Mitsubishi Electric Research Laboratories (MERL)

Annual Report

April 2022 through March 2023

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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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Table of Contents

Mitsubishi Electric Research Laboratories

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

MERL's mission—our assignment from Mitsubishi Electric:

- Generating new technology and intellectual property in areas of importance to Mitsubishi Electric.
- Impacting Mitsubishi Electric's business significantly: using our technical expertise in partnership with organizations in Mitsubishi Electric to produce new and improved products in Mitsubishi Electric's main areas of business.

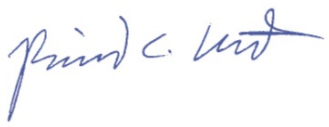
MERL's vision—our goal for ourselves:

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

MERL's values—how we operate:

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

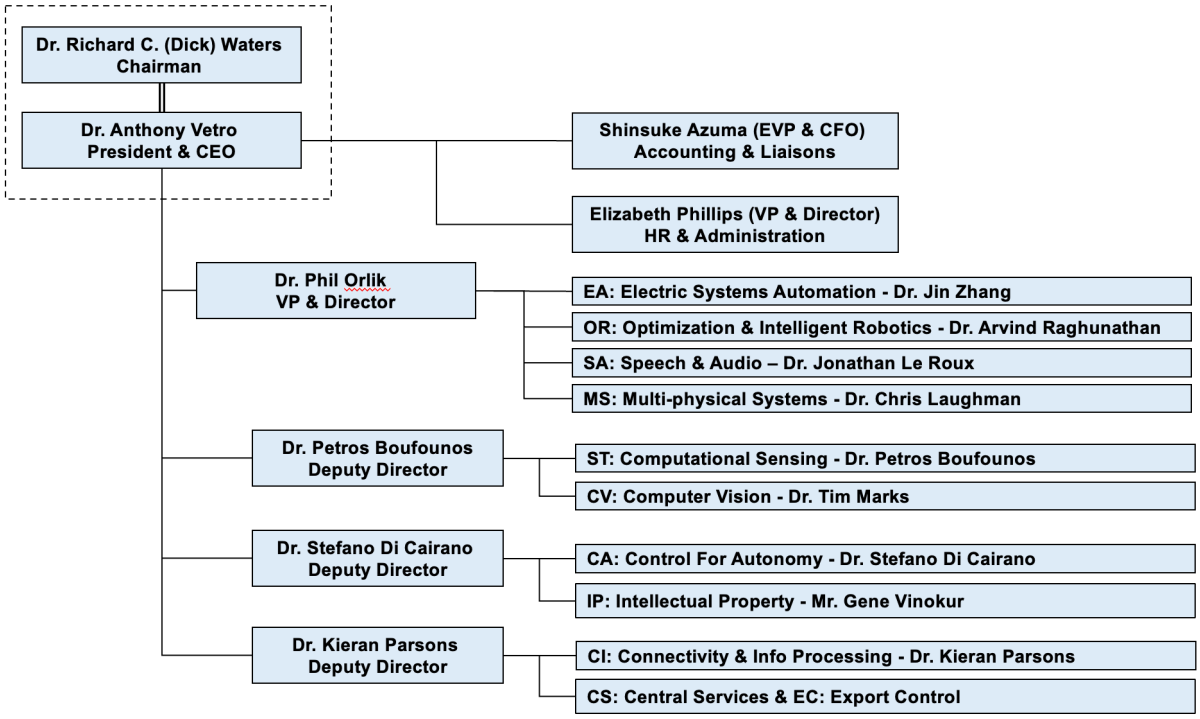
This annual report is a snapshot of MERL's web site. For additional and updated information please visit "www.merl.com".



Richard C. Waters
Chairman, MERL

MERL Organization

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



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

Dick 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. He was CEO of MERL from 1999 to 2023.

Anthony Vetro *Ph.D., NYU, 2001*
President & CEO, 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.

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.

Philip V. Orlik *Ph.D., State University of NY at Stony Brook, 1999*
Vice President & Director

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

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.

Petros T. Boufounos *Sc.D., Massachusetts Institute of Technology, 2006*
Deputy Director, Senior Team Leader,
Distinguished Research Scientist

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.

Stefano Di Cairano *Ph.D., University of Siena, 2008*
Deputy Director, Senior Team Leader,
Distinguished Research Scientist

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.

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

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.

Jinyun Zhang *Ph.D., University of Ottawa, 1991*
Advisor, Group Manager, 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.

Mitsubishi Electric

One of the world's largest companies, Mitsubishi Electric Corporation has $34 billion in annual sales, $1.9 billion in operating profits (in the year ending in March 2023) and more than 150,000 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 separate companies 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)
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 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
- **Integrated Design Center** (Ofuna, in greater Tokyo)
  Product, Interface and Concept Design
- **Communication Systems Engineering Center** (Amagasaki in greater Osaka)
  Network System and Security System
- **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

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. Petros Boufounos - Fellow, Institute of Electrical and Electronic Engineers
Dr. Toshiaki Koike-Akino - Fellow, Optica (formerly Optical Society of America)
Dr. Anthony Vetro - Fellow, Institute of Electrical and Electronic Engineers
Dr. Jin Zhang - Fellow, Institute of Electrical and Electronic Engineers

Awards and Major Events

MERL's paper, "Example-Based Super-Resolution" by William T. Freeman, Thouis R. Jones, and Egon C. Pasztor, published in a 2002 issue of IEEE Computer Graphics and Applications, was awarded a 2021 Test of Time Award in 2022 by the IEEE Computer Society. This best paper award recognizes regular or special issue papers published by the magazine that have made profound and long-lasting research impacts in bridging the theory and practice of computer graphics.

The committee of the International Conference on Artificial Intelligence Circuits and Systems (AICAS) 2022, selected MERL's paper entitled 'GaN Distributed RF Power Amplifier Automation Design with Deep Reinforcement Learning' as a winner of the AICAS 2022 Openedges Award.

Researchers from EPFL (Wenjie Xu, Colin Jones) and EMPA (Bratislav Svetozarevic), in collaboration with MERL researchers Ankush Chakrabarty and Chris Laughman, recently won the ASME Energy Systems Technical Committee Best Paper Award at the 2022 American Control Conference for their work on "VABO: Violation-Aware Bayesian Optimization for Closed-Loop Performance Optimization with Unmodeled Constraints.

The Conference committee of the 59th Design Automation Conference chose MERL's paper entitled 'Domain Knowledge-Infused Deep Learning for Automated Analog/RF Circuit Parameter Optimization', as a DAC Best Paper Award nominee. The committee evaluated both manuscript and submitted presentation recording, and has chosen MERL's paper as one of six nominees for this prestigious award. Decisions were based on the submissions' innovation, impact and exposition.

Marcus Greiff, a Visiting Research Scientist at MERL, was awarded one of three outstanding student paper awards at the IEEE CCTA 2022 conference for his paper titled "Quadrotor Control on SU(2)xR3 with SLAM Integration". The award was given for originality, clarity, and potential impact on practical applications of control.

Arvind Raghunathan, Senior Principal Research Scientist in the Data Analytics group, received the IEEE Control Systems Society Roberto Tempo Best CDC Paper Award. The award was presented at the 2022 IEEE Conference on Decision & Control (CDC). The Tempo Award Committee selects the best paper from the previous year's CDC based on originality, potential impact on any aspect of control theory, technology, or implementation, and for the clarity of writing.

MERL's research paper "IEEE 802.19.3 Standardization for Coexistence of IEEE 802.11ah and IEEE 802.15.4g Systems in Sub-1GHz Frequency Bands" won the Best Paper Award of the 2022 IPSJ Transactions on Consumer Devices and Systems. The Information Processing Society of Japan (IPSJ) award was established in 1970 and is conferred on the authors of particularly excellent papers, which are published in the IPSJ journals and transactions. Our paper was published by the IPSJ Transaction on Consumer Device and System Vol. 29 in 2021 and authors are Yukimasa Nagai, Takenori Sumi, Jianlin Guo, Philip Orlik and Hiroshi Mineno.

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: 9 papers in the American Control Conference (ACC), 8 papers in the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 6 papers in the EEE Conference on Decision and Control (CDC), 5 papers in the IEEE International Conference on Robotics and Automation (ICRA), and 4 papers in the Conference on Neural Information Processing Systems (NeurIPS).

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*
Senior Principal Research Scientist, Team Leader

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*
Chief Scientist, Distinguished Research Scientist

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.

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*
Principal 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.

Moitreya Chatterjee *Ph.D., University of Illinois Urbana-Champaign, 2022*
Research Scientist

Moitreya's research interests are in computer vision, and multimodal machine learning with a particular emphasis on learning from audio-visual data. His PhD work received the Joan and Lalit Bahl Fellowship and the Thomas and Margaret Huang Research Award. Earlier, he earned a M.S. degree in Computer Science from the University of Southern California (USC).

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

Vedang M. Deshpande *Ph.D., Texas A&M University, 2022*
Visiting Research Scientist

Vedang's research interests are in nonlinear and robust estimation and control of uncertain dynamic systems. His PhD research focused on developing theoretical frameworks and algorithms for designing sparse sensing and actuation architectures. Prior to his doctoral studies, Vedang worked in the software verification and validation group at Honeywell Aerospace.

Francois Germain *Ph.D., Stanford University, 2019*
Visiting Research Scientist

During his graduate studies, François worked on advancing the state of the art in efficient modelling of analog audio systems. Before joining MERL, he led research on music source separation and speech enhancement at iZotope. His research interests focus on efficient and robust signal processing and machine learning methods applied to speech, music, and audio content in general.

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.

Marcus Greiff *Ph.D., Lund University, 2021*
Visiting Research Scientist

Marcus' doctoral research focused on the control system design of unmanned aerial vehicles. As an intern at MERL, his work on estimation theory was acknowledged with a best student paper award at the IEEE CCTA conference. Marcus' research interests concern nonlinear control using Lyapunov and Matrosov theory, nonlinear estimation, optimal control and motion planning, and their interplay when applied to robotics and aerospace systems.

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.

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.

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.

Yoshimi Isu *M.S., Ochanomizu University, 1996*
Liaison Manager

Yoshimi joined Mitsubishi Electric in 1996 and worked on the research and development of video compression & image analysis and the application of this technology to video surveillance and digital broadcasting. She also made contributions to MPEG standardization. Prior to joining MERL, Yoshimi was the Senior Manager of the Image Analytics and Processing Technology group in Mitsubishi Electric's Information Technology R&D center.

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*
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.

Jessica Keshishian *B.S., Fisher College, 2019*
Staff Accountant

Jessica joined MERL in 2022 as an experienced staff accountant. She comes from a diverse industry background specializing in accounts receivable, accounts payable, and payroll.

Toshiaki Koike-Akino *Ph.D., Kyoto University, 2005*
Distinguished 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.

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*
Distinguished 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.

Jing Liu *Ph.D., University of California, San Diego, 2019*
Visiting Research Scientist

Before joining MERL, Jing was an Illinois Future Faculty fellow at the Computer Science department of the University of Illinois, Urbana Champaign (UIUC). Prior to that, he was a Postdoctoral Research Associate at the Coordinated Science Lab of UIUC. His research interests include Trustworthy AI, Distributed Learning and Inference, Robust and Efficient Internet-of-Things (IoT), and green AI.

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

Before coming to MERL, Suhas worked as an intern at MERL (2018), SRI International (2017) and Nvidia (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*
Principal 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, Team Leader

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, Senior Team Leader

Tim’s research at MERL spans a variety of areas in computer vision and machine learning, including generative models for computer vision, estimating vital signs from video, and face processing. Prior to joining MERL’s Computer Vision Group in 2008, Tim did postdoctoral research in robotic Simultaneous Localization and Mapping with NASA’s Jet Propulsion Laboratory.

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.

Pedro Miraldo *Ph.D., University of Coimbra, 2013*
Principal Research Scientist

Pedro Miraldo held an FCT postdoctoral researcher grant at the Institute for Systems & Robotics and the Department of Electrical & Computer Engineering, IST Instituto Superior Tecnico Lisbon from 2014 to 2018. Then, he joined the Division of Decision and Control Systems at KTH Royal Institute of Technology as a postdoctoral associate from 2018 to 2019. Finally, he returned to IST in 2019 as a second-stage Researcher (comparable to Assistant Research Professor).

Regina Mitarachi
Lab Administrator

Regina has a business background and worked many years in the banking industry in Austria. When she moved to the States, she studied photography at New England School of Photography, Boston and managed a professional photo lab in Boston. Prior to joining MERL in 2022, she was a Client Relationship Manager in a business education and research firm in Cambridge, MA.

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.

Daniel N. Nikovski *Ph.D., Carnegie Mellon University, 2002*
Chief Scientist

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.

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.

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*
Senior 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*
Senior 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, Senior Team Leader

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.

Joshua Rapp *Ph.D., Boston University, 2020*
Research Scientist

Josh's research lies at the intersection of optics, electronics, signal processing, and computer vision. His doctoral thesis investigated probabilistic models to improve the performance of single-photon lidar under real-world conditions. Prior to joining MERL, Josh was a postdoctoral researcher at Stanford University. His current research interests include computational imaging, statistical signal processing, and active sensing methods.

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.

Anita Singh *M.S., Eastern Nazarene College, 2010*
HR Generalist/Administrator

Anita brings leadership and operations experience to her role as the Human Resources Generalist at MERL. Prior to joining MERL in 2021, Anita was a Human Resources Manager and has experience with payroll, compliance, recruiting and general human resources administration.

Neil Stottler *B.S. Wentworth Institute of Technology, 2022*
Information Technology Support Specialist

After finishing his degree in Computer Networking, Neil worked at an IT provider. In addition, he was a Volunteer Firefighter in his hometown in Maine prior to moving to Cambridge.

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.

Wataru Tsujita *Dr. Eng., Tokyo Institute of Technology, 2005*
Liaison Manager

Wataru joined Mitsubishi Electric in 2005 and worked on research and development of sensing systems for various applications. Before joining MERL in 2022, he was the senior manager of the Sensor Application System Group in Sensor Information Processing Systems Division, Advanced Technology R&D Center.

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.

Anantaram Varatharajan *Ph.D., Politecnico di Torino, 2021*
Visiting Research Scientist

Anantaram's research focuses on the control of electrical machines and drives, with broader goals on efficiency and reliability. His Ph.D. work dealt with developing position sensor-less control techniques for synchronous motors and self-commissioning methods for machine identification. He is a recipient of Best Ph.D. Thesis Award from IEEE Industrial Electronics Society, Italy Chapter, and Best Student Paper Award from IEEE Workshop on Electrical Machine Design, Control and Diagnosis, 2021.

Fotios Vardaxis *B.S., Bentley University 1995*
Controller

Fotios has over 25 years of experience in accounting. Prior joining MERL in 2022 he served as CFO and Controller for financial services organizations where he was responsible for all accounting and finance functions.

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.

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

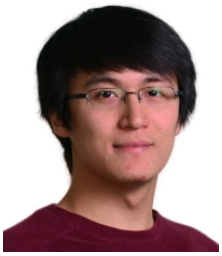
Gene graduated cum laude with distinction in Intellectual Property law. In addition, he holds advanced degrees in Mechanical Engineering and Computer Science. He is a member of Massachusetts Bar and has been a licensed patent practitioner since 2003.

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

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

Pu Wang *Ph.D., Stevens Institute of Technology, 2011*
Senior 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*
Senior 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, Team Leader

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*
Senior 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*
Senior 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.

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

Yerazunis, W.S., Weiss, A., **"UV In The Sky With Resin: A novel, on-orbit manufacturing technique"**, *SatMagazine*, Vol. April 2022 Edition, April 2022.

Wang, S., Taha, A., Chakrabarty, A., Sela, L., Abokifa, A., **"Model Order Reduction for Water Quality Dynamics"**, *Water Resources Research*, DOI: 10.1029/2021WR029856, April 2022.

Cauligi, A., Chakrabarty, A., Di Cairano, S., Quirynen, R., **"PRISM: Recurrent Neural Networks and Presolve Methods for Fast Mixed-integer Optimal Control"**, *Learning for Dynamics and Control Conference (L4DC)*, April 2022, pp. 34-46. (TR2022-039)

Zhang, J., Nikovski, D.N., **"Algorithms for Fast Computation of Pan Matrix Profiles of Time Series Under Unnormalized Euclidean Distances"**, *International Conference on Applied Statistics and Data Analytics*, April 2022. (TR2022-041)

Zhang, J., Nikovski, D.N., **"Algorithms for Fast Computation of Matrix Profiles of Time Series Under Unnormalized Euclidean Distances"**, *International Conference on Applied Statistics and Data Analytics*, April 2022. (TR2022-040)

Slizovskaia, O., Wichern, G., Wang, Z.-Q., Le Roux, J., **"Locate This, Not That: Class-Conditioned Sound Event DOA Estimation"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP43922.2022.9747604, April 2022, pp. 711-715. (TR2022-023)

Shah, A.P., Geng, S., Gao, P., Cherian, A., Hori, T., Marks, T.K., Le Roux, J., Hori, C., **"Audio-Visual Scene-Aware Dialog and Reasoning Using Audio-Visual Transformers with Joint Student-Teacher Learning"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, ISSN: 1520-6149, ISBN: 978-1-6654-0540-9, April 2022, pp. 7732-7736. (TR2022-019)

Yu, J., Wang, P., Koike-Akino, T., Orlik, P.V., **"Multi-Modal Recurrent Fusion for Indoor Localization"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP43922.2022.9746071, ISSN: 2379-190X, ISBN: 978-1-6654-0540-9, April 2022. (TR2022-018)

Moritz, N., Hori, T., Watanabe, S., Le Roux, J., **"Sequence Transduction with Graph-based Supervision"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP43922.2022.9747788, April 2022, pp. 7212-7216. (TR2022-024)

Peng, K.-C., **"Iterative Self Knowledge Distillation --- From Pothole Classification To Fine-Grained And COVID Recognition"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, Gan, W.-S. and Ma, K. K., Eds., DOI: 10.1109/ICASSP43922.2022.9746470, ISSN: 1520-6149, ISBN: 978-1-6654-0541-6, April 2022, pp. 3139-3143. (TR2022-020)

Higuchi, Y., Moritz, N., Le Roux, J., Hori, T., **"Advancing Momentum Pseudo-Labeling with Conformer and Initialization Strategy"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP43922.2022.9746275, April 2022, pp. 7672-7676. (TR2022-026)

Petermann, D., Wichern, G., Wang, Z.-Q., Le Roux, J., **"The Cocktail Fork Problem: Three-Stem Audio Separation for Real-World Soundtracks"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP43922.2022.9746005, April 2022, pp. 526-530. (TR2022-022)

Chang, X., Moritz, N., Hori, T., Watanabe, S., Le Roux, J., **"Extended Graph Temporal Classification for Multi-Speaker End-to-End ASR"**, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, DOI: 10.1109/ICASSP43922.2022.9747375, April 2022, pp. 7322-7326. (TR2022-021)

Mowlavi, S., Benosman, M., Nabi, S., **"Reinforcement Learning State Estimation for High-Dimensional Nonlinear Systems"**, *International Conference on Learning Representations (ICLR) Workshop*, April 2022. (TR2022-042)

Shirai, Y., Jha, D.K., Raghunathan, A., Romeres, D., **"Robust Pivoting: Exploiting Frictional Stability Using Bilevel Optimization"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA46639.2022.9811812, May 2022, pp. 992-998. (TR2022-045)

Ma, Y., Guo, J., Wang, Y., Chakrabarty, A., Ahn, H., Orlik, P.V., Guan, X., Lu, C., **"Optimal Dynamic Transmission Scheduling for Wireless Networked Control Systems"**, *IEEE Transactions On Control Systems Technology*, DOI: 10.1109/TCST.2022.3141581, May 2022. (TR2022-043)

Koike-Akino, T., Kojima, K., Wang, Y., **"AutoML Hyperparameter Tuning of Generative DNN Architecture for Nanophotonic Device Design"**, *Conference on Lasers and Electro-Optics (CLEO)*, DOI: 10.1364/CLEO_AT.2022.JW3A.44, ISBN: 978-1-957171-05-0, May 2022. (TR2022-046)

Jung, M., Kojima, K., Koike-Akino, T., Wang, Y., Zhu, D., Brand, M., **"Finding the Right Deep Neural Network Model for Efficient Design of Tunable Nanophotonic Devices"**, *Conference on Lasers and Electro-Optics (CLEO)*, DOI: 10.1364/CLEO_SI.2022.SW5E.6, ISBN: 978-1-957171-05-0, May 2022. (TR2022-047)

Lin, C., Ma, Y., Sels, D., **"Application of Pontryagin's Maximum Principle to Quantum Metrology in Dissipative Systems"**, *Physical Reivew A*, DOI: 10.1103/PhysRevA.105.042621, Vol. 105, No. 4, pp. 042621, May 2022. (TR2022-048)

Koike-Akino, T., Wang, P., Wang, Y., **"Quantum Transfer Learning for Wi-Fi Sensing"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC45855.2022.9839011, ISSN: 1938-1883, ISBN: 978-1-5386-8347-7, May 2022. (TR2022-044)

Zhu, D., Kojima, K., Koike-Akino, T., Brand, M., **"Global Phase Correction Improves Metalens Efficiency"**, *Conference on Lasers and Electro-Optics (CLEO)*, DOI: 10.1364/CLEO_QELS.2022.FM1B.3, ISBN: 978-1-957171-05-0, May 2022. (TR2022-049)

Song, H., Kim, K.J., Guo, J., Orlik, P.V., Parsons, K., **"Semi-Persistent Scheduling Scheme for Low-Latency and High-Reliability Transmissions in Private 5G Networks"**, *IEEE International Conference on Communications Workshops (ICC)*, May 2022, pp. 651-656. (TR2022-050)

Liu, B., Koike-Akino, T., Wang, Y., Parsons, K., **"Variational Quantum Compressed Sensing for Joint User and Channel State Acquisition in Grant-Free Device Access Systems"**, *IEEE International Conference on Communications (ICC)*, DOI: 10.1109/ICC45855.2022.9838445, ISSN: 1938-1883, ISBN: 978-1-5386-8347-7, May 2022. (TR2022-052)

Zhu, X., Jain, S., Tomizuka, M., van Baar, J., **"Learning to Synthesize Volumetric Meshes from Vision-based Tactile Imprints"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA46639.2022.9812092, ISBN: 978-1-7281-9681-7, May 2022, pp. 4833-4839. (TR2022-055)

Leu, J., Wang, Y., Tomizuka, M., Di Cairano, S., **"Autonomous Vehicle Parking in Dynamic Environments: An Integrated System with Prediction and Motion Planning"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA46639.2022.9812309, May 2022, pp. 10890-10897. (TR2022-056)

Vinod, A.P., Safaoui, S., Chakrabarty, A., Quirynen, R., Yoshikawa, N., Di Cairano, S., **"Safe multi-agent motion planning via filtered reinforcement learning"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA46639.2022.9812259, ISBN: 978-1-7281-9681-7, May 2022, pp. 7270-7276. (TR2022-053)

Danielson, C., Bortoff, S.A., Chakrabarty, A., **"Extremum Seeking Control with an Adaptive Gain Based On Gradient Estimation Error"**, *IEEE Transactions on Systems Man and Cybernetics: Systems*, DOI: 10.1109/TSMC.2022.3171132, May 2022.

Zhu, X., Jain, S., Tomizuka, M., van Baar, J., **"Synthesizing and Simulating Volumetric Meshes from Vision-based Tactile Imprints"**, *ICRA 2022 Workshop on Reinforcement Learning for Contact-Rich Manipulation*, May 2022. (TR2022-058)

Raghunathan, A., Jha, D.K., Romeres, D., **"PYROBOCOP: Python-based Robotic Control & Optimization Package for Manipulation"**, *IEEE International Conference on Robotics and Automation (ICRA)*, DOI: 10.1109/ICRA46639.2022.9812069, ISBN: 978-1-7281-9681-7, May 2022. (TR2022-057)

Chang, F., Sun, H., Kawano, S., Nikovski, D., Kitamura, S., Su, W., **"A Fault Detection and Location Technique for Inverter-Dominated Islanding Microgrids"**, *International Electrical and Energy Conference (CIEEC)*, DOI: 10.1109/CIEEC54735.2022.9846567, May 2022, pp. 2041-2046. (TR2022-073)

Nabi, S., Caulfield, C.-C., **"Airflow Optimization to Prevent Transmission of COVID-19"**, *International Conference on Building Energy and Environment (COBEE)*, May 2022. (TR2022-077)

Wollenstein-Betech, S., Sun, C., Zhang, J., Cassandras, C.G., Paschalidis, I.C., **"Joint Data-Driven Estimation of Origin-Destination Demand and Travel Latency Functions in Multi-Class Transportation Networks"**, *IEEE Transactions on Control of Network Systems*, DOI: 10.1109/TCNS.2022.3161200, June 2022. (TR2022-078)

Mamakoukas, G., Di Cairano, S., Vinod, A.P., **"Robust Model Predictive Control with Data-Driven Koopman Operators"**, *American Control Conference (ACC)*, June 2022, pp. 3885-3892. (TR2022-054)

Pervej, M.F., Guo, J., Kim, K.J., Parsons, K., Orlik, P.V., Di Cairano, S., Menner, M., Berntorp, K., Nagai, Y., Dai, H., **"Mobility, Communication and Computation Aware Federated Learning for Internet of Vehicles"**, *IEEE Intelligent Vehicles Symposium (IV)*, June 2022. (TR2022-079)

Elango, P., Di Cairano, S., Kalabic, U., Weiss, A., **"Local Eigenmotion Control for Near Rectilinear Halo Orbits"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC53348.2022.9867672, ISSN: 2378-5861, ISBN: 978-1-6654-5196-3, June 2022, pp. 1822-1827. (TR2022-060)

Berntorp, K., Menner, M., **"Online Constrained Bayesian Inference and Learning of Gaussian-Process State-Space Models"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC53348.2022.9867635, June 2022, pp. 940-945. (TR2022-066)

Sanfelice, R.G., Di Cairano, S., **"Reference Governor for Hybrid Dynamical Systems"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC53348.2022.9867303, June 2022. (TR2022-061)

Bonzanini, A.D., Mesbah, A., Di Cairano, S., **"Multi-stage Perception-aware Chance-constrained MPC with Applications to Automated Driving"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC53348.2022.9867264, June 2022. (TR2022-062)

Firoozi, R., Quirynen, R., Di Cairano, S., **"Coordination of Autonomous Vehicles and Dynamic Traffic Rules in Mixed Automated/Manual Traffic"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC53348.2022.9867802, June 2022. (TR2022-059)

Vaskov, S., Quirynen, R., Menner, M., Berntorp, K., **"Friction-Adaptive Stochastic Predictive Control for Trajectory Tracking of Autonomous Vehicles"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC53348.2022.9867523, June 2022, pp. 1970-1975. (TR2022-065)

Deshpande, V., Laughman, C.R., Ma, Y., Rackauckas, C., **"Constrained Smoothers for State Estimation of Vapor Compression Cycles"**, *American Control Conference (ACC)*, DOI: 10.23919/ACC53348.2022.9867269, ISSN: 2378-5861, ISBN: 978-1-6654-5196-3, June 2022, pp. 2333-2340. (TR2022-063)

Xu, W., Jones, C., Svetozarevic, B., Laughman, C.R., Chakrabarty, A., **"VABO: Violation-Aware Bayesian Optimization for Closed-Loop Control Performance Optimization with Unmodeled Constraints"**, *American Control Conference (ACC)*, ISBN: 978-1-6654-5197-0, June 2022, pp. 5288-5293. (TR2022-064)

Sun, Y., Benosman, M., Ma, R., **"GaN Distributed RF Power Amplifier Automation Design with Deep Reinforcement Learning"**, *International Conference on Artificial Intelligence Circuits and Systems (AICAS)*, June 2022. (TR2022-074)

Liu, B., Koike-Akino, T., Wang, Y., Kim, K.J., Brand, M., Aeron, S., Parsons, K., **"Data Privacy and Protection on Deep Leakage from Gradients by Layer-Wise Pruning"**, *IEEE Information Theory and Applications Workshop (ITA)*, June 2022. (TR2022-080)

Chatterjee, M., Ahuja, N., Cherian, A., **"Quantifying Predictive Uncertainty for Stochastic Video Synthesis from Audio"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2022. (TR2022-082)

Li, P., Wang, P., Berntorp, K., Liu, H., **"Exploiting Temporal Relations on Radar Perception for Autonomous Driving"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, June 2022. (TR2022-069)

Jin, S., Wang, P., Boufounos, P.T., Orlik, P.V., Takahashi, R., Roy, S., **"Spatial-Domain Mutual Interference Mitigation for Slow-Time MIMO-FMCW Automotive Radar"**, *IEEE Sensor Array and Multichannel Signal Processing Workshop (SAM)*, DOI: 10.1109/SAM53842.2022.9827852, ISSN: 2151-870X, ISBN: 978-1-6654-0633-8, June 2022. (TR2022-067)

Koike-Akino, T., Wang, P., Wang, Y., **"AutoQML: Automated Quantum Machine Learning for Wi-Fi Integrated Sensing and Communications"**, *IEEE Sensor Array and Multichannel Signal Processing Workshop (SAM)*, DOI: 10.1109/SAM53842.2022.9827846, June 2022. (TR2022-068)

Sullivan, A., Wang, J., Li, X., Chen, S., Abbot, L., **"PointMotionNet: Point-Wise Motion Learning for Large-Scale LiDAR Point Clouds Sequences"**, *CVPR Workshop on Autonomous Driving*, June 2022. (TR2022-083)

Dzieciol, H., Koike-Akino, T., Wang, Y., Parsons, K., **"Inverse Regular Perturbation with ML-Assisted Phasor Correction for Fiber Nonlinearity Compensation"**, *Optics Letters*, DOI: 10.1364/OL.460929, Vol. 47, No. 14, pp. 3471-3474, June 2022. (TR2022-070)

Miraldo, P., Iglesias, J.P., **"A Unified Model for Line Projections in Catadioptric Cameras with Rotationally Symmetric Mirrors"**, *IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, DOI: 10.1109/CVPR52688.2022.01534, June 2022. (TR2022-084)

Schperberg, A., Di Cairano, S., Menner, M., **"Auto-Tuning of Controller and Online Trajectory Planner for Legged Robots"**, *IEEE Robotics and Automation Letters*, DOI: 10.1109/LRA.2022.3185387, Vol. 7, No. 3, pp. 7802-7809, June 2022. (TR2022-085)

Li, K., Matsuda, T., Nishimura, K., Yagyu, E., Teo, K.H., Rakheja, S., **"Trapping Phenomena in GaN HEMTs with Fe- and C-doped Buffer"**, *Device Research Conference*, DOI: 10.1109/DRC55272.2022.9855817, June 2022. (TR2022-086)

de Castro, M., Wang, Y., Vanfretti, L., Wang, H., Liu, D., Bortoff, S.A., Takegami, T., **"Modeling, Simulation and Control of Turboelectric Propulsion Systems for More Electric Aircrafts using Modelica"**, *AIAA Aviation Forum*, DOI: 10.2514/6.2022-3873, June 2022, pp. 3873. (TR2022-087)

Zhang, J., Nikovski, D., **"APUMPEDI: Approximating Pan Matrix Profiles of Time Series Under Unnormalized Euclidean Distances by Interpolation"**, *International conference on Time Series and Forecasting (ITISE)*, June 2022. (TR2022-088)

Shirai, Y., Jha, D.K., Raghunathan, A., Romeres, D., **"Robust Pivoting Manipulation Using Bilevel Contact-Implicit Optimization"**, *RSS Workshop on The Science of Bumping into Things*, June 2022. (TR2022-090)

Kodama, T., Koike-Akino, T., Millar, D.S., Kojima, K., Parsons, K., **"DNN-assisted phase distance tuned PSK modulation for PAM4-to-QPSK format conversion gateway node"**, *Optics Express*, DOI: 10.1364/OE.449812, Vol. 30, No. 7, pp. 10866-10876, June 2022. (TR2022-091)

Raghunathan, A., Jha, D.K., Romeres, D., **"Python-based Open Source Package for Optimization of Contact-rich Systems"**, *Robotics: Science and Systems*, June 2022. (TR2022-089)

Venkatesh, S., Wichern, G., Subramanian, A.S., Le Roux, J., **"Disentangled Surrogate Task Learning for Improved Domain Generalization in Unsupervised Anomolous Sound Detection,"** Tech. Rep. TR2022-092, Detection and Classification of Acoustic Scenes and Events (DCASE) Challenge 2022, July 2022. (TR2022-092)

Greiff, M., Di Cairano, S., Berntorp, K., **"Dynamic Clustering for GNSS Positioning with Multiple Receivers"**, *International Conference on Information Fusion (FUSION)*, DOI: 10.23919/FUSION49751.2022.9841289, ISBN: 978-1-6654-8941-6, July 2022, pp. 1-7. (TR2022-094)

Berntorp, K., Greiff, M., Di Cairano, S., **"Bayesian Sensor Fusion of GNSS and Camera With Outlier Adaptation for Vehicle Positioning"**, *International Conference on Information Fusion (FUSION)*, DOI: 10.23919/FUSION49751.2022.9841302, ISBN: 978-1-7377497-2-1, July 2022, pp. 1-8. (TR2022-093)

Menner, M., Ma, Z., Berntorp, K., Di Cairano, S., **"Location and Driver-Specific Vehicle Adaptation Using Crowdsourced Data"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC55457.2022.9838135, July 2022, pp. 769-774. (TR2022-095)

Cao, W., Benosman, M., Zhang, X., Ma, R., **"Domain Knowledge-Infused Deep Learning for Automated Analog/Radio-Frequency Circuit Parameter Optimization"**, *ACM/IEEE Design Automation Conference*, July 2022. (TR2022-096)

Smedemark-Margulies, N., Wang, Y., Koike-Akino, T., Erdogmus, D., **"AutoTransfer: Subject Transfer Learning with Censored Representations on Biosignals Data"**, *International Conference of the IEEE Engineering in Medicine & Biology Society (EMBS)*, DOI: 10.1109/EMBC48229.2022.9871649, ISSN: 2694-0604, ISBN: 978-1-7281-2782-8, July 2022. (TR2022-098)

Chakrabarty, A., Burns, D.J., Guay, M., Laughman, C.R., **"Rapid Energy Optimization Of Vapor Compression Systems Using Probabilistic Machine Learning And Extremum Seeking Control"**, *International Refrigeration and Air Conditioning Conference (IRACC)*, July 2022. (TR2022-172)

Qiao, H., Laughman, C.R., **"Dynamic Modeling of Oil Transport in Vapor Compression Systems"**, *International Refrigeration and Air Conditioning Conference (IRACC)*, July 2022. (TR2022-122)

Demir, A., Koike-Akino, T., Wang, Y., Erdogmus, D., **"EEG-GAT: Graph Attention Networks for Classification of Electroencephalogram (EEG) Signals"**, *International Conference of the IEEE Engineering in Medicine & Biology Society (EMBS)*, DOI: 10.1109/EMBC48229.2022.9871984, ISSN: 2694-0604, ISBN: 978-1-7281-2782-8, July 2022. (TR2022-097)

Qiao, H., Laughman, C.R., **"A Low-Order Model for Nonlinear Dynamics of Heat Exchangers"**, *International Refrigeration and Air Conditioning Conference (IRACC)*, July 2022. (TR2022-123)

Jha, D.K., Romeres, D., Yerazunis, W.S., Nikovski, D.N., **"Imitation and Supervised Learning of Compliance for Robotic Assembly"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC55457.2022.9838102, ISBN: 978-3-9071-4407-7, July 2022, pp. 1882-1889. (TR2022-099)

Zhang, J., Tsiligkaridis, A., Taguchi, H., Raghunathan, A., Nikovski, D.N., **"Transformer Networks for Predictive Group Elevator Control"**, *European Control Conference (ECC)*, DOI: 10.23919/ECC55457.2022.9838059, July 2022. (TR2022-100)

Shirsat, A., Sun, H., Kim, K.J., Guo, J., Nikovski, D.N., **"ConvEDNet: A Convolutional Energy Disaggregation Network Using Continuous Point-On-Wave Measurements"**, *IEEE PES General Meeting*, DOI: 10.1109/PESGM48719.2022.9916802, July 2022. (TR2022-101)

Rambhatla, S., Jones, M.J., Chellappa, R., **"An Empirical Analysis of Boosting Deep Networks"**, *International Joint Conference on Neural Networks (IJCNN)*, DOI: 10.1109/IJCNN55064.2022.9892204, July 2022. (TR2022-075)

Xia, H., Wang, P., Koike-Akino, T., Wang, Y., Orlik, P.V., Ding, Z., **"Adversarial Bi-Regressor Network for Domain Adaptive Regression"**, *International Joint Conference on Artificial Intelligence (IJCAI)*, Lud De Raedt, Eds., DOI: 10.24963/ijcai.2022/501, July 2022, pp. 3608-3614. (TR2022-103)

Nasrin, S., Shylendra, A., Darabi, N., Tulabandhula, T., Gomes, W., Chakrabarty, A., Trivedi, A., **"ENOS: Energy-aware Network Operator Search in Deep Neural Networks"**, *IEEE Access*, DOI: 10.1109/ACCESS.2022.3192515, July 2022.

Koike-Akino, T., Wang, Y., **"AutoVAE: Mismatched Variational Autoencoder with Irregular Posterior Prior Pairing"**, *IEEE International Symposium on Information Theory (ISIT)*, DOI: 10.1109/ISIT50566.2022.9834769, ISSN: 2157-8117, ISBN: 978-1-6654-2159-1, July 2022. (TR2022-071)

Yerazunis, W.S., Weiss, A., Radyjowski, P., Cottrell, R., **"On-Orbit Fabrication of Spacecraft Structures by Direct Solar Photopolymerization"**, *Solid Freeform Fabrication Symposium*, July 2022, pp. 1676-1686. (TR2022-104)

Yu, J., Wang, P., Koike-Akino, T., Wang, Y., Orlik, P.V., Buehrer, R.M., **"Multi-Band Wi-Fi Sensing with Matched Feature Granularity"**, *IEEE Internet of Things Journal*, DOI: 10.1109/JIOT.2022.3190826, ISSN: 2327-4662, July 2022. (TR2022-105)

Kojima, K., Jung, M., Koike-Akino, T., Wang, Y., Brand, M., Parsons, K., **"Deep Transfer Learning for Nanophotonic Device Design"**, *Conference on Lasers and Electro-Optics (CLEO) Pacific Rim*, July 2022. (TR2022-107)

Menner, M., Chakrabarty, A., Berntorp, K., Di Cairano, S., **"Learning Optimization-based Control Policies Directly from Digital Twin Simulations"**, *IEEE Conference on Control Technology and Applications (CCTA)*, DOI: 10.1109/CCTA49430.2022.9966077, August 2022, pp. 895-900. (TR2022-108)

Wang, Z., Ahmad, A., Quirynen, R., Wang, Y., Bhagat, A., Zeino, E., Zushi, Y., Di Cairano, S., **"Motion Planning and Model Predictive Control for Automated Tractor-Trailer Hitching Maneuver"**, *IEEE Conference on Control Technology and Applications (CCTA)*, DOI: 10.1109/CCTA49430.2022.9966181, August 2022, pp. 676-682. (TR2022-109)

Koike-Akino, T., Wang, P., Yamashita, G., Tsujita, W., Nakajima, M., **"Quantum Feature Extraction for THz Multi-Layer Imaging"**, *International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, DOI: 10.1109/IRMMW-THz50927.2022.9896037, ISSN: 2162-2035, ISBN: 978-1-7281-9427-1, August 2022. (TR2022-110)

Russel, R.H., Benosman, M., van Baar, J., Corcodel, R., **"Lyapunov Robust Constrained-MDPs for Sim2Real Transfer Learning"** Federated and Transfer Learning, August 2022. (TR2022-111)

Zhan, S., Wichern, G., Laughman, C.R., Chong, A., Chakrabarty, A., **"Calibrating building simulation models using multi-source datasets and meta-learned Bayesian optimization"**, *Energy and Buildings*, DOI: 10.1016/j.enbuild.2022.112278, Vol. 270, pp. 112278, September 2022. (TR2022-072)

Higuchi, Y., Moritz, N., Le Roux, J., Hori, T., **"Momentum Pseudo-Labeling: Semi-Supervised ASR with Continuously Improving Pseudo-Labels"**, *IEEE Journal of Selected Topics in Signal Processing*, DOI: 10.1109/JSTSP.2022.3195367, ISSN: 1941-0484, Vol. 16, No. 6, pp. 1424-1438, September 2022. (TR2022-112)

Wang, B., Talukder, K., Sakamoto, Y., **"Topological Data Analysis for Image-based Machine Learning: Application to Electric Motors"**, *IEEE International Conference on Electrical Machines (ICEM)*, DOI: 10.1109/ICEM51905.2022.9910734, September 2022, pp. 1015-1021. (TR2022-113)

Elango, P., Di Cairano, S., Berntorp, K., Weiss, A., **"Sequential linearization-based station keeping with optical navigation for NRHO"**, *AAS/AIAA Astrodynamics Specialist Conference*, September 2022. (TR2022-114)

Suda, T., Nikovski, D., **"Deep Reinforcement Learning for Optimal Sailing Upwind"**, *IEEE International Joint Conference on Neural Networks IJCNN*, DOI: 10.1109/IJCNN55064.2022.9892369, ISSN: 2161-4393, ISBN: 978-1-7281-8671-9/22, September 2022, pp. 1-8. (TR2022-102)

Tzinis, E., Wichern, G., Subramanian, A.S., Smaragdis, P., Le Roux, J., **"Heterogeneous Target Speech Separation"**, *Interspeech*, DOI: 10.21437/Interspeech.2022-10717, September 2022, pp. 1796-1800. (TR2022-115)

Hori, C., Hori, T., Le Roux, J., **"Low-Latency Streaming Scene-aware Interaction Using Audio-Visual Transformers"**, *Interspeech*, DOI: 10.21437/Interspeech.2022-10891, September 2022, pp. 4511-4515. (TR2022-116)

Zawislak, R., Greiff, M., Kim, K.J., Berntorp, K., Di Cairano, S., Mao, K., Parsons, K., Orlik, P.V., Sato, Y., **"GNSS Multipath Detection Aided by Unsupervised Domain Adaptation"**, *ION-GNSS+ Conference*, DOI: 10.33012/2022.18333, September 2022, pp. 2127-2137. (TR2022-118)

Rapp, J., Mansour, H., Boufounos, P.T., Orlik, P.V., Koike-Akino, T., Parsons, K., **"Maximum Likelihood Surface Profilometry via Optical Coherence Tomography"**, *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP46576.2022.9897247, ISSN: 2381-8549, ISBN: 978-1-6654-9620-9, September 2022, pp. 1561-1565. (TR2022-117)

Wang, S., Guo, J., Wang, P., Parsons, K., Orlik, P.V., Nagai, Y., Sumi, T., Pathak, P., ,, **"X-Disco: Cross-technology Neighbor Discovery"**, *IEEE International Conference on Sensing, Communication, and Networking*, September 2022. (TR2022-119)

Tsiligkaridis, A., Zhang, J., Paschalidis, I.C., Taguchi, H., Sakajo, S., Nikovski, D.N., **"Context-Aware Destination and Time-To-Destination Prediction Using Machine Learning"**, *IEEE International Smart Cities Conference*, DOI: 10.1109/ISC255366.2022.9922593, September 2022. (TR2022-120)

Koike-Akino, T., Wang, Y., **"quEEGNet: Quantum AI for Biosignal Processing"**, *IEEE Conference on Biomedical and Health Informatics (BHI)*, DOI: 10.1109/BHI56158.2022.9926814, ISSN: 2641-3604, ISBN: 978-1-6654-8791-7, September 2022. (TR2022-121)

Bortoff, S.A., Laughman, C.R., **"Estimation: A Key Technology for Digital Twins"**, *Mitsubishi Sanden Gihou*, Vol. 96, No. 8, pp. 304-307, October 2022. (TR2022-127)

Wang, Y., **"Self-tuning Optimal Torque Control for Servomotor Drives Via Adaptive Dynamic Programming"**, *IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, DOI: 10.1109/SMC53654.2022.9945395, October 2022. (TR2022-125)

Zheng, X., Liu, D., Inoue, H., Kanemaru, M., **"Eccentricity Severity Estimation of Induction Machines using a Sparsity-Driven Regression Model"**, *The Fourteenth Annual Energy Conversion Congress and Exposition*, DOI: 10.1109/ECCE50734.2022.9947498, ISSN: 2329-3748, ISBN: 978-1-7281-9387-8, October 2022. (TR2022-126)

Nishanth, F., Wang, B., **"Topology Optimization of Electric Machines: A Review"**, *IEEE Energy Conversion Congress and Exposition (ECCE)*, DOI: 10.1109/ECCE50734.2022.9948073, October 2022, pp. 1-8. (TR2022-128)

Mansour, H., Lohit, S., Boufounos, P.T., **"Distributed Radar Autofocus Imaging Using Deep Priors"**, *IEEE International Conference on Image Processing (ICIP)*, DOI: 10.1109/ICIP46576.2022.9897332, October 2022, pp. 2511-2515. (TR2022-129)

Wang, B., Lin, C., Inoue, H., Kanemaru, M., **"Topological Data Analysis for Electric Motor Eccentricity Fault Detection"**, *Annual Conference of the IEEE Industrial Electronics Society (IECON)*, DOI: 10.1109/IECON49645.2022.9968912, October 2022, pp. 1-6. (TR2022-130)

Paul, S., Roy Chowdhury, A.K., Cherian, A., **"AVLEN: Audio-Visual-Language Embodied Navigation in 3D Environments"**, *Advances in Neural Information Processing Systems (NeurIPS)*, October 2022, pp. 6236-6249. (TR2022-131)

Sun, H., Kitamura, S., Nikovski, D.N., **"Fair Blackout Rotation for Distribution Systems under Extreme Weather Events"**, *IEEE PES ISGT EUROPE*, DOI: 10.1109/ISGT-Europe54678.2022.9960699., October 2022, pp. 1-6. (TR2022-132)

Leu, J., Wang, Y., Tomizuka, M., Di Cairano, S., **"Improved A-Search Guided Tree for Autonomous Trailer Planning"**, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, DOI: 10.1109/IROS47612.2022.9982121, October 2022. (TR2022-133)

Ahmed, S.M., Lohit, S., Peng, K.-C., Jones, M.J., Roy Chowdhury, A.K., **"Cross-Modal Knowledge Transfer Without Task-Relevant Source Data"**, *European Conference on Computer Vision (ECCV)*, Avidan, S and Brostow, G and Cisse M and Farinella, G.M. and Hassner T., Eds., DOI: 10.1007/978-3-031-19830-4_7, ISBN: 978-3-031-19830-4, October 2022, pp. 111-127. (TR2022-135)

Xia, H., Wang, P., Ding, Z., **"Incomplete Multi-view Domain Adaptation via Channel Enhancement and Knowledge Transfer"**, *European Conference on Computer Vision (ECCV)*, DOI: 10.1007/978-3-031-19830-4_12, ISBN: 978-3-031-19830-4, October 2022. (TR2022-134)

Sumi, T., Nagai, Y., Guo, J., Mineno, H., **"IEEE Wireless Standards for Internet of Things"**, *IEEE World Forum on Internet of Things (WFIoT)*, October 2022. (TR2022-136)

Qiao, H., Laughman, C.R., **"Performance Enhancements for Zero-Flow Simulation of Vapor Compression Cycles"**, *American Modelica Conference*, DOI: 10.3384/ECP21186128, October 2022, pp. 128-135. (TR2022-137)

Mowlavi, S., Nabi, S., **"Optimal control of PDEs using physics-informed neural networks"**, *Journal of Computational Physics*, DOI: j.jcp.2022.111731, Vol. 473, pp. 111731, October 2022. (TR2022-143)

Ma, Y., Wang, Y., Di Cairano, S., Koike-Akino, T., Guo, J., Orlik, P.V., Guan, X., Lu, C., **"Smart Actuation for End-Edge Industrial Control Systems"**, *IEEE Transactions on Automation Science and Engineering*, DOI: 10.1109/TASE.2022.3216217, October 2022. (TR2022-138)

Schneider, T., Belousov, B., Chalvatzaki, G., Romeres, D., Jha, D.K., Peters, J., **"Active Exploration for Robotic Manipulation"**, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, DOI: 10.1109/IROS47612.2022.9982061, ISSN: 2153-0866, ISBN: 978-1-6654-7927-1, October 2022. (TR2022-139)

Yu, X., Smedemark-Margulies, N., Aeron, S., Koike-Akino, T., Moulin, P., Brand, M., Parsons, K., Wang, Y., **"Improving Adversarial Robustness by Learning Shared Information"**, *Pattern Recognition*, DOI: 10.1016/j.patcog.2022.109054, ISSN: 0031-3203, Vol. 134, pp. 109054, November 2022. (TR2022-141)

Chatterjee, M., Ahuja, N., Cherian, A., **"Learning Audio-Visual Dynamics Using Scene Graphs for Audio Source Separation"**, *Advances in Neural Information Processing Systems (NeurIPS)*, November 2022. (TR2022-140)

Venkatesh, S., Wichern, G., Subramanian, A.S., Le Roux, J., **"Improved Domain Generalization via Disentangled Multi-Task Learning in Unsupervised Anomalous Sound Detection"**, *DCASE Workshop*, Lagrange, M. and Mesaros, A. and Pellegrini, T. and Richard, G. and Serizel, R. and Stowell, D., Eds., ISBN: 978-952-03-2677-7, November 2022. (TR2022-146)

Aguilar Marsillach, D., Di Cairano, S., Weiss, A., **"Abort-Safe Spacecraft Rendezvous on Elliptic Orbits"**, *IEEE Transactions on Control Systems Technology*, DOI: 10.1109/TCST.2022.3216077, ISSN: 1063-6536, November 2022. (TR2022-142)

Chakrabarty, A., Burns, D.J., Guay, M., Laughman, C.R., **"Extremum seeking controller tuning for heat pump optimization using failure-robust Bayesian optimization"**, *Journal of Process Control*, DOI: 10.1016/j.jprocont.2022.11.006, Vol. 120, pp. 86-96, November 2022. (TR2022-144)

Skvortcov, P., Koike-Akino, T., Millar, D.S., Kojima, K., Parsons, K., **"Dual Coding Concatenation for Burst-Error Correction in Probabilistic Amplitude Shaping"**, *IEEE Journal of Lightwave Technology*, DOI: 10.1109/JLT.2022.3178675, ISSN: 1558-2213, Vol. 40, No. 16, pp. 5502-5513, November 2022. (TR2022-145)

Romero, D., Lohit, S., **"Learning Partial Equivariances from Data"**, *Advances in Neural Information Processing Systems (NeurIPS)*, S. Koyejo and S. Mohamed and A. Agarwal and D. Belgrave and K. Cho and A. Oh, Eds., November 2022, pp. 36466-36478. (TR2022-148)

Wang, H., Lohit, S., Jones, M.J., Fu, R., **"What Makes a "Good" Data Augmentation in Knowledge Distillation – A Statistical Perspective"**, *Advances in Neural Information Processing Systems (NeurIPS)*, S. Koyejo, S. Mohamed, A. Agarwal, D. Belgrave, K. Cho and A. Oh, Eds., November 2022, pp. 13456-13469. (TR2022-147)

Shimoya, R., Morimoto, T., van Baar, J., Boufounos, P.T., Ma, Y., Mansour, H., **"Learning Occlusion-Aware Dense Correspondences for Multi-Modal Images"**, *IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS)*, DOI: 10.1109/AVSS56176.2022.9959354, ISBN: 978-1-6654-6382-9, November 2022, pp. 1-8. (TR2022-149)

Liu, D., Inoue, H., Kanemaru, M., **"Robust Motor Current Signature Analysis (MCSA)-based Fault Detection under Varying Operating Conditions"**, *International Conference on Electrical Machines and Systems (ICEMS)*, DOI: 10.1109/ICEMS56177.2022.9983454, ISSN: 2642-5513, ISBN: 978-1-6654-9302-4, November 2022. (TR2022-150)

Tu, H., Moura, S., Wang, Y., Fang, H., **"Integrating Physics-Based Modeling with Machine Learning for Lithium-Ion Batteries"**, *Applied Energy*, DOI: 10.1016/j.apenergy.2022.120289, Vol. 329, December 2022. (TR2022-155)

Naito, K., Kitamura, S., Mori, K., Raghunathan, A., Nikovski, D.N., **"Power Band Model Based on Flow Network and Weekly Unit Commitment Problem Considering Reserve Market"**, *IEEJ Transactions on Power and Energy*, DOI: 10.1541/ieejpes.142.583, Vol. 142, No. 12, pp. 583-593, December 2022.

Singla, V., Aeron, S., Koike-Akino, T., Parsons, K., Brand, M., Wang, Y., **"Learning with noisy labels using low-dimensional model trajectory"**, *NeurIPS 2022 Workshop on Distribution Shifts (DistShift)*, December 2022. (TR2022-156)

Raghunathan, A., Jha, D.K., Romeres, D., **"Homogeneous Infeasible Interior Point Method for Convex Quadratic Programs"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC51059.2022.9992979, December 2022, pp. 7571-7578. (TR2022-157)

Chakrabarty, A., **"Few-Shot Closed-Loop Performance Optimization with Bayesian Meta-Learning"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC51059.2022.9992404, December 2022. (TR2022-160)

Greiff, M., Berntorp, K., **"Distributed Kalman Filtering: When to Share Measurements"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC51059.2022.9993404, ISSN: 2576-2370, ISBN: 978-1-6654-6761-2, December 2022, pp. 5399-5404. (TR2022-158)

Paulson, J.A., Sorouifar, F., Chakrabarty, A., **"Efficient Multi-Step Lookahead Bayesian Optimization with Local Search Constraints"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC51059.2022.9992943, December 2022. (TR2022-161)

Romero, O., Benosman, M., Pappas, G., **"ODE Discretization Schemes as Optimization Algorithms"**, *IEEE Conference on Decision and Control (CDC)*, December 2022. (TR2022-159)

Tu, H., Wang, Y., Li, X., Fang, H., **"Spatio-Temporal Thermal Monitoring for Lithium-Ion Batteries via Kriged Kalman Filtering"**, *IEEE Conference on Decision and Control (CDC)*, DOI: 10.1109/CDC51059.2022.9992543, December 2022. (TR2022-162)

Mowlavi, S., Nabi, S., **"Optimal Control of PDEs Using Physics-Informed Neural Networks"**, *Advances in Neural Information Processing Systems (NeurIPS) workshop*, December 2022. (TR2022-163)

Soushi Ueno, , Fujihashi, T., Koike-Akino, T., Watanabe, T., **"Point Cloud Soft Multicast for Untethered XR Users"**, *IEEE Transactions on Multimedia*, December 2022. (TR2022-164)

Anantaram, V., Wang, Y., **"Sensorless Control of Synchronous Machines with DC-Link Voltage Immunity and Adaptation"**, *IEEE Power Electronics, Drives and Energy Systems*, DOI: 10.1109/PEDES56012.2022.10080212, December 2022. (TR2022-165)

Wang, Z.-Q., Wichern, G., Watanabe, S., Le Roux, J., **"STFT-Domain Neural Speech Enhancement with Very Low Algorithmic Latency"**, *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, DOI: 10.1109/TASLP.2022.3224285, ISSN: 2329-9304, Vol. 31, pp. 397-410, December 2022. (TR2022-166)

Kim, K.J., Liu, H., Wen, M., Tsiftsis, T.A., Orlik, P.V., Poor, H.V., **"QR Decomposition-based Cyclic Prefixed Single-Carrier Transmissions for Cooperative Communications: Concepts and Research Landscape"**, *IEEE Communications Surveys and Tutorials*, DOI: 10.1109/COMST.2022.3194997, Vol. 25, No. 1, pp. 133-155, December 2022. (TR2022-167)

Chakrabarty, A., Bortoff, S.A., Laughman, C.R., **"Simulation Failure Robust Bayesian Optimization for Data-Driven Parameter Estimation"**, *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, DOI: 10.1109/TSMC.2022.3216790, December 2022. (TR2022-168)

Masui, H., Romeres, D., Nikovski, D.N., **"Transfer Learning for Bayesian Optimization with Principal Component Analysis"**, *International Conference on Machine Learning and Applications (ICMLA)*, ISBN: 978-1-6654-6283-9, December 2022, pp. 1077-1084. (TR2022-169)

Talukder, K., Wang, B., Sakamoto, Y., **"Electric Machine Two-dimensional Flux Map Prediction with Ensemble Learning"**, *International Conference on Electrical Machines and Systems (ICEMS)*, DOI: 10.1109/ICEMS56177.2022.9982881, December 2022, pp. 1-4. (TR2022-152)

Amadio, F., Dalla Libera, A., Antonello, R., Nikovski, D.N., Carli, R., Romeres, D., **"Model-Based Policy Search Using Monte Carlo Gradient Estimation with Real Systems Application"**, *IEEE Transaction on Robotics*, DOI: 10.1109/TRO.2022.3184837, ISSN: 1941-0468, Vol. 38, No. 6, pp. 3879-3898, December 2022. (TR2022-154)

Wang, B., Albader, M., Inoue, H., Kanemaru, M., **"Induction Motor Eccentricity Fault Analysis and Quantification with Modified Winding Function based Model"**, *International Conference on Electrical Machines and Systems (ICEMS)*, DOI: 10.1109/ICEMS56177.2022.9983377, December 2022, pp. 1-6. (TR2022-153)

Bhattacharya, C., Chakrabarty, A., Laughman, C.R., Qiao, H., **"https://iwww.merl.com/TR/camready-4505.pdf"**, *Modeling, Estimation and Control Conference*, DOI: 10.1016/j.ifacol.2022.11.168, December 2022, pp. 99-106. (TR2022-170)

Garg, K., Baranwal, M., Gupta, R., Benosman, M., **"Fixed-Time Stable Proximal Dynamical System for Solving MVIPs"**, *IEEE Transactions on Automatic Control*, December 2022. (TR2022-171)

Aich, A., Peng, K.-C., Roy-Chowdhury, A.K., **"Cross-Domain Video Anomaly Detection without Target Domain Adaptation"**, *IEEE Winter Conference on Applications of Computer Vision (WACV)*, Crandall, D. and Gong, B. and Lee, Y. J. and Souvenir, R. and Yu, S., Eds., DOI: 10.1109/WACV56688.2023.00261, ISSN: 2642-9381, ISBN: 978-1-6654-9346-8, January 2023, pp. 2578-2590. (TR2023-001)

Tohme, T., Liu, D., Youcef-Toumi, K., **"GSR: A Generalized Symbolic Regression Approach"**, *Transactions on Machine Learning Research*, ISSN: 2835-8856, January 2023. (TR2023-002)

Liu, T., Cherian, A., **"Learning a Constrained Optimizer: A Primal Method"**, *AAAI Conference on Artificial Intelligence*, January 2023. (TR2023-003)

Kojima, K., Koike-Akino, T., Wang, Y., Jung Minwoo, , Brand, M., **"Inverse design of two-dimensional freeform metagrating using an adversarial conditional variational autoencoder"**, *SPIE Photonics West*, DOI: 10.1117/12.2650299, January 2023. (TR2023-004)

Chakrabarty, A., Berntorp, K., Di Cairano, S., **"Parameter-Adaptive Reference Governors with Learned Robust Constraint-Admissible Sets"**, *Control Engineering Practice*, DOI: 10.1016/j.conengprac.2023.105450, Vol. 133, February 2023. (TR2023-005)

Mateus, A., Ranade, S., Ramalingam, S., Miraldo, P., **"Fast and Accurate 3D Registration from Line Intersection Constraints"**, *International Journal of Computer Vision*, February 2023. (TR2023-007)

Lin, C., **"Magnetic Cooling with Thin Peltier Modules as Thermal Switches"**, *Journal of Magnetism and Magnetic Materials*, DOI: 10.1016/j.jmmm.2023.170482, ISSN: 0304-8853, Vol. 570, pp. 170482, February 2023. (TR2023-006)

Kantana, C., Benosman, M., Ma, R., Komatsuzaki, Y., **"A System Approach for Efficiency Enhancement and Linearization Technique of Dual-Input Doherty Power Amplifier"**, *IEEE Journal of Microwaves*, February 2023. (TR2023-008)

Sharma, A., Zhang, J., Nikovski, D., Doshi-Velez, F., **"Travel-time prediction using neural-network-based mixture models"**, *International Workshop on Statistical Methods and Artificial Intelligence*, DOI: 10.1016/j.procs.2023.03.144, March 2023. (TR2023-012)

Wang, Y., Zhang, J., Nikovski, D., Kojima, T., **"Estimating Traffic Density Using Transformer Decoders"**, *International Workshop on Statistical Methods and Artificial Intelligence*, DOI: 10.1016/j.procs.2023.03.143, March 2023. (TR2023-011)

Cherian, A., Peng, K.-C., Lohit, S., Smith, K., Tenenbaum, J.B., **"Are Deep Neural Networks SMARTer than Second Graders?"**, *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, March 2023, pp. 10834-10844. (TR2023-014)

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 seven areas MERL's research is focused on.

Computer Vision – Enabling machines to perceive, understand, navigate, and interact with the world by extracting meaning and building representations of scenes, objects, and events. Developing machine learning algorithms in a wide range of research areas including 3D vision and learning, representation learning, generative modeling, multimodal AI, and human monitoring.

Speech & Audio – Developing machine learning algorithms to perform a wide range of inference tasks in the speech and audio processing field, from robust sound signal acquisition and analysis to language understanding and generation, including audio source separation, speech enhancement and dereverberation, sound event detection and localization, anomalous sound detection, sound analysis, speaker diarization, robust automatic speech recognition, automatic audio and video captioning, and audio-visual scene-aware interaction.

Optimization & Intelligent Robotics – Research on fundamental methods to solve various decision optimization problems, including continuous optimization, combinatorial optimization, and sequential decision making, as well as predictive modeling techniques, including system identification and time series analysis, with applications to electrical grid, transportation systems, and factory automation. Additionally, research on industrial robotics with interdisciplinary focus on manipulation, perception, planning, reasoning, control & estimation, and human-robot interaction of single and multi-agent systems.

Connectivity & Information Processing – Research on communications networks performance and security, and information processing developing fundamental machine learning methods for robust inference, distributed learning, bio-signal processing, and quantum machine learning.

Computational Sensing – Exploring 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 focused on signal acquisition, modeling, and reconstruction algorithms, with applications to autonomous vehicles, factory automation, navigation systems, automotive radars, public security, non-contact sensing and radar imaging, among others.

Control for Autonomy – Developing novel control, motion planning and estimation algorithms with improved performance and robustness, and reduced computational footprint for increasing the capabilities of autonomous mobile systems. Special focus areas include model predictive control, statistical estimation, constrained control, motion planning, stochastic control, integration of learning and control, and real-time optimization. Main application areas include driver assistance and automated driving systems, spacecraft and satellites, global navigation and positioning, aerial drones, wheeled and legged ground robots, and electric vehicles.

Electric Systems Automation – Research on multi-physical modeling & simulations as a basis for producing model-based design for motors, electric systems and RF devices; develop optimal control and estimation algorithms for motor drive, motion control to achieve improved performance and reliability; apply signal processing and other fundamentals for predictive maintenance of electric machines; and utilize AI technologies to speed up design process, enable data-driven/learning-based control and intelligent performance monitoring.

Multi-Physical Systems – Research on multi-physical modeling & simulation as a basis for producing model-based designs for devices, systems, and controls to achieve optimized performance with high efficiency; developing computational methods that connect physics-based models, controls, estimation, and machine learning to enable digital twin solutions. Target applications include HVAC systems, factory automation, robotics, energy-efficient buildings, and energy systems.

Computer Vision

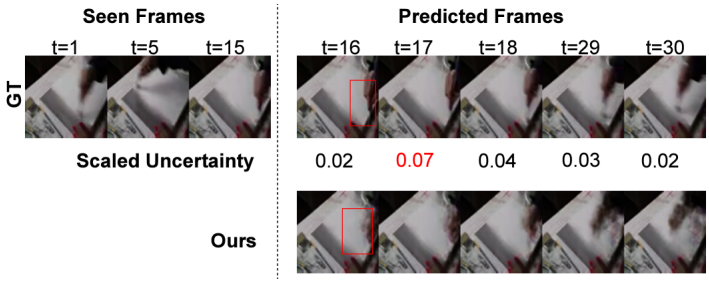
MERL's Computer Vision Team performs cutting-edge research in a wide variety of topics related to computer vision, machine learning, and multimodal processing. Much of our research concerns visual representations and analysis, including work in representation learning, generative modeling, and 3D vision and learning. We also work in multimodal AI, combining vision with other modalities of information (e.g., sound, speech, and text) to extract richer meaning. Other research focuses include human monitoring from video, and robotic perception and learning. Due to the pervasiveness of visual information in the world, our work applies to myriad applications across society, including the areas of transportation and automotive, factory automation, healthcare, surveillance, and robotics.

Recent research

Quantifying Predictive Uncertainty for Stochastic Video Synthesis from Audio

Citation: Chatterjee, M., Ahuja, N., Cherian, A., "Quantifying Predictive Uncertainty for Stochastic Video Synthesis from Audio", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), June 2022.

Contacts: Anoop Cherian

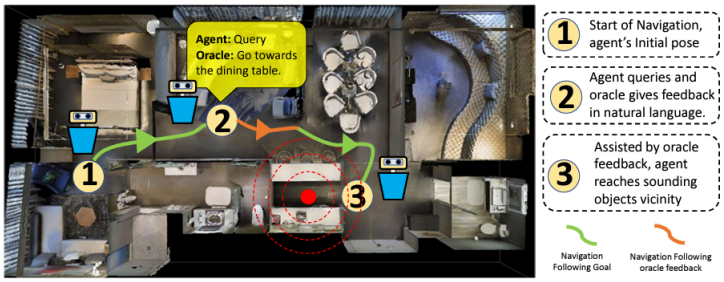


We study the problem of synthesizing video frames from the accompanying audio and a few past frames – a task with immense potential, e.g., in occlusion reasoning. Prior methods to solve this problem often train deep learning models that derive their training signal by computing the mean-squared error (MSE) between the generated frame and the ground truth. We introduce A Predictive Uncertainty Quantifier (PUQ) - a stochastic quantification of the generative model's predictive uncertainty, which is then used to weigh the MSE loss. PUQ is derived from a hierarchical, variational deep net and is easy to implement and incorporate into audio-conditioned stochastic frame generation methods.

AVLEN: Audio-Visual-Language Embodied Navigation in 3D Environments

Citation: Paul, S., Roy Chowdhury, A.K., Cherian, A., "AVLEN: Audio-Visual-Language Embodied Navigation in 3D Environments", Advances in Neural Information Processing Systems (NeurIPS), October 2022, pp. 6236-6249.

Contacts: Anoop Cherian

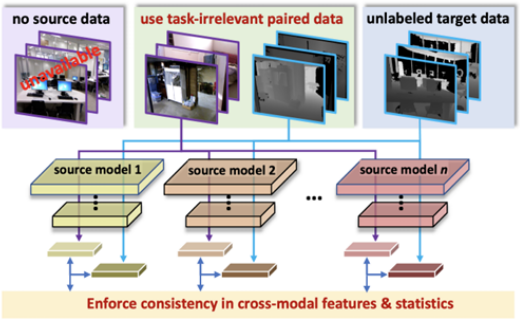


We present AVLEN – an interactive agent for Audio-Visual-Language Embodied Navigation. Similar to audio-visual navigation tasks, the goal of our embodied agent is to localize an audio event via navigating the 3D visual world; however, the agent may also seek help from a human (oracle), where the assistance is provided in free-form natural language. To realize these abilities, AVLEN uses a multimodal hierarchical reinforcement learning backbone that learns: (a) high-level policies to choose either audio-cues for navigation or to query the oracle, and (b) lower-level policies to select navigation actions based on its audio-visual and language inputs. The policies are trained via rewarding for the success on the navigation task while minimizing the number of queries to the oracle. Our results show that equipping the agent to ask for help leads to a clear improvement in performance, especially in challenging cases, e.g., when the sound is unheard during training or in the presence of distractor sounds.

Cross-Modal Knowledge Transfer Without Task-Relevant Source Data

Citation: Ahmed, S.M., Lohit, S., Peng, K.-C., Jones, M.J., Roy Chowdhury, A.K., "Cross-Modal Knowledge Transfer Without Task-Relevant Source Data", European Conference on Computer Vision (ECCV), Avidan, S and Brostow, G and Cisse M and Farinella, G.M. and Hassner T., Eds., DOI: 10.1007/978-3-031-19830-4_7, October 2022, pp. 111-127.

Contacts: Suhas Lohit, Kuan-Chuan Peng, Mike Jones

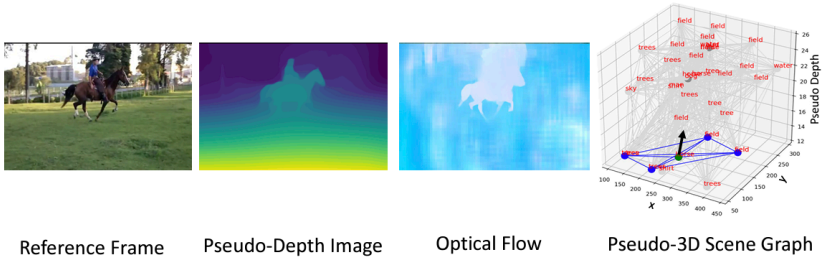


Transferring knowledge from a neural network trained on a well-labeled large dataset in a source modality (RGB) to a neural network that works on a target modality (depth, infrared, etc.) is of great value. For reasons like memory and privacy, it may not be possible to access the source data, and knowledge transfer needs to work with only the source models. We describe an effective solution, SOCKET: SOurce-free Cross-modal KnowledgE Transfer for this challenging task of transferring knowledge from one source modality to a different target modality without access to task-relevant source data. The framework reduces the modality gap using paired task-irrelevant data, as well as by matching the mean and variance of the target features with the batch-norm statistics that are present in the source models. We show through experiments that our method significantly outperforms existing source-free methods for classification tasks which do not account for the modality gap.

Learning Audio-Visual Dynamics Using Scene Graphs for Audio Source Separation

Citation: Chatterjee, M., Ahuja, N., Cherian, A., "Learning Audio-Visual Dynamics Using Scene Graphs for Audio Source Separation", Advances in Neural Information Processing Systems (NeurIPS), November 2022.

Contacts: Moitreya Chatterji, Anoop Cherian

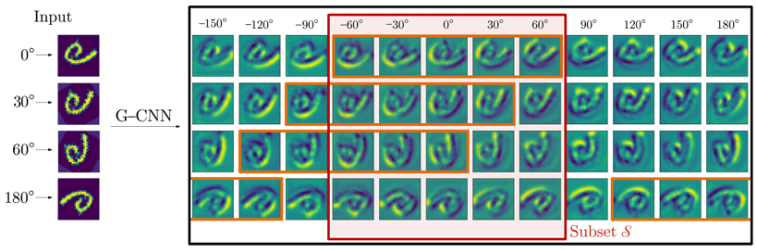


There exists an unequivocal distinction between the sound produced by a static source and that produced by a moving one, especially when the source moves towards or away from the microphone. We propose to use this connection between audio and visual dynamics for solving two challenging tasks simultaneously, namely: (i) separating audio sources from a mixture using visual cues, and (ii) predicting the 3D visual motion of a sounding source using its separated audio. At the heart of OUR Audio Separator and Motion Predictor (ASMP) is a 2.5D scene graph capturing various objects in the video and their pseudo-3D spatial proximities. Our results demonstrate that ASMP achieves a clear improvement in source separation quality, outperforming prior works, while also estimating the direction of motion of the sound sources better than other methods.

Learning Partial Equivariances from Data

Citation: Romero, D., Lohit, S., "Learning Partial Equivariances from Data", Advances in Neural Information Processing Systems (NeurIPS), S. Koyejo and S. Mohamed and A. Agarwal and D. Belgrave and K. Cho and A. Oh, Eds., November 2022, pp. 36466-36478.

Contacts: Suhas Lohit

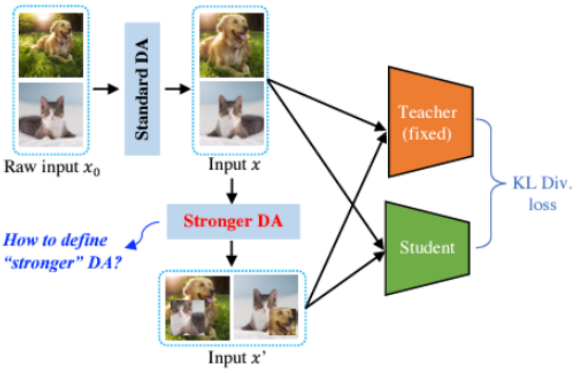


Group Convolutional Neural Networks (G-CNNs) constrain learned features to respect the symmetries in the selected group. We introduce Partial G-CNNs: G-CNNs able to learn layer-wise levels of partial and full equivariance to discrete, continuous groups and combinations thereof as part of training. Partial G-CNNs retain full equivariance when beneficial, e.g., for rotated MNIST, but adjust it whenever it becomes harmful, e.g., for classification of 6/9 digits or natural images. We empirically show that partial G-CNNs pair G-CNNs when full equivariance is advantageous, and outperform them otherwise..

What Makes a "Good" Data Augmentation in Knowledge Distillation – A Statistical Perspective

Citation: Wang, H., Lohit, S., Jones, M.J., Fu, R., "What Makes a "Good" Data Augmentation in Knowledge Distillation – A Statistical Perspective", Advances in Neural Information Processing Systems (NeurIPS), S. Koyejo and S. Mohamed and A. Agarwal and D. Belgrave and K. Cho and A. Oh, Eds., November 2022, pp. 13456-13469.

Contacts: Suhas Lohit, Mike Jones

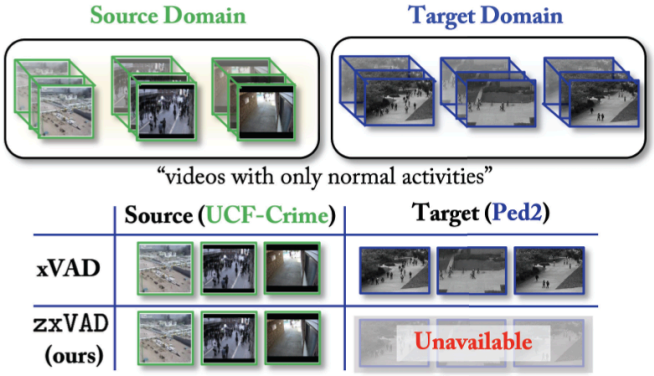


Knowledge distillation (KD) is a general neural network training approach that uses a teacher to guide a student. Existing works mainly study KD from the network output side (e.g., trying to design a better KD loss function), while few have attempted to understand it from the input side. We ask: Why do some data augmentation (DA) schemes (e.g., CutMix) inherently perform much better than others in KD? Our investigation from a statistical perspective suggests that a good DA scheme should reduce the variance of the teacher's mean probability, which will eventually lead to a lower generalization gap for the student. Extensive empirical studies support our claims and demonstrate how we can harvest considerable performance gains simply by using a better DA scheme in knowledge distillation.

Cross-Domain Video Anomaly Detection without Target Domain Adaptation

Citation: Aich, A., Peng, K.-C., Roy-Chowdhury, A.K., "Cross-Domain Video Anomaly Detection without Target Domain Adaptation", IEEE Winter Conference on Applications of Computer Vision (WACV), Crandall, D. and Gong, B. and Lee, Y. J. and Souvenir, R. and Yu, S., Eds., DOI: 10.1109/WACV56688.2023.00261, January 2023, pp. 2578-2590.

Contacts: Kuan-Chuan Peng

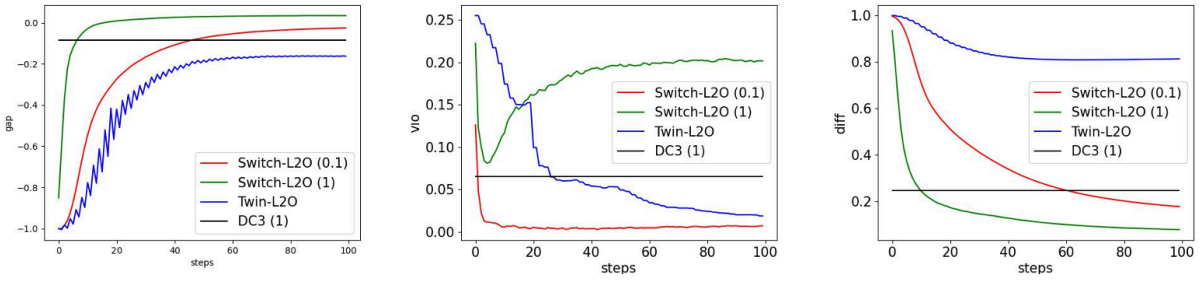


Most cross-domain unsupervised Video Anomaly Detection (VAD) work assumes that at least a few task-relevant target domain training data are available for adaptation from the source to the target domain. However, this requires laborious model tuning by the end-user. We propose a new 'Zero-shot Cross-domain Video Anomaly Detection (zxVAD)' framework that includes a future-frame prediction generative model setup. zxVAD generalizes and learns to distinguish between normal and abnormal frames in a new target domain without adaptation during inference. We show that zxVAD outperforms the state-of-the-art (SOTA),regardless of whether task-relevant (i.e., VAD) source training data are available or not.

Learning a Constrained Optimizer: A Primal Method

Citation: Liu, T., Cherian, A., "Learning a Constrained Optimizer: A Primal Method", AAAI Conference on Artificial Intelligence, January 2023.

Contacts: Anoop Cherian

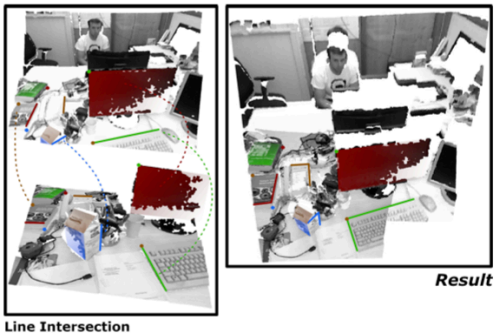


There has been significant interest in developing methods that bridge between classical optimization and modern deep learning, under the broad theme of learning to optimize (L2O), for improved optimizers. We propose Switch-L2O – a new primal-only method for learning a constraint optimizer. Empirically, our method is shown to enjoy a better optimality gap and reduces constraint violations more than prior methods on convex and nonconvex optimization problems with possibly nonconvex constraints.

Fast and Accurate 3D Registration from Line Intersection Constraints

Citation: Mateus, A., Ranade, S., Ramalingam, S., Miraldo, P., "Fast and Accurate 3D Registration from Line Intersection Constraints", International Journal of Computer Vision, DOI: 10.1007/s11263-023-01774-1, Vol. 131, pp. 2044-2069, February 2023.

Contacts: Pedro Miraldo

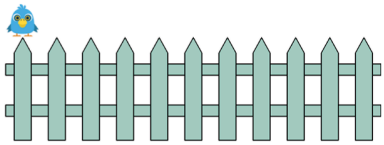


3D Registration is a fundamental part of several robotics and automation tasks. While classical methods predominantly exploit constraints from points or plane correspondences, we focus on exploiting geometric constraints arising from the intersection of two (different) 3D line segments in two scans. In particular, we derive nine minimal solvers from various geometric constraints arising from line intersections along with other constraints: plane correspondences, point correspondences, and line matches. We follow a two-step method for 3D registration: a coarse estimation with outlier rejection followed by refinement. Thorough experiments with simulated data and two real-world datasets we show that using these features and the combined solvers improves accuracy and is faster than the baselines.

Are Deep Neural Networks SMARTer than Second Graders?

Citation: Cherian, A., Peng, K.-C., Lohit, S., Smith, K., Tenenbaum, J.B., "Are Deep Neural Networks SMARTer than Second Graders?", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), March 2023, pp. 10834-10844.

Contacts: Anoop Cherian, Kuan-Chuan Peng, Suhas Lohit



Question: *Bird Bobbie jumps on a fence from the post on the left end to the other end. Each jump takes him 4 seconds. He makes 4 jumps ahead and then 1 jump back. Then he again makes 4 jumps ahead and 1 jump back, and so on. In how many seconds can Bobbie get from one end to the other end?*
Answer Options: A: 64 B: 48 C: 56 D: 68 E: 72

Recent times have witnessed an increasing number of applications of deep neural networks towards solving tasks that require superior cognitive abilities, e.g., playing Go, generating art, question answering (e.g., ChatGPT), etc. Such a dramatic progress raises the question: how generalizable are neural networks in solving problems that demand broad skills? To answer this question, we propose SMART: a Simple Multimodal Algorithmic Reasoning Task and the associated SMART-101 dataset, for evaluating the abstraction, deduction, and generalization abilities of neural networks in solving visuo-linguistic puzzles designed specifically for children in the 6–8 age group. Our experiments reveal that while powerful deep models offer reasonable performances on puzzles in a supervised setting, they are no better than random accuracy when analyzed for generalization – filling this gap may demand new approaches.

Speech & Audio

Research in the Speech & Audio team at MERL addresses a range of challenging machine-perception problems involving acoustic signals, human language, and everything in between. On the signal acquisition end, we focus on source separation in both single- and multi-channel settings, sound event detection and localization, anomalous sound detection, and sound analysis. For automatic speech recognition (ASR), we have introduced leading methods for end-to-end ASR, including novel deep-learning methods for acoustic and language modeling, and have focused more recently on robust ASR and speaker diarization. On the language end, our efforts focus on natural-language understanding and multi-modal techniques to realize scene-aware interaction.

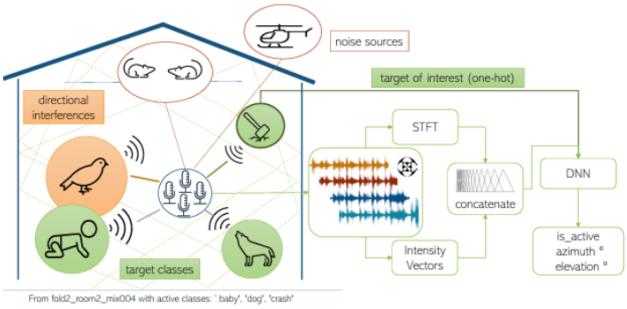
A particular difficulty in this field is bridging the gap between two differently structured domains: acoustic signals and language. Our approach has been to develop novel machine-learning techniques that go beyond classical pattern-recognition frameworks. In recent years, this has enabled us to take on a series of groundbreaking research projects, achieving world-leading performance in a wide range of tasks, and consistently placing in the top tier in international competitions.

Recent research

Locate This, Not That: Class-Conditioned Sound Event DOA Estimation

Citation: Slizovskaia, O., Wichern, G., Wang, Z.-Q., Le Roux, J., "Locate This, Not That: Class-Conditioned Sound Event DOA Estimation", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP43922.2022.9747604, April 2022, pp. 711-715.

Contacts: Gordon Wichern, Jonathan Le Roux

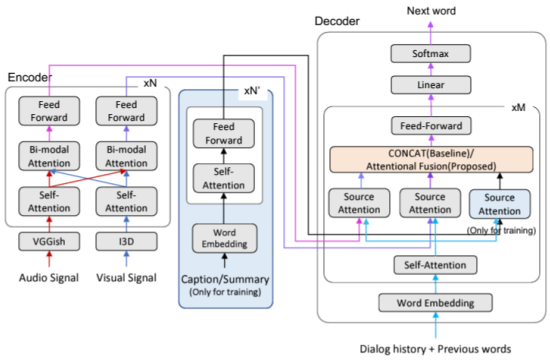


Existing systems for sound event localization and detection (SELD) typically operate by estimating a source location for all classes at every time instant. We propose an alternative class-conditioned SELD model for situations where we are not interested in localizing all classes all of the time. This class-conditioned SELD model takes as input the spatial and spectral features from the sound file, and also a one-hot vector indicating the class we are currently interested in localizing. In experiments on the DCASE 2020 Task 3 dataset, we show that the proposed class-conditioned SELD model performs better in terms of common SELD metrics

Audio-Visual Scene-Aware Dialog and Reasoning Using Audio-Visual Transformers with Joint Student-Teacher Learning

Citation: Shah, A.P., Geng, S., Gao, P., Cherian, A., Hori, T., Marks, T.K., Le Roux, J., Hori, C., "Audio-Visual Scene-Aware Dialog and Reasoning Using Audio-Visual Transformers with Joint Student-Teacher Learning", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), April 2022, pp. 7732-7736.

Contacts: Anoop Cherian, Tim K. Marks, Jonathan Le Roux, Chiori Hori

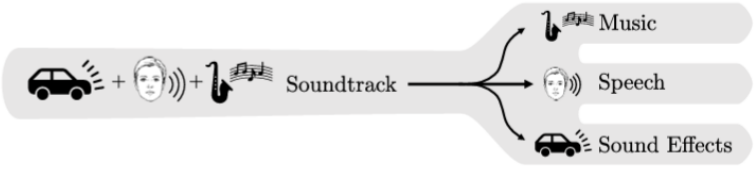


We have proposed the Audio-Visual Scene-Aware Dialog (AVSD) task, collected an AVSD dataset, developed AVSD technologies, and hosted an AVSD challenge track at both the 7th and 8th Dialog System Technology Challenges (DSTC7, DSTC8). The best-performing systems relied heavily on human-generated descriptions of the video content, which were available in the datasets but would be unavailable in real-world applications. To promote further advancements, we proposed a third AVSD challenge, at DSTC10, with two modifications: 1) the human-created description is unavailable at inference time, and 2) systems must demonstrate temporal reasoning by finding evidence from the video to support each answer. This paper introduces the new task that includes temporal reasoning and our new extension of the AVSD dataset for DSTC10.

The Cocktail Fork Problem: Three-Stem Audio Separation for Real-World Soundtracks

Citation: Petermann, D., Wichern, G., Wang, Z.-Q., Le Roux, J., "The Cocktail Fork Problem: Three-Stem Audio Separation for Real-World Soundtracks", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP43922.2022.9746005, April 2022, pp. 526-530.

Contacts: Gordon Wichern, Jonathan Le Roux



The cocktail party problem aims at isolating any source of interest within a complex acoustic scene, and has long inspired audio source separation research. Recent efforts have mainly focused on separating speech from noise, speech from speech, musical instruments from each other, or sound events from each other. However, separating an audio mixture (e.g., movie soundtrack) into the three broad categories of speech, music, and sound effects (understood to include ambient noise and natural sound events) has been left largely unexplored. This paper formalizes this task as the cocktail fork problem, and presents the Divide and Remaster (DnR) dataset to foster research on this topic.

Extended Graph Temporal Classification for Multi-Speaker End-to-End ASR

Citation: Chang, X., Moritz, N., Hori, T., Watanabe, S., Le Roux, J., "Extended Graph Temporal Classification for Multi-Speaker End-to-End ASR", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP43922.2022.9747375, April 2022, pp. 7322-7326.

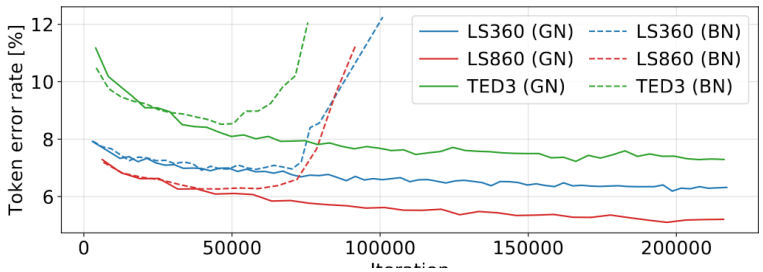
Contacts: Jonathan Le Roux

Graph-based temporal classification (GTC), a generalized form of the connectionist temporal classification loss, was recently proposed to improve automatic speech recognition (ASR) systems using graph-based supervision. We propose an extension of GTC to model the posteriors of both labels and label transitions by a neural network, which can be applied to a wider range of tasks. As an example application, we use the extended GTC (GTC-e) for the multi-speaker speech recognition task. Using GTC-e, multi-speaker ASR modelling becomes very similar to single-speaker ASR modeling, in that tokens by multiple speakers are recognized as a single merged sequence in chronological order. For evaluation, we perform experiments on a simulated multi-speaker speech dataset derived from LibriSpeech, obtaining promising results with performance close to classical benchmarks for the task.

Momentum Pseudo-Labeling: Semi-Supervised ASR with Continuously Improving Pseudo-Labels

Citation: Higuchi, Y., Moritz, N., Le Roux, J., Hori, T., "Momentum Pseudo-Labeling: Semi-Supervised ASR with Continuously Improving Pseudo-Labels", IEEE Journal of Selected Topics in Signal Processing, DOI: 10.1109/JSTSP.2022.3195367, Vol. 16, No. 6, pp. 1424-1438, September 2022.

Contacts: Jonathan Le Roux

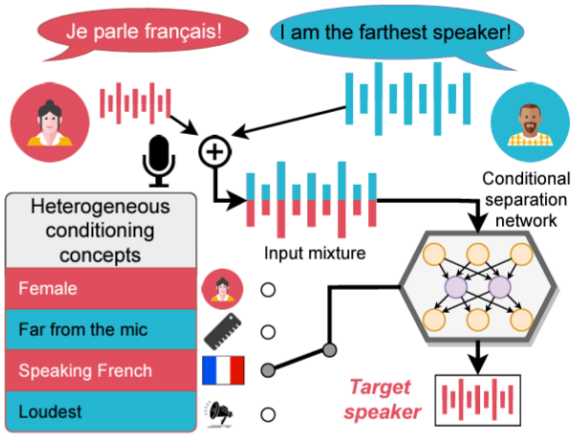


Pseudo-labeling (PL), a semi-supervised learning (SSL) method where a seed model performs self-training using pseudo-labels generated from untranscribed speech, has been shown to enhance the performance of end-to-end automatic speech recognition (ASR). Our prior work proposed momentum pseudo-labeling (MPL), which performs PL-based SSL via an interaction between online and offline models. We propose to enhance MPL by (1) introducing the Conformer architecture to boost the overall recognition accuracy and (2) exploiting iterative pseudo-labeling with a language model to improve the seed model before applying MPL.

Heterogeneous Target Speech Separation

Citation: Tzinis, E., Wichern, G., Subramanian, A.S., Smaragdis, P., Le Roux, J., "Heterogeneous Target Speech Separation", Interspeech, DOI: 10.21437/Interspeech.2022-10717, September 2022, pp. 1796-1800.

Contacts: Gordon Wichern, Jonathan Le Roux

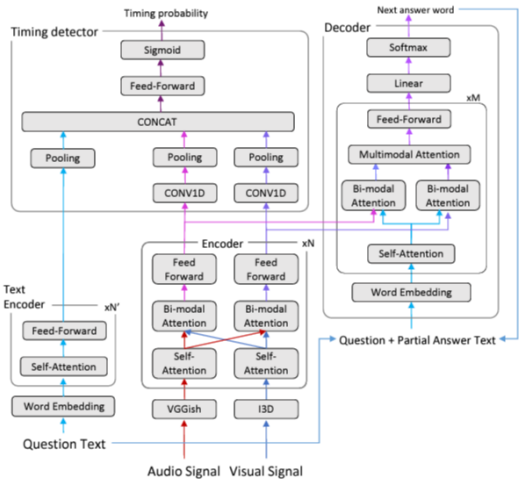


We introduce a new paradigm for single-channel target source separation where the sources of interest can be distinguished using non-mutually exclusive concepts (e.g., loudness, gender, language, spatial location, etc). Our proposed heterogeneous separation framework can seamlessly leverage datasets with large distribution shifts and learn cross-domain representations under a variety of concepts used as conditioning. Our ex- periments show that training separation models with heterogeneous conditions facilitates the generalization to new concepts with unseen out-of-domain data while also performing substantially higher than single-domain specialist models. Notably, such training leads to more robust learning of new harder source separation discriminative concepts and can yield improvements over permutation invariant training with oracle source selection.

Low-Latency Streaming Scene-aware Interaction Using Audio-Visual Transformers

Citation: Hori, C., Hori, T., Le Roux, J., "Low-Latency Streaming Scene-aware Interaction Using Audio-Visual Transformers", Interspeech, DOI: 10.21437/Interspeech.2022-10891, September 2022, pp. 4511-4515.

Contacts: Chiori Hori , Jonathan Le Roux

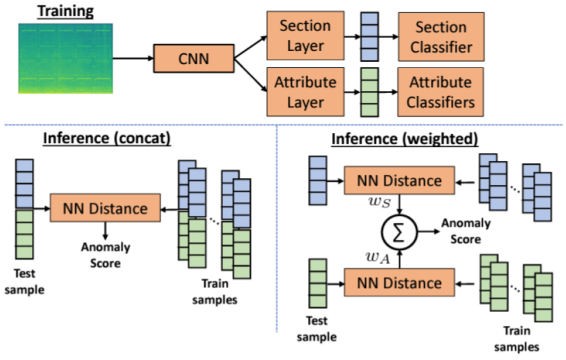


To apply scene-aware interaction technology to real-time dialog systems, we propose an online low-latency response generation framework for scene-aware interaction using a video question answering setup. This paper extends our prior work on low-latency video captioning to build a novel approach that can optimize the timing to generate each answer under a tradeoff between latency of generation and quality of answer. Our system built for the 10th Dialog System Technology Challenge was extended to exploit a low-latency function. Experiments with the MSRVTT-QA and AVSD datasets show that our approach achieves between 97% and 99% of the answer quality of the upper bound given by a pre-trained Transformer using the entire video clips, using less than 40% of frames from the beginning.

Improved Domain Generalization via Disentangled Multi-Task Learning in Unsupervised Anomalous Sound Detection

Citation: Venkatesh, S., Wichern, G., Subramanian, A.S., Le Roux, J., "Improved Domain Generalization via Disentangled Multi-Task Learning in Unsupervised Anomalous Sound Detection", DCASE Workshop, Lagrange, M. and Mesaros, A. and Pellegrini, T. and Richard, G. and Serizel, R. and Stowell, D., Eds., November 2022.

Contacts: Gordon Wichern, Jonathan Le Roux

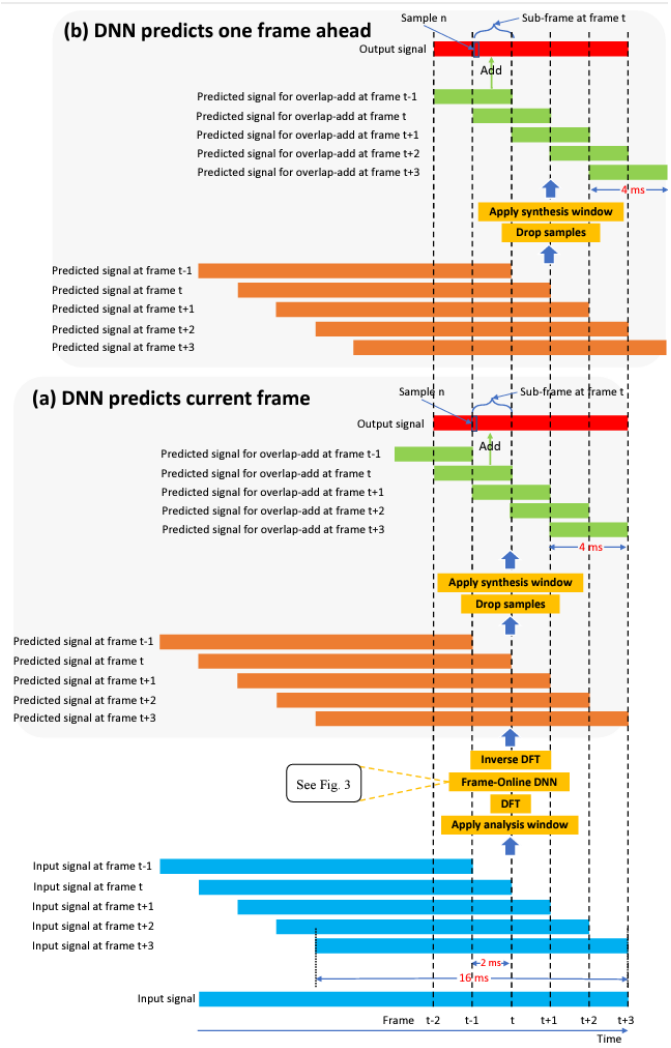


We investigate a novel multi-task learning framework that disentangles domain-shared features and domain-specific features for domain generalization in anomalous sound detection. Disentanglement leads to better latent features and also increases flexibility in post-processing due to the availability of multiple embedding spaces. The framework was at the core of our submissions to the DCASE2022 Challenge Task 2. We ranked 5th out of 32 teams in the competition, obtaining an overall harmonic mean of 67.57% on the blind evaluation set, surpassing the baseline by 13.5% and trailing the top rank by 3.4%.

STFT-Domain Neural Speech Enhancement with Very Low Algorithmic Latency

Citation: Wang, Z.-Q., Wichern, G., Watanabe, S., Le Roux, J., "STFT-Domain Neural Speech Enhancement with Very Low Algorithmic Latency", IEEE/ACM Transactions on Audio, Speech, and Language Processing, DOI: 10.1109/TASLP.2022.3224285, Vol. 31, pp. 397-410, December 2022.

Contacts: Gordon Wichern, Jonathan Le Roux



Deep learning based speech enhancement in the short-term Fourier transform (STFT) domain typically uses a large window length such as 32 ms. A larger window contains more samples and the frequency resolution can be higher for potentially better enhancement. This however incurs an algorithmic latency of 32 ms in an online setup, because the overlap-add algorithm used in the inverse STFT (iSTFT) is also performed based on the same 32 ms window size. To reduce this inherent latency, we adapt a conventional dual window size approach, where a regular input window size is used for STFT but a shorter output window is used for the overlap-add in the iSTFT, for STFT- domain deep learning based frame-online speech enhancement. Based on this STFT and iSTFT configuration, we employ single- or multi-microphone complex spectral mapping for frame-online enhancement, where a deep neural network (DNN) is trained to predict the real and imaginary (RI) components of target speech from the mixture RI components. In addition, we use the RI components predicted by the DNN to conduct frame- online beamforming, the results of which are then used as extra features for a second DNN to perform frame-online post-filtering. The frequency-domain beamforming in between the two DNNs can be easily integrated with complex spectral mapping and is designed to not incur any algorithmic latency. Additionally, we propose a future-frame prediction technique to further reduce the algorithmic latency. Evaluation results on a noisy-reverberant speech enhancement task demonstrate the effectiveness of the proposed algorithms. Compared with Conv-TasNet, our STFT- domain system can achieve better enhancement performance for a comparable amount of computation, or comparable performance with less computation, maintaining strong performance at an algorithmic latency as low as 2 ms.

Optimization & Intelligent Robotics

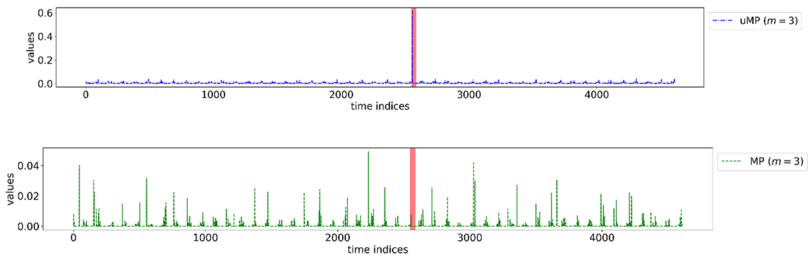
Optimization research emphasizes numerical methods for fast solution of continuous and discrete optimization problems that can be scaled up to problems of industrial size and complexity. Optimization methods find application in many application domains, including the analysis of electrical power systems 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, several 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. The robotics research focuses on the conjunction of dexterous robotics and human robot interaction supported by fundamental research on perception, control & estimation, machine learning, optimization, augmented/virtual reality, planning and reasoning of single and multi-agent systems.

Recent research

Algorithms for Fast Computation of Pan Matrix Profiles of Time Series Under Unnormalized Euclidean Distances

Citation: Zhang, J., Nikovski, D.N., "Algorithms for Fast Computation of Pan Matrix Profiles of Time Series Under Unnormalized Euclidean Distances", International Conference on Applied Statistics and Data Analytics, April 2022.

Contacts: Jing Zhang, Daniel N. Nikovski

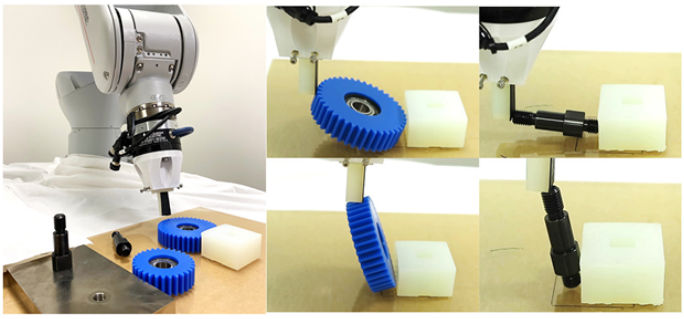


We propose an approximation algorithm called LINKUMP to compute the Pan Matrix Profile (PMP) under the unnormalized distance (useful for value-based similarity search) using double-ended queue and linear interpolation. The algorithm has comparable time/space complexities to the state-of-the-art algorithm for typical PMP computation under the normalized `2 distance (useful for shape-based similarity search).We validate its efficiency and effectiveness through extensive numerical experiments and a real-world anomaly detection application.

Robust Pivoting: Exploiting Frictional Stability Using Bilevel Optimization

Citation: Shirai, Y., Jha, D.K., Raghunathan, A., Romeres, D., "Robust Pivoting: Exploiting Frictional Stability Using Bilevel Optimization", IEEE International Conference on Robotics and Automation (ICRA), DOI: 10.1109/ICRA46639.2022.9811812, May 2022, pp. 992-998.

Contacts: Devesh Jha, Arvind Raghunathan, Diego Romeres

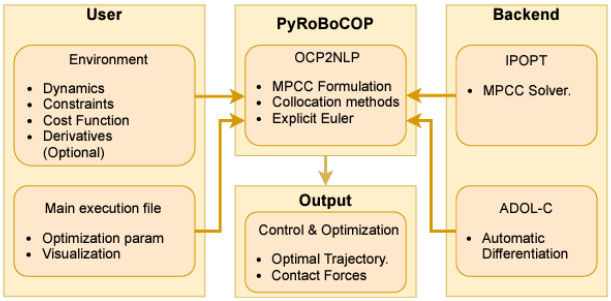


Generalizable manipulation requires that robots be able to interact with novel objects and environment. This requirement makes manipulation extremely challenging as a robot has to reason about complex frictional interaction with uncertainty in physical properties of the object. In this paper, we study robust optimization for control of pivoting manipulation in the presence of uncertainties. We present insights about how friction can be exploited to compensate for the inaccuracies in the estimates of the physical properties during manipulation. In particular, we derive analytical expressions for stability margin provided by friction during pivoting manipulation. This margin is then used in a bilevel trajectory optimization algorithm to design a controller that maximizes this stability margin to provide robustness against uncertainty in physical properties of the object. We demonstrate our proposed method using a 6 DoF manipulator for manipulating several different objects.

PYROBOCOP: Python-based Robotic Control & Optimization Package for Manipulation

Citation: Raghunathan, A., Jha, D.K., Romeres, D., "PYROBOCOP: Python-based Robotic Control & Optimization Package for Manipulation", IEEE International Conference on Robotics and Automation (ICRA), DOI: 10.1109/ICRA46639.2022.9812069, May 2022.

Contacts: Arvind Raghunathan, Devesh Jha, Diego Romeres

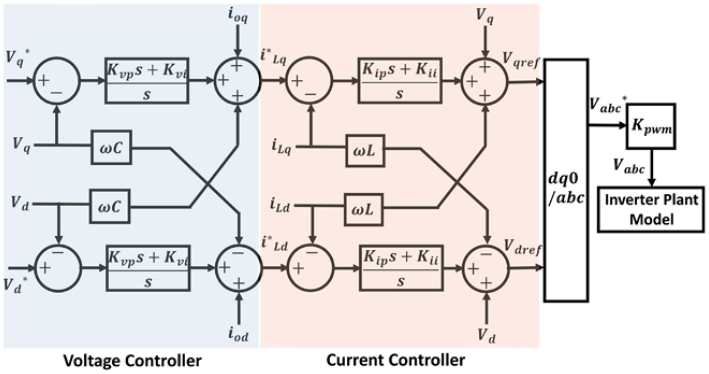


PYROBOCOP is a Python-based package for control, optimization and estimation of robotic systems described by nonlinear Differential Algebraic Equations (DAEs). In particular, the package can handle systems with contacts that are described by complementarity constraints and provides a general framework for specifying obstacle avoidance constraints. The package performs direct transcription of the DAEs into a set of nonlinear equations by performing orthogonal collocation on finite elements and provides automatic reformulation of the complementarity constraints.

A Fault Detection and Location Technique for Inverter-Dominated Islanding Microgrids

Citation: Chang, F., Sun, H., Kawano, S., Nikovski, D., Kitamura, S., Su, W., "A Fault Detection and Location Technique for Inverter-Dominated Islanding Microgrids", International Electrical and Energy Conference (CIEEC), DOI: 10.1109/CIEEC54735.2022.9846567, May 2022, pp. 2041-2046.

Contacts: Hongbo Sun, Daniel N. Nikovski

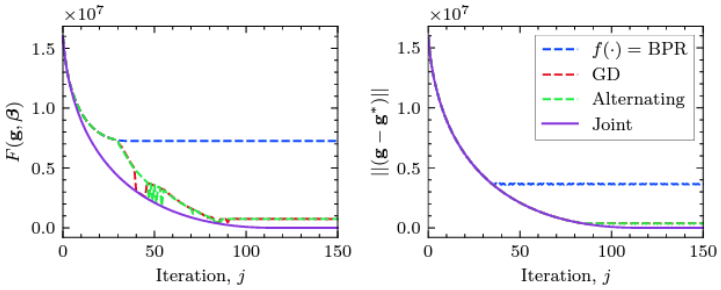


Microgrids are attracting increasing interest since they can work disconnected from large-scale commercial distribution networks when large disasters occur. However, disconnected microgrids do not contain appropriate protection systems. We develop a transient analysis for islanding ungrounded microgrids, in which multiple inverter-based distributed generators (IBGDs) are deployed under different control strategies, during different types of faults. Furthermore, we propose a fault detection and location method based on two-terminal measurements instead of the single-terminal measurements often utilized in conventional protection schemes such as overcurrent protection.

Joint Data-Driven Estimation of Origin-Destination Demand and Travel Latency Functions in Multi-Class Transportation Networks

Citation: Wollenstein-Betech, S., Sun, C., Zhang, J., Cassandras, C.G., Paschalidis, I.C., "Joint Data-Driven Estimation of Origin-Destination Demand and Travel Latency Functions in Multi-Class Transportation Networks", IEEE Transactions on Control of Network Systems, DOI: 10.1109/TCNS.2022.3161200, June 2022.

Contacts: Jing Zhang

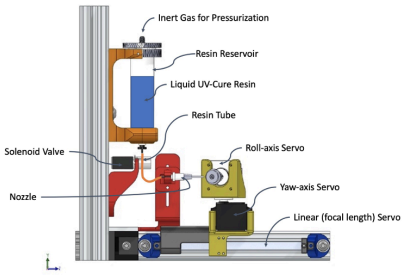


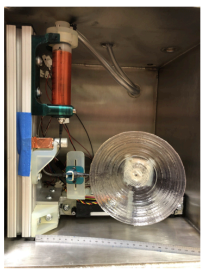
The Traffic Assignment Problem (TAP) is a widely used formulation for designing, analyzing, and evaluating transportation networks. The inputs to this model, besides the network topology, are the Origin-Destination (OD) demand matrix and travel latency cost functions. We present a kernel-based framework that jointly estimates the OD demand matrix and travel latency function in single and multi-class vehicle networks. We formulate a bilevel optimization problem and then transform it to a Quadratic Constraint Quadratic Program (QCQP). To solve this QCQP, we propose a trust-region feasible direction algorithm that sequentially solves a quadratic program. Our results show that the QCQP method achieves better estimates when compared with disjoint and sequential methods.

On-Orbit Fabrication of Spacecraft Structures by Direct Solar Photopolymerization

Citation: Yerazunis, W.S., Weiss, A., Radyjowski, P., Cottrell, R., "On-Orbit Fabrication of Spacecraft Structures by Direct Solar Photopolymerization", Solid Freeform Fabrication Symposium, July 2022, pp. 1676-1686.

Contacts: William S. Yerazunis, Avishai Weiss



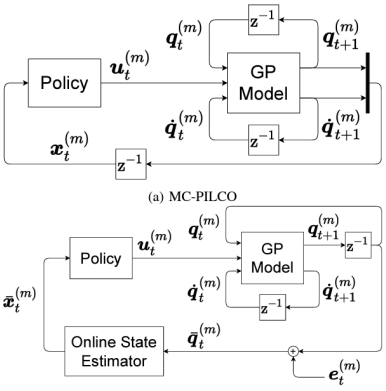


One of the paradoxes of spacecraft design is that spacecraft are destined to operate in orbit where maneuvering thruster firings produce stresses below 0.01 G, but the spacecraft must be strong enough (and heavy enough) to survive the roughly 10 G's of linear acceleration and 50 G's of vibration in a rocket launch. We developed and tested an alternative: the post-launch freeform additive manufacture of a major communications satellite structural element in UV cured resin, using solar UV to trigger polymerization. In tests, we successfully freeform 3D printed a small (60 mm) parabolic dish at 0.2 kPa using simulated solar UV.

Model-Based Policy Search Using Monte Carlo Gradient Estimation with Real Systems Application

Citation: Amadio, F., Dalla Libera, A., Antonello, R., Nikovski, D.N., Carli, R., Romeres, D., "Model-Based Policy Search Using Monte Carlo Gradient Estimation with Real Systems Application", IEEE Transaction on Robotics, DOI: 10.1109/TRO.2022.3184837, Vol. 38, No. 6, pp. 3879-3898, December 2022.

Contacts: Diego Romeres, Daniel N. Nikovski

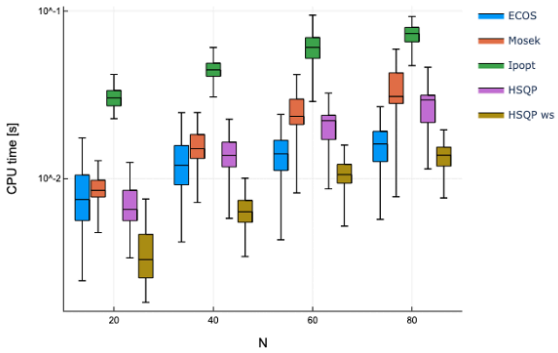


We present a Model-Based Reinforcement Learning (MBRL) algorithm named Monte Carlo Probabilistic Inference for Learning COntrol (MC-PILCO). The algorithm relies on Gaussian Processes (GPs) to model the system dynamics and on a Monte Carlo approach to estimate the policy gradient. This defines a framework in which we ablate the choice of the following components: (i) the selection of the cost function, (ii) the optimization of policies using dropout, (iii) an improved data efficiency through the use of structured kernels in the GP models. Numerical comparisons in a simulated cart-pole environment show that MC-PILCO exhibits better data efficiency and control performance w.r.t. state-of-the-art GP-based MBRL algorithms. The effectiveness of the proposed solutions has been tested in simulation and on two real systems, a Furuta pendulum and a ball-and-plate rig.

Homogeneous Infeasible Interior Point Method for Convex Quadratic Programs

Citation: Raghunathan, A., Jha, D.K., Romeres, D., "Homogeneous Infeasible Interior Point Method for Convex Quadratic Programs", IEEE Conference on Decision and Control (CDC), DOI: 10.1109/CDC51059.2022.9992979, December 2022, pp. 7571-7578.

Contacts: Arvind Raghunathan, Devesh Jha, Diego Romeres

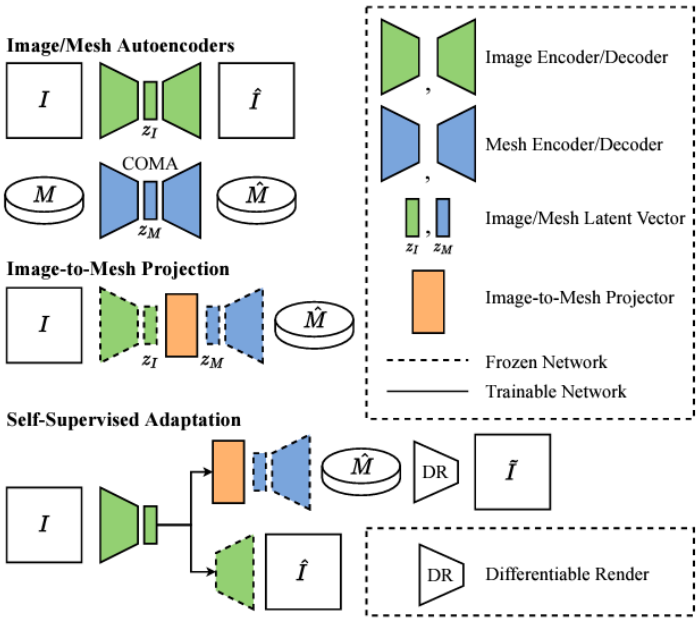


We present an Infeasible Interior Point Method (IIPM) for the solution of convex quadratic programs, such as those arising in Model Predictive Control (MPC) of constrained linear dynamical systems, using a novel homogeneous formulation. The homogenization is applied on a slacked reformulation of the QP. We describe a tailored step computation in the IIPM that addresses the potential loss of sparsity resulting from the homogenization. We demonstrate that the warms-starts of the proposed IIPM reduces the computational time by 50% on an MPC application.

Learning to Synthesize Volumetric Meshes from Vision-based Tactile Imprints

Citation: Zhu, X., Jain, S., Tomizuka, M., van Baar, J., "Learning to Synthesize Volumetric Meshes from Vision-based Tactile Imprints", IEEE International Conference on Robotics and Automation (ICRA), DOI: 10.1109/ICRA46639.2022.9812092, May 2022, pp. 4833-4839.

Contacts: Siddarth Jain



Vision-based tactile sensors typically utilize a deformable elastomer and a camera mounted above to provide high-resolution image observations of contacts. Obtaining accurate volumetric meshes for the deformed elastomer can provide direct contact information and benefit robotic grasping and manipulation. This paper focuses on learning to synthesize the volumetric mesh of the elastomer based on the image imprints acquired from vision-based tactile sensors. Synthetic image-mesh pairs and real-world images are gathered from 3D finite element methods (FEM) and physical sensors, respectively. A graph neural network (GNN) is introduced to learn the image-to-mesh mappings with supervised learning. A self-supervised adaptation method and image augmentation techniques are proposed to transfer networks from simulation to reality, from primitive contacts to unseen contacts, and from one sensor to another. Using these learned and adapted networks, our proposed method can accurately reconstruct the deformation of the real-world tactile sensor elastomer in various domains, as indicated by the quantitative and qualitative results.

Connectivity & Information Processing

Connectivity research focuses on enhancing the performance and security of communications networks, particularly at network and system levels. Current areas of research include heterogenous IoT networking for smart infrastructure; reconfigurable networks; and cyber security.

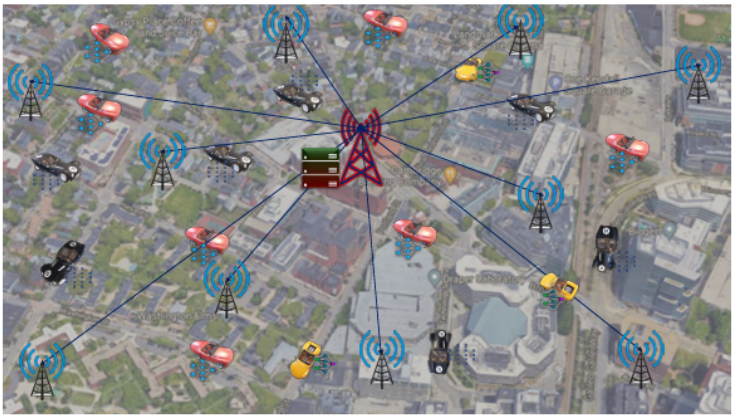
Information processing research areas include fundamental methods to enhance the robustness of machine learning methods; distributed learning methods such as federated learning; bio-signal processing; and quantum machine learning. Applications include security for cyber physical systems, collaborative learning for connected automated vehicles, and man-machine interfaces with multi-modal bio-sensors.

Recent research

Mobility, Communication and Computation Aware Federated Learning for Internet of Vehicles

Citation: Pervej, M.F., Guo, J., Kim, K.J., Parsons, K., Orlik, P.V., Di Cairano, S., Menner, M., Berntorp, K., Nagai, Y., Dai, H., "Mobility, Communication and Computation Aware Federated Learning for Internet of Vehicles", IEEE Intelligent Vehicles Symposium (IV), June 2022.

Contacts: Jianlin Guo, Kieran Parsons, Philip V. Orlik, Stefano Di Cairano, Marcel Menner, Karl Berntorp



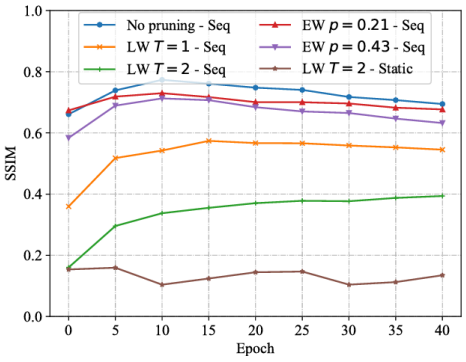
We propose a novel mobility, communication and computation aware online Federated Learning (FL) platform that uses on-road vehicles as learning agents. Thanks to the advanced features of modern vehicles, the on-board sensors can collect data as vehicles travel along their trajectories, while the on-board processors can train machine learning models using the collected data. The central server accepts partially trained models, the distributed roadside units (a) perform downlink multicast beamforming to minimize global model distribution delay and (b) allocate optimal uplink radio resources to minimize local model offloading delay, while the vehicle agents conduct heterogeneous local model training.

Data Privacy and Protection on Deep Leakage from Gradients by Layer-Wise Pruning

Citation: Liu, B., Koike-Akino, T., Wang, Y., Kim, K.J., Brand, M., Aeron, S., Parsons, K., "Data Privacy and Protection on Deep Leakage from Gradients by Layer-Wise Pruning", IEEE Information Theory and Applications Workshop (ITA), June 2022.

Contacts: Toshiaki Koike-Akino, Ye Wang, Matthew Brand, Kieran Parsons

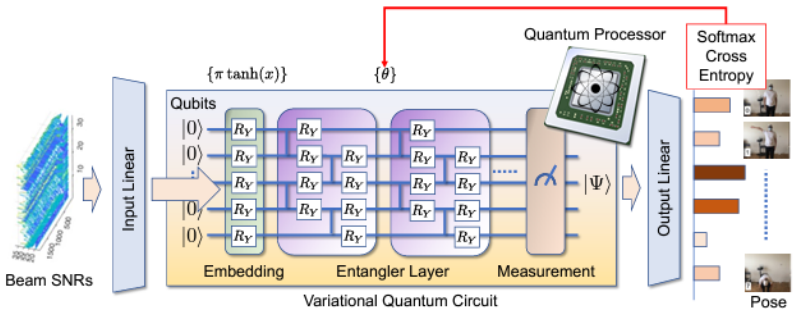
We study a data privacy and protection problem in a federated learning system for image classification. We assume that an attacker has full knowledge of the shared gradients during the model update. We propose a layer-wise pruning defense to prevent data leakage to the attacker. We also propose a sequential update attack method, which accumulates the information across training epochs. Simulation results show that the sequential update can gradually improve the image reconstruction results for the attacker.



AutoQML: Automated Quantum Machine Learning for Wi-Fi Integrated Sensing and Communications

Citation: Koike-Akino, T., Wang, P., Wang, Y., "AutoQML: Automated Quantum Machine Learning for Wi-Fi Integrated Sensing and Communications", IEEE Sensor Array and Multichannel Signal Processing Workshop (SAM), DOI: 10.1109/SAM53842.2022.9827846, June 2022.

Contacts: Toshiaki Koike-Akino, Pu Wang, Ye Wang

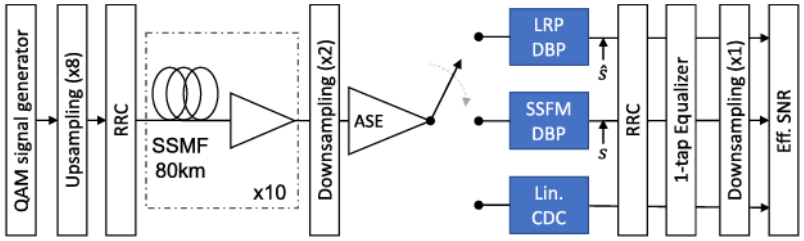


Commercial Wi-Fi devices can be used for integrated sensing and communications (ISAC) to jointly exchange data and monitor indoor environment. We investigate a proof-of-concept approach using an automated quantum machine learning (AutoQML) framework called AutoAnsatz to recognize human postures. We address how to efficiently design quantum circuits to configure quantum neural networks (QNN). The effectiveness of AutoQML is validated by an in-house experiment for human pose recognition, achieving state-of-theart performance greater than 80% accuracy for a limited data size with a significantly small number of trainable parameters.

Inverse Regular Perturbation with ML-Assisted Phasor Correction for Fiber Nonlinearity Compensation

Citation: Dzieciol, H., Koike-Akino, T., Wang, Y., Parsons, K., "Inverse Regular Perturbation with ML-Assisted Phasor Correction for Fiber Nonlinearity Compensation", Optics Letters, DOI: 10.1364/OL.460929, Vol. 47, No. 14, pp. 3471-3474, June 2022.

Contacts: Toshiaki Koike-Akino, Ye Wang, Kieran Parsons

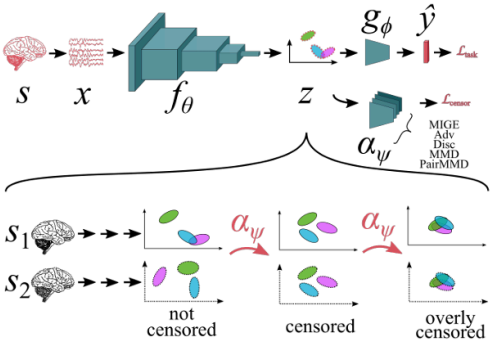


We improve an inverse regular perturbation (RP) model using a machine learning technique. The proposed learned RP (LRP) model jointly optimizes step-size, gain and phase rotation for individual RP branches. We demonstrate that the proposed LRP can outperform the corresponding learned digital back-propagation (DBP) method based on a split-step Fourier method (SSFM), with up to 0.75 dB gain in a 800km standard single mode fiber link. Our LRP also allows a fractional step-per-span (SPS) modelling to reduce complexity while maintaining superior performance over a 1-SPS SSFM-DBP.

AutoTransfer: Subject Transfer Learning with Censored Representations on Biosignals Data

Citation: Smedemark-Margulies, N., Wang, Y., Koike-Akino, T., Erdogmus, D., "AutoTransfer: Subject Transfer Learning with Censored Representations on Biosignals Data", International Conference of the IEEE Engineering in Medicine & Biology Society (EMBS), DOI: 10.1109/EMBC48229.2022.9871649, July 2022.

Contacts: Ye Wang, Toshiaki Koike-Akino

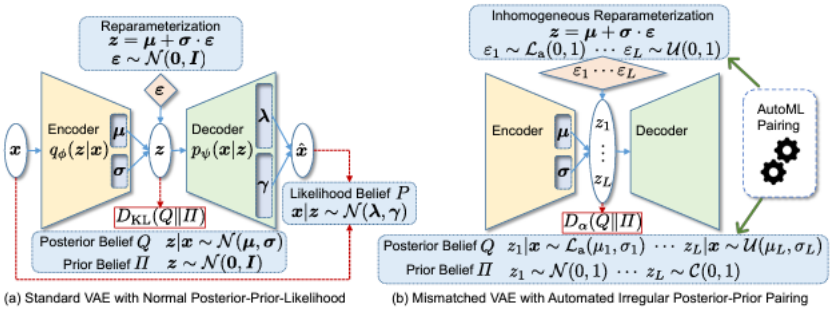


We investigate a regularization framework for subject transfer learning in which we train an encoder and classifier to minimize classification loss, subject to a penalty measuring independence between the latent representation and the subject label. We introduce three notions of independence and corresponding penalty terms using mutual information or divergence as a proxy for independence. For each penalty term, we provide several concrete estimation algorithms, using analytic methods as well as neural critic functions. We propose a hands-off strategy for applying this diverse family of regularization schemes to a new dataset, which we call "AutoTransfer".

AutoVAE: Mismatched Variational Autoencoder with Irregular Posterior Prior Pairing

Citation: Koike-Akino, T., Wang, Y., "AutoVAE: Mismatched Variational Autoencoder with Irregular Posterior Prior Pairing", IEEE International Symposium on Information Theory (ISIT), DOI: 10.1109/ISIT50566.2022.9834769, July 2022.

Contacts: Toshiaki Koike-Akino, Ye Wang

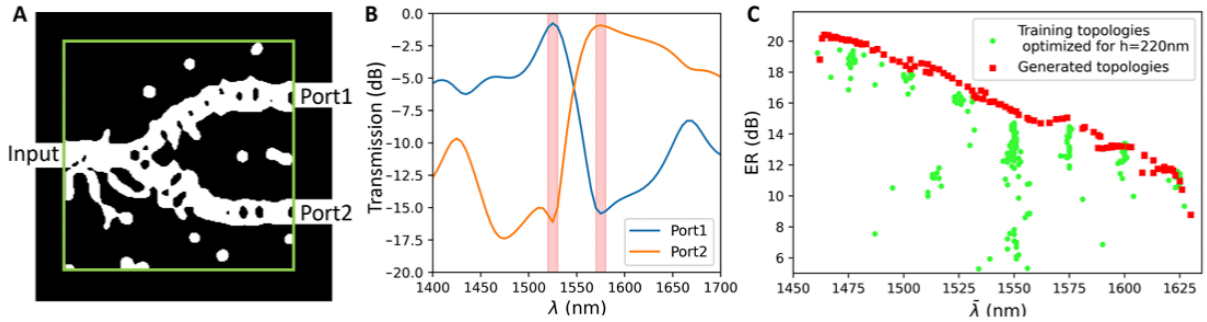


We investigate possibilities of mismatched variational autoencoders (VAEs), e.g., where the uniform distribution is used as a posterior belief at the encoder while the Cauchy distribution is used as a prior belief at the decoder. To design a mismatched VAE, the total number of potential combinations to explore grows rapidly with the number of latent nodes when allowing different distributions across latent nodes. We propose a novel framework called AutoVAE, which searches for a better pairing set of posterior-prior beliefs in the context of automated machine learning for hyperparameter optimization.

Deep Transfer Learning for Nanophotonic Device Design

Citation: Kojima, K., Jung, M., Koike-Akino, T., Wang, Y., Brand, M., Parsons, K., "Deep Transfer Learning for Nanophotonic Device Design", Conference on Lasers and Electro-Optics (CLEO) Pacific Rim, July 2022.

Contacts: Toshiaki Koike-Akino, Ye Wang, Matthew Brand, Kieran Parsons



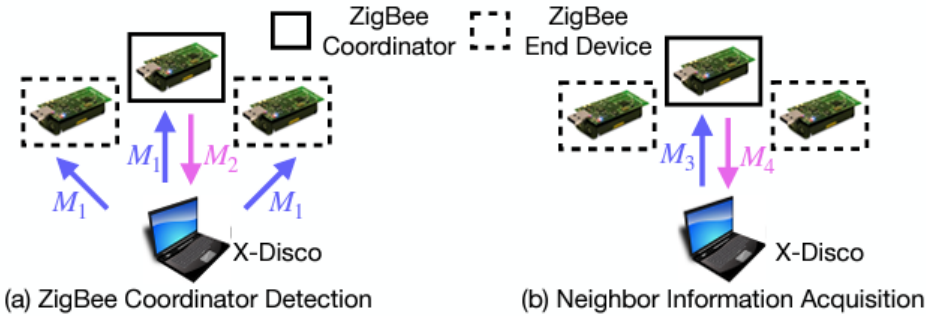
Applying a transfer-learning technique for generative deep neural networks, we demonstrate a very time-efficient inverse design framework for photonic integrated circuit devices, when there are new demands for structural/material parameters from an existing device library.

X-Disco: Cross-Technology Neighbor Discovery

Citation: Wang, S., Guo, J., Wang, P., Parsons, K., Orlik, P.V., Nagai, Y., Sumi, T., Pathak, P., ,, "X-Disco: Cross-technology Neighbor Discovery", IEEE International Conference on Sensing, Communication, and Networking, September 2022.

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

We present X-Disco, the first cross-Technology neighbor discovery mechanism alowing a WiFi device to detect ZigBee neighbors,

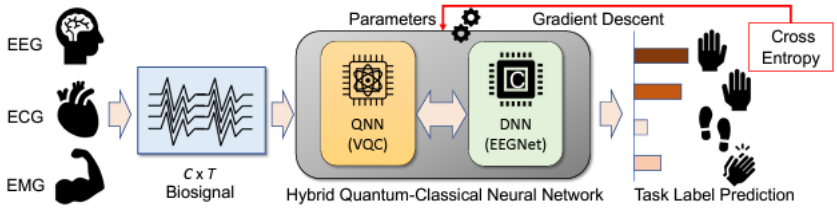


without modification to hardware or firmware. With the help of the recently proposed cross-technology communication, X-Disco enables a commodity WiFi device to trigger responses, containing ZigBee neighbor information, from the ambient ZigBee coordinators (including routers). Through exployting the WiFi PHY-layer information accessible by a WiFi driver, X-Disco decodes the responded ZigBee messages and obtains ZigBee neighbor information. To improve X-Disco's reliability, we also propose ZigBee neighbor validation and interruption mitigation to exclude hidden node terminals and mitigate the interference caused by the ambient WiFi traffic respectively.

quEEGNet: Quantum AI for Biosignal Processing

Citation: Koike-Akino, T., Wang, Y., "quEEGNet: Quantum AI for Biosignal Processing", IEEE Conference on Biomedical and Health Informatics (BHI), DOI: 10.1109/BHI56158.2022.9926814, September 2022.

Contacts: Toshiaki Koike-Akino, Ye Wang

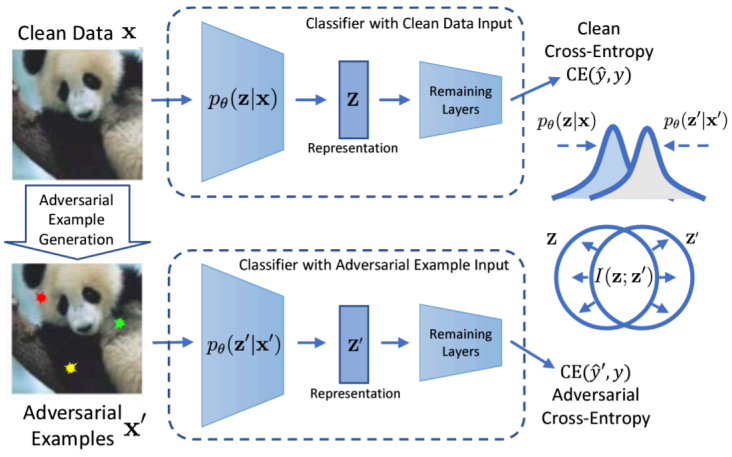


We introduce an emerging quantum machine learning (QML) framework to assist classical deep learning methods for biosignal processing applications. We propose a hybrid quantum-classical neural network model that integrates a variational quantum circuit (VQC) into a deep neural network (DNN) for electroencephalogram (EEG), electromyogram (EMG), and electrocorticogram (ECoG) analysis. We demonstrate that the proposed quantum neural network (QNN) achieves state-of-the-art performance while the number of trainable parameters is kept small for VQC.

Improving Adversarial Robustness by Learning Shared Information

Citation: Yu, X., Smedemark-Margulies, N., Aeron, S., Koike-Akino, T., Moulin, P., Brand, M., Parsons, K., Wang, Y., "Improving Adversarial Robustness by Learning Shared Information", Pattern Recognition, DOI: 10.1016/j.patcog.2022.109054, Vol. 134, pp. 109054, November 2022.

Contacts: Toshiaki Koike-Akino, Matthew Brand, Kieran Parsons, Ye Wang,



We consider the problem of improving the adversarial robustness of neural networks while retaining natural accuracy. Motivated by the multi-view information bottleneck formalism, we seek to learn a representation that captures the shared information between clean samples and their corresponding adversarial samples while discarding these samples' view-specific information. We show that this approach leads to a novel multi-objective loss function, and we provide mathematical motivation for its components towards improving the robust vs. natural accuracy tradeoff. We demonstrate enhanced tradeoff compared to current state-of-the-art methods with extensive evaluation on various benchmark image datasets and architectures. Ablation studies indicate that learning shared representations is key to improving performance.

Computational Sensing

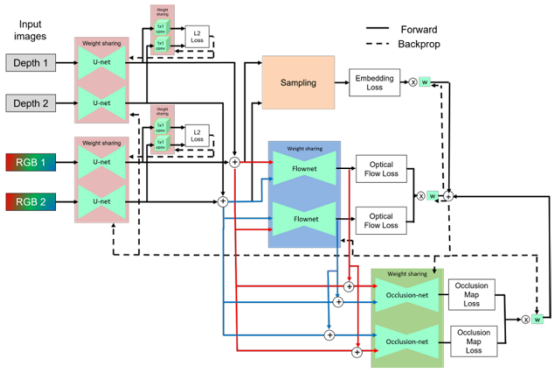
Our research in computational sensing focuses on signal acquisition, signal and system modeling, and reconstruction algorithms. We apply our work to a variety of sensing modalities, including radar and optical and explore a variety of sensing environments, including ones governed by dynamical systems, multiple scattering, or interactions difficult to model. 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. Our work has applications to product areas such as autonomous vehicles, factory automation, navigation systems, automotive radars, public security, non-contact sensing and radar imaging, among others. Our research agenda combines state-of-the art theoretical developments with widely available computational power and learning to overhaul the signal acquisition pipeline, significantly enhance sensing capabilities, and improve inference systems that seek to understand signal propagation and behavior.

Recent research

Learning Occlusion-Aware Dense Correspondences for Multi-Modal Images

Citation: Shimoya, R., Morimoto, T., van Baar, J., Boufounos, P.T., Ma, Y., Mansour, H., "Learning Occlusion-Aware Dense Correspondences for Multi-Modal Images", IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS), DOI: 10.1109/AVSS56176.2022.9959354, November 2022, pp. 1-8.

Contacts: Petros Boufounos, Yanting Ma, Hassan Mansour

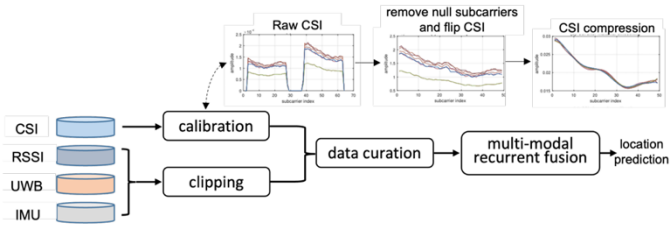


We introduce a scalable multi-modal approach to learn dense, i.e., pixel-level, correspondences and occlusion maps, between images in a video sequence. We jointly train a deep network to tackle both, with a shared feature extraction stage. We use depth and color images with ground truth optical flow and occlusion maps to train the network end-to-end. From the multi-modal input, the network learns to estimate occlusion maps, optical flows, and a correspondence embedding providing a meaningful latent feature space. We evaluate the performance on a dataset of images derived from synthetic characters, and perform a thorough ablation study to demonstrate that the proposed components of our architecture combine to achieve the lowest correspondence error. The scalability of our proposed method comes from the ability to incorporate additional modalities, e.g., infrared images.

Multi-Modal Recurrent Fusion for Indoor Localization

Citation: Yu, J., Pu, W., Koike-Akino, T., Orlik, P.V., "Multi-Modal Recurrent Fusion for Indoor Localization", IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), DOI: 10.1109/ICASSP43922.2022.9746071, April 2022.

Contacts: Pu Wang, Toshiaki Koike-Akino, Philip V. Orlik

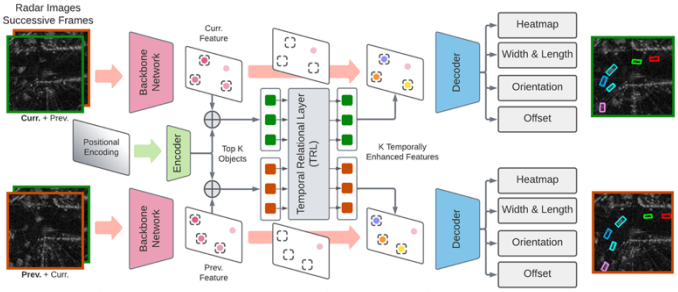


This paper considers indoor localization using multi-modal wireless signals including Wi-Fi, inertial measurement unit (IMU) and ultra-wideband (UWB). A multi-stream recurrent fusion method is proposed to combine the current hidden state of each modality in the context of recurrent neural networks while accounting for the modality uncertainty, which is directly learned from its own immediate past states. The proposed method was evaluated on the large-scale SPAWC2021 multi-modal localization dataset and compared with a wide range of baseline methods including the trilateration method, traditional fingerprinting methods, and convolution network-based methods.

Exploiting Temporal Relations on Radar Perception for Autonomous Driving

Citation: Li, P., Pu, W., Berntorp, K., Liu, H., "Exploiting Temporal Relations on Radar Perception for Autonomous Driving", IEEE Conference on Computer Vision and Pattern Recognition (CVPR), June 2022.

Contacts: Pu Wang, Karl Berntorp

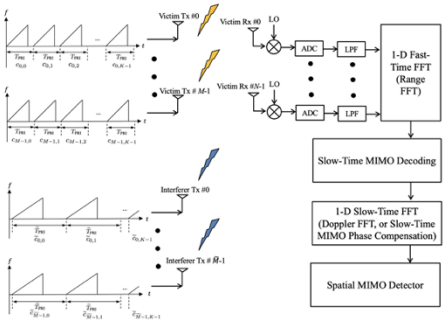


We consider the object recognition problem in autonomous driving using automotive radar sensors. Compared to Lidar sensors, radar is cost-effective and robust in all-weather conditions for perception in autonomous driving. However, radar signals suffer from low angular resolution and precision in recognizing surrounding objects. To enhance the capacity of automotive radar, we exploit the temporal information from successive ego-centric bird's-eye-view radar image frames for radar object recognition. We leverage the consistency of an object's existence and attributes (size, orientation, etc.), and propose a temporal relational layer to explicitly model the relations between objects within successive radar images. In both object detection and multiple object tracking, we show the superiority of our method compared to several baseline approaches

Spatial-Domain Mutual Interference Mitigation for Slow-Time MIMO-FMCW Automotive Radar

Citation: Jin, S., Pu, W., Boufounos, P.T., Orlik, P.V., Takahashi, R., Roy, S., "Spatial-Domain Mutual Interference Mitigation for Slow-Time MIMO-FMCW Automotive Radar", IEEE Sensor Array and Multichannel Signal Processing Workshop (SAM), DOI: 10.1109/SAM53842.2022.9827852, June 2022.

Contacts: Pu Wang, Petros T. Boufounos, Philip V. Orlik

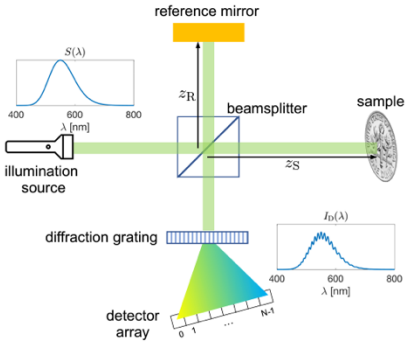


This paper considers mutual interference mitigation among automotive radars using frequency modulated continuous wave (FMCW) for the signaling scheme and multiple-input multiple-output (MIMO) for achieving a virtual array. For the first time, we derive a general interference signal model that fully accounts for not only the time-frequency incoherence, but also the slow-time code incoherence. Together with a standard MIMO-FMCW object signal model, we formulate the interference mitigation as a spatial-domain detection problem and propose a generalized likelihood ratio test (GLRT) detector. Moreover, we derive the exact theoretical performance of the proposed GLRT detector, proving that it is a constant false alarm rate (CFAR) detector against MIMO-FMCW mutual interference.

Maximum Likelihood Surface Profilometry via Optical Coherence Tomography

Citation: Rapp, J., Mansour, H., Boufounos, P.T., Orlik, P.V., Koike-Akino, T., Parsons, K., "Maximum Likelihood Surface Profilometry via Optical Coherence Tomography", IEEE International Conference on Image Processing (ICIP), DOI: 10.1109/ICIP46576.2022.9897247, September 2022, pp. 1561-1565.

Contacts: Joshua Rapp, Hassan Mansour, Petros T. Boufounos, Philip V. Orlik, Toshiaki Koike-Akino, Kieran Parsons

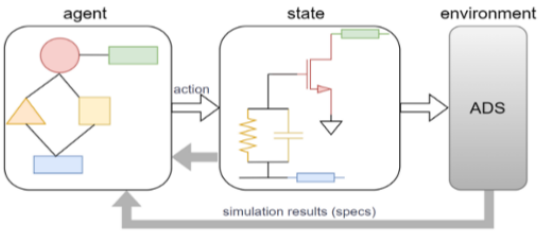


Optical coherence tomography (OCT) using Fourier domain processing can resolve micrometer-scale depth information. However, the conventional volumetric reconstruction approach is unnecessary for opaque samples with only one reflector per lateral position, and the required sample interpolation degrades performance. We show that surface depth profilometery with a Fourier-domain OCT system simplifies to a sinusoidal parameter estimation problem. We derive approximate maximum likelihood estimators for the sample depth and reflectivity, which can easily be computed by backprojecting the data without interpolating. Iterative refinement further improves results at high signal-to-noise ratio (SNR). Our results show that maximum likelihood profilometry is fast and more robust to noise than the Fourier approaches at moderate SNR.

GaN Distributed RF Power Amplifier Automation Design with Deep Reinforcement Learning

Citation: Sun, Y., Benosman, M., Ma, R., "GaN Distributed RF Power Amplifier Automation Design with Deep Reinforcement Learning", International Conference on Artificial Intelligence Circuits and Systems (AICAS), June 2022.

Contacts: Mouhacine Benosman



Radio frequency (RF) circuit design demands rich experience of practical know-how and extensive simulation. Complicated interactions among different building blocks must be considered. This becomes more challenging at higher frequency and for sophisticated circuits. We proposed a novel design automation methodology based on deep reinforcement learning (RL). For the first time, we applied RL to design a wideband non-uniform distributed RF power amplifier known for its high dimensional design challenges. Our results show that the design principles can be learned effectively and the agent can generate the optimal circuit parameters to meet the design specifications. Notably, our well-trained RL agent outperforms human expert given the same design task,.

Control for Autonomy

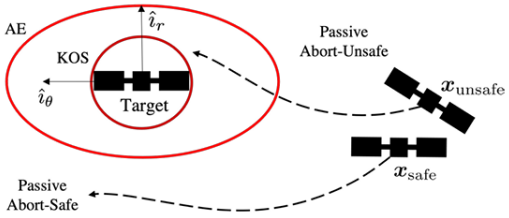
Autonomous mobile systems, such as automated cars, transport and inspection drones, robotic spacecrafts, ground mobile robots, and zoomorphic robots, show promises to improve safety, efficiency, and life enjoyment in tomorrow's society. At the core of highly capable autonomous systems there are advanced algorithms that estimate reliable information on the system operation and its surrounding environment, determine effective actions and motion plans, and control the system to robustly execute such desired behaviors. MERL's research focuses on developing advanced estimation, planning, and control algorithms for autonomous systems that increase the capabilities, the performance, and the robustness with respect state-of-the-art in academia and industry, yet they require limited computations and memory, to be viable for mass production. Recent results of MERL algorithms include safe and robust vehicle control and motion planning for automated vehicles, high precision GNSS positioning, reliable statistical estimation of vehicle driving conditions, fault tolerant spacecraft rendezvous control, fast planning for teams of drones, energy management of electric vehicles. MERL fundamental research in control theory with general applicability has a strong focus on model predictive control, statistical estimation, constrained control, motion planning, stochastic control, integration of learning and control, and real-time optimization algorithms.

Recent research

Abort-Safe Spacecraft Rendezvous on Elliptic Orbits

Citation: Aguilar Marsillach, D., Di Cairano, S., Weiss, A., "Abort-Safe Spacecraft Rendezvous on Elliptic Orbits", IEEE Transactions on Control Systems Technology, DOI: 10.1109/TCST.2022.3216077, November 2022.

Contacts: Stefano Di Cairano, Avishai Weiss

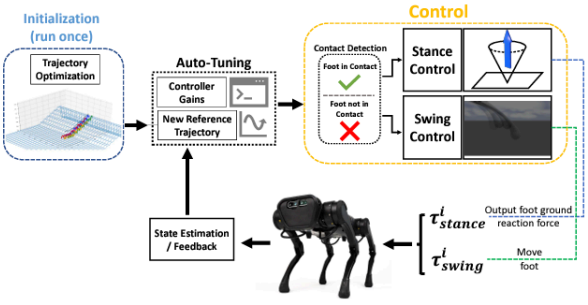


We develop a spacecraft rendezvous policy that ensures safe, collision-free trajectories under various thrust failure scenarios. We use backward reachable sets to characterize the unsafe region where, if a failure occurs, a collision between a chaser and a target spacecraft cannot be avoided with the remaining available thrust. The chaser spacecraft is guided towards the target via model predictive control that ensures abort-safety by avoiding the unsafe region, which is locally convexified with half-spaces. Simulations of the rendezvous policy on various orbits demonstrate that the approach ensures safe aborts in the event of multiple thruster failures, passive abort safety under total thruster failure, and achieves some robustness to unmodeled orbital perturbations.

Auto-Tuning of Controller and Online Trajectory Planner for Legged Robots

Citation: Schperberg, A., Di Cairano, S., Menner, M., **"Auto-Tuning of Controller and Online Trajectory Planner for Legged Robots"**, *IEEE Robotics and Automation Letters*, DOI: 10.1109/LRA.2022.3185387, Vol. 7, No. 3, pp. 7802-7809, June 2022.

Contacts: Stefano Di Cairano, Marcel Menner

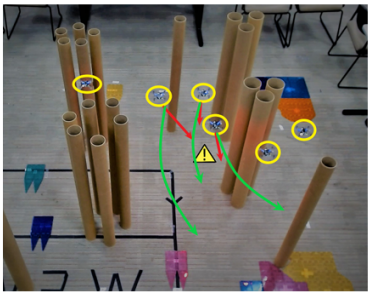


This letter presents an approach for auto-tuning feedback controllers and online trajectory planners to achieve robust locomotion of a legged robot. The auto-tuning approach uses an Unscented Kalman Filter (UKF) formulation, which adapts/calibrates control parameters online using a recursive implementation. In particular, this letter shows how to use the auto-tuning approach to calibrate cost function weights of a Model Predictive Control (MPC) stance controller and feedback gains of a swing controller for a quadruped robot. Furthermore, this letter extends the auto-tuning approach to calibrating parameters of an online trajectory planner, where the height of a swing leg and the robot's walking speed are optimized, while minimizing its energy consumption and foot slippage. This allows us to generate stable reference trajectories online and in real time. Results using a high-fidelity Unitree A1 robot simulator in Gazebo provided by the robot manufacturer show the advantages of using auto-tuning for calibrating feedback controllers and for computing reference trajectories online for reduced development time and improved tracking performance

Safe multi-agent motion planning via filtered reinforcement learning

Citation: Vinod, A.P., Safaoui, S., Chakrabarty, A., Quirynen, R., Yoshikawa, N., Di Cairano, S., "Safe multi-agent motion planning via filtered reinforcement learning", IEEE International Conference on Robotics and Automation (ICRA), DOI: 10.1109/ICRA46639.2022.9812259, May 2022, pp. 7270-7276.

Contacts: Abraham P. Vinod, Ankush Chakrabarty, Rien Quirynen, Stefano Di Cairano

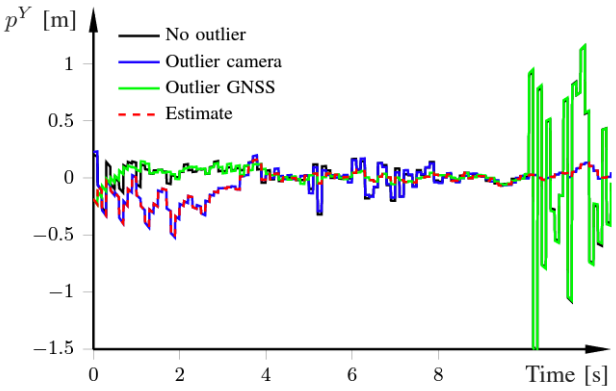


We study the problem of safe multi-agent motion planning in cluttered environments. Existing multi-agent reinforcement learning-based motion planners only provide approximate safety enforcement. We propose a safe reinforcement learning algorithm that leverages single-agent reinforcement learning for target regulation and a subsequent convex optimization-based filtering that ensures the collective safety of the system. Our approach yields a safe, real-time implementable multi-agent motion planner that is simpler to train and enforces safety as hard constraints. Our approach can handle state and control constraints on the agents, and enforce collision avoidance among themselves and with static obstacles in the environment.

Bayesian Sensor Fusion of GNSS and Camera With Outlier Adaptation for Vehicle Positioning

Citation: Berntorp, K., Greiff, M., Di Cairano, S., "Bayesian Sensor Fusion of GNSS and Camera With Outlier Adaptation for Vehicle Positioning", International Conference on Information Fusion (FUSION), DOI: 10.23919/FUSION49751.2022.9841302, July 2022, pp. 1-8.

Contacts: Karl Berntorp, Marcus Greiff, Stefano Di Cairano

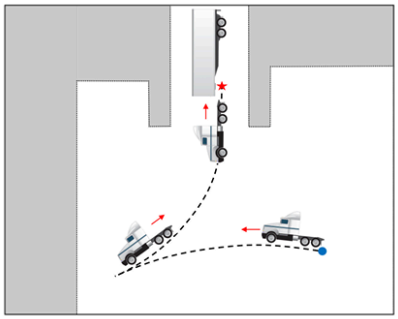


We develop a method for vehicle positioning based on global navigation satellite system (GNSS) and camera information. Both GNSS and camera measurements have noise characteristics that vary in time. As a result, the measurements can abruptly change from reliable to unreliable from one time step to another. To adapt to the changing noise levels and hence improve positioning performance, we combine GNSS information with measurements from a forward looking camera, a steering-wheel angle sensor, wheel-speed sensors, and optionally an inertial sensor. We pose the estimation problem in an interacting multiple-model (IMM) setting and use Bayes recursion to choose the best combination of the estimators.

Motion Planning and Model Predictive Control for Automated Tractor-Trailer Hitching Maneuver

Citation: Wang, Z., Ahmad, A., Quirynen, R., Wang, Y., Bhagat, A., Zeino, E., Zushi, Y., Di Cairano, S., "Motion Planning and Model Predictive Control for Automated Tractor-Trailer Hitching Maneuver", IEEE Conference on Control Technology and Applications (CCTA), DOI: 10.1109/CCTA49430.2022.9966181, August 2022, pp. 676-682.

Contacts: Rien Quirynen, Yebin Wang, Stefano Di Cairano

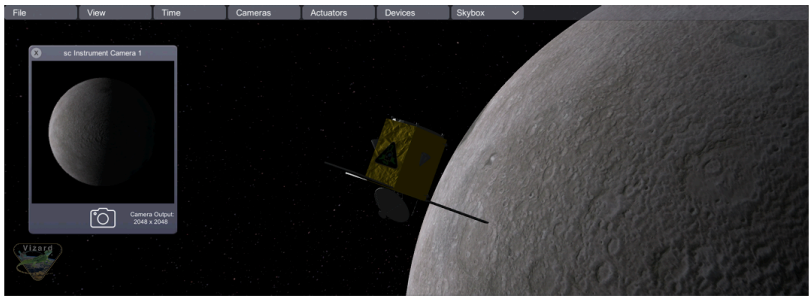


Significant progress has been made in optimization-based planning and control for automated vehicle operation. For heavy-duty vehicles, the research focus has been on platooning and control of articulated vehicles especially when cruising on the highway. This paper proposes an integrated system using a motion planning algorithm and a real-time reference tracking controller, tailored to the task of automated tractor-trailer hitching which is a critical maneuver in heavy-duty vehicle operations, due to requiring a very high precision. The motion planner is based on a bi-directional A-search guided tree algorithm and the tracking controller is implemented using nonlinear model predictive control.

Sequential linearization-based station keeping with optical navigation for NRHO

Citation: Elango, P., Di Cairano, S., Berntorp, K., Weiss, A., "Sequential linearization-based station keeping with optical navigation for NRHO", AAS/AIAA Astrodynamics Specialist Conference, September 2022.

Contacts: Stefano Di Cairano, Karl Berntorp, Avishai Weiss

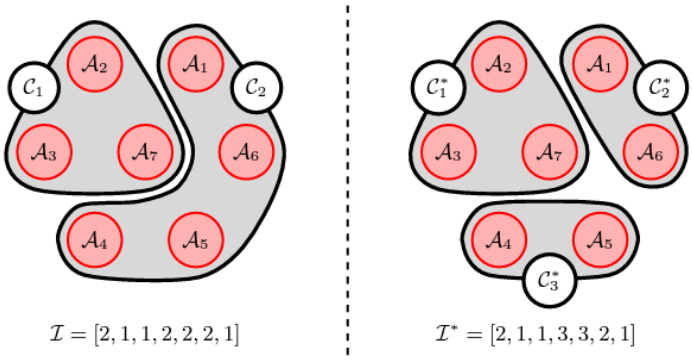


Fuel-efficient station-keeping techniques have been developed for the planned Lunar Gateway mission to a near rectilinear halo orbit (NRHO). Station-keeping approaches that rely on an autonomous navigation system that don't require communications with Earth are particularly important for ensuring safety and reliability. This paper presents a targeting approach for NRHO station keeping based on sequential linearization and evaluates its performance in a closed- loop simulation with a state estimator that receives position measurements from horizon-based optical navigation (OPNAV). Simulation results indicate an annual station-keeping cost (delta-v) of about 1.14 m s-1 for the proposed OPNAV-based station keeping.

Mixed- Dynamic Clustering for GNSS Positioning with Multiple Receivers

Citation: Greiff, M., Di Cairano, S., Berntorp, K., "Dynamic Clustering for GNSS Positioning with Multiple Receivers", International Conference on Information Fusion (FUSION), DOI: 10.23919/FUSION49751.2022.9841289, July 2022, pp. 1-7.

Contacts: Marcus Greiff, Stefano Di Cairano, Karl Berntorp

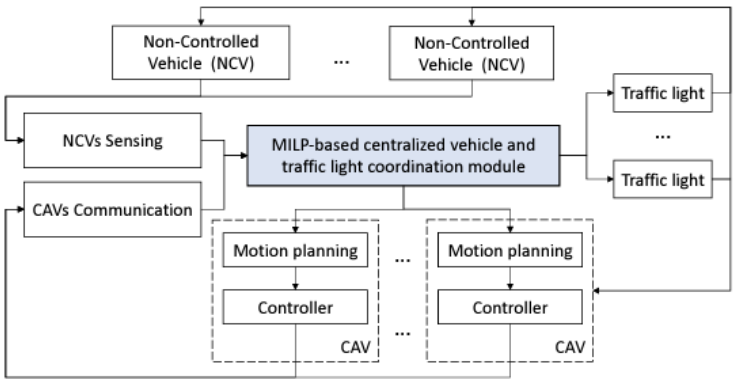


We consider the problem of jointly estimating the states of multiple global navigation satellite system (GNSS) receivers modeled with shared biases. In particular, we explore how to best assign these receivers to disjoint sets, so as to retain computational feasibility in the resulting filters. We propose a genetic algorithm that dynamically assigns agents to clusters subject to constraints on the maximum number of states in the clusters. Several numerical examples illustrate the flexibility of the approach, and the choice of genetic operations in the clustering algorithm is motivated by their effect on the algorithm's expected convergence rate.

Coordination of Autonomous Vehicles and Dynamic Traffic Rules in Mixed Automated/Manual Traffic

Citation: Firoozi, R., Quirynen, R., Di Cairano, S., "Coordination of Autonomous Vehicles and Dynamic Traffic Rules in Mixed Automated/Manual Traffic", American Control Conference (ACC), DOI: 10.23919/ACC53348.2022.9867802, June 2022.

Contacts: Stefano Di Cairano, Rien Quirynen

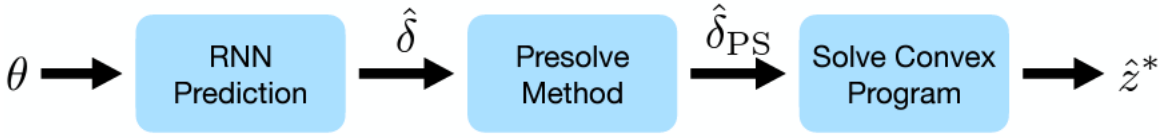


We consider the coordination of multiple connected automated vehicles (CAVs) by a central coordinator (CC) in mixed traffic where also non-controlled vehicles (NCVs) are present. The CC directly provides motion target commands to the CAVs and affects the behavior of NCVs by controlling dynamic traffic rules, such as changing traffic lights. We model the traffic rules for these scenarios by mixed-logical constraints, and the response of the NCVs to the changing traffic rules by a switched system with switches triggered by logic conditions.

PRISM: Recurrent Neural Networks and Presolve Methods for Fast Mixed-integer Optimal Control

Citation: Cauligi, A., Chakrabarty, A., Di Cairano, S., Quirynen, R., "PRISM: Recurrent Neural Networks and Presolve Methods for Fast Mixed-integer Optimal Control", Learning for Dynamics and Control Conference (L4DC), April 2022, pp. 34-46.

Contacts: Ankush Chakrabarty, Stefano Di Cairano, Rien Quirynen



While mixed-integer convex programs (MICPs) arise frequently in mixed-integer optimal control problems (MIOCPs), current state-of-the-art MICP solvers are often too slow for real-time applications, limiting the practicality of MICP-based controller design. Although supervised learning has been proposed to hasten the solution of MICPs via convex approximations, they are not designed to scale well to problems with >100 decision variables. In this paper, we present PRISM: Presolve and Recurrent network-based mixed-Integer Solution Method, to leverage deep recurrent neural network (RNN) architectures such as long short-term memory (LSTMs) networks, in conjunction with numerical optimization tools to enable scalable acceleration of MICPs arising in MIOCPs. Our key insight is to learn the underlying temporal structure of MIOCPs and to combine this with presolve routines employed in MICP solvers. We demonstrate how PRISM can lead to significant performance improvements, compared to branch-and-bound (B&B) methods and to existing supervised learning techniques, for stabilizing a cart-pole with contact dynamics, and a motion planning problem under obstacle avoidance constraints.

Electric Systems Automation

This area covers research on modeling & simulation, model-based design, optimal control, predictive maintenance and system integration of electric machines and devices. The multi-physical modeling serves as a foundation and is integrated with other technologies, such as signal processing, control, optimization, and machine learning to meet different application needs.

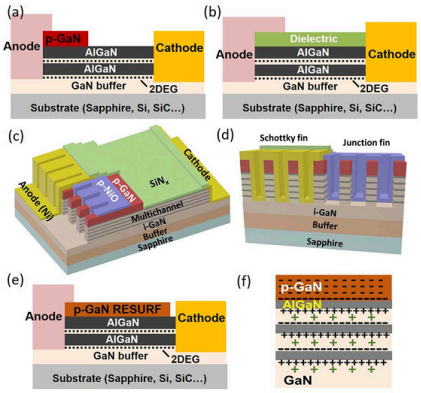
We investigate modeling fundamentals including fast computation methodologies via analytical magnetic modeling and combination with Machine-Learning models for improving accuracy. The developed models can be utilized for model-based design of new motors to achieve high density and high torque, parameter estimation for motor customization and as well as system co-design. We apply the latest signal processing techniques, refined physical models, and in conjunction with data-driven learning methods to enable high-performance online condition monitoring. For optimal control of electric machines, our effort is to develop advanced control algorithms that can increase performance and robustness with limited resources in terms of computations and memory. In the area of devices, we focus on emerging GaN technologies for power, RF, digital and quantum computing applications, and incorporating domain knowledge with machine learning to develop high accuracy and efficiency for integrated circuits. In addition, we spend some effort to explore modern quantum technology using optimal control to manipulate its wave function.

Recent research

Emerging GaN technologies for power, RF, digital and quantum computing applications: recent advances and prospects

Citation: Teo, K.H., Zhang, Y., Chowdhury, N., Rakheja, S., Ma, R., Xie, Q., Yagyu, E., Yamanaka, K., Li, K., Palacios, T., "Emerging GaN technologies for power, RF, digital and quantum computing applications: recent advances and prospects", Journal of Applied Physics, DOI: 10.1063/5.0061555, December 2021.

Contacts: Koon Hoo Teo

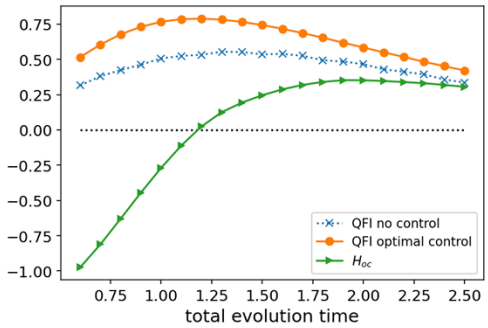


GaN technology is not only gaining traction in power and RF electronics but is rapidly expanding into other application areas including digital and quantum computing electronics. This paper provides a glimpse of future GaN device technologies and advanced modeling approaches that can push the boundaries of these applications in terms of performance and reliability. While GaN power devices have recently been commercialized in the 15-900 V classes, new GaN devices are greatly desirable to explore both the higher-voltage and ultra-low-voltage power applications. Moving into the RF domain, ultra-high frequency GaN devices are being used to implement digitized power amplifier circuits, and further advances using hardware-software co-design approach can be expected.

Application of Pontryagin's Maximum Principle to Quantum Metrology in Dissipative Systems

Citation: Lin, C., Ma, Y., Sels, D., "Application of Pontryagin's Maximum Principle to Quantum Metrology in Dissipative Systems", Physical Reivew A, DOI: 10.1103/PhysRevA.105.042621, Vol. 105, No. 4, pp. 042621, May 2022.

Contacts: Chungwei Lin, Yanting Ma

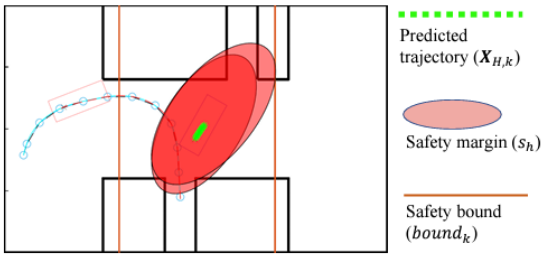


Optimal control theory, also known as Pontryagin's Maximum Principle, is applied to quantum parameter estimation in the presence of decoherence. An efficient procedure is devised to compute the gradient of quantum Fisher information with respect to the control parameters and is used to construct the optimal control protocol. The proposed procedure keeps the control problem in the time-invariant form so that both first-order and second-order optimality conditions apply; the second-order condition turns out to be crucial when the optimal control contains singular arcs. Concretely we look for the optimal control that maximizes quantum Fisher information for the "twist and turn" problem. We find that the optimal control is singular without dissipation but can become unbounded once the quantum decoherence is introduced.

Autonomous Vehicle Parking in Dynamic Environments: An Integrated System with Prediction and Motion Planning

Citation: Leu, J., Wang, Y., Tomizuka, M., Di Cairano, S., "Autonomous Vehicle Parking in Dynamic Environments: An Integrated System with Prediction and Motion Planning", IEEE International Conference on Robotics and Automation (ICRA), DOI: 10.1109/ICRA46639.2022.9812309, May 2022, pp. 10890-10897.

Contacts: Yebin Wang, Stefano Di Cairano

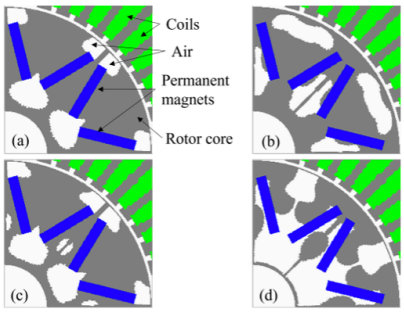


This paper presents an integrated motion planning system for autonomous vehicle (AV) parking in the presence of other moving vehicles. The system includes 1) a hybrid environment predictor that predicts the motions of the surrounding vehicles and 2) a strategic motion planner that reacts to the predictions. The hybrid environment predictor performs short-term predictions via an extended Kalman filter and an adaptive observer. It also combines short-term predictions with a driver behavior cost-map to make long-term predictions. Simulation validation demonstrates the effectiveness of the proposed method in terms of initial planning, motion prediction, safe tracking, retreating in an emergency, and trajectory repairing.

Topological Data Analysis for Image-based Machine Learning: Application to Electric Motors

Citation: Wang, B., Talukder, K., Sakamoto, Y., "Topological Data Analysis for Image-based Machine Learning: Application to Electric Motors", IEEE International Conference on Electrical Machines (ICEM), DOI: 10.1109/ICEM51905.2022.9910734, September 2022, pp. 1015-1021.

Contacts: Bingnan Wang

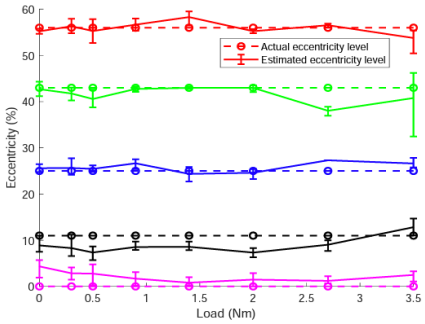


Many finite-element simulations are required to fully evaluate the performance of a motor design candidate at different operating points. We investigate a deep learning based surrogate modeling technique for motor design optimization to reduce the simulations required. We introduce topological data analysis to electric machine design, which extracts topological features from motor design images for the training of machine learning models. We introduce the process of computing persistence homology and Betti sequences, which serve as vectorized input data for machine learning models. We propose two-channel deep learning models, with one convolutional network branch built for motor image data, and another multi-layer perceptron branch for Betti sequences. We show with numerical tests that two-channel models perform better in prediction accuracy and generalization capability compared with models without topological feature input.

Eccentricity Severity Estimation of Induction Machines using a Sparsity-Driven Regression Model

Citation: Zheng, X., Liu, D., Inoue, H., Kanemaru, M., "Eccentricity Severity Estimation of Induction Machines using a Sparsity-Driven Regression Model", The Fourteenth Annual Energy Conversion Congress and Exposition, DOI: 10.1109/ECCE50734.2022.9947498, October 2022.

Contacts: Dehong Liu

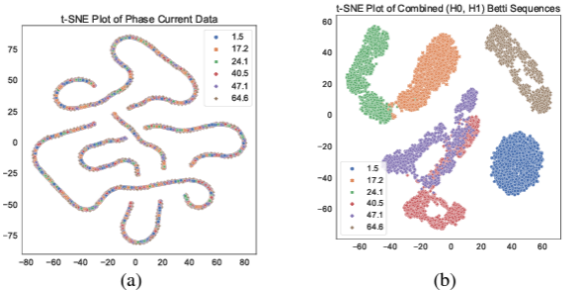


Eccentricity severity level estimation is of great importance in rotary machine fault detection. However, in practice machine operation conditions may influence the magnitude of fault signatures, making eccentricity severity estimation a challenging problem. We develop a linear regression model incorporating multiple fault signature features to estimate the eccentricity severity level of induction machines under different operating conditions. In particular, the eccentricity severity level is modeled as a function of operating conditions and fault signature features including rotating speed, load torque, vibration, as well as current harmonics, etc, with corresponding weights to be determined. Experimental results show that our trained model exhibits satisfactory accuracy in quantitatively estimating eccentricity under various operation conditions.

Topological Data Analysis for Electric Motor Eccentricity Fault Detection

Citation: Wang, B., Lin, C., Inoue, H., Kanemaru, M., "Topological Data Analysis for Electric Motor Eccentricity Fault Detection", Annual Conference of the IEEE Industrial Electronics Society (IECON), DOI: 10.1109/IECON49645.2022.9968912, October 2022, pp. 1-6.

Contacts: Bingnan Wang, Chungwei Lin

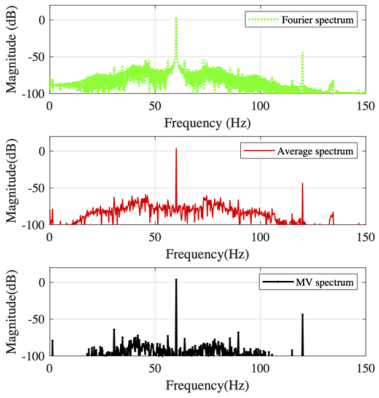


We develop topological data analysis (TDA) method for motor current signature analysis (MCSA), and apply it to induction motor eccentricity fault detection. We introduce TDA and present the procedure of extracting topological features from time-domain data that will be represented using persistence diagrams and vectorized Betti sequences. The procedure is applied to induction machine phase current signal analysis, and shown to be highly effective in differentiating signals from different eccentricity levels. With TDA, we are able to use a simple regression model that can predict the fault levels with reasonable accuracy, even for the data of eccentricity levels that are not seen in the training data. The proposed method is model-free, and only requires a small segment of time-domain data to make prediction. These advantages make it attractive for a wide range of fault detection applications.

Robust Motor Current Signature Analysis (MCSA)-based Fault Detection under Varying Operating Conditions

Citation: Liu, D., Inoue, H., Kanemaru, M., "Robust Motor Current Signature Analysis (MCSA)-based Fault Detection under Varying Operating Conditions", International Conference on Electrical Machines and Systems (ICEMS), DOI: 10.1109/ICEMS56177.2022.9983454, November 2022.

Contacts: Dehong Liu

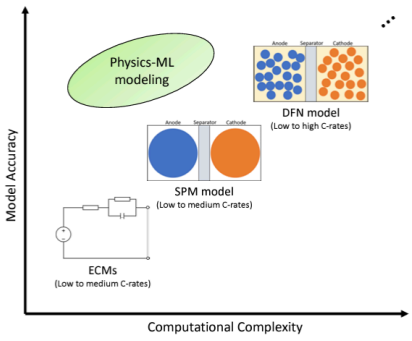


Motor current signature analysis (MCSA) has been widely used in motor fault detection including bearing fault, broken-bar, and eccentricity, etc. When a motor's fault is in its early stage or a faulty motor is operating in varying load conditions, the fault signature may be submerged in the background noise and interference, making fault detection a very challenging problem. We address the problem of extracting a small fault signature of frequency components under varying load conditions and a noisy background. To this end, we segment the time-domain stator current into overlapped sequences, and treat each sequence as an independent measurement of an imaginary sensor. A minimum variance beam-forming method is then employed to generate the current frequency spectrum with robust performance under varying-load operations.

Integrating Physics-Based Modeling with Machine Learning for Lithium-Ion Batteries

Citation: Tu, H., Moura, S., Wang, Y., Fang, H., "Integrating Physics-Based Modeling with Machine Learning for Lithium-Ion Batteries", Applied Energy, DOI: 10.1016/j.apenergy.2022.120289, Vol. 329, December 2022.

Contacts: Yebin Wang

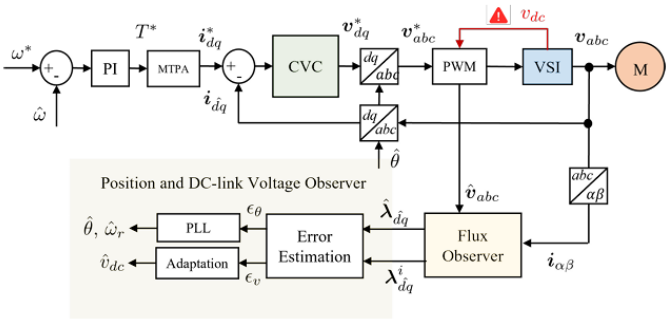


Mathematical modeling of lithium-ion batteries (LiBs) is a primary challenge in advanced battery management. This paper proposes two new frameworks to integrate physics-based models with machine learning to achieve high-precision modeling for LiBs. The frameworks are characterized by informing the machine learning model of the state information of the physical model, enabling a deep integration between physics and machine learning. Based on the frameworks, a series of hybrid models are constructed, through combining an electrochemical model and an equivalent circuit model, respectively, with a feedforward neural network. The hybrid models are relatively parsimonious in structure and can provide considerable voltage predictive accuracy under a broad range of C-rates, as shown by extensive simulations and experiments. The study further expands to conduct aging-aware hybrid modeling, leading to the design of a hybrid model conscious of the state-of-health to make prediction.

Sensorless Control of Synchronous Machines with DC-Link Voltage Immunity and Adaptation

Citation: Anantaram, V., Wang, Y., "Sensorless Control of Synchronous Machines with DC-Link Voltage Immunity and Adaptation", IEEE Power Electronics, Drives and Energy Systems, DOI: 10.1109/PEDES56012.2022.10080212, December 2022.

Contacts: Anantaram Varatharajan, Yebin Wang

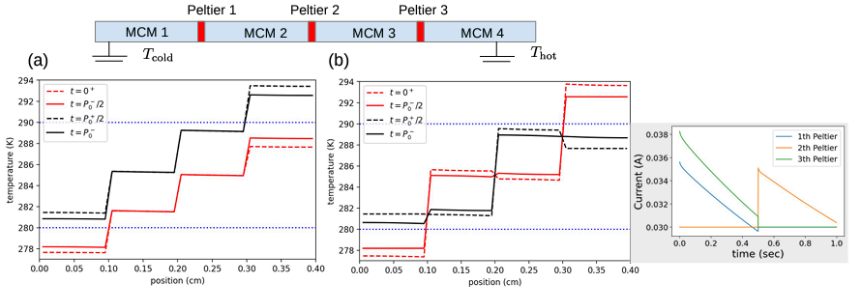


Position sensorless techniques have implicit dependence on the DC-link voltage sensor which acts as a single point of failure. This work presents a novel position estimation technique that is immune and resilient to the errors in the DC-link voltage measurement. The proposed sensorless scheme is developed within the projection vector framework from the linearized dynamics of the hybrid flux observer. In addition, a DC-link voltage estimation that is independent and decoupled from the position estimation is developed for a potential DC-link voltage sensorless and position sensorless operation capability.

Magnetic Cooling with Thin Peltier Modules as Thermal Switches

Citation: Lin, C., "Magnetic Cooling with Thin Peltier Modules as Thermal Switches", Journal of Magnetism and Magnetic Materials, DOI: 10.1016/j.jmmm.2023.170482, Vol. 570, pp. 170482, February 2023.

Contacts: Chungwei Lin



Magnetic refrigeration is a promising alternative to existing vapor-compression technology. The refrigerant of magnetic cooling is the magnetocaloric material whose temperature is controlled by applying/removing the magnetic field during the cooling cycle. In this work we consider the scenario where thin Peltier modules are used to control the heat flow in the magnetic cooling device. A phenomenological 3-parameter model is adopted to describe the Peltier modules, based on which we develop a simple numerical procedure to simulate the cooling device that includes both magnetocaloric materials and Peltier modules. Using coefficient of performance as the performance metric, we find that the inclusion of Peltier modules can greatly reduce the design complexity, particularly to simplify the pumping and valving systems of the working fluid.

Multi-Physical Systems

This area covers research on methods and tools for the model-based design and creation of digital twins 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 processes for optimization of architecture, control and performance of systems and their digital twins.

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 systems; motion control; energy systems; advanced assembly lines in factories; and digital twin systems for zero-energy buildings and factory automation.

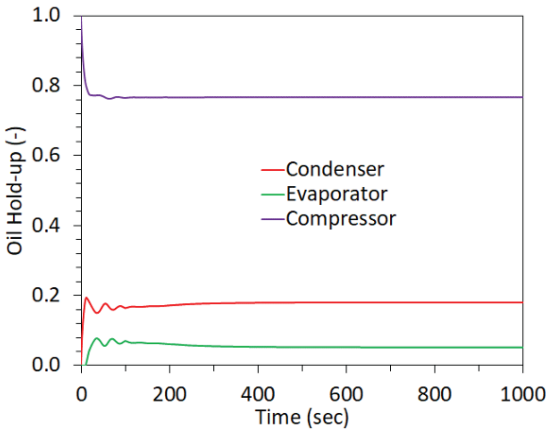
Recent research

Dynamic Modeling of Oil Transport in Vapor Compression Systems

Citation: Qiao, H., Laughman, C.R., "Dynamic Modeling of Oil Transport in Vapor Compression Systems", *International Refrigeration and Air Conditioning Conference (IRACC)*, July 2022.

Contacts: Hongtao Qiao, Christopher R. Laughman

We propose a new model describing the dynamics of refrigerant-oil mixtures in vapor compression systems. This model uses the approach presented by Thome (1995) to calculate the thermodynamic properties of refrigerant-oil mixture. The governing equations for one-dimensional flow are augmented with the oil mass balance, and partial derivatives of mixture density are computed to ensure the consistence of the choice of state variables for all flow conditions. The existing models for heat exchanger and other components are then refined accordingly. Numerical simulation for the start-up operation of an air-conditioning cycle is conducted to evaluate the efficacy of the proposed model.

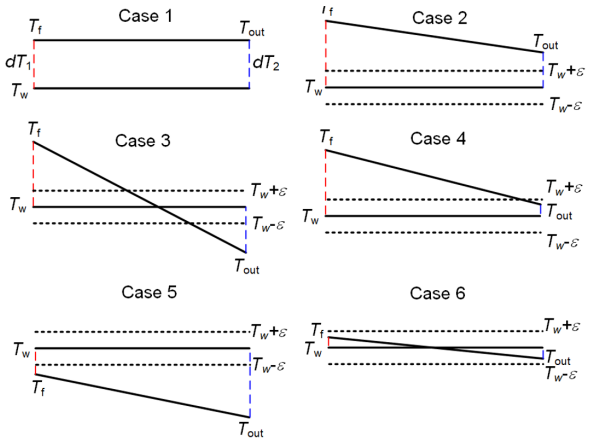


A Low-Order Model for Nonlinear Dynamics of Heat Exchangers

Citation: Qiao, H., Laughman, C.R., "A Low-Order Model for Nonlinear Dynamics of Heat Exchangers", *International Refrigeration and Air Conditioning Conference (IRACC)*, July 2022.

Contacts: Hongtao Qiao, Christopher R. Laughman

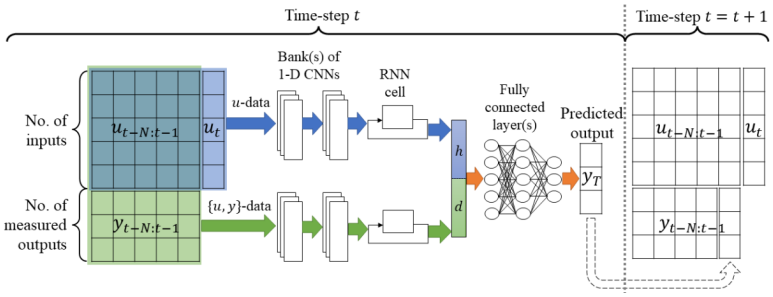
We propose a novel low-order heat exchanger model that possesses the merits of both lumped parameter and moving boundary models. The dynamics of refrigerant flow are described by the average mass and energy balances across the entire heat exchanger, and the phase transition boundaries are estimated by assuming a linear or exponential profile of refrigerant enthalpy distribution. This modeling approach exhibits invariant model structure to eliminate chattering during the simulation. A direct comparison of the proposed model with finite volume and moving boundary models demonstrates the significant improvements in computational speed exhibited by this new approach while still maintaining reasonable accuracy and good numerical stability.



CNN-GRU: Efficient Learning of Thermo-Fluid Dynamical Systems with Convolutions and Recurrence

Citation: Bhattacharya, C., Chakrabarty, A., Laughman, C., Qiao, H., "CNN-GRU: Efficient Learning of Thermo-Fluid Dynamical Systems with Convolutions and Recurrence", *Modeling, Estimation and Control Conference*, DOI: 10.1016/j.ifacol.2022.11.168, December 2022, pp. 99-106.

Contacts: Hongtao Qiao

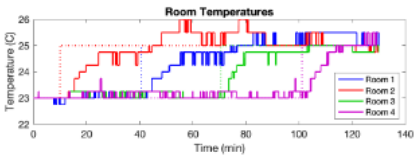


Deep state-space models of dynamical systems exploit the flexibility and scalability inherent to neural architectures to describe a wide range of dynamics directly from data in applications where physics-informed models are either absent or too complex to be used efficiently for analysis and control. In this paper, we propose a deep state-space modeling framework that leverages convolutional neural networks (CNNs) for automatic feature extraction from multi-input multi-output data and gated recurrent units (GRUs) for realizing short-term dynamical trends. This highly generalizable architecture is used to generate accurate one-step predictions given windowed prior data, as required in typical predictive modeling applications. We compare CNN-GRU to state-of-the-art deep state-space modeling tools and demonstrate that our proposed method often outperforms contemporary algorithms and is effective on real-world application of learning heat-exchanger dynamics.

H-Infinity Loop-Shaped Model Predictive Control with HVAC Application

Citation: Bortoff, S.A., Schwerdtner, P., Danielson, C., Di Cairano, S., Burns, D.J., "H-Infinity Loop-Shaped Model Predictive Control with HVAC Application", IEEE Transactions on Control Systems Technology, DOI: 10.1109/TCST.2022.3141937, Vol. 30, No. 5, pp. 2188-2203, March 2022.

Contacts: Scott A. Bortoff, Stefano Di Cairano

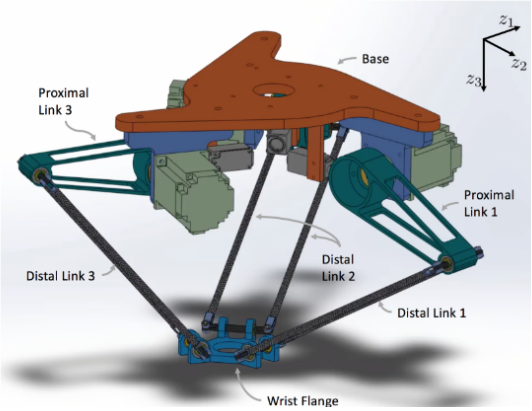


We formulate a Model Predictive Control (MPC) for linear time-invariant systems based on H-infinity loop-shaping. The design results in a closed-loop system that includes a state estimator and attains an optimized stability margin. Input and output weights are designed in the frequency domain to satisfy steady-state and transient performance requirements, in lieu of standard MPC plant model augmentations. The H-infinity loop-shaping synthesis results in an observer-based state feedback structure. An inverse optimal control problem is solved to construct the MPC cost function, so that the control input computed by MPC is equal to the H-infinity control input when the constraints are inactive. The MPC inherits the closed-loop performance and stability margin of the loop-shaped design when constraints are inactive.

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, DOI: doi.org/10.1115/DSCC2020-3158, December 2020.

Contacts: Scott A. Bortoff

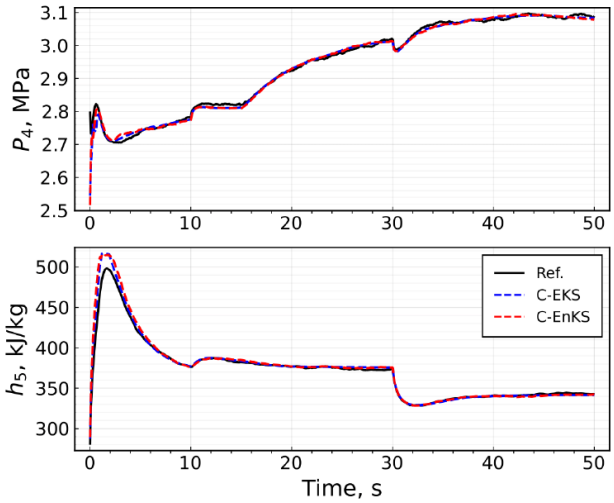


We derive a dynamic model of the delta robot and two formulations of the manipulator Jacobian that comprise a system of singularity-free, index-one differential algebraic equations that is well-suited for model-based control design and computer simulation. One of the Jacobians is intended for time-domain simulation, while the other is for use in discrete-time control algorithms. The model is well posed and numerically well-conditioned throughout the workspace, including at kinematic singularities. We use the model to derive an approximate feedback linearizing control algorithm that can be used for both trajectory tracking and impedance control.

Constrained Smoothers for State Estimation of Vapor Compression Cycles

Citation: Deshpande, V., Laughman, C.R., Ma, Y., Rackauckas, C., "Constrained Smoothers for State Estimation of Vapor Compression Cycles", American Control Conference (ACC), DOI: 10.23919/ACC53348.2022.9867269, ISSN: 2378-5861, ISBN: 978-1-6654-5196-3, June 2022, pp. 2333-2340.

Contacts: Vedang Deshpande, Christopher R. Laughman

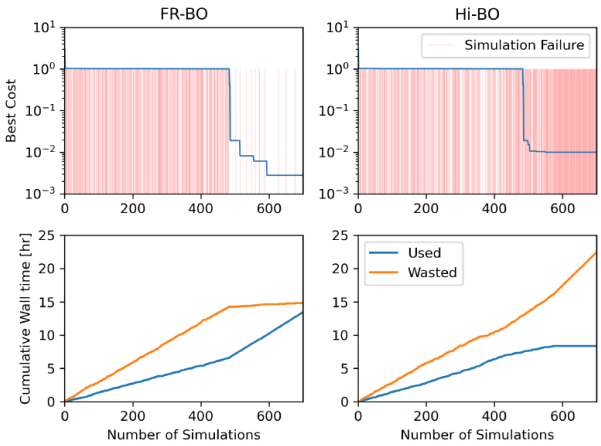


State estimators can be a powerful tool in the development of advanced controls and performance monitoring capabilities for vapor compression cycle-based equipment, but the nonlinear and numerically stiff aspects of these systems pose challenges for their practical implementation on large physics-based models. We develop smoothing methods in the extended and ensemble Kalman estimation frameworks that satisfy physical constraints and address practical limitations with standard implementations of these estimators. These methods are tested on a model built in the Julia language, and are demonstrated to successfully estimate unmeasured variables with high accuracy.

Simulation Failure-Robust Bayesian Optimization for Data-Driven Parameter Estimation

Citation: Chakrabarty, A., Bortoff, S.A., Laughman, C.R., "Simulation Failure Robust Bayesian Optimization for Data-Driven Parameter Estimation", IEEE Transactions on Systems, Man, and Cybernetics: Systems, DOI: 10.1109/TSMC.2022.3216790, December 2022.

Contacts: Ankush Chakrabarty, Scott A. Bortoff, Christopher R. Laughman

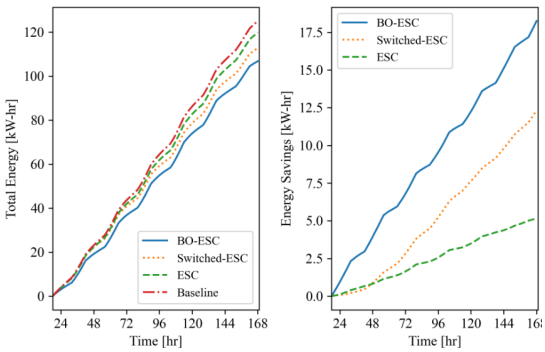


While searching over the parameter space is an inevitable part of the calibration process, the fact that models are seldom designed to be valid for arbitrarily large parameter spaces causes this process to often result in repeated model evaluations over regions of parameters that can cause the simulations to be unreasonably slow or fail altogether. We propose a novel failure-robust Bayesian optimization (FR-BO) algorithm that learns these failure regions from online simulations and informs a Bayesian optimization algorithm to avoid failure regions while searching for optimal parameters. This results in acceleration of the optimizer's convergence and prevents wastage of time trying to simulate parameters with high failure probabilities.

Accelerating Self-Optimization Control of Refrigerant Cycles

Citation: Chakrabarty, A., Danielson, C., Bortoff, S.A., Laughman, C.R., "Accelerating self-optimization control of refrigerant cycles with Bayesian optimization and adaptive moment estimation", Applied Thermal Engineering, DOI: 10.1016/j.applthermaleng.2021.117335, Vol. 197, pp. 117335, February 2022.

Contacts: Ankush Chakrabarty, Scott A. Bortoff, Christopher R. Laughman

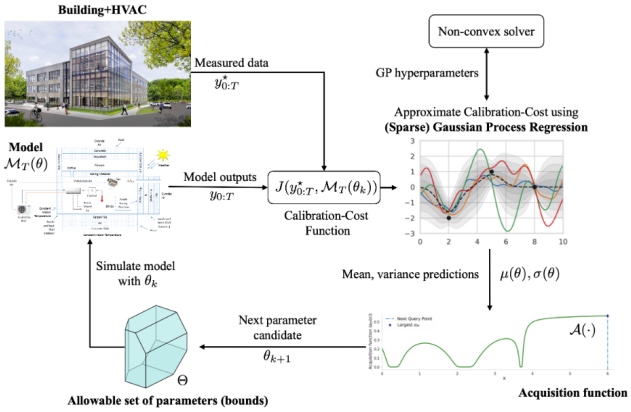


This paper presents a model-free self-optimization control algorithm for modulating multiple inputs simultaneously to minimize the power consumption of a vapor compression system (VCS). We propose the use of Bayesian optimization (BO) to warm-start a state-of-the- art extremum seeking control (ESC) algorithm and then accelerate the ESC on-line with Adam, a well-studied algorithm used to train deep neural networks. The warm-start increases the likelihood of attaining a global optimum for locally convex, but globally non-convex, objective functions by identifying regions where the global optimum most likely resides.

Scalable Bayesian Optimization for Model Calibration

Citation: Chakrabarty, A., Maddalena, E., Qiao, H., Laughman, C.R., "Scalable Bayesian Optimization for Parameter Estimation of Coupled Building and HVAC Dynamics", Energy and Buildings, DOI: 10.1016/j.enbuild.2021.111460, Vol. 253, pp. 111460, March 2022.

Contacts: Ankush Chakrabarty, Hongtao Qiao, Christopher R. Laughman

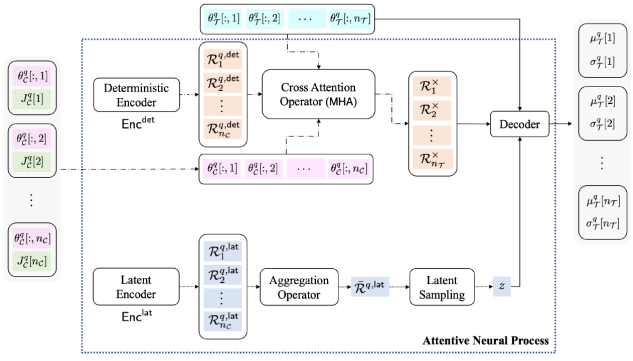


Model calibration for building systems is a key step to achieving accurate and reliable predictions that reflect the dynamics of real systems under study. Calibration becomes particularly challenging when integrating building and HVAC dynamics, due to large-scale, nonlinear, and stiff underlying differential algebraic equations. We describe a framework for calibrating multiple parameters of coupled building/HVAC models using scalable Bayesian optimization (BO), whose advantages include global optimization without requiring gradient information. The proposed methodology is improved online via two additional steps: domain tightening and domain slicing, both of which leverage the surrogate calibration cost function.

Calibrating building simulation models using multi-source datasets and meta-learned Bayesian optimization

Citation: Zhan, S., Wichern, G., Laughman, C.R., Chong, A., Chakrabarty, A., "Calibrating building simulation models using multi-source datasets and meta-learned Bayesian optimization", Energy and Buildings, DOI: 10.1016/j.enbuild.2022.112278, Vol. 270, pp. 112278, September 2022.

Contacts: Ankush Chakrabarty, Gordon Wichern, Christopher R. Laughman



Current automatic calibration algorithms for building simulation models do not leverage data collected from multiple sources, such as data obtained from previous calibration tasks on other buildings. In this work, we employ probabilistic deep learning to meta-learn a distribution using multi-source data acquired during previous calibration. Subsequently, the meta-learned Bayesian optimizer accelerates calibration of new, unseen tasks. The few-shot nature of the proposed algorithm (that is, requiring few model simulations) is demonstrated on a Modelica library of residential buildings validated by the United States Department of Energy (USDoE).