worked on computer vision projects for applications such as autonomous driving, automated material handling and video anomaly detection. His interests are focused on artificial intelligence including computer vision, deep learning and robotics.

**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.

**Teruaki Ito** M.S., Carnegie Mellon University, 2003
Liaison Manager

Teruaki joined Mitsubishi Electric in 1994 and worked on research and development of computer networks and industrial networks. He is an architect of the CC-Link IE families, an ethernet-based industrial network, used in factory automation systems. Prior to joining MERL, he worked at the Information Technology R&D center of Mitsubishi Electric Corporation as a senior manager of the network technology group.

**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.

**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.

**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.

**Marcel Menner** Ph.D., ETH Zurich, 2020
Visiting Research Scientist

Marcel's research interests include optimization-based control, machine learning, learning from human interactions, as well as their applications to vehicles and robots. During his Ph.D. research, he developed data-based control methodologies for improving the operation of dynamical systems.

**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.

**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.

**Norihiro Nishiuma** M.Eng., The University of Tokyo, 1999
Liaison Manager

Nori joined Mitsubishi Electric in 1999 working as a researcher in the area of Intelligent Transport Systems (ITS) including road infrastructure and automotive navigation systems. Then, he engaged in product development as a software engineer for automotive equipment in the Sanda Works. Before joining MERL, he was a member of the Systems Technology Dept. in the Advanced Technology R&D Center.

**Carlos J. Nohra** Ph.D., Carnegie Mellon University, 2020
Visiting Research Scientist

Carlos' research focuses on the development of algorithms and software for mixed-integer nonlinear programs, with applications in electric power grids and heat exchanger design.

**Abraham P. Vinod** Ph.D., University of New Mexico Albuquerque, 2018
Research Scientist

Abraham's Ph.D. research developed scalable algorithms for providing safety guarantees for stochastic, control-constrained, dynamical systems. His research work has been applied in motion planning under uncertainty, spacecraft rendezvous planning, and human-automation interactions. His current research interests lie in the intersection of optimization, control, and learning.

**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.

**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

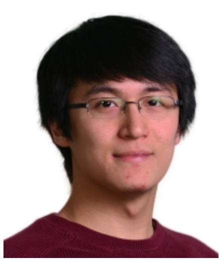
Bingnan’s doctoral work focused on the study of wave propagation in novel electromagnetic materials, including photonic crystals and meta-materials. His research interests include electromagnetics and photonics, and their applications to communications, imaging, and energy systems.

**Hongyu Wang** Ph.D., Tsinghua University, 2006
Visiting Research Scientist

Hongyu's main research interest is electric machine design and analysis, including electromagnetic field, thermal field and mechanical aspects of electric machines, transient processes, steady-state and transient parameter calculations, stability, fault/post-fault operation analysis, and drive system control. Before joining MERL, he worked as a Senior Research Associate at The Ohio State University and previously was an Associate Professor at the North China Electrical Power University.

**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).

**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.

Tian, N., Fang, H., Chen, J., Wang, Y., **"Nonlinear Double-Capacitor Model for Rechargeable Batteries: Modeling, Identification and Validation"**, *IEEE Transactions on Control Systems Technology*, DOI: 10.1109/TCST.2020.2976036, pp. 1-15, April 2020. (TR2020-035)

Burghal, D., Kim, K.J., Guo, J., Orlik, P.V., Hori, T., Sumi, T., Nagai, Y., **"Multi-Channel Delay Sensitive Scheduling for Convergecast Network"**, *IEEE Wireless Communications and Networking Conference (WCNC)*, April 2020, pp. 1-7. (TR2020-036)

Pishdadian, F., Wichern, G., Le Roux, J., **"Learning to Separate Sounds From Weakly Labeled Scenes"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053055, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 91-95. (TR2020-038)

Sari, L., Moritz, N., Hori, T., Le Roux, J., **"Unsupervised Speaker Adaptation Using Attention-Based Speaker Memory For End-To-End ASR"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9054249, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 7384-7388. (TR2020-037)

Yu, L., Liu, D., Mansour, H., Boufounos, P.T., Ma, Y., **"Blind Multi-Spectral Image Pan-Sharpening"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053554, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 1429-1433. (TR2020-047)

Maciejewski, M., Wichern, G., McQuinn, E., Le Roux, J., **"WHAMR!: Noisy and Reverberant Single-Channel Speech Separation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053327, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 696-700. (TR2020-042)

Chang, X., Zhang, W., Qian, Y., Le Roux, J., Watanabe, S., **"End-To-End Multi-Speaker Speech Recognition with Transformer"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9054029, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 6134-6138. (TR2020-043)

Liu, J., Chen, B., Chen, S., Berges, M., Bielak, J., Noh, H.Y., **"Damage-Sensitive and Domain-Invariant Feature Extraction for Vehicle-Vibration-Based Bridge Health Monitoring"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053450, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 3007-3011. (TR2020-053)

Xia, Y., Wang, P., Berntorp, K., Koike-Akino, T., Mansour, H., Pajovic, M., Boufounos, P.T., Orlik, P.V., **"Extended Object Tracking Using Hierarchical Truncation Measurement Model with Automotive Radar"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9054614, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 4900-4904. (TR2020-044)

Wang, P., Boufounos, P.T., Mansour, H., Orlik, P.V., **"Slow-Time MIMO-FMCW Automotive Radar Detection with Imperfect Waveform Separation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053892, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 8634-8638. (TR2020-039)

Ma, Y., Lodhi, M.A., Mansour, H., Boufounos, P.T., Liu, D., **"Inverse Multiple Scattering With Phaseless Measurements"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053430, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 1519-1523. (TR2020-041)

Shi, L., Geng, S., Shuang, K., Hori, C., Liu, S., Gao, P., Su, S., **"Multi-Layer Content Interaction Through Quaternion Product For Visual Question Answering"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053595, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 4412-4416. (TR2020-046)

Moritz, N., Hori, T., Le Roux, J., **"Streaming Automatic Speech Recognition With The Transformer Model"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9054476, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 6074-6078. (TR2020-040)

Xie, Y., Liu, D., Mansour, H., Boufounos, P.T., **"Robust Parameter Estimation of Contaminated Damped Exponentials"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9053507, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 5500-5504. (TR2020-052)

Al-Shabili, A., Mansour, H., Boufounos, P.T., **"Learning Plug-and-Play Proximal Quasi-Newton Denoisers"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP40776.2020.9054537, ISSN: 2379-190X, ISBN: 978-1-5090-6631-5, April 2020, pp. 8896-8900. (TR2020-045)

Fehenberger, T., Millar, D.S., Koike-Akino, T., Kojima, K., Parsons, K., **"Parallel-Amplitude Architecture and Subset Ranking for Fast Distribution Matching"**, *IEEE Transactions on Communications*, DOI: 10.1109/TCOMM.2020.2966693, ISSN: 1558-0857, Vol. 68, No. 4, pp. 1981-1990, April 2020. (TR2020-050)

Ozdenizci, O., Wang, Y., Koike-Akino, T., Erdogmus, D., **"Learning Invariant Representations from EEG via Adversarial Inference"**, *IEEE Access*, DOI: 10.1109/ACCESS.2020.2971600, ISSN: 2169-3536, Vol. 8, pp. 27074-27085, April 2020. (TR2020-049)

Fujihashi, T., Koike-Akino, T., Orlik, P.V., Watanabe, T., **"High-Throughput Visual MIMO Systems for Screen-Camera Communications"**, *IEEE Transactions on Mobile Computing*, April 2020. (TR2020-048)

Fehenberger, T., Millar, D.S., Koike-Akino, T., Kojima, K., Parsons, K., Griesser, H., **"Huffman-coded Sphere Shaping and Distribution Matching Algorithms via Lookup Tables"**, *IEEE Journal of Lightwave Technology*, DOI: 10.1109/JLT.2020.2987210, ISSN: 1558-2213, Vol. 38, No. 10, pp. 2825-2833, April 2020. (TR2020-051)

Koike-Akino, T., Wang, P., Pajovic, M., Sun, H., Orlik, P.V., **"Fingerprinting-Based Indoor Localization with Commercial MMWave WiFi: A Deep Learning Approach"**, *IEEE Access*, DOI: 10.1109/ACCESS.2020.2991129, ISSN: 2169-3536, April 2020. (TR2020-054)

Ioannidis, V., Chen, S., Giannakis, G., **"Pruned Graph Scattering Transforms"**, *International Conference on Learning Representations (ICLR)*, April 2020. (TR2020-055)

Zhang, S., Wang, B., Kanemaru, M., Lin, C., Liu, D., Habetler, T., **"Model-Based Analysis and Quantification of Bearing Faults in Induction Machines"**, *IEEE Transactions on Industry Applications*, DOI: 10.1109/TIA.2020.2979383, ISSN: 1939-9367, Vol. 56, No. 3, pp. 2158-2170, May 2020. (TR2020-059)

Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., **"Artificial Intelligence-Based Distributed Belief Propagation and Recurrent Neural Network Algorithm for Wide-Area Monitoring Systems"**, *IEEE Network*, DOI: 10.1109/MNET.011.1900322, Vol. 34, No. 3, pp. 64-72, May 2020. (TR2020-058)

Fujihashi, T., Koike-Akino, T., Watanabe, T., Orlik, P.V., **"High-Quality Soft Image Delivery with Deep Image Denoising"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC40277.2020.9148611, ISSN: 1938-1883, ISBN: 978-1-7281-5089-5, May 2020. (TR2020-060)

Fujihashi, T., Koike-Akino, T., Watanabe, T., Orlik, P.V., **"Overhead Reduction in Graph-Based Point Cloud Delivery"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC40277.2020.9148650, ISSN: 1938-1883, ISBN: 978-1-7281-5089-5, May 2020. (TR2020-061)

Sun, H., Wang, P., Pajovic, M., Koike-Akino, T., Orlik, P.V., Taira, A., Nakagawa, K., **"Fingerprinting-Based Outdoor Localization with 28-GHz Channel Measurement: A Field Study"**, *IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, DOI: 10.1109/SPAWC48557.2020.9154212, ISSN: 1948-3252, ISBN: 978-1-7281-5478-7, May 2020. (TR2020-056)

Chen, S., Zhang, N., Sun, H., **"Collaborative Localization Based on Traffic Landmarks for Autonomous Driving"**, *IEEE International Symposium on Circuits and Systems (ISCAS)*, DOI: 10.1109/ISCAS45731.2020.9180894, May 2020. (TR2020-064)

Romeres, D., Dalla Libera, A., Jha, D.K., Yerazunis, W.S., Nikovski, D.N., **"Model-Based Reinforcement Learning for Physical Systems Without Velocity and Acceleration Measurements"**, *Robotics and Automation Letters*, DOI: 10.1109/LRA.2020.2977255, ISSN: 2377-3766, Vol. 5, No. 2, pp. 3548-3555, May 2020. (TR2020-063)

Chen, S., Liu, B., Feng, C., Vallespi-Gonzalez, C., Wellington, C., **"3D Point Cloud Processing and Learning for Autonomous Driving"**, *IEEE Signal Processing Magazine*, DOI: 10.1109/MSP.2020.2984780, Vol. 38, No. 1, pp. 68-86, May 2020. (TR2020-066)

Jha, D.K., Kolaric, P., Raghunathan, A., Lewis, F., Benosman, M., Romeres, D., Nikovski, D.N., **"Local Policy Optimization for Trajectory-Centric Reinforcement Learning"**, *IEEE International Conference on Robotics and Automation (ICRA)*, Ayanna Howard, Eds., ISBN: 978-1-7281-7395-5, May 2020, pp. 5094-5100. (TR2020-062)

Onol, A.O., Corcodel, R., Long, P., Padir, T., **"Tuning-Free Contact-Implicit Trajectory Optimization"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA40945.2020.9196805, ISSN: 2577-087X, ISBN: 978-1-7281-7395-5, May 2020, pp. 1183-1189. (TR2020-065)

Wu, P., Chen, S., **"MotionNet: Joint Perception and Motion Prediction for Autonomous Driving Based on Bird's Eye View Maps"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR42600.2020.01140, June 2020, pp. 11382-11392. (TR2020-068)

Kumar, A., Marks, T.K., Mou, W., Wang, Y., Cherian, A., Jones, M.J., Liu, X., Koike-Akino, T., Feng, C., **"LUVLi Face Alignment: Estimating Landmarks' Location, Uncertainty, and Visibility Likelihood"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR42600.2020.00826, ISSN: 2575-7075, ISBN: 978-1-7281-7168-5, June 2020. (TR2020-067)

Hu, Y., Chen, S., Zhang, Y., Gu, X., **"Collaborative Motion Prediction via Neural Motion Message Passing"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR42600.2020.00635, June 2020, pp. 6318-6327. (TR2020-072)

Li, M., Chen, S., Zhao, Y., Zhang, Y., Wang, Y., Tia, Q., **"Dynamic Multiscale Graph Neural Networks for 3D Skeleton-Based Human Motion Prediction"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR42600.2020.00029, June 2020, pp. 211-220. (TR2020-073)

Nowara, E., Marks, T.K., Mansour, H., Pai, A., Nagamatsu, G., Kawasaki, H., Veeraraghavan, A., **"HeartCam: Camera-Based Physiology Monitoring in the Wild"**, *IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, June 2020.

Kim, K.J., Liu, H., Lei, H., Ding, Z., Orlik, P.V., Poor, H.V., **"A dCDD-Based Transmit Diversity for NOMA Systems"**, *IEEE International Conference on Communications (ICC)*, June 2020, pp. 1-7. (TR2020-070)

Wang, Y., Koike-Akino, T., **"Learning to Modulate for Non-coherent MIMO"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC40277.2020.9149438, ISSN: 1938-1883, ISBN: 978-1-7281-5089-5, June 2020. (TR2020-071)

Lei, H., Gao, R., Park, K.-H., Ansari, I.S., Kim, K.J., Alouini, M.-S., **"Security Performance Analysis for the Downlink NOMA Systems with Outage Constraint"**, *IEEE International Conference on Communications Workshops (ICC)*, DOI: 10.1109/ICCWorkshops49005.2020.9145372, June 2020, pp. 1-6. (TR2020-074)

Xia, Y., Wang, P., Berntorp, K., Mansour, H., Boufounos, P.T., Orlik, P.V., **"Extended Object Tracking Using Hierarchical Truncation Model With Partial-View Measurements"**, *IEEE Sensor Array & Multichannel Signal Processing Workshop (SAM)*, DOI: 10.1109/SAM48682.2020.9104388, June 2020. (TR2020-069)

Kalabic, U., Grover, P., Aeron, S., **"Optimization-based incentivization and control scheme for autonomous traffic"**, *IEEE Intelligent Vehicle Symposium*, DOI: 10.1109/IV47402.2020.9304641, June 2020. (TR2020-079)

Sravan Kumar, P., Ma, R., **"Design Considerations and FPGA Implementation of a Wideband All-Digital Transmit Beamformer with 50% Fractional Bandwidth"**, *IEEE International Microwave Symposium (IMS)*, DOI: 10.1109/IMS30576.2020.9223888, ISSN: 2576-7216, ISBN: 978-1-7281-6815-9, June 2020, pp. 1073-1076. (TR2020-078)

Komatsuszaki, Y., Ma, R., Sakata, S., Nakatani, K., Shinjo, S., **"A Dual-Mode Bias Circuit Enabled GaN Doherty Amplifier Operating in 0.85-2.05GHz and 2.4-4.2GHz"**, *IEEE International Microwave Symposium (IMS)*, DOI: 10.1109/IMS30576.2020.9223999, ISSN: 2576-7216, ISBN: 978-1-7281-6815-9, June 2020, pp. 277-280. (TR2020-080)

Sakata, S., Kato, K., Teranishi, E., Sugitani, T., Ma, R., Chuang, K., Wu, Y., Fukunaga, K., Komatsuszaki, Y., Kenichi, H., Yamanaka, K., Shinjo, S., **"A Fully-Integrated GaN Doherty Power Amplifier Module with a Compact Frequency-Dependent Compensation Circuit for 5G massive MIMO Base Stations"**, *IEEE International Microwave Symposium (IMS)*, DOI: 10.1109/IMS30576.2020.9223897, ISSN: 2576-7216, ISBN: 978-1-7281-6816-6, June 2020, pp. 711-714. (TR2020-077)

Koike-Akino, T., Wang, Y., **"Stochastic Bottleneck: Rateless Auto-Encoder for Flexible Dimensionality Reduction"**, *IEEE International Symposium on Information Theory (ISIT)*, DOI: 10.1109/ISIT44484.2020.9174523, ISSN: 2157-8117, ISBN: 978-1-7281-6432-8, June 2020. (TR2020-075)

Benosman, M., Chakrabarty, A., Borggaard, J., **"Reinforcement Learning-based Model Reduction for Partial Differential Equations"**, *World Congress of the International Federation of Automatic Control (IFAC)*, Rolf Findeisen, Sandra Hirche, Klaus Janschek, Martin Mönnigmann, Eds., DOI: 10.1016/j.ifacol.2020.12.1515, June 2020, pp. 7704-7709. (TR2020-076)

Lee, G., Guo, J., Kim, K.J., Orlik, P.V., Ahn, H., Di Cairano, S., Saad, W., **"Edge Computing for Interconnected Intersections in Internet of Vehicles"**, *IEEE Intelligent Vehicles Symposium*, ISBN: 978-1-7281-6672-8, June 2020, pp. 209-215. (TR2020-081)

Huang, T., Sun, H., Kim, K.J., Nikovski, D.N., Xie, L., **"A Holistic Framework for Parameter Coordination of Interconnected Microgrids against Disasters"**, *IEEE Power & Energy Society General Meeting (PES)*, DOI: 10.1109/PESGM41954.2020.9281628, June 2020. (TR2020-082)

Ota, K., Oiki, T., Jha, D.K., Mariyama, T., Nikovski, D.N., **"Can Increasing Input Dimensionality Improve Deep Reinforcement Learning?"**, *International Conference on Machine Learning (ICML)*, Daumé III , Hal and Singh, Aarti, Eds., June 2020, pp. 7424-7433. (TR2020-083)

Quirynen, R., Hespanhol, P., **"Adjoint-based SQP Method with Block-wise quasi-Newton Jacobian Updates for Nonlinear Optimal Control"**, *Journal of Optimization Methods and Software*, DOI: 10.1080/10556788.2019.1653869, June 2020. (TR2020-086)

Kim, K.J., Liu, H., Wen, M., Orlik, P.V., Poor, H.V., **"Secrecy Performance Analysis of Distributed Asynchronous Cyclic Delay Diversity-Based Cooperative Single Carrier Systems"**, *IEEE Transactions on Communications*, DOI: 10.1109/TCOMM.2020.2971680, Vol. 68, No. 5, pp. 2680-2694, June 2020. (TR2020-084)

Romero, O., Benosman, M., **"Time-Varying Continuous-Time Optimization with Pre-Defined Finite-Time Stability"**, *International Journal of Control*, DOI: 10.1080/00207179.2020.1756415, pp. 1-18, June 2020. (TR2020-088)

Tian, N., Fang, H., Wang, Y., **"Real-Time Optimal Lithium-Ion Battery Charging Based on Explicit Model Predictive Control"**, *IEEE Transactions on Industrial Informatics*, DOI: 10.1109/TII.2020.2983176, June 2020. (TR2020-090)

Vijayshankar, S., Nabi, S., Chakrabarty, A., Grover, P., Benosman, M., **"Dynamic Mode Decomposition and Robust Estimation: Case Study of a 2D Turbulent Boussinesq Flow"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147823, ISSN: 2378-5861, ISBN: 978-1-5386-8266-1, July 2020, pp. 2351-2356. (TR2020-091)

Romero, O., Benosman, M., **"Continuous-Time Optimization of Time-Varying Cost Functions via Finite-Time Stability with Pre-Defined Convergence Time"**, *American Control Conference (ACC)*, July 2020. (TR2020-085)

Danielson, C., Di Cairano, S., **"A Reference Governor for Wheel-Slip Prevention in Railway Vehicles with Pneumatic Brakes"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147647, July 2020. (TR2020-087)

Danielson, C., Berntorp, K., Di Cairano, S., Weiss, A., **"Motion-Planning for Unicycles using the Invariant-Set Motion-Planner"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147919, ISSN: 2378-5861, ISBN: 978-1-5386-8266-1, July 2020, pp. 1235-1240. (TR2020-089)

Hansen, E., Wang, Y., **"Improving Path Accuracy for Autonomous Parking Systems: An Optimal Control Approach"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147980, July 2020, pp. 5243-5249. (TR2020-099)

Sahin, Y.E., Quirynen, R., Di Cairano, S., **"Autonomous Vehicle Decision-Making and Monitoring based on Signal Temporal Logic and Mixed-Integer Programming"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147917, July 2020. (TR2020-095)

Chakrabarty, A., Berntorp, K., Di Cairano, S., **"Learning-based Parameter-Adaptive Reference Governors"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147615, July 2020, pp. 956-961. (TR2020-092)

Quirynen, R., Berntorp, K., Kambam, K., Di Cairano, S., **"Integrated Obstacle Detection and Avoidance in Motion Planning and Predictive Control of Autonomous Vehicles"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147820, July 2020. (TR2020-096)

Greiff, M., Berntorp, K., **"Optimal Measurement Projections with Adaptive Mixture Kalman Filtering for GNSS Positioning"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147675, July 2020, pp. 4435-4441. (TR2020-097)

Aguilar Marsillach, D., Di Cairano, S., Weiss, A., **"Fail-safe Rendezvous Control on Elliptic Orbits using Reachable Sets"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC45564.2020.9147957, ISSN: 2378-5861, ISBN: 978-1-5386-8266-1, July 2020, pp. 4920-4925. (TR2020-098)

Konno, N., Raghunathan, A., **"Data-Driven Joint Optimization of Pricing and Seat Allocation in Trains"**, *International Conference on Railway Engineering Design and Operation (COMPRAIL)*, DOI: 10.2495/CR200351, July 2020, pp. 379-392. (TR2020-094)

Cherian, A., Aeron, S., **"Representation Learning via Adversarially-Contrastive Optimal Transport"**, *International Conference on Machine Learning (ICML)*, H. Daumé and A. Singh, Eds., July 2020, pp. 10675-10685. (TR2020-093)

Romero, O., Benosman, M., **"Finite-Time Convergence in Continuous-Time Optimization"**, *International Conference on Machine Learning (ICML)*, July 2020. (TR2020-100)

Skvortcov, P., Phillips, I., Forysiak, W., Koike-Akino, T., Kojima, K., Parsons, K., Millar, D.S., **"Nonlinearity Tolerant LUT-based Probabilistic Shaping for Extended-Reach Single-Span Links"**, *IEEE Photonics Technology Letters*, DOI: 10.1109/LPT.2020.3006737, ISSN: 1941-0174, Vol. 32, No. 16, pp. 967-970, July 2020. (TR2020-107)

Maske, H., Chu, T., Kalabic, U., **"Control of traffic light timing using decentralized deep reinforcement learning"**, *World Congress of the International Federation of Automatic Control (IFAC)*, Findeisen, Sandra Hirche, Klaus Janschek, Martin Mönnigmann, Eds., DOI: 10.1016/j.ifacol.2020.12.1980, July 2020, pp. 14936-14941. (TR2020-101)

Muralidharan, V., Weiss, A., Kalabic, U., **"Tracking neighboring quasi-satellite orbits around Phobos"**, *World Congress of the International Federation of Automatic Control (IFAC)*, Rolf Findeisen, Sandra Hirche, Klaus Janschek, Martin Mönnigmann, Eds., DOI: 10.1016/j.ifacol.2020.12.1952, July 2020, pp. 14906–14911. (TR2020-102)

Berntorp, K., **"Online Bayesian Tire-Friction Learning by Gaussian-Process State-Space Models"**, *World Congress of the International Federation of Automatic Control (IFAC)*, Rolf Findeisen, Sandra Hirche, Klaus Janschek, Martin Mönnigmann, Eds., DOI: 10.1016/j.ifacol.2020.12.910, July 2020, pp. 13939-13944. (TR2020-104)

Quirynen, R., Frey, J., Di Cairano, S., **"Active-Set based Inexact Interior Point QP Solver for Model Predictive Control"**, *World Congress of the International Federation of Automatic Control (IFAC)*, Rolf Findeisen, Sandra Hirche, Klaus Janschek, Martin Mönnigmann, Eds., July 2020, pp. 6522-6528. (TR2020-105)

Quirynen, R., Feng, X., Di Cairano, S., **"Inexact Adjoint-based SQP Algorithm for Real-Time Stochastic Nonlinear MPC"**, *World Congress of the International Federation of Automatic Control (IFAC)*, Rolf Findeisen, Sandra Hirche, Klaus Janschek, Martin Mönnigmann, Eds., July 2020, pp. 6529-6535. (TR2020-103)

Steeves, D., Camacho-Solorio, L., Benosman, M., Krstic, M., **"Prescribed–time tracking for triangular systems of reaction–diffusion PDEs"**, *World Congress of the International Federation of Automatic Control (IFAC)*, July 2020. (TR2020-118)

Romero, O., Benosman, M., **"Robust Time-Varying Continuous-Time Optimization with Pre-Defined Finite-Time Stability"**, *World Congress of the International Federation of Automatic Control (IFAC)*, July 2020. (TR2020-120)

Menner, M., Berntorp, K., Di Cairano, S., **"Inverse Learning for Data-driven Calibration of Model-based Statistical Path Planning"**, *Transactions on Intelligent Vehicles*, DOI: 10.1109/TIV.2020.3000323, July 2020. (TR2020-106)

Romeres, D., Liu, Y., Jha, D.K., Nikovski, D.N., **"Understanding Multi-Modal Perception Using Behavioral Cloning for Peg-In-a-Hole Insertion Tasks"**, *Robotics: Science and Systems*, July 2020. (TR2020-110)

Chakrabarty, A., Jha, D.K., Buzzard, G.T., Wang, Y., Vamvoudakis, K., **"Safe Approximate Dynamic Programming via Kernelized Lipschitz Estimation"**, *IEEE Transactions on Neural Networks and Learning Systems*, DOI: 10.1109/TNNLS.2020.2978805, July 2020. (TR2020-108)

Seetharaman, P., Wichern, G., Le Roux, J., Pardo, B., **"Bootstrapping Unsupervised Deep Music Separation from Primitive Auditory Grouping Principles"**, *ICML 2020 Workshop on Self-supervision in Audio and Speech*, July 2020. (TR2020-111)

Tsiligkaridis, A., Zhang, J., Taguchi, H., Nikovski, D.N., **"Personalized Destination Prediction Using Transformers in a Contextless Data Setting"**, *IEEE World Congress on Computational Intelligence (WCCI)*, DOI: 10.1109/IJCNN48605.2020.9207514, July 2020. (TR2020-112)

Liu, D., Chen, S., Boufounos, P.T., **"Graph-Based Array Signal Denoising for Perturbed Synthetic Aperture Radar"**, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, ISBN: 978-1-7281-6374-1, July 2020, pp. 1881-1884. (TR2020-114)

Xu, X., Dhifallah, O., Mansour, H., Boufounos, P.T., Orlik, P.V., **"Robust 3D Tomographic Imaging of the Ionospheric Electron Density"**, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, DOI: 10.1109/IGARSS39084.2020.9324189, July 2020, pp. 437-440. (TR2020-113)

Danielson, C., Berntorp, K., Weiss, A., Di Cairano, S., **"Robust Motion-Planning for Uncertain Systems with Disturbances using the Invariant-Set Motion-Planner"**, *IEEE Transactions on Automatic Control*, DOI: 10.1109/TAC.2020.3008126, Vol. 65, No. 10, pp. 4456-4463, July 2020. (TR2021-038)

Di Cairano, S., Danielson, C., **"Indirect Adaptive Model Predictive Control and its Application to Uncertain Linear Systems"**, *International Journal of Robust and Nonlinear Control*, DOI: 10.1002/rnc.5166, July 2020. (TR2020-115)

Han, M., Ozdenizci, O., Wang, Y., Koike-Akino, T., Erdogmus, D., **"Disentangled Adversarial Transfer Learning for Physiological Biosignals"**, *International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, DOI: 10.1109/EMBC44109.2020.9175233, ISSN: 1558-4615, ISBN: 978-1-7281-1990-8, July 2020. (TR2020-109)

Kim, K.J., Liu, H., Ding, Z., Orlik, P.V., Poor, H.V., **"Diversity Gain Analysis of Distributed CDD Systems in Non-identical Fading Channels"**, *IEEE Transactions on Communications*, DOI: 10.1109/TCOMM.2020.3010995, Vol. 68, No. 11, pp. 7218-7231, July 2020. (TR2021-024)

Guay, M., Benosman, M., **"Finite-time extremum seeking control for a class of unknown static maps"**, *International Journal of Adaptive Control and Signal Processing*, July 2020. (TR2020-117)

Samad, T., Di Cairano, S., Fagiano, L., Odgaard, P., Rhinehart, R., Bortoff, S.A., **"Industry Engagement with Control Research: Perspective and Messages"**, *Annual Reviews In Control*, Vol. 49, pp. 1-14, August 2020. (TR2020-119)

Birch, D.A., Brand, M.E., **"Design of freeforms to uniformly illuminate polygonal targets from extended sources via edge ray mapping"**, *Applied Optics*, DOI: 10.1364/AO.392193, Vol. 59, No. 22, pp. 6490-6496, August 2020. (TR2020-183)

Cherian, A., Chatterjee, M., Ahuja, N., **"Sound2Sight: Generating Visual Dynamics from Sound and Context"**, *European Conference on Computer Vision (ECCV)*, Vedaldi, A., Bischof, H., Brox, Th., Frahm, J.-M., Eds., August 2020. (TR2020-121)

Zhou, L., Wang, Y., **"Improve Speed Estimation for Speed-Sensorless Induction Machines: A Variable Adaptation Gain and Feedforward Approach"**, *International Conference on Electrical Machines (ICEM)*, DOI: 10.1109/ICEM49940.2020.9270821, August 2020, pp. 1150-1156. (TR2020-123)

Wang, Y., Satake, A., Furutani, S., Sano, S., **"Stable Adaptive Estimation for Speed-sensorless Induction Motor Drives: A Geometric Approach"**, *International Conference on Electrical Machines (ICEM)*, DOI: 10.1109/ICEM49940.2020.9270926, August 2020, pp. 1232-1238. (TR2020-122)

Chakrabarty, A., Danielson, C., Wang, Y., **"Data-Driven Optimal Tracking with Constrained Approximate Dynamic Programming for Servomotor Systems"**, *IEEE Conference on Control Technology and Applications* (CCTA), DOI: 10.1109/CCTA41146.2020.9206315, August 2020, pp. 352-357. (TR2020-116)

Greiff, M., Robertsson, A., Berntorp, K., **"MSE-optimal measurement dimension reduction in Gaussian filtering"**, *Conference on Control Technology and Applications (CCTA)*, DOI: 10.1109/CCTA41146.2020.9206162, ISBN: 978-1-7281-7141-8, August 2020. (TR2020-124)

Pishdadian, F., Wichern, G., Le Roux, J., **"Finding Strength in Weakness: Learning to Separate Sounds with Weak Supervision"**, *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, DOI: 10.1109/TASLP.2020.3013105, Vol. 28, pp. 2386-2399, September 2020. (TR2020-126)

Guo, J., Nagai, Y., Sumi, T., Orlik, P.V., Yamauchi, T., **"Hybrid CSMA/CA for Sub-1 GHz Frequency Band Coexistence of IEEE 802.11ah and IEEE 802.15.4g"**, *International Workshop on Informatics (IWIN)*, September 2020. (TR2020-127)

Komatsuszaki, Y., Ma, R., Sakata, S., Nakatani, K., Shinjo, S., **"A Dual-Mode Bias Circuit Enabled GaN Doherty Amplifier Operating in 0.85-2.05GHz and 2.4-4.2GHz"**, *IEICE Society Conference*, September 2020.

Han, M., Ozdenizci, O., Wang, Y., Koike-Akino, T., Erdogmus, D., **"Disentangled Adversarial Autoencoder for Subject-Invariant Physiological Feature Extraction"**, *IEEE Signal Processing Letters*, DOI: 10.1109/LSP.2020.3020215, ISSN: 1558-2361, Vol. 27, pp. 1565-1569, September 2020. (TR2020-128)

Kojima, K., Tang, Y., Koike-Akino, T., Wang, Y., Jha, D.K., Parsons, K., TaherSima, M., Sang, F., Klamkin, J., Qi, M., **"Inverse Design of Nanophotonic Devices using Deep Neural Networks"**, *Asia Communications and Photonics Conference (ACP)*, ISBN: 978-1-943580-82-8, September 2020, pp. Su1A.1. (TR2020-130)

Ioannidis, V.N., Chen, S., Giannakis, G.B., **"Efficient and Stable Graph Scattering Transforms via Pruning"**, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, DOI: 10.1109/TPAMI.2020.3025258, September 2020. (TR2021-018)

Kalabic, U., Chiu, M., **"Cap-and-trade scheme for ridesharing"**, *Intelligent Transportation Systems Conference*, DOI: 10.1109/ITSC45102.2020.9294268, September 2020, pp. 3182-3187. (TR2020-129)

Xia, Y., Wang, P., Berntorp, K., Boufounos, P.T., Orlik, P.V., Svensson, L., Granstrom, K., **"Extended Object Tracking with Automotive Radar Using Learned Structural Measurement Model"**, *IEEE Radar Conference (RadarCon)*, DOI: 10.1109/RadarConf2043947.2020.9266598, ISSN: 2375-5318, ISBN: 978-1-7281-8943-7, September 2020, pp. 1-6. (TR2020-131)

Seetharaman, P., Wichern, G., Pardo, B., Le Roux, J., **"Autoclip: Adaptive Gradient Clipping For Source Separation Networks"**, *IEEE International Workshop on Machine Learning for Signal Processing (MLSP)*, DOI: 10.1109/MLSP49062.2020.9231926, September 2020. (TR2020-132)

Nagai, Y., Sumi, T., Guo, J., Orlik, P.V., Mineno, H., **"Hybrid CSMA/CA for Sub-1 GHz Frequency Band Coexistence of IEEE 802.11ah and IEEE 802.15.4g"**, *Consumer Device System 28th Research Presentation*, September 2020. (TR2020-133)

Quirynen, R., Di Cairano, S., **"PRESAS: Block-Structured Preconditioning of Iterative Solvers within a Primal Active-Set Method for fast MPC"**, *Optimal Control Applications & Methods*, DOI: 10.1002/oca.2652, Vol. 41, No. 6, pp. 2282-2307, September 2020. (TR2020-134)

Tang, Y., Kojima, K., Koike-Akino, T., Wang, Y., Wu, P., TaherSima, M., Jha, D.K., Parsons, K., Qi, M., **"Generative Deep Learning Model for Inverse Design of Integrated Nanophotonic Devices"**, *Lasers and Photonics Reviews*, DOI: 10.1002/lpor.202000287, Vol. 2020, pp. 2000287, October 2020. (TR2020-135)

Manilow, E., Wichern, G., Le Roux, J., **"Hierarchical Musical Instrument Separation"**, *International Society for Music Information Retrieval (ISMIR) Conference*, ISBN: 978-0-9813537-0-8, October 2020, pp. 376-383. (TR2020-136)

Moritz, N., Wichern, G., Hori, T., Le Roux, J., **"All-in-One Transformer: Unifying Speech Recognition, Audio Tagging, and Event Detection"**, *Annual Conference of the International Speech Communication Association (Interspeech)*, DOI: 10.21437/Interspeech.2020-2757, ISSN: 1990-9772, October 2020, pp. 3112-3116. (TR2020-138)

Hori, T., Moritz, N., Hori, C., Le Roux, J., **"Transformer-based Long-context End-to-end Speech Recognition"**, *Annual Conference of the International Speech Communication Association (Interspeech)*, DOI: 10.21437/Interspeech.2020-2928, ISSN: 1990-9772, October 2020, pp. 5011-5015. (TR2020-139)

Jayashankar, T., Le Roux, J., Moulin, P., **"Detecting Audio Attacks on ASR Systems with Dropout Uncertainty"**, *Annual Conference of the International Speech Communication Association (Interspeech)*, DOI: 10.21437/Interspeech.2020-1846, ISSN: 1990-9772, October 2020, pp. 4671-4675. (TR2020-137)

Atalar, O., Millar, D.S., Wang, P., Koike-Akino, T., Kojima, K., Orlik, P.V., Parsons, K., **"Spectrally sparse optical coherence tomography"**, *Optics Express*, DOI: 10.1364/OE.409539, Vol. 28, No. 25, pp. 37798-37810, October 2020. (TR2020-156)

Ota, K., Sasaki, Y., Jha, D.K., Yoshiyasu, Y., Kanezaki, A., **"Efficient Exploration in Constrained Environments with Goal-Oriented Reference Path"**, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, November 2020. (TR2020-141)

Zhang, W., Seto, S., Jha, D.K., **"CAZSL: Zero-Shot Regression for Pushing Models by Generalizing Through Context"**, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, November 2020. (TR2020-140)

Corcodel, R., Jain, S., van Baar, J., **"Interactive Tactile Perception for Classification of Novel Object Instances"**, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, DOI: 10.1109/IROS45743.2020.9341795, November 2020, pp. 9861-9868. (TR2020-143)

Yamashita, G., Tsujita, W., Tsutada, H., Ma, R., Wang, P., Orlik, P.V., **"Evaluation of Position Error of Terahertz Polarimetric Encoder By Ray-Tracing Method"**, *International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, DOI: 10.1109/IRMMW-THz46771.2020.9370683, ISSN: 2162-2035, ISBN: 978-1-7281-6621-6, November 2020, pp. 1-2. (TR2020-145)

Wang, P., Koike-Akino, T., Orlik, P.V., Sertel, K., Yamashita, G., Tsujita, W., Tsutada, H., **"Terahertz QR Positioning: Experimental Results"**, *International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, DOI: 10.1109/IRMMW-THz46771.2020.9370971, ISSN: 2162-2035, ISBN: 978-1-7281-6620-9, November 2020. (TR2020-146)

Ota, K., Jha, D.K., Onishi, T., Kanezaki, A., Yoshiyasu, Y., Mariyama, T., Nikovski, D.N., **"Deep Reactive Planning in Dynamic Environments"**, *Conference on Robot Learning (CoRL)*, November 2020. (TR2020-144)

Sun, H., Shoichi, K., Nikovski, D.N., Mori, K., Hashimoto, H., **"Illegitimate Trade Detection for Electricity Energy Markets"**, *International Conference on Smart Grids and Energy Systems (SGES)*, DOI: doi: 10.110910.1109/SGES51519.2020.00066, November 2020. (TR2020-147)

Wang, B., Hotta, A., **"Contactless Eddy Current Sensing for Carbon Fiber Reinforced Polymer Defect Detection"**, *Biennial IEEE Conference on Electromagnetic Field Computation (CEFC)*, November 2020. (TR2020-148)

Liang, J., Di Cairano, S., Quirynen, R., **"Early Termination of Convex QP Solvers in Mixed-Integer Programming for Real-Time Decision Making"**, *L-CSS with ACC 2021 Option*, DOI: 10.1109/LCSYS.2020.3038677, Vol. 5, No. 4, pp. 1417-1422, November 2020. (TR2020-152)

Liu, D., Sugawara, R., Orlik, P.V., **"EMI reduction in PWM inverters using adaptive frequency modulation carriers"**, *International Conference on Electrical Machines and Systems (ICEMS)*, DOI: 10.23919/ICEMS50442.2020.9291046, ISSN: 2642-5513, November 2020. (TR2020-150)

Zhang, S., Ye, F., Wang, B., Habetler, T.G., **"Few-Shot Bearing Anomaly Detection via Model-Agnostic Meta-Learning"**, *International Conference on Electrical Machines and Systems (ICEMS)*, DOI: 10.23919/ICEMS50442.2020.9291099, November 2020, pp. 1341-1346. (TR2020-151)

Shin, K.-H., Wang, B., **"Semi-Analytical Modeling for Interior Permanent Magnet Synchronous Machines Considering Permeability of Rotor Core"**, *International Conference on Electrical Machines and Systems (ICEMS)*, DOI: 10.23919/ICEMS50442.2020.9291153, November 2020, pp. 19-22. (TR2020-149)

Xiao, D., Sun, H., Nikovski, D.N., Shoichi, K., Mori, K., Hashimoto, H., **"CVaR-constrained Stochastic Bidding Strategy for a Virtual Power Plant with Mobile Energy Storages"**, *IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, DOI: 10.1109/ISGT-Europe47291.2020.9248799, November 2020, pp. 1171-1175. (TR2020-142)

Jones, M.J., Ramachandra, B., Vatsavai, R., **"A Survey of Single-Scene Video Anomaly Detection"**, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, DOI: 10.1109/TPAMI.2020.3040591, November 2020. (TR2021-029)

Talreja, V., Koike-Akino, T., Wang, Y., Millar, D.S., Kojima, K., Parsons, K., **"End-to-End Deep Learning for Phase Noise-Robust Multi-Dimensional Geometric Shaping"**, *European Conference on Optical Communication (ECOC)*, DOI: 10.1109/ECOC48923.2020.9333382, ISBN: 978-1-7281-7361-0, November 2020. (TR2020-155)

Teo, K.H., Chowdhury, N., Zhang, Y., Palacios, T., Yamanaka, K., Yamaguchi, Y., **"Recent Development in 2D and 3D GaN devices for RF and Power Electronics Applications"**, *IEEE International Symposium on Radio-Frequency Integration Technology (RFIT)*, DOI: 10.1109/RFIT49453.2020.9226187, November 2020. (TR2020-162)

Ahn, H., Berntorp, K., Inani, P., Ram, A.J., Di Cairano, S., **"Reachability-based Decision Making for Autonomous Driving: Theory and Experiment"**, *IEEE Transactions on Control Systems Technology*, DOI: 10.1109/TCST.2020.3022721, December 2020. (TR2020-165)

Caverly, R., Di Cairano, S., Weiss, A., **"Electric Satellite Station Keeping, Attitude Control, and Momentum Management by MPC"**, *IEEE Transactions on Control Systems Technology*, DOI: 10.1109/TCST.2020.3014601, ISSN: 1063-6536, Vol. 29, No. 4, pp. 1475-1489, December 2020. (TR2020-153)

Chakrabarty, A., Raghunathan, A., Di Cairano, S., Danielson, C., **"Active Learning for Estimating Reachable Sets for Systems with Unknown Dynamics"**, *IEEE Transactions on Cybernetics*, DOI: 10.1109/TCYB.2020.3000966, December 2020. (TR2020-164)

Lin, C., Sels, D., Ma, Y., Wang, Y., **"Stochastic optimal control formalism for an open quantum system"**, *Physical Review*, DOI: 10.1103/PhysRevA.102.052605, Vol. 102, pp. 052605, December 2020. (TR2020-163)

Li, M., Chen, S., Chen, X., Zhang, Y., Wang, Y., Tian, Q., **"Symbiotic Graph Neural Networks for 3D Skeleton-based Human Action Recognition and Motion Prediction"**, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, December 2020. (TR2020-166)

Yu, J., Wang, P., Koike-Akino, T., Wang, Y., Orlik, P.V., **"Human Pose and Seat Occupancy Classification with Commercial MMWave WiFi"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GCWkshps50303.2020.9367535, ISBN: 978-1-7281-7307-8, December 2020. (TR2020-158)

Kim, K.J., Liu, H., Yeoh, P.L., Orlik, P.V., Poor, H.V., **"Backhaul Reliability Analysis on Cluster-Based Transmit Diversity Schemes in Private Networks"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM42002.2020.9322178, December 2020. (TR2020-170)

Wang, P., Koike-Akino, T., Orlik, P.V., **"Fingerprinting-Based Indoor Localization with Commercial MMWave WiFi: NLOS Propagation"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM42002.2020.9348144, ISSN: 2576-6813, ISBN: 978-1-7281-8298-8, December 2020. (TR2020-159)

Matsumine, T., Koike-Akino, T., Wang, Y., **"Polar Coding with Chemical Reaction Networks for Molecular Communications"**, *IEEE Global Communications Conference (GLOBECOM)*, DOI: 10.1109/GLOBECOM42002.2020.9321980, ISSN: 2576-6813, ISBN: 978-1-7281-8298-8, December 2020. (TR2020-160)

Bortoff, S.A., Okasha, A., **"Modelica-Based Control of A Delta Robot"**, *ASME Dynamic Systems and Control Conference*, DOI: doi.org/10.1115/DSCC2020-3158, December 2020. (TR2020-154)

Greiff, M., Robertsson, A., Berntorp, K., **"Exploiting linear substructure in linear regression Kalman filters"**, *IEEE Annual Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC42340.2020.9304191, December 2020. (TR2020-171)

Aguilar Marsillach, D., Di Cairano, S., Weiss, A., **"Abort-Safe Spacecraft Rendezvous in case of Partial Thrust Failure"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC42340.2020.9303782, December 2020, pp. 1490-1495. (TR2020-175)

Ahn, H., Berntorp, K., Di Cairano, S., **"Cooperating Modular Goal Selection and Motion Planning for Autonomous Driving"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC42340.2020.9304101, December 2020. (TR2020-168)

Laftchiev, E., Yan, Q., Nikovski, D.N., **"The Missing Input Problem"**, *IEEE Big Data*, DOI: 10.1109/BigData50022.2020.9378144, December 2020, pp. 1565-1573. (TR2020-172)

Nowara, E., Marks, T.K., Mansour, H., Veeraraghavan, A., **"Near-Infrared Imaging Photoplethysmography During Driving"**, *IEEE Transactions on Intelligent Transportation Systems*, DOI: 10.1109/TITS.2020.3038317, pp. 1-12, December 2020. (TR2020-161)

Romeres, D., Dalla Libera, A., Amadio, F., Carli, R., **"Feedback Linearization Robot Control based on Gaussian Process Inverse Dynamics Model"**, *Conferenza Italiana di Robotica e Macchine Intelligenti*, December 2020. (TR2020-173)

Romeres, D., Amadio, F., Dalla Libera, A., Nikovski, D.N., Carli, R., **"Model-based Policy Search for Partially Measurable Systems"**, *Advances in Neural Information Processing Systems (NeurIPS)*, December 2020. (TR2020-174)

Anantharaman, R., Ma, Y., Gowda, S., Laughman, C.R., Shah, V., Edelman, A., Rackauckas, C., **"Accelerating Simulation of Stiff Nonlinear Systems using Continuous-Time Echo State Networks"**, *Advances in Neural Information Processing Systems (NeurIPS)*, December 2020. (TR2020-169)

Li, M., Chen, S., Zhang, Y., **"Graph Cross Networks with Vertex Infomax Pooling"**, *Advances in Neural Information Processing Systems (NeurIPS)*, December 2020. (TR2020-167)

Goukhshtein, M., Boufounos, P.T., Koike-Akino, T., Draper, S.C., **"Distributed Coding of Quantized Random Projections"**, *IEEE Transactions on Signal Processing*, DOI: 10.1109/TSP.2020.3029499, ISSN: 1941-0476, Vol. 68, pp. 5924-5939, December 2020. (TR2020-157)

Kalur, A., Benosman, M., Nabi, S., **"Adaptive-Robust Dynamic Mode Decomposition for Reduced-Order Modeling and Control"**, *American Physical Society, Division of Fluid Dynamics*, December 2020.

Kim, K.J., Liu, H., Lei, H., Ding, Z., Orlik, P.V., Poor, H.V., **"A dCDD-Based Transmit Diversity Scheme for Downlink Pseudo-NOMA Systems"**, *IEEE Transactions on Wireless Communications*, DOI: 10.1109/TWC.2020.3031809, Vol. 20, No. 2, pp. 1217-1232, December 2020. (TR2020-176)

Poveda, J., Benosman, M., Vamvoudakis, K., **"Data-Enabled Extremum Seeking: A Cooperative Concurrent Learning-Based Approach"**, *International Journal of Adaptive Control and Signal Processing*, December 2020. (TR2020-180)

Jha, D.K., Wang, Y., Zhu, M., **"Sampling-based Algorithms for Feedback Motion Planning"**, *IEEE/CAA Journal of Automatica Sinica*, December 2020.

Serra, T., Huang, T., Raghunathan, A., Bergman, D., **"Template-based Minor Embedding for Adiabatic Quantum Optimization"**, *INFORMS Journal on Computing*, DOI: 10.1287/ijoc.2021.1065, December 2020. (TR2020-181)

Benosman, M., Borggaard, J., **"Data-Driven Robust State Estimation for Reduced-Order Models of 2D Boussinesq Equations with Parametric Uncertainties"**, *Journal of Computers and Fluids*, December 2020. (TR2020-177)

Nohra, C.J., Raghunathan, A., Sahinidis, N.V., **"Spectral relaxations and branching strategies for global optimization of mixed-integer quadratic programs"**, *SIAM Journal on Optimization*, DOI: 10.1137/19M1271762, Vol. 31, No. 1, pp. 142–171, December 2020. (TR2020-178)

Anirudh, R., Lohit, S., Turaga, P., **"Generative Patch Priors for Practical Compressive Image Recovery"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, January 2021. (TR2021-003)

Lohit, S., Anirudh, R., Turaga, P., **"Recovering Trajectories of Unmarked Joints in 3D Human Actions Using Latent Space Optimization"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, January 2021. (TR2021-004)

Zhang, S., Ye, F., Wang, B., Habetler, T.G., **"Semi-Supervised Bearing Fault Diagnosis and Classification using Variational Autoencoder-Based Deep Generative Models"**, *IEEE Sensors Journal*, DOI: 10.1109/JSEN.2020.3040696, Vol. 21, No. 5, pp. 6476-6486, January 2021. (TR2021-002)

Hayashi, N., Weiss, A., Di Cairano, S., **"Model Predictive Control Approach for Autonomous Sun-Synchronous Sub-Recurrent Orbit Control"**, *AIAA SciTech*, DOI: 10.2514/6.2021-1953, January 2021. (TR2021-005)

Chen, D., Danielson, C., Masahiro, I., **"Improving Passenger Comfort by Exploiting Hub Motors in Electric Vehicles: Suspension Modeling"**, *ASME Dynamic Systems and Control Conference (DSCC)*, DOI: 10.1115/DSCC2020-3167, January 2021. (TR2021-019)

Kojima, K., TaherSima, M., Koike-Akino, T., Jha, D.K., Tang, Y., Wang, Y., Parsons, K., **"Deep Neural Networks for Inverse Design of Nanophotonic Devices"**, *IEEE Journal of Lightwave Technology*, DOI: 10.1109/JLT.2021.3050083, ISSN: 1558-2213, January 2021. (TR2021-001)

Sumi, T., Nagai, Y., Guo, J., Orlik, P.V., Yokoyama, T., Mineno, H., **"Sub-1 GHz Coexistence Using Reinforcement Learning based IEEE 802.11ah RAW scheduling"**, *Information Processing Society Japan / 30th Consumer Devices & Systems Conference*, January 2021.

Russel, R.H., Benosman, M., van Baar, J., **"Robust Constrained-MDPs: Soft-Constrained Robust Policy Optimization under Model Uncertainty"**, *Advances in Neural Information Processing Systems (NeurIPS)-workshop*, January 2021. (TR2021-009)

Li, S., Mansour, H., Wakin, M., **"Recovery Analysis of Damped Spectrally Sparse Signals and Its Relation to MUSIC"**, *Information and Inference: A Journal of the IMA*, DOI: 10.1093/imaiai/iaaa024, ISSN: 2049-8772, January 2021. (TR2021-008)

Geng, S., Gao, P., Chatterjee, M., Hori, C., Le Roux, J., Zhang, Y., Li, H., Cherian, A., **"Dynamic Graph Representation Learning for Video Dialog via Multi-Modal Shuffled Transformers"**, *AAAI Conference on Artificial Intelligence*, ISBN: 978-1-57735-866-4, February 2021, pp. 1415-1423. (TR2021-010)

Skvortcov, P., Phillips, I., Forysiak, W., Koike-Akino, T., Kojima, K., Parsons, K., Millar, D.S., **"Huffman-Coded Sphere Shaping for Extended-Reach Single-Span Links"**, *IEEE Journal of Selected Topics in Quantum Electronics*, DOI: 10.1109/JSTQE.2021.3055476, ISSN: 1558-4542, Vol. 27, No. 3, February 2021. (TR2021-007)

Xia, Y., Wang, P., Berntorp, K., Svensson, L., Granstrom, K., Mansour, H., Boufounos, P.T., Orlik, P.V., **"Learning-based Extended Object Tracking Using Hierarchical Truncation Measurement Model with Automotive Radar"**, *IEEE Journal of Selected Topics in Signal Processing*, DOI: 10.1109/JSTSP.2021.3058062, ISSN: 1941-0484, Vol. 15, No. 4, pp. 1013-1029, February 2021. (TR2021-006)

Chiu, M., Kalabic, U., **"Short Paper: Debt Representation in UTXO Blockchains"**, *Financial Cryptography and Data Security*, Borisov, Nikita and Diaz, Claudia, Eds., DOI: 10.1007/978-3-662-64331-0_3, February 2021, pp. 57-64. (TR2021-014)

Kojima, K., Tang, Y., Koike-Akino, T., Wang, Y., Jha, D.K., TaherSima, M., Parsons, K., **"Application of Deep Learning for Nanophotonic Device Design"**, *SPIE Photonics West*, Bahram Jalali and Ken-ichi Kitayama, Eds., DOI: 10.1117/12.2579104, March 2021. (TR2020-182)

Demir, A., Koike-Akino, T., Wang, Y., Erdogmus, D., **"AutoBayes: Automated Bayesian Graph Exploration for Nuisance-Robust Inference"**, *IEEE Access*, DOI: 10.1109/ACCESS.2021.3064530, ISSN: 2169-3536, Vol. 9, pp. 39955-39972, March 2021. (TR2021-016)

Ramachandra, B., Jones, M.J., Vatsavai, R., **"Perceptual Metric Learning for Video Anomaly Detection"**, *Machine Vision and Applications*, DOI: 0.1007/s00138-021-01187-5, Vol. 32, No. 63, March 2021. (TR2021-028)

Wen, M., Lin, S., Kim, K.J., Li, F., **"Cyclic Delay Diversity with Index Modulation for Green Internet of Things"**, *IEEE Transactions on Green Communications and Networking*, DOI: 10.1109/TGCN.2021.3067705, Vol. 5, No. 2, pp. 600-610, March 2021. (TR2021-077)

Anantharaman, R., Ma, Y., Gowda, S., Laughman, C.R., Shah, V., Edelman, A., Rackauckas, C., **"Accelerating Simulation of Stiff Nonlinear Systems using Continuous-Time Echo State Networks"**, *AAAI Spring Symposium on Combining Artificial Intelligence with Physical Sciences*, March 2021. (TR2021-021)

Ota, K., Jha, D.K., Romeres, D., van Baar, J., Smith, K., Semistsu, T., Oiki, T., Sullivan, A., Nikovski, D.N., Tenanbaum, J., **"Data-Efficient Learning for Complex and Real-Time Physical Problem Solving using Augmented Simulation"**, *IEEE Robotics and Automation Letters*, DOI: 10.1109/LRA.2021.3068887, Vol. 6, No. 2, March 2021. (TR2021-032)

Kadu, A., Mansour, H., Boufounos, P.T., **"High-Contrast Reflection Tomography with Total-Variation Constraints"**, *IEEE Transactions on Computational Imaging*, DOI: 10.1109/TCI.2020.3038171, Vol. 6, pp. 1523-1536, March 2021. (TR2021-013)

Bergman, D., Huang, T., Brooks, P., Lodi, A., Raghunathan, A., **"JANOS: An Integrated Predictive and Prescriptive Modeling Framework"**, *INFORMS Journal on Computing*, DOI: 10.1287/ijoc.2020.1023, March 2021.

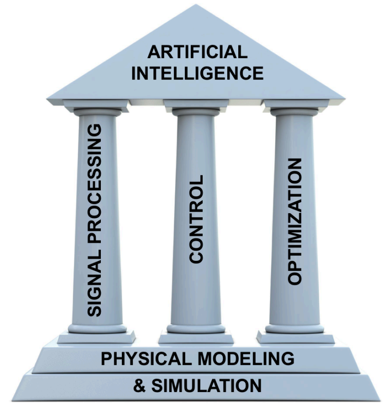
Sanz-Gorrachategui, I., Pastor-Flores, P., Pajovic, M., Wang, Y., Orlik, P.V., Bernal-Ruiz, C., Bono-Nuez, A., Artal-Sevil, J.S., **"Remaining Useful Life Estimation for LFP Cells in Second Life Applications"**, *IEEE Transactions on Instrumentation and Measurement*, DOI: 10.1109/TIM.2021.3055791, ISSN: 1557-9662, Vol. 70, pp. 1-10, March 2021. (TR2021-023)

Poveda, J., Benosman, M., Teel, A.R., Sanfelice, R.G., **"Robust Coordinated Hybrid Source Seeking with Obstacle Avoidance in Multi-Vehicle Autonomous Systems"**, *IEEE Transactions on Automatic Control*, DOI: 10.1109/TAC.2021.3056365, March 2021. (TR2021-022)

Haruna, M., Ogino, M., Koike-Akino, T., **"Comparison of Three Feedback Modalities for Haptics Sensation in Remote Machine Manipulation"**, *IEEE Robotics and Automation Letters*, DOI: 10.1109/LRA.2021.3070301, ISSN: 2377-3766, Vol. 6, No. 3, pp. 5040-5047, March 2021. (TR2021-031)

Berntorp, K., **"Online Bayesian Inference and Learning of Gaussian-Process State-SpaceModels"**, *Automatica*, DOI: 10.1016/j.automatica.2021.109613, ISSN: 0005-1098, Vol. 129, March 2021. (TR2021-026)

# 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 research on modeling, simulation, and model-based design of dynamic systems, advanced machines and devices. This research serves as a foundation for and is integrated with 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 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 and motor drive systems; motion control; energy systems; advanced assembly lines in factories; and digital twin systems for zero-energy buildings and factory automation.

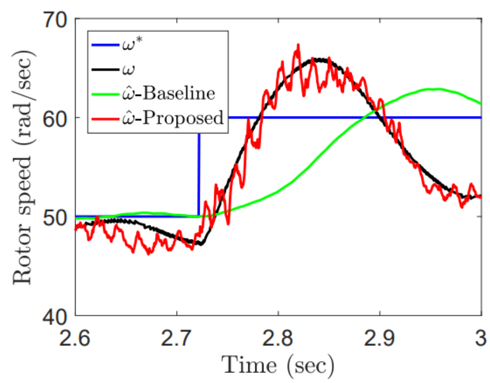
## Recent Research

## Stable Adaptive Estimation for Speed-Sensor-Less Induction Motor Drives: A Geometric Approach

Citation: Wang, Y., Satake, A., Furutani, S., Sano, S., "Stable Adaptive Estimation for Speed-sensorless Induction Motor Drives: A Geometric Approach", International Conference on Electrical Machines (ICEM), August 2020, pp. 1232-1238.

Contacts: Yebin Wang

Rotor speed estimation is one of the key problems in speed-sensorless motor drives. Adaptation-based approaches, assuming the rotor speed as a parameter and based on the original coordinates allow simple estimator designs, but suffer from the lack of guaranteed convergence of estimation error dynamics. Focusing on stable speed estimation, this paper proposes a new algorithm based on transforming the motor model into an adaptive observer form via a change of state coordinates. The resultant adaptive estimator has globally exponentially convergent estimation error dynamics, under persistent excitation conditions. The proposed algorithm is advantageous for its guaranteed stability, ease of tuning, and robustness.

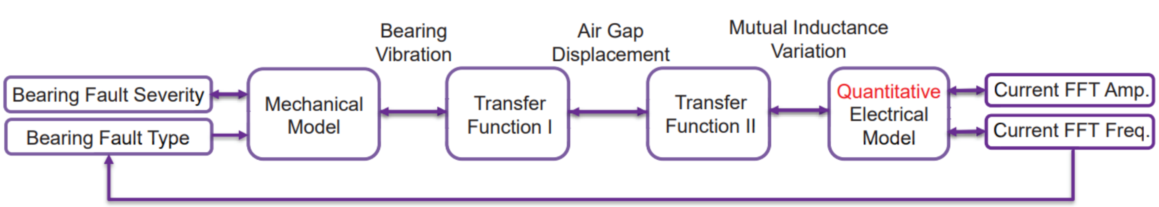



(a) Baseline-in-the-loop, $K_\omega^P = 2.5$

## Model-Based Analysis and Quantification of Bearing Faults in Induction Machines

Citation: Zhang, S., Wang, B., Kanemaru, M., Lin, C., Liu, D., Habetler, T., "Model-Based Analysis and Quantification of Bearing Faults in Induction Machines", IEEE Transactions on Industry Applications, Vol. 56, No. 3, pp. 2158-2170, May 2020.

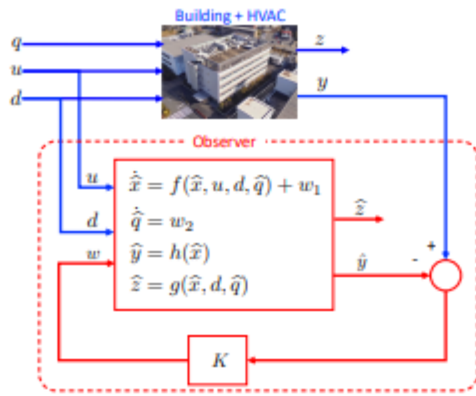
Contacts: Bingnan Wang, Chungwei Lin, Dehong Liu




The detection of rolling-element bearing fault can be accomplished by monitoring and interpreting a variety of signals, including the vibration, the acoustic noise, and the stator current. This paper proposes a quantitative approach to estimate the bearing fault severity based on the air gap displacement profile, which is reconstructed from the mutual inductance variation profile estimated from a quantitative electrical model that takes the stator current as input. The proposed method offers a quantitative and universal bearing fault indicator for induction machines with any power rating and operating under any speed and load condition.

## An Extended Luenberger Observer for HVAC Application using FMI

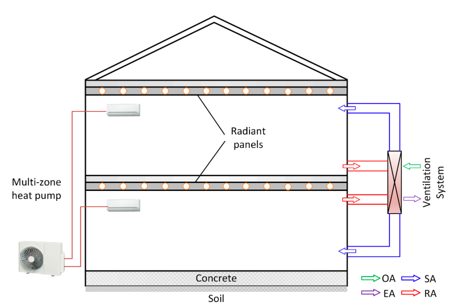
Citation: Bortoff, S.A.; Laughman, C.R., "An Extended Luenberger Observer for HVAC Application using FMI", *International Modelica Conference*, March 2019
Contacts: Scott A. Bortoff, Christopher R. Laughman




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, September 2019.
Contacts: Chris Laughman, Scott Bortoff

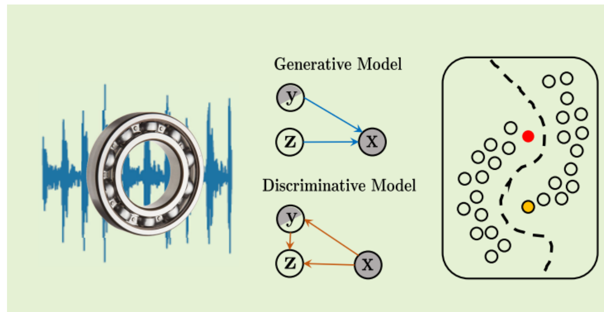



The variety of ventilation requirements, thermal comfort specifications, and lower cooling loads for high-performance buildings can motivate the use of multiple HVAC systems whose dynamic interactions can strongly affect performance. We develop a Modelica energy model of a multi-zone residential building, 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.

## Semi-Supervised Bearing Fault Diagnosis and Classification using Variational Autoencoder-Based Deep Generative Models

Citation: Zhang, S., Ye, F., Wang, B., Habetler, T.G., "Semi-Supervised Bearing Fault Diagnosis and Classification using Variational Autoencoder-Based Deep Generative Models", IEEE Sensors Journal, Vol. 21, No. 5, pp. 6476-6486, January 2021.

Contacts: Bingnan Wang

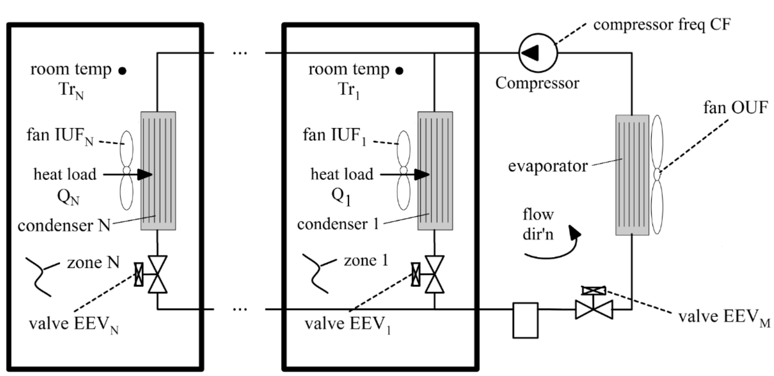



Although many data-driven methods have been applied to bearing fault diagnosis, most of them belong to the supervised learning paradigm that requires a large amount of labeled training data to be collected in advance. We thus propose a semi-supervised learning scheme for bearing fault diagnosis using Variational AutoEncoder (VAE)-based deep generative models, which can effectively utilize a dataset when only a small subset of data have labels. Experimental results show that the proposed semi-supervised learning schemesoutperforms some mainstream supervised and semi-supervised benchmarks.

## 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), December 2019, pp. 2952-2957.

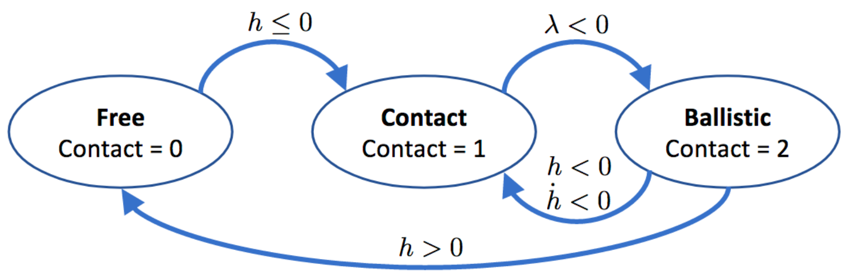
Contacts: Scott Bortoff, Stefano Di Cairano




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

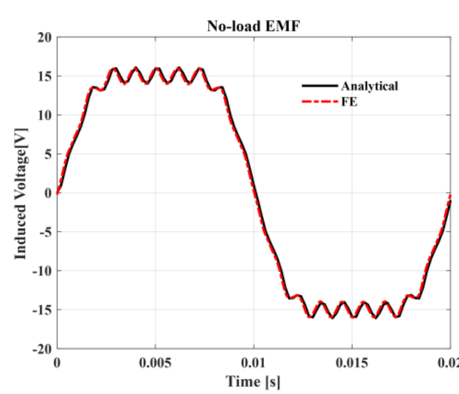



We propose an implicit, event-driven, penalty-based method for modeling rigid body contact and collision that is useful for design and analysis of control algorithms for precision robotic assembly tasks. The method is based on Baumgarte's method of differential algebraic equation index reduction in which 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.

## Semi-Analytical Modeling for Interior Permanent Magnet Synchronous Machines Considering Permeability of Rotor Core

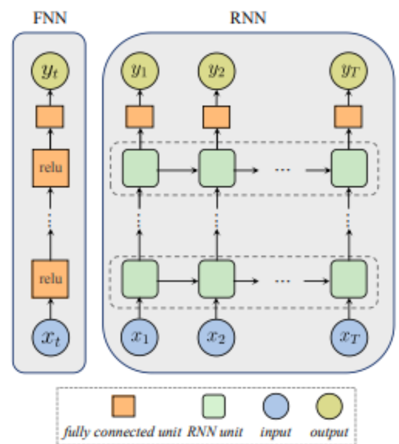
Citation: Shin, K.-H., Wang, B., "Semi-Analytical Modeling for Interior Permanent Magnet Synchronous Machines Considering Permeability of Rotor Core", International Conference on Electrical Machines and Systems (ICEMS), November 2020, pp. 19-22.
Contacts: Bingnan Wang

This paper proposes an improved semi-analytical model based on subdomain methods for the performance analysis of an interior permanent magnet synchronous machine. In particular, the pole-piece and the bridge region of the rotor were modeled with finite permeability. This enables the calculation of the magnetic field in the core region to account for the saturation effect, and improves the accuracy of the motor electromagnetic performance calculation



## Learning Dynamical Demand Response Model in Real-Time Pricing Program

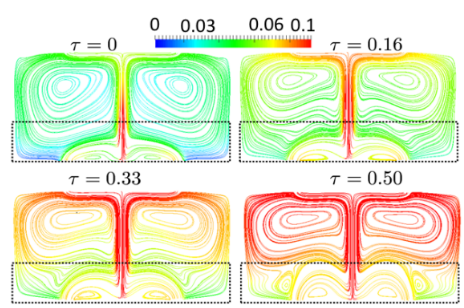
Citation: Xu, H.; Sun, H.; Nikovski, D.N.; Shoichi, K.; Mori, K., "Learning Dynamical Demand Response Model in Real-Time Pricing Program", IEEE ISGT, February 2019.
Contacts: Hongbo Sun, Daniel N. Nikovski




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.

## Nonlinear Optimal Control Strategies for Buoyancy-Driven Flows in the Built Environment

Citation: Nabi, S., Grover, P., Caulfield, C., "Nonlinear Optimal Control Strategies for Buoyancy-Driven Flows in the Built Environment", Journal of Computers and Fluids, Vol. 194, No. 104313, December 2019.
Contacts: Saleh Nabi

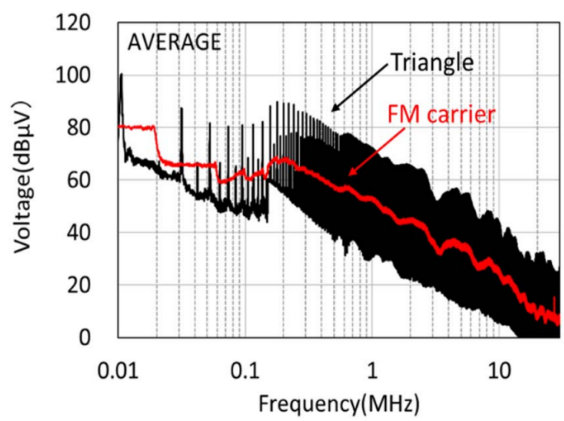



We consider the problem of optimally controlling turbulent buoyancy-driven flows in the built environment, focusing on a model test case of displacement ventilation with a time-varying heat source. The flow is modeled using the unsteady Reynolds-averaged equations (URANS). A direct-adjoint-looping implementation of the nonlinear optimal control problem yields time-varying values of temperature and velocity of the inlet flow that lead to 'optimal' time-averaged temperature relative to appropriate objective functionals in a region of interest. The resulting dynamics of both 'filling' and 'intruding' added layers due to a time-varying source and inlet flow are discussed. The robustness of the optimal solution is demonstrated.

# EMI Reduction in PWM Inverters Using Adaptive Frequency Modulation Carriers

Citation: Liu, D., Sugawara, R., Orlik, P.V., "EMI reduction in PWM inverters using adaptive frequency modulation carriers", International Conference on Electrical Machines and Systems (ICEMS), November 2020.

Contacts: Dehong Liu, Philip V. Orlik

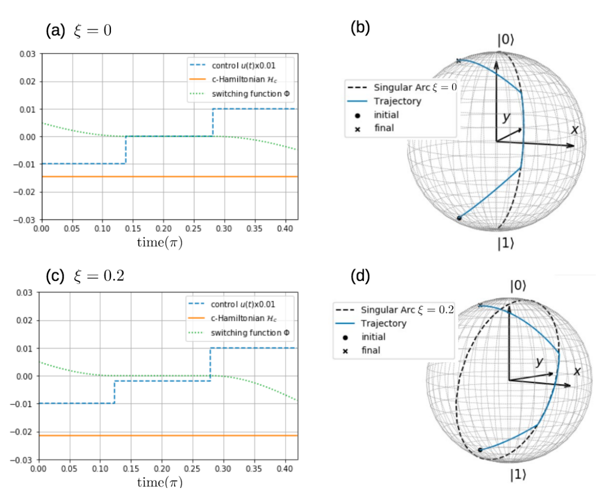



We propose deterministic carrier frequency modulation (FM) techniques instead of random carrier frequency modulation (RCFM) to reduce EMI of carrier harmonics in PWM inverters. In particular, we first propose a linear frequency modulation (LFM) method to spread the carrier harmonic energy out in a certain frequency range. Second, considering the characteristic of EMI propagation from the EMI source to the victim under test, we propose a nonlinear frequency modulation (NFM) method to adaptively modulate the carrier frequency based on the EMI spectrum received by the victim such that the influence of propagation path can be properly compensated. Consequently the EMI spectrum received by the victim is flattened and the carrier harmonic EMI level is reduced. Simulation and experimental results validate our EMI reduction scheme using deterministic carrier frequency modulations.

# Time-optimal Control of a Dissipative Qubit

Citation: Lin, C., Sels, D., Wang, Y., "Time-optimal Control of a Dissipative Qubit", Physical Review, Vol. 101, No. 2, pp. 022320, February 2020.

Contacts: Chungwei Lin, Yebin Wang

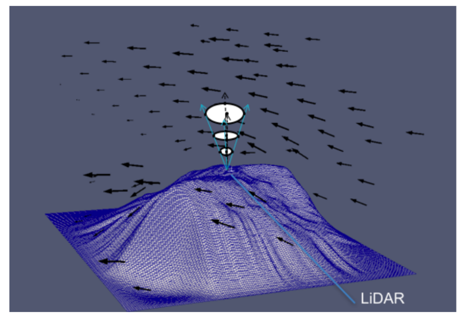



A formalism based on Pontryagin's maximum principle is applied to determine the time-optimal protocol that drives a general initial state to a target state by a Hamiltonian with limited control, i.e., there is a single control field with bounded amplitude. The coupling between the bath and the qubit 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, Vol. 1452, November 2019.

Contacts: Saleh Nabi

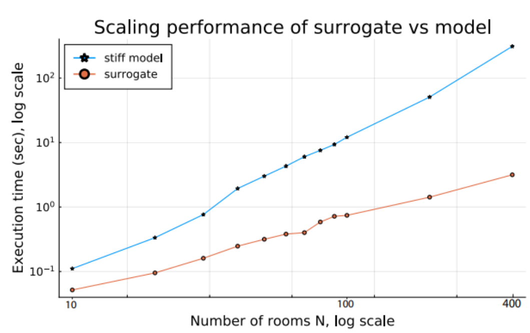



Naive estimation of horizontal wind velocity over complex terrain using measurements from a single wind-LiDAR introduces a bias due to the assumption of uniform velocity in any horizontal plane. While Computational Fluid Dynamics (CFD)-based methods have been proposed for bias removal, several issues 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).

## Accelerating Simulation of Stiff Nonlinear Systems using Continuous-Time Echo State Networks

Citation: Anantharaman, R., Ma, Y., Gowda, S., Laughman, C.R., Shah, V., Edelman, A., Rackauckas, C., "Accelerating Simulation of Stiff Nonlinear Systems using Continuous-Time Echo State Networks", AAAI Spring Symposium on Combining Artificial Intelligence with Physical Sciences, March 2021.

Contacts: Christopher R. Laughman




Modern design, control, and optimization often require multiple expensive simulations of highly nonlinear stiff models. These costs can be amortized by training a cheap surrogate of the full model, which can then be used repeatedly. Here we present a general data-driven method, the continuous-time echo state network (CTESN), for generating surrogates of nonlinear ordinary differential equations with dynamics at widely separated timescales. We empirically demonstrate the ability to accelerate a physically motivated scalable model of a heating system by 98x while maintaining relative error of within 0.2 %.We showcase the ability for this surrogate to accurately handle highly stiff systems which have been shown to cause training failures with common surrogate methods. We show that our model captures fast transients as well as slow dynamics.

# 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, smart metering, 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.

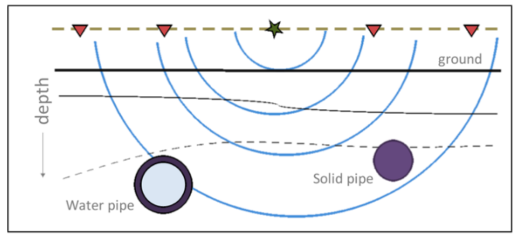
Research topics focus on exploiting widely available computational power to overhaul the signal acquisition and significantly enhance sensing capabilities, improve inference systems that seek to understand signal propagation and behavior, and develop novel communications/networking/IoT algorithms for 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), May 2019.

Contacts: Hassan Mansour, Petros Boufounos, Dehong Liu

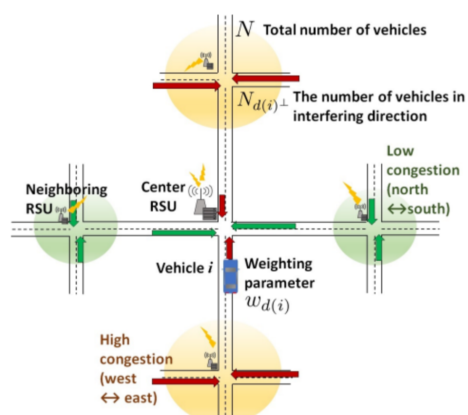



Reflection tomography is an inverse scattering technique that estimates the spatial distribution of an object's permittivity by illuminating it with a probing pulse and measuring the scattered wavefields by receivers located on the same side as the transmitter. Unlike conventional transmission tomography, 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.

## Edge Computing for Interconnected Intersections in Internet of Vehicles

Citation: Lee, G., Guo, J., Kim, K.J., Orlik, P.V., Ahn, H., Di Cairano, S., Saad, W., "Edge Computing for Interconnected Intersections in Internet of Vehicles", IEEE Intelligent Vehicles Symposium, June 2020, pp. 209-215.

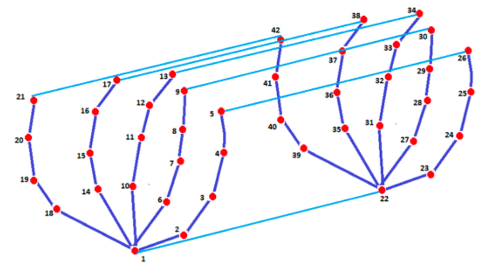
Contacts: Jianlin Guo, Kyeong Jin (K.J.) Kim, Philip V. Orlik, Stefano Di Cairano




To improve the traffic flow in the interconnected intersections, the vehicles and infrastructure such as road side units (RSUs) need to collaboratively determine vehicle scheduling while exchanging information via vehicle-to-everything (V2X) communications. An edge computing framework is proposed to solve a travel time minimization problem at the interconnected intersections. The proposed framework enables each RSU to decide intersection scheduling while the vehicles individually determine travel trajectory by controlling their dynamics. Simulation results show that the proposed edge computing can successfully reduce total travel time by up to 14% based on optimal scheduling for the interconnected intersections.

## Hand Graph Representations for Unsupervised Segmentation of Complex Activities

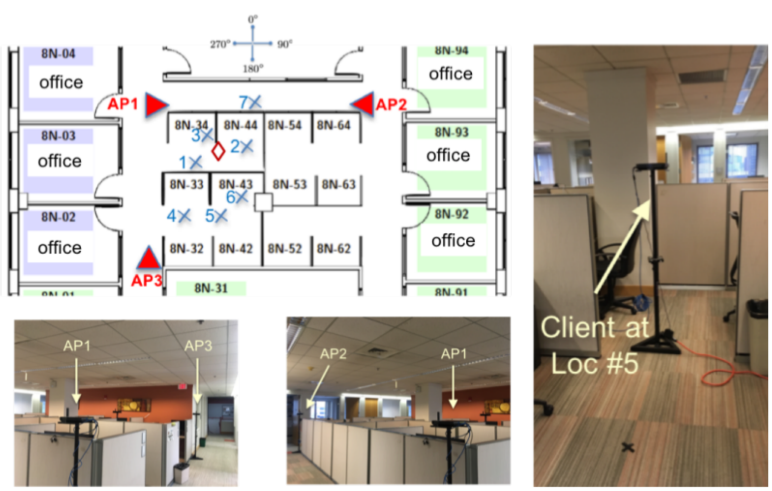
Citation: Das, P., Kao, J.-Y., Ortega, A., Mansour, H., Vetro, A., Sawada, T., Minezawa, A., "Hand Graph Representations for Unsupervised Segmentation of Complex Activities", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), May 2019.
Contacts: Hassan Mansour, Anthony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

Citation: Koike-Akino, T., Wang, P., Pajovic, M., Sun, H., Orlik, P.V., "Fingerprinting-Based Indoor Localization with Commercial MMWave WiFi: A Deep Learning Approach", IEEE Access, April 2020.
Contacts: Toshiaki Koike-Akino, Pu Wang, Philip V. Orlik

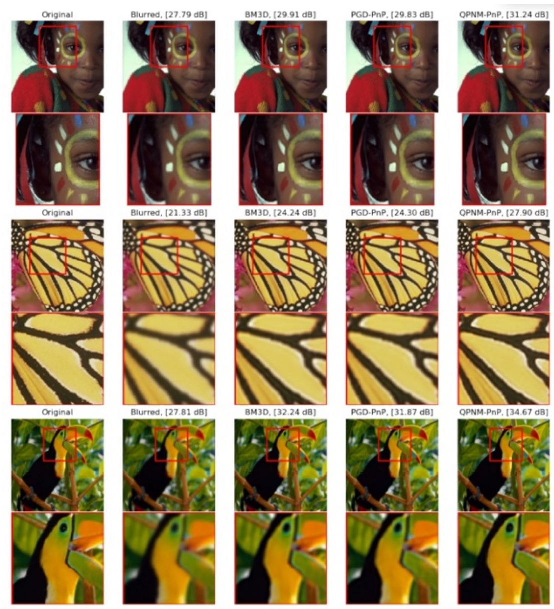



Existing fingerprint-based indoor localization uses either fine-grained channel state information (CSI) from the physical layer or coarse-grained received signal strength indicator (RSSI) measurements. We propose to use a mid-grained intermediate-level channel measurement (spatial beam signal-to-noise ratios (SNRs) that are inherently available and defined in the IEEE 802.11ad/ay standards) to construct the fingerprinting database. These intermediate channel measurements are further utilized by a deep learning approach for multiple purposes: 1) location-only classification; 2) simultaneous locationand orientation classification; and 3) direct coordinate estimation.

## Learning Plug-and-Play Proximal Quasi-Newton Denoisers

Citation: Al-Shabili, A., Mansour, H., Boufounos, P.T., "Learning Plug-and-Play Proximal Quasi-Newton Denoisers", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), April 2020, pp. 8896-8900.

Contacts: Hassan Mansour, Petros T. Boufounos



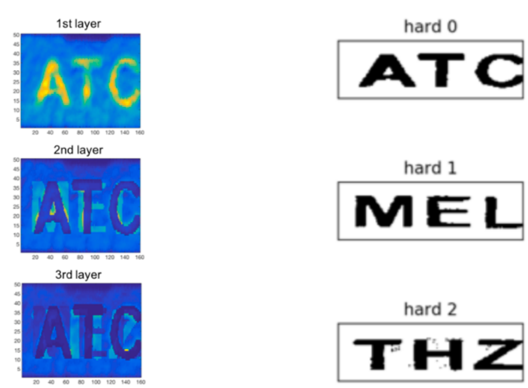

Plug-and-play (PnP) denoising for solving inverse problems has received significant attention recently thanks to its state of the art signal reconstruction performance. However, the performance improvement hinges on carefully choosing the noise level of the Gaussian denoiser and the descent step size in every iteration. We propose a strategy for training a Gaussian denoiser inspired by an unfolded proximal quasi-Newton algorithm, where the noise level of the input signal to the denoiser is estimated in each iteration and at every entry in the signal. Our scheme deploys a small convolutional neural network (mini-CNN) to estimate an element-wise noise level, mimicking a diagonal approximation of the Hessian matrix in quasi-Newton methods. Empirical simulation results on image deblurring demonstrate that our proposed approach achieves approximately 1dB improvement over state of the art methods.

## 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), September 2019.

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

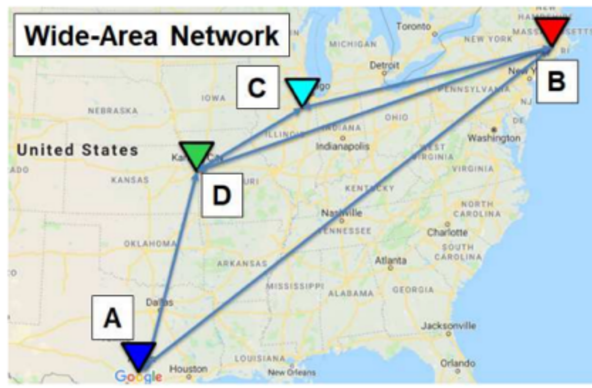
This paper proposes a learning-based approach to mitigate the shadow effect in the pixel domain for Terahertz Time-Domain Spectroscopy (THz-TDS) multi-layer imaging. Compared with model-based approaches, this learning-based approach requires no prior knowledge of material properties of the sample. Preliminary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



## Artificial Intelligence-Based Distributed Belief Propagation and Recurrent Neural Network Algorithm for Wide-Area Monitoring Systems

Citation: Bhamidipati, S., Kim, K.J., Sun, H., Orlik, P.V., "Artificial Intelligence-Based Distributed Belief Propagation and Recurrent Neural Network Algorithm for Wide-Area Monitoring Systems", IEEE Network, Vol. 34, No. 3, pp. 64-72, May 2020.

Contacts: Kyeong Jin (K.J.) Kim, Hongbo Sun, Philip V. Orlik

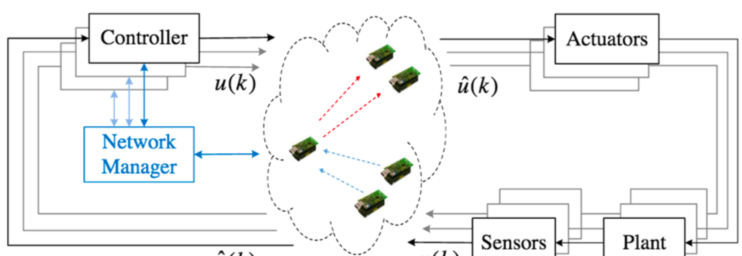



A Wide-area monitoring systems (WAMS) for power grids depends on Global Positioning System (GPS) receivers at each location to provide trusted timing. Unfortunately, GPS timing is susceptible to spoofing due to its unencrypted signal structure and low signal power. To obtain trusted GPS timing, we have developed a new wide-area monitoring algorithm, which uses distributed belief propagation (BP) and a bi-directional recurrent neural network (RNN). This joint BP-RNN algorithm authenticates the time at each power substation by evaluating the estimated GPS timing error through its distributed processing capability.

## 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), , May 2019, pp. 77-86.

Contacts: Jianlin Guo, Yebin Wang

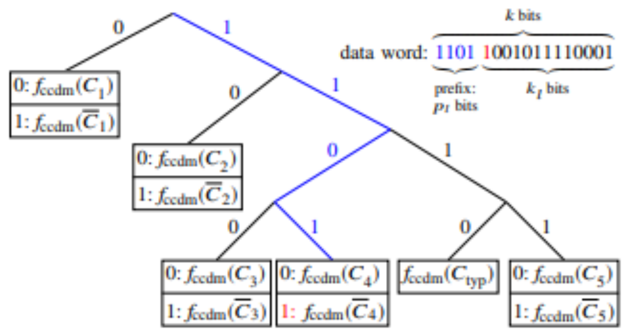



Wireless networked control system is gaining momentum in industrial cyber-physical systems, e.g., smart factory. Suffering from limited bandwidth and nondeterministic link quality, a critical challenge in its deployment is how to optimize the closed-loop control system performance as well as maintain 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.

## 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*, December 2018.

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

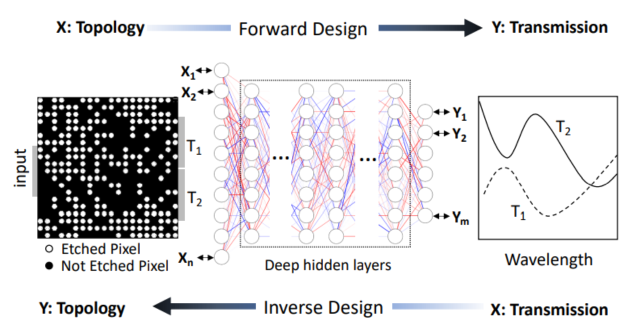



Distribution matching is a fixed-length invertible mapping from a uniformly distributed bit sequence to shaped amplitudes and plays an important role in the probabilistic amplitude shaping framework. With conventional constant composition distribution matching (CCDM), all output sequences have identical 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).

## Deep Neural Networks for Inverse Design of Nanophotonic Devices

Citation: Kojima, K., TaherSima, M., Koike-Akino, T., Jha, D.K., Tang, Y., Wang, Y., Parsons, K., "Deep Neural Networks for Inverse Design of Nanophotonic Devices", IEEE Journal of Lightwave Technology, January 2021.

Contacts: Keisuke Kojima, Toshiaki Koike-Akino, Devesh K. Jha, Ye Wang, Kieran Parsons

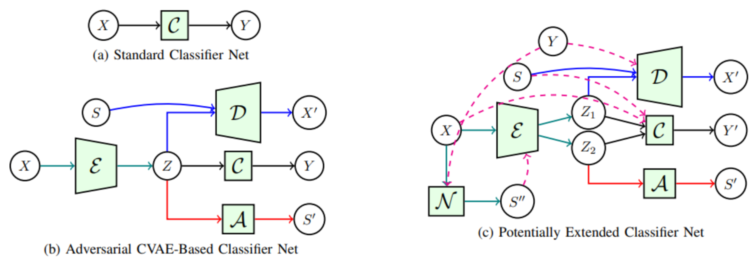



Deep learning is now playing a major role in designing photonic devices, including nanostructured photonics. In this paper, we investigate three models for designing nanophonic power splitters with multiple splitting ratios. The first model is a forward regression model, wherein the trained deep neural network (DNN) is used within the optimization loop. The second is an inverse regression model, in which the trained DNN constructs a structure with the desired target performance given as input. The third model is a generative network, which can randomly produce a series of optimized designs for a target performance. Focusing on the nanophotonic power splitters, we show how the devices can be designed by these three types of DNN models.

## AutoBayes: Automated Bayesian Graph Exploration for Nuisance-Robust Inference

Citation: Demir, A., Koike-Akino, T., Wang, Y., Erdogmus, D., "AutoBayes: Automated Bayesian Graph Exploration for Nuisance-Robust Inference", IEEE Access, Vol. 9, pp. 39955-39972, March 2021.

Contacts: Toshiaki Koike-Akino, Ye Wang

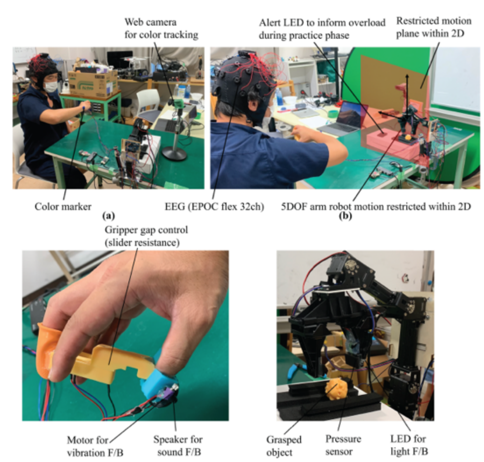



Learning data representations that capture task-related features, but are invariant to nuisance variations remains a key challenge in machine learning. We introduce an automated Bayesian inference framework, called AutoBayes, that explores different graphical models linking classifier, encoder, decoder, estimator and adversarial network blocks to optimize nuisance-invariant machine learning pipelines. AutoBayes also enables learning disentangled representations, where the latent variable is split into multiple pieces to impose various relationships with the nuisance variation and task labels. We benchmark the framework on several public datasets, demonstrating a significant performance improvement with ensemble learning across explored graphical models

## Comparison of Three Feedback Modalities for Haptics Sensation in Remote Machine Manipulation

Citation: Haruna, M., Ogino, M., Koike-Akino, T., "Comparison of Three Feedback Modalities for Haptics Sensation in Remote Machine Manipulation", IEEE Robotics and Automation Letters, Vol. 6, No. 3, pp. 5040-5047, March 2021.

Contacts: Toshiaki Koike-Akino

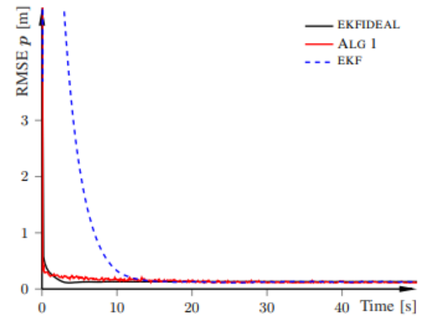



Previous studies have shown the usefulness of visual haptics for achieving the appropriate grasping force and task success rate to operate remote machines. However, its capabilities have not been evaluated objectively and quantitatively. We comprehensively compare three feedback modalities (i.e., sound, vibration, and light) for providing pseudo-haptic information on contact with an object. Experimental results verify that the light modality (i.e., visual haptics) minimizes the grasping force and processing load in the operator's brain. We then develop a prototype to demonstrate the feasibility of visual haptic feedback. We demonstrate that our visual haptics method (superimposing haptic information as images on the contact points of the robot's fingertips) can significantly improve the operability of remote machines without the need for complex and expensive interfaces.

## 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)*, July 2018.

Contacts: Karl Berntorp, Avishai Weiss, Stefano Di Cairano

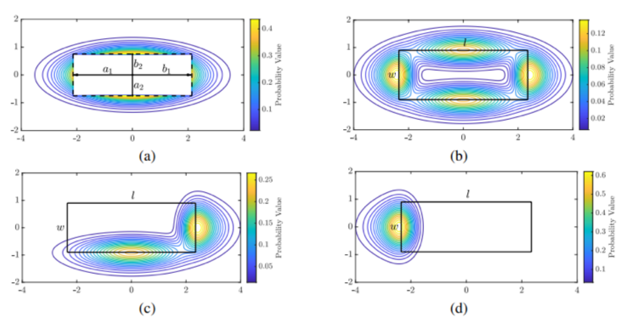



The precision of global navigation satellite systems (GNSSs) relies heavily on accurate carrier phase ambiguity resolution. The ambiguities are known to take integer values, but the set of ambiguity values is unbounded. We propose a mixture Kalman filter solution to GNSS ambiguity resolution. By marginalizing 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.

## Learning-based Extended Object Tracking Using Hierarchical Truncation Measurement Model with Automotive Radar

Citation: Xia, Y., Wang, P., Berntorp, K., Svensson, L., Granstrom, K., Mansour, H., Boufounos, P.T., Orlik, P.V., "Learning-based Extended Object Tracking Using Hierarchical Truncation Measurement Model with Automotive Radar", IEEE Journal of Selected Topics in Signal Processing, Vol. 15, No. 4, pp. 1013-1029, February 2021.

Contacts: Pu Wang, Karl Berntorp, Hassan Mansour, Petros T. Boufounos, Philip V. Orlik




This paper presents a data-driven measurement model for extended object tracking (EOT) with automotive radar. The spatial distribution of automotive radar measurements is modeled as a hierarchical truncated Gaussian (HTG) with structural geometry parameters that can be learned from the training data. The HTG measurement model provides an adequate resemblance to the spatial distribution of real-world automotive radar measurements. The learned HTG measurement model is further incorporated into a random matrix based EOT approach with two (multi-sensor) measurement updates: one is based on a factorized Gaussian inverse Wishart density representation and the other is based on a Rao-Blackwell-ized particle density representation.

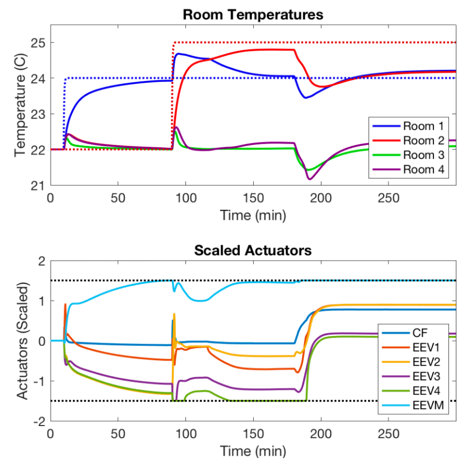
# Control

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 advanced control algorithms that increase the performance and robustness with respect state-of-the-art in academia and industry, yet require limited resources in terms of computations and memory, in order to be viable for production. Recent results of MERL control algorithms in applications include safe and highly high performant vehicle control and motion planning for automated vehicles, more energy efficient air conditioners and servomotors, higher throughput laser processing, high precision GNSS positioning, reliable statistical estimation of vehicle driving conditions, fuel-efficient satellite station keeping, energy management of electric vehicles. 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

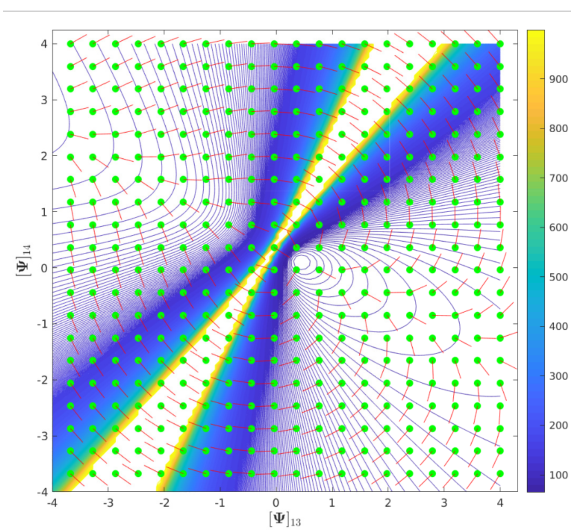
Citation: Bortoff, S.A., Schwerdtner, P., Danielson, C., Di Cairano, S., "H Infinity Loop-Shaped Model Predictive Control with Heat Pump Application", European Control Conference (ECC), June 2019, pp. 2386-2393.
Contacts: Scott Bortoff, Stefano Di Cairano




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.

## MSE-optimal measurement dimension reduction in Gaussian filtering

Citation: Greiff, M., Robertsson, A., Berntorp, K., "MSE-optimal measurement dimension reduction in Gaussian filtering*", Conference on Control Technology and Applications (CCTA), August 2020.
Contacts: Karl Berntorp

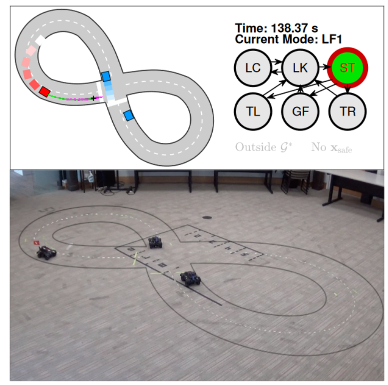



We present a framework for measurement dimension reduction in Gaussian filtering, defined in terms of a linear operator acting on the measurement vector. This operator is optimized to minimize the Cramer–Rao bound of the estimate's mean squared error (MSE), yielding a measurement subspace from which elements minimally worsen the filter MSE performance, as compared to filtering with the original measurements. This is demonstrated with Kalman filtering in a linear Gaussian setting and various non-linear Gaussian filters with an on-line adaption of the operator. The proposed method improves computational time in exchange for a quantifiable and sometimes negligibly worsened MSE of the estimate

## Reachability-based Decision Making for Autonomous Driving: Theory and Experiment

Citation: Ahn, H., Berntorp, K., Inani, P., Ram, A.J., Di Cairano, S., "Reachability-based Decision Making for Autonomous Driving: Theory and Experiment", IEEE Transactions on Control Systems Technology, December 2020.

Contacts: Karl Berntorp, Stefano Di Cairano

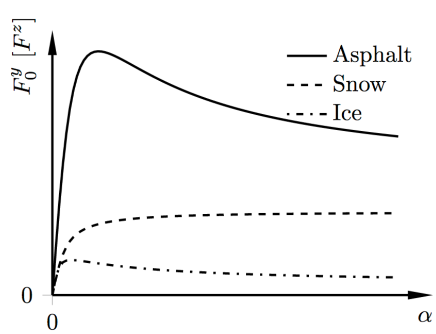



We describe the design and validation of a decision making system in the guidance and control architecture for automated driving. The decision making system determines the timing of transitions through a sequence of driving modes, such as lane following and stopping, for the vehicle to eventually arrive at the destination without colliding with obstacles. The decision making system commands a transition to the next mode only when it is possible for an underlying motion planner to generate a feasible trajectory that reaches the target region of the next mode. Using forward and backward reachable sets based on a simplified dynamical model, the decision making system determines the existence of a trajectory that reaches the target region, without actually computing it. Thus, the decision making system achieves fast computation, resulting in reactivity to a varying environment and reduced computational burden.

## 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, January 2020.

Contacts: Karl Berntorp, Rien Quirynen, Stefano Di Cairano

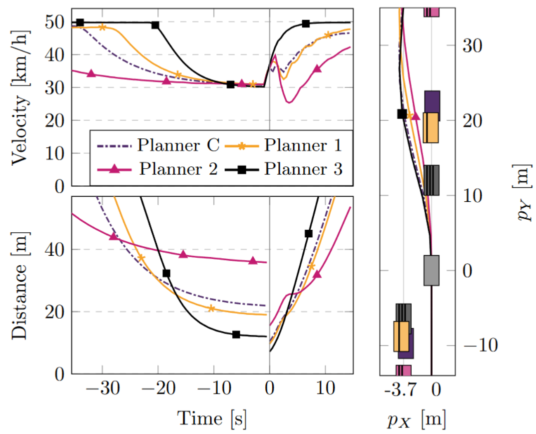



We propose an adaptive nonlinear model predictive control (NMPC) for vehicle tracking control. The controller learns in real time a tire force model to adapt to a varying road surface that is only indirectly observed from the effects of the tire forces determining the vehicle dynamics. Learning the entire 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.

## Inverse Learning for Data-driven Calibration of Model-based Statistical Path Planning

Citation: Menner, M., Berntorp, K., Di Cairano, S., "Inverse Learning for Data-driven Calibration of Model-based Statistical Path Planning", Transactions on Intelligent Vehicles, July 2020.

Contacts: Karl Berntorp, Stefano Di Cairano, Marcel Menner

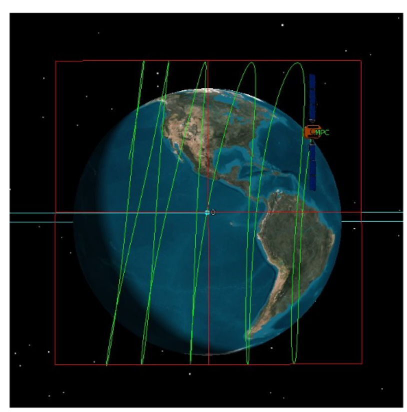



This paper presents a method for inverse learning of a control objective defined in terms of requirements and their joint probability distribution from data. The probability distribution characterizes tolerated deviations from the deterministic requirements and is learned using maximum likelihood estimation from data. Both the parametrized requirements and their joint probability distributions are estimated using a posterior distribution such that the control objective is personalized from a prior as driver data are accumulated. Key advantages of the proposed inverse learning method are a relatively low computational complexity, a need for a limited amount of data, and that the data do not have to be segmented into specific maneuvers.

## Electric Satellite Station Keeping, Attitude Control, and Momentum Management by MPC

Citation: Caverly, R., Di Cairano, S., Weiss, A., "Electric Satellite Station Keeping, Attitude Control, and Momentum Management by MPC", IEEE Transactions on Control Systems Technology, Vol. 29, No. 4, pp. 1475-1489, December 2020.

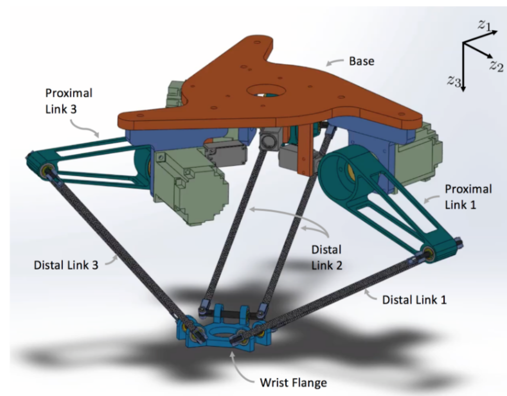
Contacts: Stefano Di Cairano, Avishai Weiss



We propose a model predictive control (MPC) policy for simultaneous station keeping, attitude control, and momentum management of a low-thrust nadir-pointing geostationary satellite equipped with reaction wheels and on-off electric thrusters mounted on boom assemblies. Attitude control is performed using an inner-loop SO(3)-based control law with the reaction wheels, while the outer-loop MPC policy maintains the satellite within a narrow station keeping window and performs momentum management using electric thrusters. To handle the on-off nature of the thruster while retaining low computational burden, we develop a strategy for quantizing the continuous thrust command, which also allows for trading off the number of thrust pulses and fuel consumption.

## Modelica-Based Control of a Delta Robot

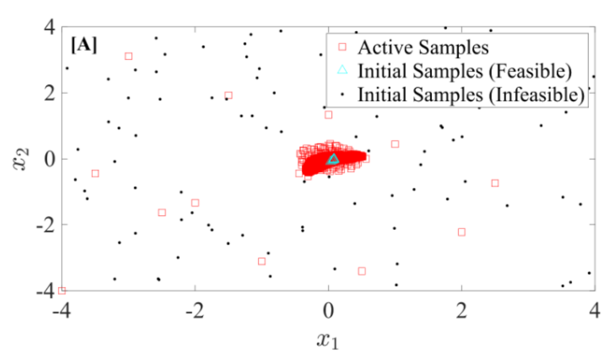
Citation: Bortoff, S.A., Okasha, A., "Modelica-Based Control of A Delta Robot", ASME Dynamic Systems and Control Conference, December 2020.
Contacts: Scott A. Bortoff




In this paper we derive a dynamic model of the delta robot and two formulations of the manipulator Jacobian that comprise a system of singularity-free, index-one differential algebraic equations that is well-suited for model-based control design and computer simulation. One of the Jacobians is intended for time-domain simulation, while the other is for use in discretetime control algorithms. We use the model to derive an approximate feedback linearizing control algorithm that can be used for both trajectory tracking and impedance control, enabling some assembly tasks involving contact and collisions. The model and control algorithms are realized in the open-source Modelica language, and a Modelica-based software architecture is described that allows for a seamless development process from mathematical derivation of control algorithms, to desktop simulation, and finally to laboratory-scale experimental testing without the need to recode any aspect of the control algorithm.

## Active Learning for Estimating Reachable Sets for Systems with Unknown Dynamics

Citation: Chakrabarty, A., Raghunathan, A., Di Cairano, S., Danielson, C., "Active Learning for Estimating Reachable Sets for Systems with Unknown Dynamics", IEEE Transactions on Cybernetics, December 2020.
Contacts: Ankush Chakrabarty, Arvind Raghunathan, Stefano Di Cairano

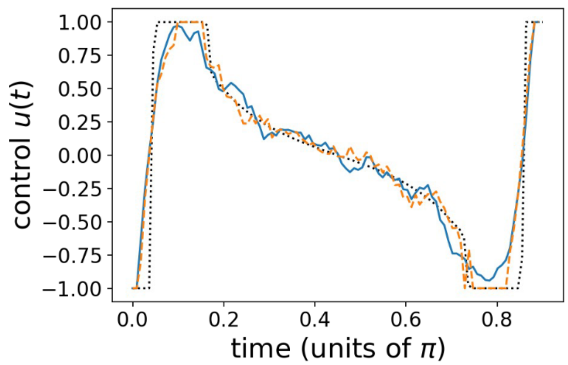



This paper presents a data-driven method for computing reachable sets where active learning is used to reduce the computational burden. Set-based methods used to estimate reachable sets typically do not scale well with state-space dimension, or rely heavily on the existence of a model. If such a model is not available, one can generate state trajectory data by numerically simulating black-box oracles of systems (whose dynamics are unknown) from sampled initial conditions. Using these data samples, the estimation of reachable sets can be posed as a classification problem, wherein active learning (AL) can intelligently select samples that are most informative and least similar to previously labeled samples. By exploiting submodularity, the actively learned samples can be selected efficiently, with bounded sub-optimality.

## Stochastic optimal control formalism for an open quantum system

Citation: Lin, C., Sels, D., Ma, Y., Wang, Y., "Stochastic optimal control formalism for an open quantum system", Physical Review, Vol. 102, pp. 052605, December 2020.

Contacts: Chungwei Lin, Yanting Ma, Yebin Wang

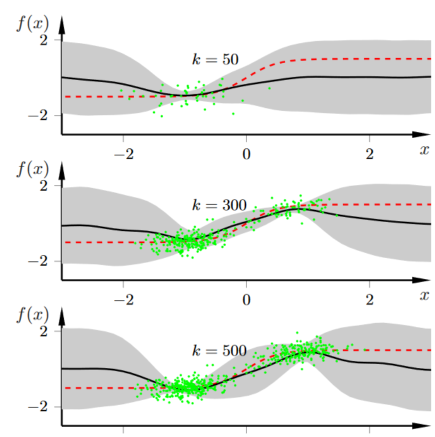



A stochastic procedure is developed which allows one to express Pontryagin's maximum principle for dissipative quantum system solely in terms of stochastic wave functions. Time-optimal controls can be efficiently computed without computing the density matrix. Specifically, the proper dynamical update rules are presented for the stochastic costate variables introduced by Pontryagin's maximum principle and restrictions on the form of the terminal cost function are discussed. The proposed procedure is confirmed by comparing the results to those obtained from optimal control on Lindbladian dynamics. Numerically, the proposed formalism becomes time and memory efficient for large systems, and it can be generalized to describe non-Markovian dynamics

## Online Bayesian Inference and Learning of Gaussian-Process State-SpaceModels

Citation: Berntorp, K., "Online Bayesian Inference and Learning of Gaussian-Process State-SpaceModels", Automatica, Vol. 129, March 2021.

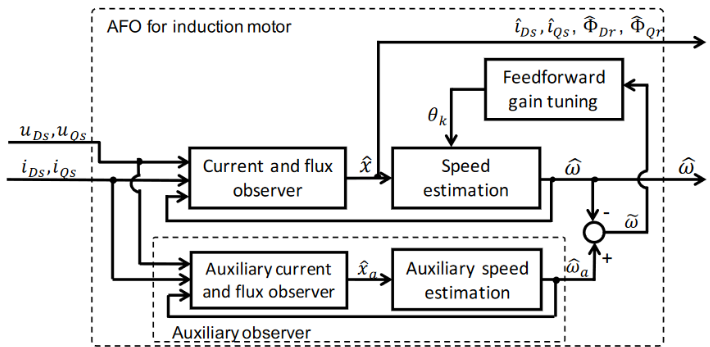
Contacts: Karl Berntorp




This paper addresses the recursive joint inference (state estimation) and learning (system identification) problem for nonlinear systems admitting a state-space formulation. We model the system as a Gaussian-process state-space model (GP-SSM) and leverage a recently developed reduced-rank formulation of GP-SSMs to enable efficient, online learning. The unknown dynamical system is expressed as a basis-function expansion, where a connection to the GP makes it possible to systematically assign priors to the basis-function weights. The approach is formulated within the sequential Monte-Carlo framework, wherein each particle retains its own weights of the basis functions, which are updated recursively as measurements arrive. We apply the method to a case study concerning tire-friction estimation. The results indicate that our method can accurately learn the tire friction using automotive-grade sensors in an online setting, and quickly detect sudden changes of the road surface.

## Improve Speed Estimation for Speed-Sensor-less Induction Machines: A Variable Adaptation Gain and Feedforward Approach

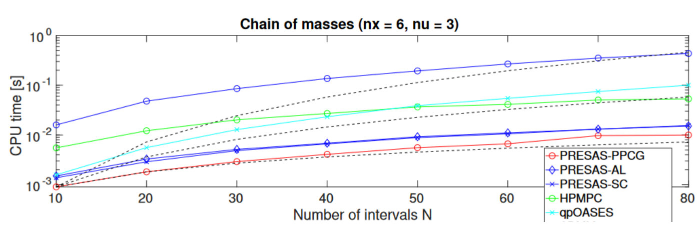
Citation: Zhou, L., Wang, Y., "Improve Speed Estimation for Speed-Sensorless Induction Machines: A Variable Adaptation Gain and Feedforward Approach", International Conference on Electrical Machines (ICEM), August 2020, pp. 1150-1156.
Contacts: Yebin Wang




This paper investigates the speed-sensor-less estimation problem for induction machines, aiming to offer a better balance between speed estimation bandwidth and robustness than a classic adaptive full-order observer (AFO). An AFO suffers from a trade-off in selecting its speed adaptation gains: large gains for high bandwidth versus low gains for suppression of ripples induced by model mismatches and noises. We propose two revisions on the AFO to relax the trade-off. First is to adopt a variable speed adaptation gain which is large during transient and is small in steady-state. Second is to include a feedforward term in the speed adaptation law to accommodate the rotor's mechanical dynamics.

## PRESAS: Block-Structured Preconditioning of Iterative Solvers within a Primal Active-Set Method for fast MPC

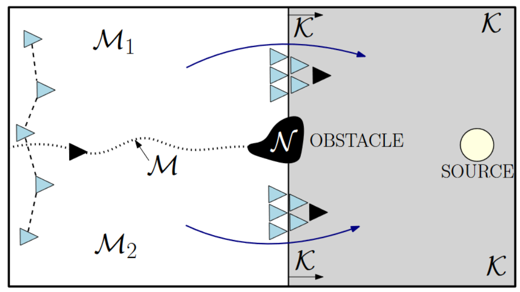
Citation: Quirynen, R., Di Cairano, S., "PRESAS: Block-Structured Preconditioning of Iterative Solvers within a Primal Active-Set Method for fast MPC", Optimal Control Applications & Methods, Vol. 41, No. 6, pp. 2282-2307, September 2020.
Contacts: Rien Quirynen, Stefano Di Cairano




Model predictive control (MPC) for linear dynamical systems requires solving an optimal control structured quadratic program (QP) at each sampling instant. This paper proposes a primal active-set strategy, called PRESAS, for the efficient solution of such block-sparse QPs, based on a preconditioned iterative solver to compute the search direction in each iteration. Three different block-structured preconditioning techniques are presented and their numerical properties are studied further. In addition, an augmented Lagrangian based implementation is proposed to avoid a costly initialization procedure to find a primal feasible starting point.

## Robust Coordinated Hybrid Source Seeking with Obstacle Avoidance in Multi-Vehicle Autonomous Systems

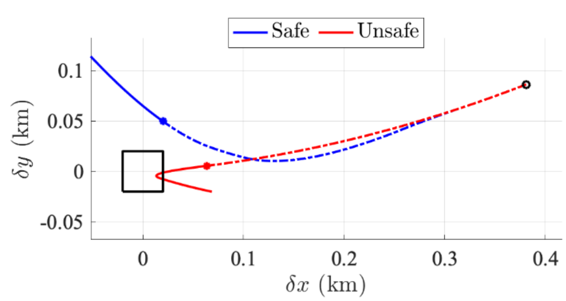
Citation: Poveda, J., Benosman, M., Teel, A.R., Sanfelice, R.G., "Robust Coordinated Hybrid Source Seeking with Obstacle Avoidance in Multi-Vehicle Autonomous Systems", IEEE Transactions on Automatic Control, March 2021.
Contacts: Mouhacine Benosman




In multi-vehicle autonomous systems that operate under unknown or adversarial environments, it is a challenging task to simultaneously achieve source seeking and obstacle avoidance. Indeed, even for single-vehicle systems, smooth time-invariant feedback controllers based on navigation or barrier functions have been shown to be highly susceptible to arbitrarily small jamming signals that can induce instability in the closed-loop system. When the location of the source is further unknown, adaptive smooth source seeking dynamics based on averaging theory may suffer from similar limitations. We address this problem by introducing a class of novel distributed hybrid model-free controllers, that achieve robust source seeking and obstacle avoidance in multi-vehicle autonomous systems, with vehicles characterized by nonlinear continuous-time dynamics stabilizable by hybrid feedback. The hybrid source seeking law switches between a family of cooperative gradient-free controllers, derived from potential fields that satisfy mild invexity assumptions.

## Abort-Safe Spacecraft Rendezvous in case of Partial Thrust Failure

Citation: Aguilar Marsillach, D., Di Cairano, S., Weiss, A., "Abort-Safe Spacecraft Rendezvous in case of Partial Thrust Failure", IEEE Conference on Decision and Control (CDC), December 2020, pp. 1490-1495.
Contacts: Stefano Di Cairano, Avishai Weiss




A spacecraft rendezvous policy is developed that yields safe rendezvous trajectories under various thruster failure scenarios. The policy makes use of polytopic robust backwards reachable sets to characterize the state-space that under a given thruster failure scenario would lead to collision between a deputy and a chief spacecraft no matter the remaining available thrust. That is, this region of state-space is such that no feasible evasive abort maneuver exists for the given failure scenario. Abort-safety constraints are formulated as local hyperplanes separating the deputy spacecraft and the unsafe state-space. These constraints are incorporated in a model predictive control-based online trajectory generation scheme in order to guide the deputy to rendezvous with its chief through an inherently safe approach.

# Optimization

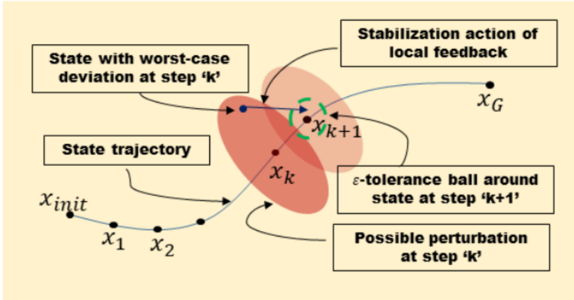
Decision optimization research emphasizes numerical methods for fast solution of continuous and discrete optimization problems that can be scaled up to problems of industrial size and complexity. Optimization methods find application in many application domains, including the analysis of electrical power 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 of dynamical systems. Conversely, and somewhat unusually, we have borrowed some ideas from the field of dynamical systems to design superior optimization algorithms. We have also started to explore the application of quantum computing to optimization problems that, due to their structure, might end up being some of the first where this exciting new computational technology will achieve practical use.

## Recent Research

## Local Policy Optimization for Trajectory-Centric Reinforcement Learning

Citation: Jha, D.K., Kolaric, P., Raghunathan, A., Lewis, F., Benosman, M., Romeres, D., Nikovski, D.N., "Local Policy Optimization for Trajectory-Centric Reinforcement Learning", IEEE International Conference on Robotics and Automation (ICRA), Ayanna Howard, Eds., May 2020, pp. 5094-5100.

Contacts: Devesh K. Jha, Arvind Raghunathan, Mouhacine Benosman, Diego Romeres, Daniel N. Nikovski

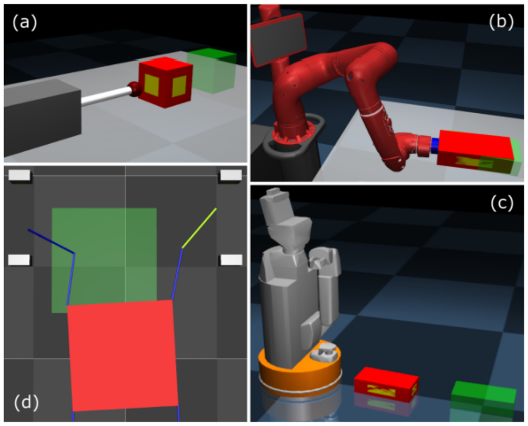



The goal of this paper is to present a method for simultaneous trajectory and local stabilizing policy optimization for trajectory-centric model-based reinforcement learning (MBRL). This is motivated by the fact that global policy optimization for non-linear systems can be a very challenging problem both algorithmically and numerically. However, a lot of robotic manipulation tasks are trajectorycentric, and thus do not require a global model or policy. Due to inaccuracies in learned model estimates, an openloop trajectory optimization process mostly results in very poor performance when used in a real system. Motivated by these problems, we formulate the problem of trajectory optimization and local policy synthesis as a single optimization problem. It is then solved simultaneously as an instance of nonlinear programming.

## Tuning-Free Contact-Implicit Trajectory Optimization

Citation: Onol, A.O., Corcodel, R., Long, P., Padir, T., "Tuning-Free Contact-Implicit Trajectory Optimization", IEEE International Conference on Robotics and Automation (ICRA), May 2020, pp. 1183-1189.

Contacts: Radu Corcodel

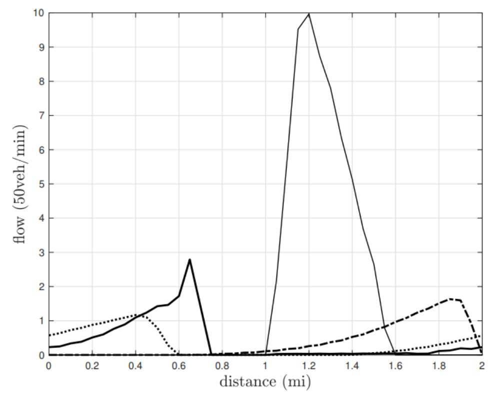



We present a contact-implicit trajectory optimization framework that can plan contact-interaction trajectories for different robot architectures and tasks using a trivial initial guess and without requiring any parameter tuning. This is achieved by using a relaxed contact model along with an automatic penalty adjustment loop for suppressing the relaxation. Moreover, the structure of the problem enables us to exploit the contact information implied by the use of relaxation in the previous iteration, such that the solution is explicitly improved with little computational overhead. We test the proposed approach in simulation experiments for nonprehensile manipulation using a 7-DOF arm The results demonstrate that our method provides an out-of-the-box solution with good performance for a wide range of applications.

## Optimization-based incentivization and control scheme for autonomous traffic

Citation: Kalabic, U., Grover, P., Aeron, S., "Optimization-based incentivization and control scheme for autonomous traffic", IEEE Intelligent Vehicle Symposium, June 2020.

Contacts: Uroš Kalabić

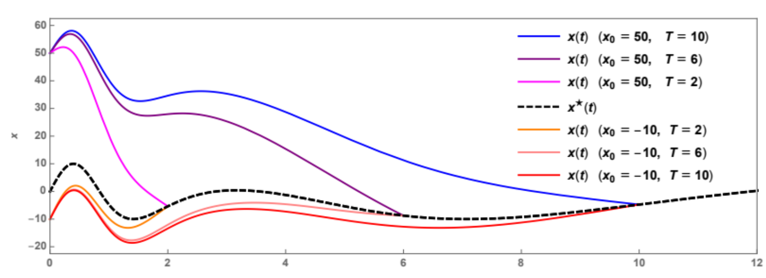



We consider the problem of incentivization and optimal control of autonomous vehicles for improving traffic congestion. In our scenario, autonomous vehicles must be incentivized in order to participate in traffic improvement. Using the theory and methods of optimal transport, we propose a constrained optimization framework over dynamics governed by partial differential equations, so that we can optimally select a portion of vehicles to be incentivized and controlled. The goal of the optimization is to obtain a uniform distribution of vehicles over the spatial domain. To achieve this, we consider two types of penalties on vehicle density, one is the L2 cost and the other is a multiscale-norm cost, commonly used in fluid-mixing problems. To solve this nonconvex optimization problem, we introduce a novel algorithm, which iterates between solving a convex optimization problem and propagating the flow of uncontrolled vehicles according to the Lighthill-Whitham-Richards model. We perform numerical simulations, which suggest that the optimization of the L2 cost is ineffective while optimization of the multiscale norm is effective.

## Continuous-Time Optimization of Time-Varying Cost Functions via Finite-Time Stability with Pre-Defined Convergence Time

Citation: Romero, O., Benosman, M., "Continuous-Time Optimization of Time-Varying Cost Functions via Finite-Time Stability with Pre-Defined Convergence Time", American Control Conference (ACC), June 2020.

Contacts: Mouhacine Benosman

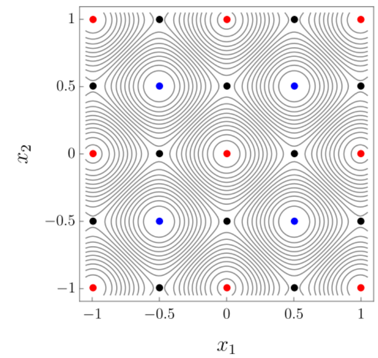



We propose a new family of continuous-time optimization algorithms for time-varying, locally strongly-convex cost functions, based on discontinuous second-order gradient optimization flows with provable finite-time convergence to local optima. To analyze our flows, we first extend a well-know Lyapunov inequality condition for finite-time stability, to the case of arbitrary time-varying differential inclusions, particularly of the Filippov type. We then prove the convergence of our proposed flows in finite time.

## Time-Varying Continuous-Time Optimization with Pre-Defined Finite-Time Stability

Citation: Romero, O., Benosman, M., "Time-Varying Continuous-Time Optimization with Pre-Defined Finite-Time Stability", International Journal of Control, pp. 1-18, June 2020.

Contacts: Mouhacine Benosman

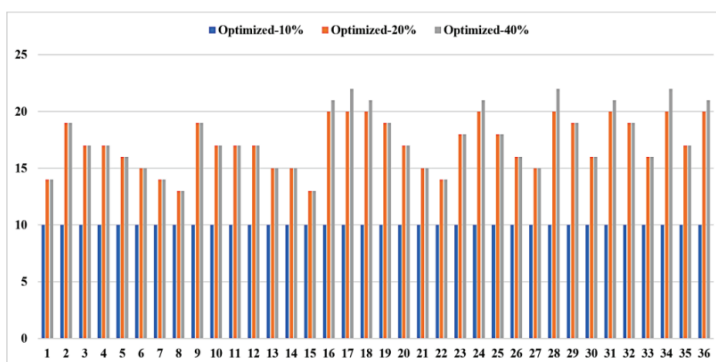



We propose a new family of continuous-time optimization algorithms based on discontinuous second order gradient optimization flows, with finite-time convergence guarantees to local optima, for locally strongly convex (time-varying) cost functions. To analyze our flows, we first extend a well-know Lyapunov inequality condition for finite-time stability, to the case of (time-varying) differential inclusions. We then prove the convergence of these second-order flows in finite-time. In some particular cases, we can show that the finite-time convergence can be pre-defined by the user. We propose a robustification of the flows to bounded additive uncertainties, and extend some of the results to the case of constrained optimization.

## Data-Driven Joint Optimization of Pricing and Seat Allocation in Trains

Citation: Konno, N., Raghunathan, A., "Data-Driven Joint Optimization of Pricing and Seat Allocation in Trains", International Conference on Railway Engineering Design and Operation (COMPRAIL), July 2020, pp. 379-392.

Contacts: Arvind Raghunathan

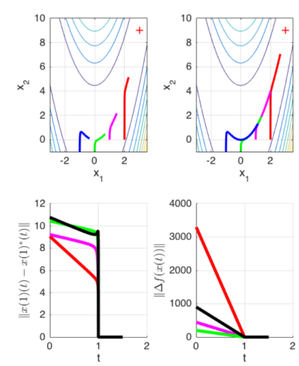



Revenue management (RM), a management science method, employs demand predictions to maximize revenue. Since its introduction in the airline industry in the 1980s, it is now widely used in various industries such as hotel, retail, and railway, among others. In recent years, RM has seen increased adoption in the railway industry. Existing approaches to RM in trains have mostly considered the determination of price and capacity separately. We consider the problem of maximizing revenue by optimizing over price and capacity simultaneously. For the first time, we consider the problem of train sizing, i.e. number of coaches in each fare class. Second, instead of logic-based models estimated from price-demand data, we consider data-driven models that alleviate the problem of modelling errors. Finally, we formulate the optimization as an Integer Linear Program as opposed to the nonlinear formulations that result from logit-based models.

## Finite-Time Convergence in Continuous-Time Optimization

Citation: Romero, O., Benosman, M., "Finite-Time Convergence in Continuous-Time Optimization", International Conference on Machine Learning (ICML), July 2020.

Contacts: Mouhacine Benosman

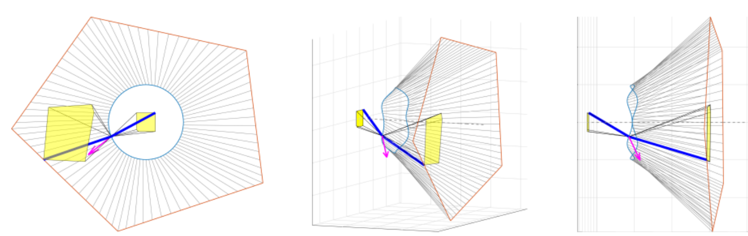


we investigate a Lyapunov-like differential inequality that allows us to establish finite-time stability of a continuous-time state-space dynamical system represented via a multivariate ordinary differential equation or differential inclusion. Equipped with this condition, we synthesize first and second-order (in an optimization variable) dynamical systems that achieve finite-time convergence to the minima of a given sufficiently regular cost function. As a byproduct, we show that the q-rescaled gradient flow (q-RGF) proposed by Wibisono et al. (2016) is indeed finite-time convergent, provided the cost function is gradient dominated of order p E (1, q). This way, we effectively bridge a gap between the q-RGF and the finite-time convergent normalized gradient flow (NGF) (q = infinity) proposed by Cortes' (2006).

## Design of freeforms to uniformly illuminate polygonal targets from extended sources via edge ray mapping

Citation: Birch, D.A., Brand, M.E., "Design of freeforms to uniformly illuminate polygonal targets from extended sources via edge ray mapping", Applied Optics, No. 22, pp. 6490-6496, August 2020.

Contacts: Matthew E. Brand

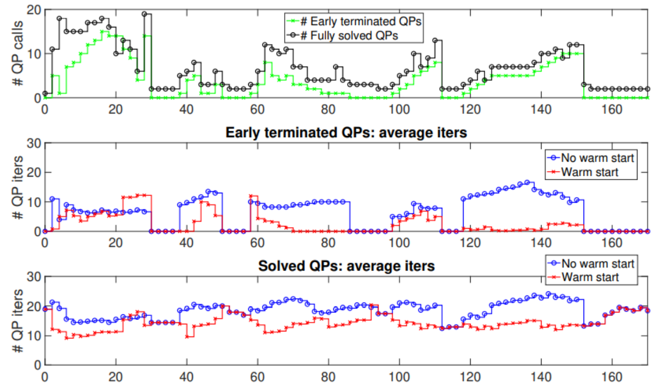


We consider the design of a compact freeform optical surface that uniformly irradiates an arbitrary convex polygonal region from an extended light source while controlling spill. This problem has attracted a large literature, mainly treating highly symmetric special cases or cases where the solution is approximated by a zero-étendue design based on a point source. Practical versions of this illumination design problem will likely feature large asymmetric LEDs, compact lenses, and irregular targets on angled projection surfaces. For these settings, we develop a solution method based on an edge ray mapping that routes maximally off-axis rays from the edges of the source through the edge of the optic to the edges of the target polygon. This determines the sag and normals along the boundary of the freeform surface. A "spill-free" surface is then interpolated from the boundary information, and optimized to uniformize the irradiance while preserving the polygonal boundary. Highly uniform irradiances (relative standard deviation < .01) can be attained with good control of spill, even when the exit surface is < 3 source diameters from the embedded source.

## Early Termination of Convex QP Solvers in Mixed-Integer Programming for Real-Time Decision Making

Citation: Liang, J., Di Cairano, S., Quirynen, R., "Early Termination of Convex QP Solvers in Mixed-Integer Programming for Real-Time Decision Making", L-CSS with ACC 2021 Option, , Vol. 5, No. 4, pp. 1417-1422, November 2020.

Contacts: Stefano Di Cairano, Rien Quirynen

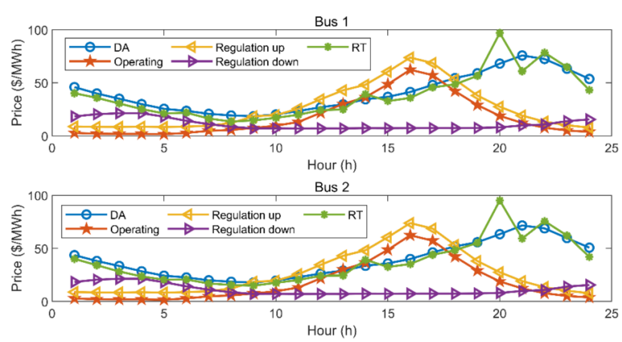



The branch-and-bound optimization algorithm for mixed-integer model predictive control (MI-MPC) solves several convex quadratic program relaxations, but often the solutions are discarded based on already known integer feasible solutions. This paper presents a projection and early termination strategy for infeasible interior point methods to reduce the computational effort of finding a globally optimal solution for MI-MPC. The method is shown to be also effective for infeasibility detection of the convex relaxations. We present numerical simulation results with a reduction of the total number of solver iterations by 42% for an MI-MPC example of decision making for automated driving with obstacle avoidance constraints.

## CVaR-constrained Stochastic Bidding Strategy for a Virtual Power Plant with Mobile Energy Storages

Citation: Xiao, D., Sun, H., Nikovski, D.N., Shoichi, K., Mori, K., Hashimoto, H., "CVaR-constrained Stochastic Bidding Strategy for a Virtual Power Plant with Mobile Energy Storages", IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), November 2020, pp. 1171-1175.

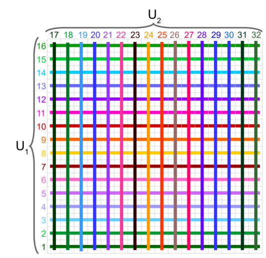
Contacts: Hongbo Sun, Daniel N. Nikovski




This paper proposes a stochastic optimizationbased energy and reserve bidding strategy for a virtual power plant (VPP) with mobile energy storages, renewable energy resources (RESs) and load demands at multiple buses. In the proposed bidding strategy, the energy markets include the day-ahead and real-time energy markets, and the reserve markets include operating, regulation up and regulation down reserve markets. In view of the differences of energy and reserve prices, renewable generations and load demands between buses on the next day, the mobile energy storages can be delivered to different buses for maximizing the VPP's total expected profit considering its risk preference.

## Template-based Minor Embedding for Adiabatic Quantum Optimization

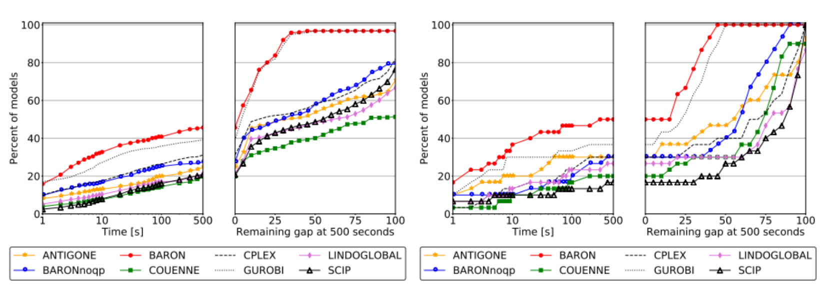
Citation: Serra, T., Huang, T., Raghunathan, A., Bergman, D., "Template-based Minor Embedding for Adiabatic Quantum Optimization", INFORMS Journal on Computing, December 2020.
Contacts: Arvind Raghunathan




Quantum Annealing (QA) can be used to quickly obtain near-optimal solutions for Quadratic Unconstrained Binary Optimization (QUBO) problems. In QA hardware, each decision variable of a QUBO should be mapped to one or more adjacent qubits in such a way that pairs of variables defining a quadratic term in the objective function are mapped to some pair of adjacent qubits. However, qubits have limited connectivity in existing QA hardware. This has spurred work on preprocessing algorithms for embedding the graph representing problem variables with quadratic terms into the hardware graph representing qubits adjacencies, such as the Chimera graph in hardware produced by D-Wave Systems. In this paper, we use integer linear programming to search for an embedding of the problem graph into certain classes of minors of the Chimera graph, which we call template embeddings. One of these classes corresponds to complete bipartite graphs, for which we show the limitation of the existing approach based on minimum Odd Cycle Transversals (OCTs). We can embed more graphs than a state-of-the-art OCT-based approach, our approach scales better with the hardware size, and the runtime is generally orders of magnitude smaller.

## Spectral relaxations and branching strategies for global optimization of mixed-integer quadratic programs

Citation: Nohra, C.J., Raghunathan, A., Sahinidis, N.V., "Spectral relaxations and branching strategies for global optimization of mixed-integer quadratic programs", SIAM Journal on Optimization, Vol. 31, No. 1, pp. 142–171, December 2020.
Contacts: Arvind Raghunathan

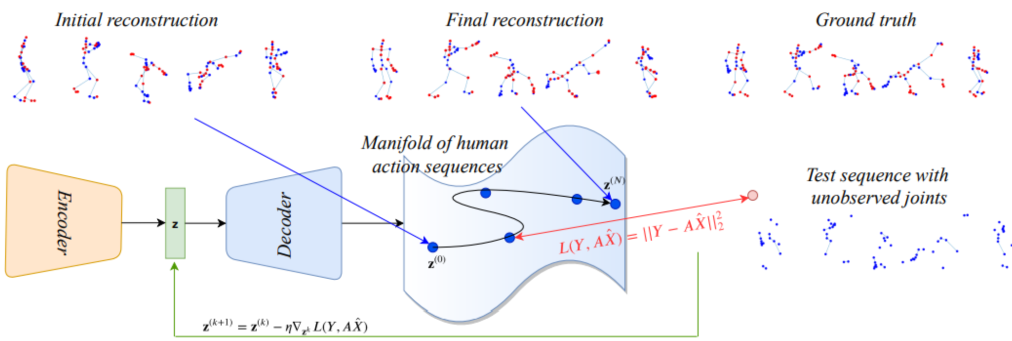



(a) 960 CBQP instances. (b) 30 QSAP instances.

We consider the global optimization of non-convex quadratic programs and mixed-integer quadratic programs. We present a family of convex quadratic relaxations which are derived by convexifying nonconvex quadratic functions through perturbations of the quadratic matrix. We investigate the theoretical properties of these quadratic relaxations and show that they are equivalent to some particular semidefinite programs. Results demonstrate that the proposed implementation leads to very significant reductions in BARON's computational times to solve the test problems

## Recovering Trajectories of Unmarked Joints in 3D Human Actions Using Latent Space Optimization

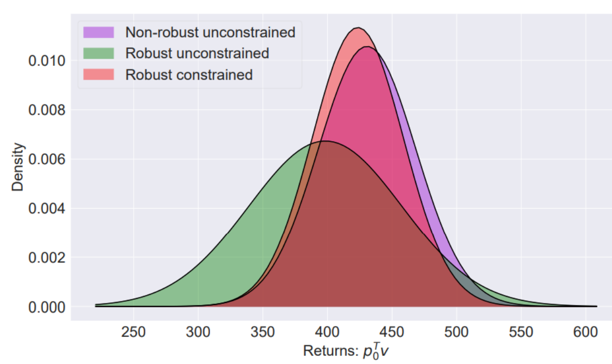
Citation: Lohit, S., Anirudh, R., Turaga, P., "Recovering Trajectories of Unmarked Joints in 3D Human Actions Using Latent Space Optimization", IEEE Winter Conference on Applications of Computer Vision (WACV), January 2021.
Contacts: Suhas Lohit




Motion capture (mocap) and time-of-flight based sensing of human actions are becoming increasingly popular modalities to perform robust activity analysis. We pose the problem of reconstructing unmarked joint data as an ill-posed linear inverse problem. We recover missing joints for a given action by projecting it onto the manifold of human actions, this is achieved by optimizing the latent space representation of a deep autoencoder. Experiments on both mocap and Kinect datasets clearly demonstrate that the proposed method performs very well in recovering semantics of the actions and dynamics of missing joints.

## Robust Constrained-MDPs: Soft-Constrained Robust Policy Optimization under Model Uncertainty

Citation: Russel, R.H., Benosman, M., van Baar, J., "Robust Constrained-MDPs: Soft-Constrained Robust Policy Optimization under Model Uncertainty", Advances in Neural Information Processing Systems (NeurIPS)-workshop, January 2021.
Contacts: Mouhacine Benosman




We focus on the problem of robustifying reinforcement learning (RL) algorithms with respect to model uncertainties. Indeed, in the framework of model-based RL, we propose to merge the theory of constrained Markov decision process (CMDP), with the theory of robust Markov decision process (RMDP), leading to a formulation of robust constrained-MDPs (RCMDP). This formulation, simple in essence, allows us to design RL algorithms that are robust in performance, and provides constraint satisfaction guarantees, with respect to uncertainties in the system's states transition probabilities.

# Artificial Intelligence

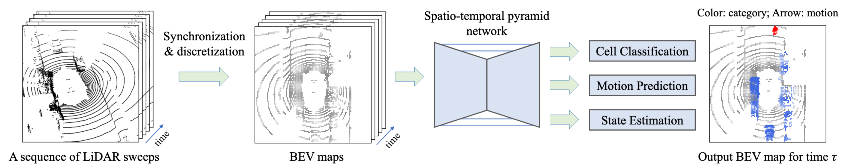
AI research at MERL aims to make machines smarter for improved safety, efficiency and comfort. While AI techniques are being applied broadly at MERL for a wide range of control, optimization, modeling, and signal processing tasks, the work reported in this section focuses on advances in media intelligence and robotics. Key research themes include robust machine learning for improved scene understanding, data-efficient learning using semi-/un-supervised techniques, imitation, supervised, and reinforcement learning for robot control, effective utilization of multiple data modalities, 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

## MotionNet: Joint Perception and Motion Prediction for Autonomous Driving Based on Bird's Eye View Maps

Citation: Wu, P., Chen, S., "MotionNet: Joint Perception and Motion Prediction for Autonomous Driving Based on Bird's Eye View Maps", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), DOI: 10.1109/CVPR42600.2020.01140, June 2020, pp. 11382-11392.

Contacts: Anoop Cherian

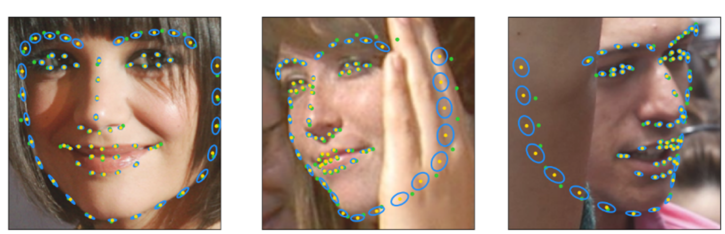



The ability to reliably perceive the environmental states, particularly the existence of objects and their motion behavior, is crucial for autonomous driving. In this work, we propose an efficient deep model, called MotionNet, to jointly perform perception and motion prediction from 3D point clouds. MotionNet takes a sequence of LiDAR sweeps as input and outputs a bird's eye view (BEV) map, which encodes the object category and motion information in each grid cell. Extensive experiments show that the proposed method overall outperforms the state-of-the-art, including the latest scene-flow- and 3D-object-detection-based methods.

## LUVLi Face Alignment: Estimating Landmarks' Location, Uncertainty, and Visibility Likelihood

Citation: Kumar, A., Marks, T.K., Mou, W., Wang, Y., Cherian, A., Jones, M.J., Liu, X., Koike-Akino, T., Feng, C., "LUVLi Face Alignment: Estimating Landmarks' Location, Uncertainty, and Visibility Likelihood", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), DOI: 10.1109/CVPR42600.2020.00826, June 2020.

Contacts: Tim Marks, Ye Wang, Anoop Cherian, Michael J. Jones, Toshiaki Koike-Akino

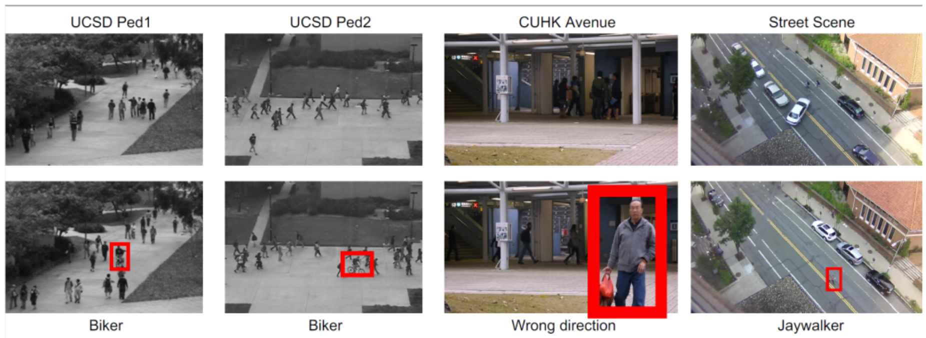


Modern face alignment methods have become quite accurate at predicting the locations of facial landmarks, but they do not typically estimate the uncertainty of their predicted locations nor predict whether landmarks are visible. In this paper, we present a novel framework for jointly predicting landmark locations, associated uncertainties of these predicted locations, and landmark visibilities. We model these as mixed random variables and estimate them using a deep network trained with our proposed Location, Uncertainty, and Visibility Likelihood (LUVLi) loss. Not only does our joint estimation yield accurate estimates of the uncertainty of predicted landmark locations, but it also yields state-of-the-art estimates for the landmark locations themselves on multiple standard face alignment datasets.

## A Survey of Single-Scene Video Anomaly Detection

Citation: Jones, M.J., Ramachandra, B., Vatsavai, R., "A Survey of Single-Scene Video Anomaly Detection", IEEE Transactions on Pattern Analysis and Machine Intelligence, DOI: 10.1109/TPAMI.2020.3040591, November 2020.

Contacts: Mike Jones

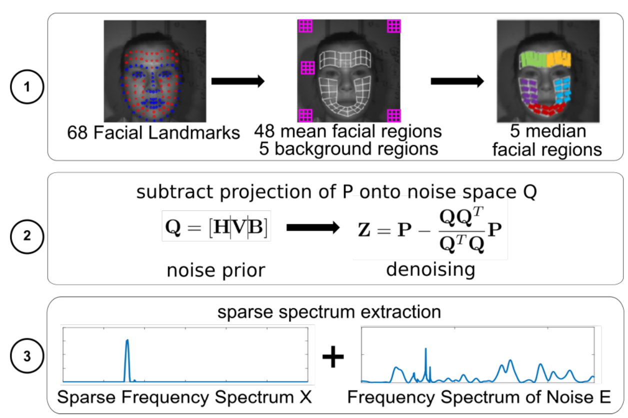



This survey article summarizes research trends in anomaly detection in video feeds of a single scene. We discuss the various problem formulations, publicly available datasets and evaluation criteria. We categorize and situate past research into an intuitive taxonomy and provide a comprehensive comparison of the accuracy of many algorithms on standard test sets. Finally, we also provide best practices and suggest some possible directions for future research.

## Near-Infrared Imaging Photoplethysmography During Driving

Citation: Nowara, E., Marks, T.K., Mansour, H., Veeraraghavan, A., "Near-Infrared Imaging Photoplethysmography During Driving", IEEE Transactions on Intelligent Transportation Systems, DOI: 10.1109/TITS.2020.3038317, pp. 1-12, December 2020.

Contacts: Tim K. Marks, Hassan Mansour




Imaging photoplethysmography (iPPG) could greatly improve driver safety systems by enabling capabilities ranging from identifying driver fatigue to unobtrusive early heart failure detection. Unfortunately, the driving context poses unique challenges to iPPG, including illumination and motion. Drastic illumination variations present during driving can overwhelm the small intensity-based iPPG signals. Second, significant driver head motion during driving, as well as camera motion (e.g., vibration) make it challenging to recover iPPG signals. To address these two challenges, we present two innovations. First, we demonstrate that we can reduce most outside light variations using narrow-band near-infrared (NIR) video recordings and obtain reliable heart rate estimates. Second, we present a novel optimization algorithm, which we call AutoSparsePPG, that leverages the quasi-periodicity of iPPG signals and achieves better performance than the stateof-the art methods.

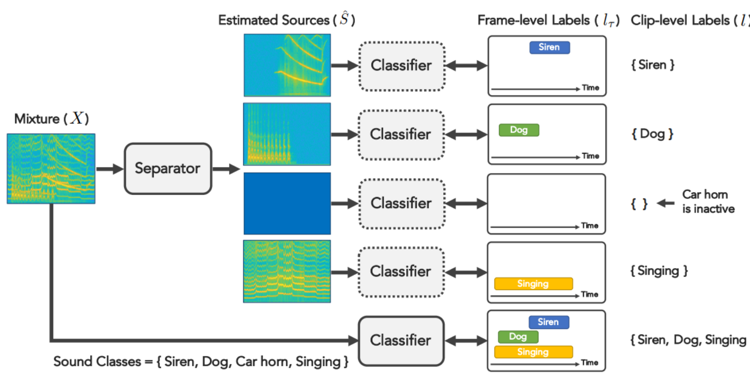
## WHAMR!: Noisy and Reverberant Single-Channel Speech Separation

Citation: Maciejewski, M., Wichern, G., McQuinn, E., Le Roux, J., "WHAMR!: Noisy and Reverberant Single-Channel Speech Separation", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP40776.2020.9053327, April 2020, pp. 696-700.
Contacts: Gordon Wichern, Jonathan Le Roux

While significant advances have been made with respect to the separation of overlapping speech signals, studies have been largely constrained to mixtures of clean, near anechoic speech, not representative of real-world scenarios. Although the WHAM! dataset introduced noise to the ubiquitous wsj0-2mix dataset, it did not include reverberation, which is generally present in indoor recordings outside of recording studios. The spectral smearing caused by reverberation can result in significant performance degradation for standard deep learning-based speech separation systems, which rely on spectral structure and the sparsity of speech signals to tease apart sources. To address this, we introduce WHAMR!, an augmented version of WHAM! with synthetic reverberated sources.

## Finding Strength in Weakness: Learning to Separate Sounds with Weak Supervision

Citation: Pishdadian, F., Wichern, G., Le Roux, J., "Finding Strength in Weakness: Learning to Separate Sounds with Weak Supervision", IEEE/ACM Transactions on Audio, Speech, and Language Processing, DOI: 10.1109/TASLP.2020.3013105, Vol. 28, pp. 2386-2399, September 2020.
Contacts: Gordon Wichern, Jonathan Le Roux

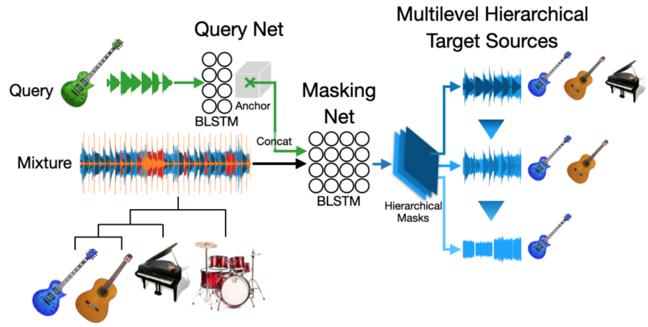



We propose objective functions and network architectures that enable training a source separation system with weak labels. In this scenario, weak labels are defined in contrast with strong time-frequency (TF) labels such as those obtained from isolated sources and refer either to frame-level weak labels where one only has access to the time periods when different sources are active in an audio mixture, or to clip-level weak labels that only indicate the presence or absence of sounds in an entire audio clip. We train a separator that estimates a TF mask for each type of sound event, using a sound event classifier as an assessor of the separator's performance to bridge the gap between the TF-level separation and the ground truth weak labels only available at the frame or clip level. We benchmark the performance of our algorithm using synthetic mixtures of overlapping events created from a database of sounds recorded in urban environments and show that the method can also be applied to other tasks such as music source separation.

## Hierarchical Musical Instrument Separation

Citation: Manilow, E., Wichern, G., Le Roux, J., "Hierarchical Musical Instrument Separation", International Society for Music Information Retrieval (ISMIR) Conference, October 2020, pp. 376-383.

Contacts: Gordon Wichern, Jonathan Le Roux

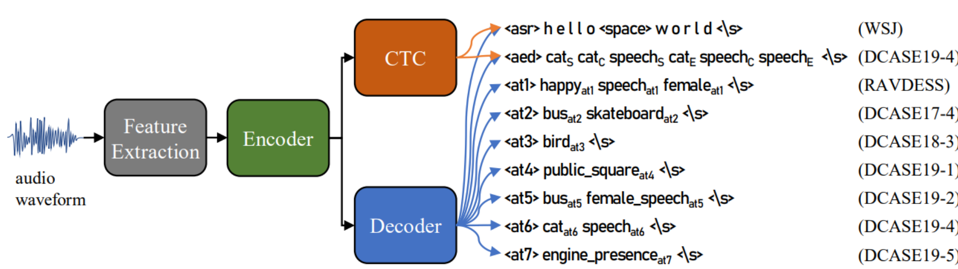



Many sounds that humans encounter are hierarchical in nature; a piano note is one of many played during a performance, which is one of many instruments in a band, which might be playing in a bar with other noises occurring. Inspired by this, we re-frame the musical source separation problem as hierarchical, combining similar instruments together at certain levels and separating them at other levels. This allows us to deconstruct the same mixture in multiple ways, depending on the appropriate level of the hierarchy for a given application. In this paper, we present various methods for hierarchical musical instrument separation, with some methods focusing on separating specific instruments (like guitars) and other methods that determine what to separate based on a user-supplied audio example.

## All-in-One Transformer: Unifying Speech Recognition, Audio Tagging, and Event Detection

Citation: Moritz, N., Wichern, G., Hori, T., Le Roux, J., "All-in-One Transformer: Unifying Speech Recognition, Audio Tagging, and Event Detection", Annual Conference of the International Speech Communication Association (Interspeech), DOI: 10.21437/Interspeech.2020-2757, October 2020, pp. 3112-3116.

Contacts: Gordon Wichern, Takaaki Hori, Jonathan Le Roux

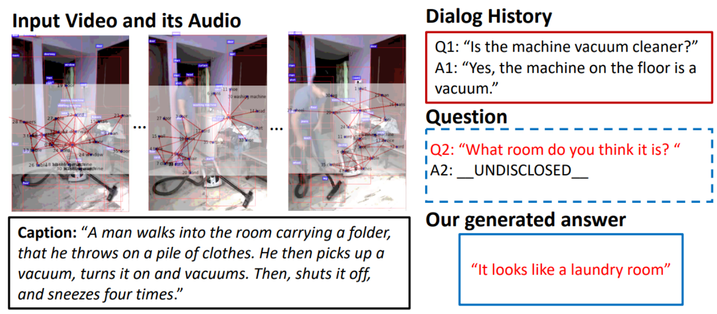



Automatic speech recognition (ASR), audio tagging (AT), and acoustic event detection (AED) are typically treated as separate problems, where each task is tackled using specialized system architectures. In this work, an all-in-one (AIO) acoustic model based on the Transformer architecture is trained to solve ASR, AT, and AED tasks simultaneously, where model parameters are shared across all tasks. Experiments demonstrate that the AIO Transformer achieves better performance compared to all baseline systems on various recent DCASE challenge tasks and is suitable for the total transcription of an acoustic scene, simultaneously transcribing speech and recognizing acoustic events.

## Dynamic Graph Representation Learning for Video Dialog via Multi-Modal Shuffled Transformers

Citation: Geng, S., Gao, P., Chatterjee, M., Hori, C., Le Roux, J., Zhang, Y., Li, H., Cherian, A., "Dynamic Graph Representation Learning for Video Dialog via Multi-Modal Shuffled Transformers", AAAI Conference on Artificial Intelligence, February 2021, pp. 1415-1423.

Contacts: Chiori Hori, Jonathan Le Roux, Anoop Cherian




Given an input video, its associated audio, and a brief caption, the audio-visual scene aware dialog (AVSD) task requires an agent to indulge in a question-answer dialog with a human about the audio-visual content. To solve this task, we introduce a semantics-controlled multi-modal shuffled Transformer reasoning framework, consisting of a sequence of Transformer modules, each taking a modality as input and producing representations conditioned on the input question. To encode fine-grained visual information, we present a novel dynamic scene graph representation learning pipeline that consists of an intra-frame reasoning layer producing spatio-semantic graph representations for every frame, and an inter-frame aggregation module capturing temporal cues.

## Model-Based Reinforcement Learning for Physical Systems Without Velocity and Acceleration Measurements

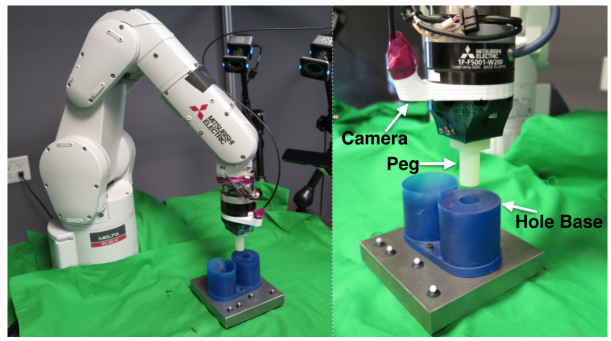
Citation: Romeres, D., Dalla Libera, A., Jha, D.K., Yerazunis, W.S., Nikovski, D.N., "Model-Based Reinforcement Learning for Physical Systems Without Velocity and Acceleration Measurements", Robotics and Automation Letters, DOI: 10.1109/LRA.2020.2977255, Vol. 5, No. 2, pp. 3548-3555, May 2020.

Contacts: Diego Romeres, Devesh K. Jha, William S. Yerazunis, Daniel N. Nikovski

We propose a derivative-free model learning framework for Reinforcement Learning (RL) algorithms based on Gaussian Process Regression (GPR). In many mechanical systems, only positions can be measured by the sensing instruments. Then, instead of representing the system state as suggested by the physics with a collection of positions, velocities, and accelerations, the state is represented as a set of past position measurements. However, the equation of motions derived by physical first principles cannot be directly applied in this framework. We introduce a novel derivative-free physically-inspired kernel, which can be combined with nonparametric derivative-free Gaussian Process models. Tests performed on two real platforms show that a positional state definition combined with the proposed model improves estimation performance and data-efficiency w.r.t. traditional models based on GPR.

## Understanding Multi-Modal Perception Using Behavioral Cloning for Peg-In-a-Hole Insertion Tasks

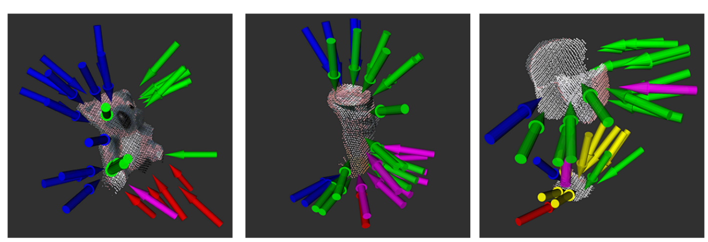
Citation: Romeres, D., Liu, Y., Jha, D.K., Nikovski, D.N., "Understanding Multi-Modal Perception Using Behavioral Cloning for Peg-In-a-Hole Insertion Tasks", Robotics: Science and Systems, July 2020.
Contacts: Diego Romeres, Devesh K. Jha, Daniel N. Nikovski




One of the main challenges in peg-in-a-hole (PiH) insertion tasks is in handling the uncertainty in the location of the target hole. In order to address this, high-dimensional sensor inputs from sensor modalities such as vision, force/torque sensing, and proprioception can be combined to learn control policies that are robust to this uncertainty in the target pose. Whereas deep learning has shown success in recognizing objects and making decisions with high-dimensional inputs, the learning procedure might damage a robot when applied directly to trial-and-error algorithms on a real system. At the same time, learning from Demonstration (LfD) methods have been shown to achieve compelling performance in real robotic systems by leveraging demonstration data provided by experts. In this paper, we investigate the merits of multiple sensor modalities such as vision, force/torque sensors, and proprioception when combined to learn a controller for real world assembly operation tasks using LfD techniques.

## Interactive Tactile Perception for Classification of Novel Object Instances

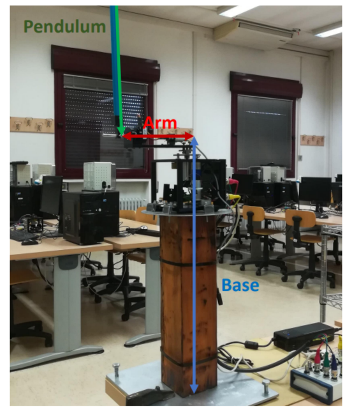
Citation: Corcodel, R., Jain, S., van Baar, J., "Interactive Tactile Perception for Classification of Novel Object Instances", IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), DOI: 10.1109/IROS45743.2020.9341795, November 2020, pp. 9861-9868.
Contacts: Radu Corcodel, Siddarth Jain



We present a novel approach for classification of unseen object instances from interactive tactile feedback. We demonstrate the utility of a low resolution tactile sensor array for tactile perception that can potentially close the gap between vision and physical contact for manipulation. We contrast our sensor to high-resolution camera-based tactile sensors. Our proposed approach interactively learns a one-class classification model using 3D tactile descriptors, and thus demonstrates an advantage over the existing approaches, which require pre-training on objects. We validate our proposed method on a set of household objects and results indicate good classification performance in real-world experiments

## Model-based Policy Search for Partially Measurable Systems

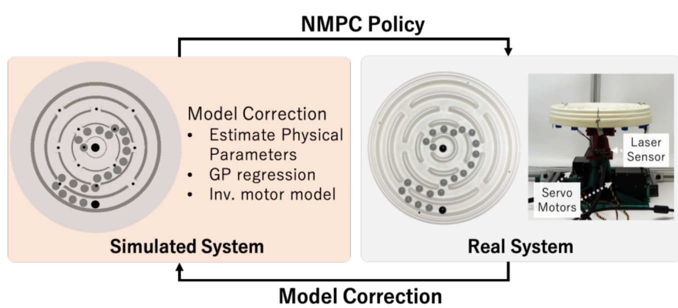
Citation: Romeres, D., Amadio, F., Dalla Libera, A., Nikovski, D.N., Carli, R., "Model-based Policy Search for Partially Measurable Systems", Advances in Neural Information Processing Systems (NeurIPS), December 2020.
Contacts: Diego Romeres, Daniel N. Nikovski




We propose a Model-Based Reinforcement Learning (MBRL) algorithm for Partially Measurable Systems (PMS), i.e., systems where the state can not be directly measured, but must be estimated through proper state observers. The proposed algorithm, named Monte Carlo Probabilistic Inference for Learning Control for Partially Measurable Systems (MC-PILCO4PMS), relies on Gaussian Processes (GPs) to model the system dynamics, and on a Monte Carlo approach to update the policy parameters. W.r.t. previous GP-based MBRL algorithms, MC-PILCO4PMS models explicitly the presence of state observers during policy optimization, allowing to deal PMS. The effectiveness of the proposed algorithm has been tested both in simulation and real systems.

## Data-Efficient Learning for Complex and Real-Time Physical Problem Solving using Augmented Simulation

Citation: Ota, K., Jha, D.K., Romeres, D., van Baar, J., Smith, K., Semistsu, T., Oiki, T., Sullivan, A., Nikovski, D.N., Tenanbaum, J., "Data-Efficient Learning for Complex and Real-Time Physical Problem Solving using Augmented Simulation", IEEE Robotics and Automation Letters, DOI: 10.1109/LRA.2021.3068887, Vol. 6, No. 2, March 2021.
Contacts: Devesh K. Jha, Diego Romeres, Alan Sullivan, Daniel N. Nikovski




Humans quickly solve tasks in novel systems with complex dynamics, without requiring much interaction. While deep reinforcement learning algorithms have achieved tremendous success in many complex tasks, these algorithms need a large number of samples to learn meaningful policies. We present a system that learns to move a marble to the center of a marble maze within minutes of interacting with the real system. Learning consists of initializing a physics engine with parameters estimated using data from the real system. The error in the physics engine is then corrected using Gaussian process regression, which is used to model the residual between real observations and physics engine simulations. The physics engine augmented with the residual model is then used to control the marble in the maze environment using a model-predictive feedback over a receding horizon.