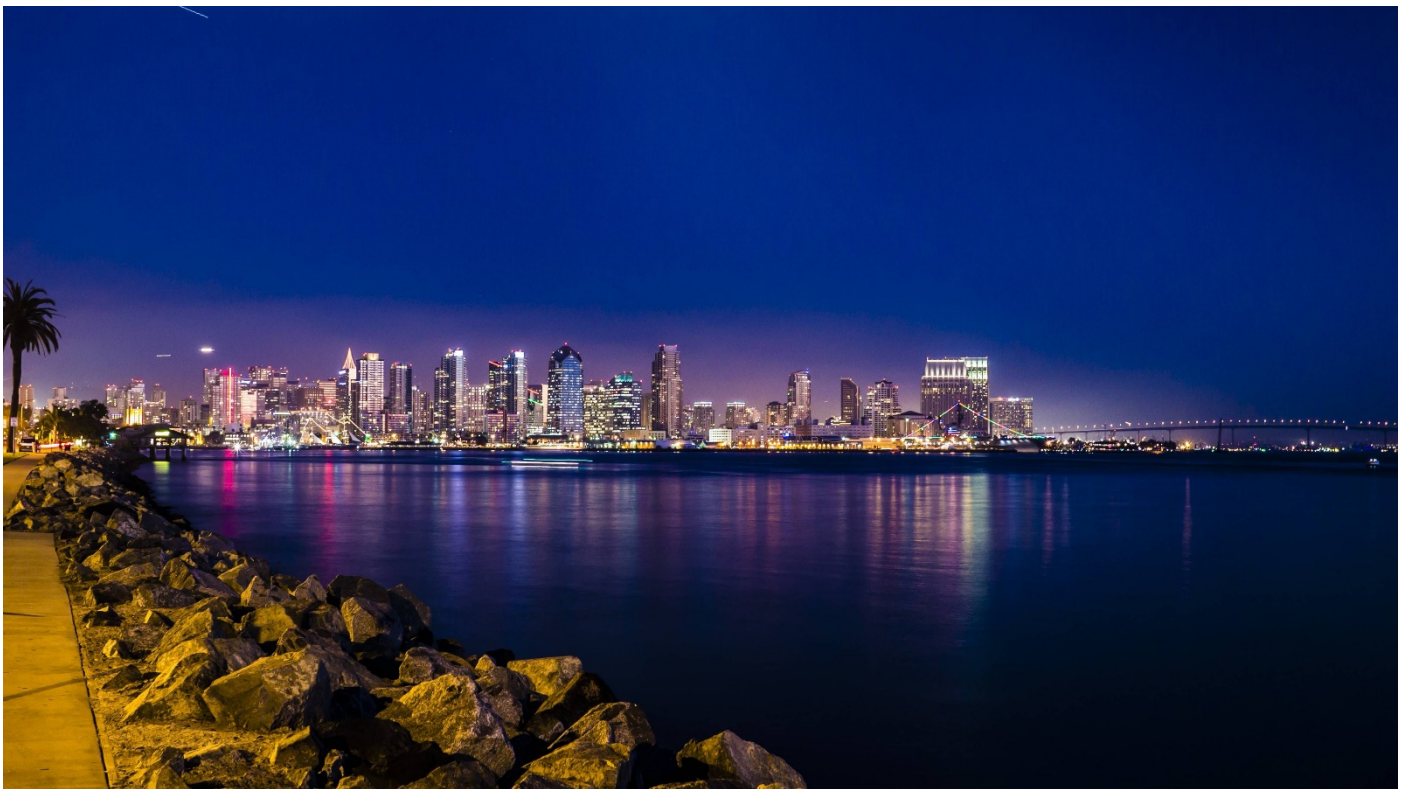
IEEE CCTA 2021

5th IEEE Conference on Control Technology and Applications

FINAL PROGRAM



San Diego Skyline

August 8-11, 2021

San Diego, California

(held online)

2021 IEEE Conference on Control Technology and Applications (CCTA).

IEEE Catalog Number CFP21CCV-ART (Xplore) ISBN 978-1-6654-3643-4

Additional copies of this publication are available from

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CCTA 2021 Final Program Book

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Welcome

Greetings from the General Chair

I am delighted to welcome all contributors and participants to the 2021 IEEE Conference on Control Technology and Applications (CCTA2021) the 5th conference in a series that started in 2017. CCTA is one of the two conferences financially sponsored by IEEE Control Systems Society (CSS), with the other being the IEEE Conference on Decision and Control (CDC).

The planning for CCTA2021 began three years ago. After a thorough search, we decided to hold the conference in San Diego. Little did we know at the time that the COVID-19 pandemic that began in 2020 would leave us no choice but to hold CCTA2021 as a virtual conference. However, I am pleased with the control systems society's recent decision to return to San Diego for CCTA2025, meaning that much of our initial planning will be useful to the organizers of that conference. Speaking of initial planning, I should state that I am indeed grateful to Faryar Jabbari, former CSS Vice President for Conference Activities, who offered enormous help and support during those early months. I should also thank Alessandro Giua, who offered help and guidance ever since he took over the role from Faryar.

Many individuals contributed to the organization of this conference. First, I would like to thank my Program Chair, Tsu-Chin Tsao, who was responsible for putting together the overall CCTA2021 technical program. Tsu-Chin was always available to discuss and help with various aspects of organizing this conference. I thank him for his support and dedication. Stefano Di Cairano chaired the CCTA Editorial Board. He and his colleagues did a wonderful job of reviewing the submitted manuscripts on time and with a high standard. I thank all of them for their great service to our community. Zongxuan Sun, Invited Sessions Chair, oversaw the review process of invited session proposals and their associated manuscripts. Juan Ren, the Registration Chair, spent many hours dealing with numerous requests and questions related to registration. I thank her for her patience and diligence. Justin Ruths, Publicity Chair, established, maintained, and regularly updated, conference website and publicized the conference through various channels. Tyler Summers, Workshops Chair, organized five workshops for CCTA2021 attendees. Ian Manchester, Publications Chair, put together the conference booklet. I would also like to thank Simona Onori for taking care of finances for the conference and Ann Majewicz Fey for agreeing to serve as Diversity and Inclusion Chair. Finally, I would like to thank Mike Borrello, who coordinated online delivery of conference sessions.

As I pointed out earlier, we hoped and planned to hold CCTA2021 as a regular in-person conference. However, in early spring it became clear that it was highly unlikely for international travel to resume in time to enable our colleagues from overseas to participate in the conference. Therefore, a decision was made to hold CCTA as a fully virtual conference for the second time. Organizing a virtual conference is a non-trivial task and the organizing committee worked hard to put together a program of highest quality, given the circumstances. I do hope that all CCTA2021 participants will enjoy this rich program, and I hope that we will be able to meet each other again in future CCTAs that will be held in person.

Reza Moheimani
General Chair, IEEE CCTA 2021

Welcome

Greetings from the Program Chair

Dear participants and authors: a warm welcome to you in joining and/or contributing to the 5th IEEE Conference on Control Technology and Applications (CCTA 2021). The CCTA continues the long-time success of its predecessor IEEE Multi-Conference on Systems and Control (MSC). The CCTA 2021 is held as a virtual conference August 8-11, 2021.

We handled the reviews of the 246 Submission by the Conference Editorial Board led by Dr. Stefano Di Cairano and the Program Committee led by the Invited Session Chair Prof. Zongxuan Sun. After careful deliberations, we selected 163 contributed, invited, and tutorial papers and 13 presentations of recently accepted IEEE Transactions on Control System Technology papers for the Conference Program. We have truly global participations with presentations from the North and South America, Asia, Australia, Europe, and Africa. To accommodate the different time zones, we structured the daily programs within a five and half hour time widow. Each day starts with the Opening and Plenary session, followed by two sessions over six parallel tracks. The second day features a dedicated slot of four hourly Keynote talks in two parallel sessions and a tutorial session in the other regular time slot. The Program is completed with a total of 30 focused sessions of contributed and invited paper, and five workshops held in the pre-conference day.

The conference disseminates the current technological advances and applications of systems theory and control engineering. The mostly mentioned key words in the accepted papers -- Control applications, Optimization, Automotive applications, Autonomous systems, Nonlinear systems, Cooperative control, Predictive control, Adaptive control, Modeling, Estimation, Reinforcement learning, Mechatronic systems, indicate the community's current interest areas. The invited speakers on three plenary and four keynote talks: Jing Sun, Ian Peterson, Guy Dumont, Marcel Heertjes, George T.C. Chiu, Lucy Y. Pao, and Santosh Devasia cover broad range of topics on their fields, and we look forward to their sharing of inspiring perspectives.

I would like to thank in particular Dr. Stefano Di Cairano, Chair of the CCTA Editorial Board, for all of his help in the reviewing process as well as his help in compiling a high-quality program. Also, I would like to thank the CCTA EB Associate Editors for all their help in selecting reviewers and handling the review process for the contributed papers, the 2021 Program Committee members who were involved in the review process of the invited session paper submissions, and all the reviewers who assisted in the review process. Finally, I would like to express my great appreciation for the General Chair Prof. Reza Moheimani for his dedicated and professional coordination of the whole team.

We look forward to meeting you in this digital way and help to progress the impact of our field on the major societal challenges facing us today and in the future.

Tsu-Chin Tsao
Program Chair, IEEE CCTA 2021

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The Organizing Committee wishes to acknowledge the many individuals who contributed to the peer review process of submitted manuscripts to CCTA 2021. In particular, the International Program Committee (responsible for invited sessions) and the Technical Conference Editorial Board (responsible for contributed papers), worked with the Program Chair and the CCTA Editorial Board Chair as well as hundreds of dedicated referees to ensure a high-quality technical program for the conference. Their names are listed below:

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Conference Highlights

The 2021 IEEE Conference on Control Technology and Applications (CCTA) will be held Monday through Wednesday, August 9 – 11, online. The CCTA 2021 technical program will feature the presentation of contributed and invited papers, as well as tutorial sessions and pre-conference workshops, focusing on technological advances and applications of control engineering. This focus includes all aspects of control engineering for practical control systems, from analysis and design, through simulation and hardware. Themes such as energy, healthcare, manufacturing, and transportation will feature applications of control technology for robotic, automotive, biomechanical, aerospace, power and energy systems, control of networks, and many others. Plenary lectures focused on conference themes will be delivered on Monday and Tuesday as part of the conference program. Four keynote lectures will be delivered on Tuesday in two dedicated sessions. Transition to Practice Award Lecture will be presented on Wednesday. Five tutorial workshops will be presented on Sunday preceding the conference. For the first time in this conference series, participants will have the opportunity to present their papers that were published in IEEE Transactions on Control Systems Technology. Papers that appeared in TCST from issue 4, 2019 or have been accepted for publication are eligible.

Sunday, August 8, 2021:

- Pre-conference **Tutorial Workshops**, 8:30 to 17:30

Monday, August 9, 2021:

- Opening Remarks, 6:30 – 6:45
- **Plenary Lecture**, 6:45 – 7:45
- Technical Program, regular and invited sessions, 7:55 – 9:55 and 10:00 – 12:00

Tuesday, August 10, 2021:

- **Plenary Lecture**, 6:45 – 7:45
- **Keynote Sessions**, 7:55 – 9:55
- Technical Program, regular and invited sessions, 10:00 – 12:00

Wednesday, August 11, 2021:

- **Plenary Lecture**, Transition to Practice Award Recipient, 6:45 – 7:45
- Technical Program regular and invited sessions, 7:55 – 9:55 and 10:00 – 12:00
- IEEE Control Systems Society **Awards Ceremony,**
  Transition to Practice award, Student Best Paper finalists and award, and **CCTA 2021 Closing Ceremony**, 12:00 – 12:30

Pre-Conference Workshops

CCTA 2021 is pleased to be offering workshops on topics in control technology and applications. These tutorials are proposed, organized and delivered by international experts from academia, national laboratories, and industry.

All Workshops will take place prior to the conference on Sunday, August 8, and will be held online. Participants may register for workshops via the conference webpage.

SuW1: Half Day Workshop 8:30 to 12:30 Pacific

Multi-Vehicle and Assured Autonomous Control for Aerospace Applications

Full-Day, 8:30am-5:00pm, Pacific

This one-day workshop will focus on current control system topics that are having an impact in the aerospace industry. The workshop will be presented by leading control systems experts from industry and academia that are involved in some of the most exciting researchand development efforts in the field of Aerospace. This workshop is intended for students and professors in search of current applications in need of solutions as well as industry and government professionals interested in potential solutions from academia and adjacent branches of the aerospace industry. This workshop is sponsored and presented by members of the IEEE CSS Technical Committee on Aerospace Controls and their collaborators. The purpose of the technical committee is to help build an international scientific community and promote awareness of outstanding achievements in the field of Aerospace Controls.

In this offering the workshop will present a sample of current topics related to the intelligent control of cooperating groups of unmanned air vehicles (UAV's), spacecraft, drones and miniature projectiles. Our experts will present the theoretical background, rigorous methods and experimental results that are creating an exciting new chapter in field of Aerospace Control. Recent advances in adaptive and nonlinear robust control theory are used to form the basis for safe, resilient and certifiable systems of co-operative platforms. Future directions for research are included in discussion of the roles of artificial intelligence (AI) and augmented and virtual reality (AR/VR), as well as emerging applications in Aerospace Control for adversarially robust cyber resistant systems. The workshop will offer opportunities for questions and answers, and provide an open forum for discussion of applications for current theoretical advances and potential enabling technologies. The proceeds from this workshop will be donated by the organizers and presenters to help fund student awards and participation in CSS technical committee and conference activities.

Organizers: Richard Hull (Collins Aerospace), Venanzio Cichella (University of Iowa)

SuW2: Half Day Workshop 8:30 to 12:30 Pacific

Motion Planning, Control, and Learning for Autonomous Driving Systems

Half-Day, 8:30am-12:30pm Pacific

This workshop is designed to stimulate a discussion on the state of the art and roadmap for the research and application of advanced techniques on the Motion Planning, Control, and Learning for Autonomous Driving Systems. As we move to increasingly complex transportation systems and more complex urban environments, new approaches are needed to accommodate the challenges associated with agent interactions, planning and control under uncertainty, and long-tail scenarios.

The intersection of motion planning, control, and learning provides opportunities to explore the solutions for these challenges and apply those solutions to real-world applications (including driver-assistance systems, connected and automated vehicles, and fully autonomous driving systems).

We will discuss the strengths and limitations of the different approaches and assist with system level design choices. We will also discuss how to leverage real world driving data to address the challenges of the motion planning and control of autonomous driving systems through different learning methods.

Organizers: Yan Chang (Lyft), Andreas Malikopoulos (University of Delaware)

SuW3: Full Day Workshop 8:30 to 12:30 Pacific

Practical Methods for Real-World Control Systems

Half-Day, 8:30am-1:00pm Pacific

Rationale: The proverbial "gap" between control theory and practice has been discussed since the 1960s, but it shows no signs of being any smaller today than it was back then. Despite this, the growing ubiquity of powerful and inexpensive computation platforms, of sensors, actuators and small devices, the "Internet of Things", of automated vehicles and quadcopter drones, means that there is an exploding application of control in the world. Any material that allows controls researchers to more readily apply their work and/or allows practitioners to improve their devices through best practices consistent with well understood theory, should be a good contribution to both the controls community and the users of control. This workshop is intended as a small but useful step in that direction.

Prerequisite skills (of participants): Undergraduate level knowledge of feedback systems, sampled data systems, and programming. An honest interest in being able to translate control theory into physical control systems.

Intended Audience: We believe that this workshop will be of great interest to three types of audience members:

1. Academic researchers who are well versed in control theory but would like to learn more about issues practicing control engineers often encounter as well as techniques and methods often used outside of standard textbook solutions to enhance their students' experience in the classroom and laboratory.
2. Practicing engineers who work on physical control systems and products that use control with an interest in connecting their work to "best practices" motivated by theory.
3. Students who may be interested in adding laboratory experiments to their research or want to know how to make what they have learned applicable in industry.

For each of these groups – and those that are somewhere in the intersection of them – this workshop will address the gap from both sides, so as to give the participant a more complete understanding of how it applies to their particular situation.

Topic overview: The general style for each topic will be to present the issue, discuss rational ways of thinking about a solution, and where possible, show a demo to illustrate the idea.

Pre-Conference Workshops

Schedule

- Overview, a.k.a. “Mind the Gap.”
- System Models and Characterizing Them with Measurements, or why it’s both important and annoying to be discrete
- Simple Controllers for Simple Models, or why so many controllers are PIDs, and why some are not Practical Loop Design, Or Why Most Open Loops Should Be an Integrator, and How to Get There Resonances, Anti-Resonances, Filtering, and Equalization Signal Detection, Sensors, Sample Rates, and Noise (Oh My!)
- Integrating in Feedforward Control
- Ask Your Doctor: Is State Space Right for You?
- Pick a Chip, Any Chip: Or why real-time programming is too important to leave to folks who only know programming
- Closing Thoughts/Discussion

Organizer: Daniel Abramovitch

SuW4: Full Day Workshop 8:30 to 17:30 Pacific

Smart Control Engineering (SCE), Digital Twins, and Industrial AI (IAI) – A New Research Frontier

Half-Day: 8:30am-1:00pm Pacific

Experienced control engineers and researchers agree that before designing a controller, we need to ask two questions 1) “What do we have/know?” and 2) “What do we want?” and after we have designed a controller, we also need to ask two questions 1) “How optimal?” and 2) “How robust?”. With the emerging wave of “Digital Transformation” such as Industry 4.0, I promote asking the third question: “How smart?”. This talk introduces a new frontier for control engineering: Smart Control Engineering (SCE), using Digital Twins (DT) as the enabler technology combined with IAI (industrial artificial intelligence) and breaking technologies like Deep Learning, AI, Data Analytics, Big Data, and edge computing.

For SCE, the concept of “smartness” follows the notion of the US NSF program on S&AS (smart and autonomous systems) based on the following attributes 1) Taskable; 2) Cognitive; 3) Reflective; 4) Ethical; 5) Knowledge-rich. It means that a smart control system can learn from past actions and induced errors (resilience), discover hidden patterns and anomalous behaviors at multiple time scales and reach the desired closed-loop and operation specifications. This workshop will present a case study to illustrate the SCE fundamentals enabled by DT using IAI for process control engineering.

This tutorial workshop prepares CCTA2021 our audience with:

- What is SCE – smart control engineering and how to make control systems smarter?
- Digital Twins (DT) concept, example DT platforms, and DT behavior matching algorithms, and practical implementation
- SCE control design based on DT (SOC, ITL, R2R)
- Edge computing, embedded and industrial AI applications towards SCE
- Rich future research opportunities in SCE and DT.

Organizer: Prof. Yang Quan Chen, UC Merced, yqchen@ieee.org

Website: https://mechatronics.ucmerced.edu/sce

Pre-Conference Workshops

SuW5: Full Day Workshop 9:00 to 17:30

The Confluence of Vision and Control

Full-Day, 8:30am-5:00pm, Pacific

The use of visual sensors in feedback control has been an active topic of research for decades. As the cost of hardware lowers and computational capabilities increase, vision-based control is reaching new levels of capability and application. Recent innovations in computer vision can provide greater capabilities to control applications such as autonomous vehicles and robots. At the same time, open problems in computer vision can be solved through control theory, such as nonlinear and adaptive control. We present twelve discussions on recent work in vision-based control, the application of control to computer vision, and topics in which vision and control are uniquely intertwined. We seek to highlight recent developments and open problems that exist at the intersection of vision and control and spur further research and development in the community.

Organizers: Kaveh Fathian (MIT), Nicholas Gans (University of Texas at Arlington)

Website: https://sites.google.com/view/ccta-2021-vision-and-control/home

Plenary Sessions

Monday, August 9, 6:45am - 7:45am (PST)

Prediction, Estimation, and Control of Connected and Autonomous Vehicles

Jing Sun
Univ. of Michigan, Ann Arbor

Jing Sun received her Ph.D. degree from the University of Southern California in 1989 and her master's and bachelor's degrees from the University of Science and Technology of China in 1984 and 1982. From 1989-1993, she was an assistant professor in the Electrical and Computer Engineering Department at Wayne State University. She joined Ford Research Laboratory in 1993, where she worked on advanced powertrain system controls. After spending almost ten years in the industry, she returned to academia in 2003. She joined the University of Michigan, where she is the Michael G. Parsons Collegiate Professor and the chair in the Naval Architecture and Marine Engineering Department. She holds joint appointments in the Electrical Engineering and Computer Science Department and Mechanical Engineering Department at the same university. She has been named the inventor of 41 US patents and has published over 300 archived journal and conference papers. She is a fellow NAI (the National Academy of Inventors), IEEE, IFAC, and SNAME (the Society of Naval Architecture and Marine Engineering). She is one of the three recipients of the 2003 IEEE Control System Technology Award.

Prediction, Estimation, and Control of Connected and Autonomous Vehicles: Connected and Automated Vehicles (CAV) have been heralded as the transformative technology, leading us to the new era of transportation with unprecedented safety and mobility benefits. They also push the energy efficiency of the transportation systems at both the macro and micro (vehicle) levels to the next height with abundant new opportunities for communication and optimization. While advanced sensors and hardware, such as camera, radar, and lidar and those used in V2V and V2I communications, have been featured predominantly in CAV showcases, control again is playing the role of the "unsung" hero that enables the CAV technology in the "hidden" world with algorithms and computational intelligence. In this talk, we will discuss some fundamental technical challenges for prediction, estimation, and control at the core of the CAV technology. Using the integrated power and thermal management for CAV as an example, we will show how model-based design, complemented by data-driven approaches, has led to control and optimization solutions with a significant impact on energy efficiency and operational reliability. Open problems will be highlighted to stimulate interest from our community to sing our song loudly and collectively on this CAV platform.

IEEE Control Systems Society, Transition to Practice Award

Tuesday, August 9, 6:45am-7:45am

Using Systems and Control Theory Ideas in the Design of Quantum Amplifiers

Ian R. Peterson
Australian National University

Ian R. Petersen was born in Victoria, Australia. He received a Ph.D. in Electrical Engineering in 1984 from the University of Rochester. From 1983 to 1985 he was a Postdoctoral Fellow at the Australian National University. From 2017 he has been a Professor at the Australian National University. He was the Interim Director of the Research School of Electrical, Energy and Materials Engineering at the Australian National University from 2018-2019. From 1985 until 2016 he was with UNSW Canberra where he was a Scientia Professor and an Australian Research Council Laureate Fellow in the School of Engineering and Information Technology. He has previously been ARC Executive Director for Mathematics Information and Communications, Acting Deputy Vice-Chancellor Research for UNSW and an Australian Federation Fellow. He has served as an Associate Editor for the IEEE Transactions on Automatic Control, Systems and Control Letters, Automatica, IEEE Transactions on Control Systems Technology and SIAM Journal on Control and Optimization. Currently he is an Editor for Automatica. He is a fellow of IFAC, the IEEE and the Australian Academy of Science. His main research interests are in robust control theory, quantum control theory and stochastic control theory.

Using Systems and Control Theory Ideas in the Design of Quantum Amplifiers: One of the most significant areas emerging in the area of quantum technology is that of quantum computing. Companies such as Google, IBM, and Microsoft have made significant investments in quantum computing to develop small scale quantum computers using microwave frequency technologies involving arrays of superconducting Josephson junctions operating at millikelvin temperatures. Other technologies which have been investigated for the implementation of quantum computers include quantum optics, ion trap devices and solid-state quantum technologies. Quantum amplifiers play a critical role in many of these quantum computing technologies in that they are required to read out qubit states and transfer the information to the classical world.

Quantum amplifiers are examples of linear quantum systems and can be analysed using the recently developed theory of quantum linear systems. We begin with an introduction to quantum linear systems theory including the concept of physical realizability. We then present a systems theory approach to the design of quantum amplifiers minimizing the amount of quantum noise introduced by the amplifier whilst still guaranteeing desired properties of the amplifier such as the phase-insensitive property and the non-reciprocal property. We also consider the achievable gain and bandwidth of quantum amplifiers. These methods can be applied to amplifiers implemented using a quantum optics technology or a superconducting microwave technology. Our approach is based on a singularly perturbed quantum system involving the broadband approximation of a Bogoliubov transformation. In the case the optical implementation of a phase-insensitive amplifier it requires two squeezers and two beamsplitters. In the case of the optical implementation of a non-reciprocal and phase-insensitive quantum amplifier it requires three squeezers and two beamsplitters.

IEEE Control Systems Society, Transition to Practice Award

Wednesday, August 10, 6:45am-7:45am

From rotary kilns and paper machines to anesthesia and COVID-19: the broad reach of control engineering

Guy A Dumont
University of British Columbia

Guy A. Dumont received the Dipl. Ing. degree from Ecole Nationale Supérieure d'Arts et Metiers, Paris, France, in 1973, and the Ph.D. degree in electrical engineering from McGill University, Montreal, QC, Canada, in 1977. He was with Tioxide, France, from 1973 to 1974, and again from 1977 to 1979. He was with Paprican from 1979 to 1989, first in Montreal and then in Vancouver. In 1989, he joined the Department of Electrical and Computer Engineering, University of British Columbia, where he is a Professor and Distinguished University Scholar. From 2000 to 2002, he was the Associate Dean, Research for the Faculty of Applied Science Since 2008 he has been an Associate Member of the UBC Department of Anesthesiology Pharmacology and Therapeutics. He also is a Principal Investigator at the BC Children's Hospital Research Institute and co-founder and co-Director of the Digital Health Innovation Laboratory (DHIL).His current research interests include patient monitoring; signal processing for physiological monitoring; physiological closed-loop control systems such as automated drug delivery in anesthesia; circadian rhythms; global and mobile health; non-contact patient vital sign assessment; and brain monitoring via electroencephalography and near-infrared spectrometry.Dr. Dumont was awarded a 1979 IEEE Transactions on Automatic Control Honorable Paper Award; a 1985 Paprican Presidential Citation; a 1990 UBC Killam Research Prize; the 1995 CPPA Weldon Medal; the 1998 Universal Dynamics Prize for Leadership in Process Control Technology; the IEEE Control Systems Society 1998 Control Systems Technology Award; three NSERC Synergy Awards, the latest one in 2016 for the development of the Phone Oximeter; the 2010 Brockhouse Canada Prize for Interdisciplinary Research in Science and Engineering. In 2011–12, and again in 2018-19, he was a UBC Peter Wall Distinguished Scholar in Residence. In 2020 he was awarded the IEEE Control Systems Society Transition to Practice Award. He has been a Fellow of the IEEE since 1998, and in 2017 he was elected a Fellow of the International Federation of Automatic Control as well as a Fellow of the Royal Society of Canada.

From rotary kilns and paper machines to anesthesia and COVID-19: the broad reach of control engineering: Karl Aström once famously called automatic control the hidden technology in recognition of the fact that despite its pervasiveness, it is rarely mentioned. Control is indeed a critical component of so many technologies used in industry and in our everyday life. In this talk I want to illustrate the broad reach of control engineering through applications I performed over the last forty years. In the process industries, I have developed and implemented adaptive control of rotary kilns for the production of TiO2 pigments, robust cross-directional control of paper machines, adaptive control of continuous digesters, dual adaptive control of wood-chip refiners and paper coating. I have developed a general-purpose adaptive controller based on Laguerre functions, that has been applied to the control of processes for the production of lime, glass, oil and gas, food and beverage. For the last two decades, working in close collaboration with clinicians I have focused on biomedical applications especially in critical care and automated intravenous anesthesia. Over the last year, COVID-19 has presented a challenge to the public health authorities. By representing control of COVID-19 explicitly in a feedback framework, transparent and effective public health policies can be systematically designed and rigorously analyzed, replacing ad-hoc policies. This requires us to work closely with epidemiologists and public health experts. Through this talk I want to illustrate the breadth of control applications and the sense of excitement a career in control can bring particularly when working in a multidisciplinary environment. I have been at it for some 45 years and still feel as passionate about my work as when I started, and I hope to convey this passion to our younger colleagues. We bring a unique perspective and have much to contribute to society at large, it is time to come out of hiding!

Keynote Speakers

Keynote Session1: Wednesday, August 10, 7:55pm - 9:55pm
Room T8

A. Control of Wafer Scanners: Use the Unstable, Heertjes, Marcel

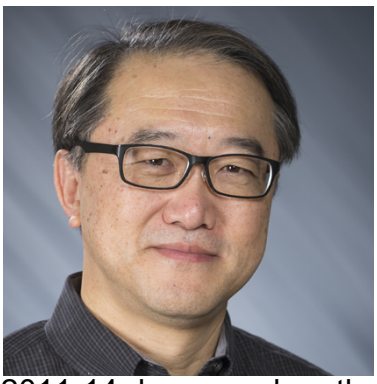
Marcel Heertjes received the M.Sc. and Ph.D. degrees from the Eindhoven University of Technology, Eindhoven, The Netherlands, in 1995 and 1999, respectively. In 2000, he joined the Philips Center for Industrial Technology, Eindhoven. In 2007, he joined ASML, Mechatronics Development, Veldhoven, The Netherlands. He was appointed full professor of Industrial nonlinear control for high-precision systems at the Department of Mechanical Engineering at Eindhoven University of Technology (TU/e) on February 1, 2019 for one day a week. His current research interests include the control of industrial motion systems with special focus on nonlinear control, feedforward and learning control, and data-driven optimization. Marcel Heertjes was a recipient of the IEEE Control Systems Technology Award 2015 for variable gain control and its applications to wafer scanners. He acts as an Associate Editor for IFAC Mechatronics since 2016.

Control of Wafer Scanners: Use the Unstable: Wafer scanners are complex lithography machines that are critical to the production of integrated circuits (or chips). Driven by the constant need to improve performance in terms of throughput, overlay, focus, and imaging, which can be linked to Moore's law, the control design of wafer scanners is pushed to its limits. In this context, inherent design limitations in linear feedback control have often provided the motivation for researchers and engineers to explore nonlinear feedback strategies. In the wafer scanner industry, an example is given by the recent developments in hybrid integrator-gain systems, abbreviated with HIGS. HIGS, that operate alternately in so-called integrator mode or in gain mode, have properties and associated (phase) benefits inherited from reset control, in particular the Clegg integrator. However, HIGS do not produce discontinuous control signals due to the absence of (partial) state resets. The latter is considered a favorable property in dealing with structural dynamics of the wafer scanner and the generation of higher harmonics through nonlinear feedback control, especially in the presence of weakly damped resonances. HIGS, and in particular HIGS-PID control, offer the possibility to outperform any linear control, for example in avoiding overshoot, and can benefit from unstable control designs in its underlying modes. The price to pay is increased complexity of the design, stability and performance analysis. In the keynote lecture, an industrial perspective on HIGS-PID control will be sketched that includes the following aspects: (a) inherent design limitations, (b) time- and frequency-domain stability tools, (c) robust nonlinear control design, and (d) lithographic stage applications and performances.

Keynote Speakers

Keynote Session1: Wednesday, August 10, 7:55pm - 9:55pm
Room T8

B. Modeling and Control of Digital Printing and Imaging Systems, Chiu, George T.-Chiu



George Chiu is a Professor in the School of Mechanical Engineering with courtesy appointments in the School of Electrical and Computer Engineering and the Department of Psychological Sciences at Purdue University. He also has a half time appointment as the Assistant Dean for Global Engineering Programs and Partnerships in the College of Engineering. Chiu received the B.S. degree in Mechanical Engineering from National Taiwan University in 1985 and the M.S. and Ph.D. degrees from the University of California at Berkeley, in 1990 and 1994, respectively. Before joining Purdue, he worked for the Hewlett-Packard Company, designing inkjet printer and multi-function devices. From 2011-14, he served as the Program Director for the Control Systems Program in the Engineering Directorate of the National Science Foundation. His current research interests are mechatronics and dynamic systems and control with applications to digital printing and imaging systems, digital fabrications, human motor control and robotics, motion and vibration perception and control. He received the *2012 NSF Director's Collaboration Award,* the *2010 IEEE Transactions on Control System Technology Outstanding Paper Award* and the Purdue University College of Engineering *2010 Faculty Engagement/Service Excellence Award* and 2006 *Team Excellence Award*. Dr. Chiu served as the Editor-in-Chief for the *IEEE/ASME Transactions on Mechatronics* from 2017-19 and as the Editor for the *Journal of Imaging Science and Technology* from 2012-14. He is a Fellow of ASME and the Society for Imaging Science and Technology (IS&T) and a senior member of IEEE.

Modeling and Control of Digital Printing and Imaging Systems: Digital printing and imaging systems are well-recognized mechatronics devices. They are an integral part of our daily lives. Although traditional print media has been in decline, recent interests in leveraging printing as a scalable fabrication/manufacturing process has renewed the development of functional printing as an additive manufacturing process. In addition to deposit precisely controlled amount of material with the necessary spatial accuracy, interaction between material and substrate as well as material with themselves all contribute to the geometry, functionality and quality of the final product, be it an image, device or structure. In this talk, I will present our experiences in applying different mechatronic techniques to several digital printing and imaging processes as well as sharing some insights gained when translating these approaches to other applications with similar implementation and real-world constraints.

Keynote Speakers

Keynote Session 2: Wednesday, August 10, 7:55pm - 9:55pm
Room T9

A. Control of Floating Offshore Wind Turbines, Pao, Lucy Y.

Lucy Pao is a Palmer Endowed Chair Professor in the Electrical, Computer, and Energy Engineering Department at the University of Colorado Boulder. She earned B.S., M.S., and Ph.D. degrees in Electrical Engineering from Stanford University. Her research has primarily focused on engineering control systems, with applications ranging from atomic force microscopes to multi-megawatt wind energy systems. She is a Fellow of the IEEE and IFAC. Selected awards include a National Science Foundation CAREER Award, an Office of Naval Research Young Investigator Award, an IFAC World Congress Young Author Prize, an IEEE Control Systems Magazine Outstanding Paper Award (with K. Johnson), a SIAM Journal on Control and Optimization Best Paper Prize (with J. Marden and H. P. Young), the AACC Control Engineering Practice Award, the European Academy of Wind Energy Scientific Award, and the ASME Nyquist Lecturer Award. Selected past professional society activities include being General Chair of the American Control Conference, an elected member of the IEEE Control Systems Society Board of Governors, Member of the US Defense Science Study Group, and Member of the IFAC Executive Board. Selected current activities include being a Fellow of the Renewable and Sustainable Energy Institute, the Education Liaison on the IFAC Technical Board, and the IFAC Pavel J. Nowacki Distinguished Lecturer.

Control of Floating Offshore Wind Turbines: Wind energy is among the fastest-growing sources of electrical energy worldwide. Compared to land-based wind energy, offshore wind energy has the advantages of increased wind resource availability and consistency, proximity to major population centers, and enabling larger-scale turbines. As such, over the last decade, installed offshore wind power capacity has grown at a phenomenal average annual rate of 33%. Currently, more than 99% of installed offshore wind capacity consists of fixed-bottom wind turbines in shallow waters (<60m deep). Globally, however, 80% of offshore wind resources are at water depths greater than 60m. For such deep waters, floating offshore wind turbines are expected eventually to be as economically competitive as shallow-water fixed-bottom wind turbines. Basic types of floating wind substructures have been derived from platforms used in the oil and gas industry and result in safe but bulky and expensive designs. A novel Ultraflexible Smart FLoating Offshore Wind Turbine (USFLOWT) concept that better optimizes the design of the floating platform may be able to lower the cost of energy for floating offshore wind turbines. This talk will outline how, as part of a large team, we are using a control co-design approach to develop the USFLOWT concept. We describe some of the control challenges and highlight initial controllers and performance results. We close by discussing on-going and future research avenues for the growing floating offshore wind energy area.

Keynote Speakers

Keynote Session 2: Wednesday, August 10, 7:55pm - 9:55pm
Room T9

B. Cohesive networks using delayed self-reinforcement, Devasia, Santosh

Santosh Devasia received the B.Tech. (Hons) from the Indian Institute of Technology, Kharagpur, India, in 1988, and the M.S. and Ph.D. degrees in Mechanical Engineering (ME) from the University of California at Santa Barbara in 1990 and 1993 respectively. He is the Director of the Boeing Advanced Research Center (BARC) at the University of Washington (UW) https://depts.washington.edu/barc/ and the faculty lead of the new Advanced Composite Center aimed at robotic manufacturing methods for emerging recyclable thermoplastic composites. He is the Nabtesco Professor of Engineering at the UW, Seattle. He joined the faculty of the UW Mechanical Engineering (ME) Department in 2000 after teaching from 1994 to 2000 in the ME Department at the University of Utah, Salt Lake City. He served as the Associate Chair of the UW ME Department at UW from 2010-2013, and as the Associate Dean of Research and Faculty Affairs in the College of Engineering at UW from 2013-2017. He was the General Chair for the 2020 American Control Conference and will chair the 2023 Advanced Intelligent Mechatronics Conference in Seattle, WA. He is a fellow of ASME and IEEE. His current research interests include control of multi-agent systems and precision human-machine systems. Additional details of current efforts can be found at: http://faculty.washington.edu/devasia/

Cohesive networks using delayed self-reinforcement: How a decentralized network gets to the goal (a consensus value) can be as important as reaching the consensus value. While prior methods focus on rapidly getting to a new consensus value, maintaining cohesion, during the transition between consensus values or during tracking, remains challenging and has not been addressed. Maintaining cohesion is important, e.g., to maintain inter-vehicle spacing in connected automated transportation systems, alignment synchronization to help maintain formations during maneuvers of flocks and swarms in nature, to avoid damage due to large deformations when transporting flexible objects and to maintain formation of engineered networks such as satellites, unmanned autonomous vehicles and collaborative robots. The challenge to maintain cohesion arises because information about the desired response (such as the desired orientation or speed of the agents) might be available to only a few agents in a decentralized framework. The desired-response information needs to be propagated through the network to other agents, which results in response-time delays between agents that are “close to” the information source and those that are “farther away.” The talk will present a delayed self-reinforcement (DSR) approach, where each individual augments its neighbor-based information update using its previously available updates, to improve cohesiveness of the response during transitions. The advantages of the proposed DSR approach are that it only requires already-available information from a given network to improve the cohesion and does not require network-connectivity modifications (which might not be always feasible) nor increases in the system’s overall response speed (which can require larger input). Results are presented that show substantial improvement in cohesion with DSR.

Student Programs

Student Best Paper Award

The CCTA 2021 Organizing Committee is pleased to announce the CCTA 2021 Student Best Paper Award. The award is funded by the IEEE Control Systems Society (CSS) and has been established to recognize excellence in a CCTA paper whose primary contributor is a Student Member of the IEEE. Selection for the award is based on originality, clarity, and potential impact on practical applications of control, and all student nominees are expected to present their paper at the CCTA 2021. Details of the award, including a list of past recipients, can be found at: http://ieeecss.org/awards/conference-control-technology-and-applications-best-student-paper-award

Eligibility
The primary author must be a student at the time of the CCTA 2021 deadline for the initial paper submission, and an IEEE Student Member for the year 2021. The nominated paper must have been accepted for presentation at the CCTA 2021.

Prize
Each finalist will receive a certificate and the winner receives a plaque.

Presentation of Award
The winner will be announced during the CCTA 2021 Awards Ceremony on Wednesday, August 11, 12:00-12:30 (PST).

Finalists
Evaluation of the nominated papers was carried out by an independent CSS committee. We are happy to announce the three finalists, from which the winner will be selected:

- Davide Marcato, for the paper entitled: “Machine Learning-based Anomaly Detection for Particle Accelerators” (advisor: Professor Gian Antonio Susto). Session Mo 07:55-09:55, Track T7, Room T7.

- Muhammad Aadil Khan, for the paper entitled: “Global Sensitivity Analysis of Aging Parameters for a Lithium-ion Battery Cell using Optimal Charging Profiles” (advisor: Professor Simona Onori). Session Mo 07:55-09:55, Track T7, Room T7.

- Jairo Viola, for the paper entitled: “Fractional-Order Stochastic Extremum Seeking Control with Dithering Noise for Plasma Impedance Matching” (advisor: Professor YangQuan Chen Session Mo 07:55-09:55, Track T7, Room T7.

Program at a Glance

CCTA 2021 Technical Program Sunday August 8, 2021

Track T1	Track T2	Track T3	Track T4	Track T5
08:30-12:30 SuW1 Room T1 Workshop 1 - Multi-Vehicle and Assured Autonomous Control for Aerospace Applications	08:30-12:30 SuW2 Room T2 Workshop 2 - Motion Planning, Control, and Learning for Autonomous Driving Systems	08:30-12:30 SuW3 Room T3 Workshop 3 - Practical Methods for Real World Control Systems	08:30-17:30 SuW4 Room T4 Workshop 4 - Smart Control Engineering (SCE), Digital Twins, and Industrial AI (IAI) – a New Research Frontier	08:30-17:30 SuW5 Room T5 Workshop 5 - the Confluence of Vision and Control

Program at a Glance

CCTA 2021 Technical Program Monday August 9, 2021

Track T1	Track T2	Track T3	Track T4	Track T5	Track T6	Track T7
06:30-06:45 MoOR Room T10 Opening Remarks I						
06:45-07:45 MoPL Room T8 Monday Plenary Session - Prediction, Estimation, and Control of Connected and Autonomous Vehicles Sun, Jing (University of Michigan)						
07:45-07:55 MoAMBR Room T9 [Title not available]						
07:55-09:55 MoAT1 Room T1 Automotive Applications I	07:55-09:55 MoAT2 Room T2 Energy I	07:55-09:55 MoAT3 Room T3 Multi-Agent and Multi Robot Systems	07:55-09:55 MoAT4 Room T4 Heterogeneous Multiagent Autonomous Systems	07:55-09:55 MoAT5 Room T5 Biosystems	07:55-09:55 MoAT6 Room T6 Optimization	07:55-09:55 MoAT7 Room T7 Student Award Finalists
09:55-10:00 MoMMBR Room T9 [Title not available]						
10:00-12:00 MoBT1 Room T1 Automotive Applications II	10:00-12:00 MoBT2 Room T2 Energy II	10:00-12:00 MoBT3 Room T3 Aerial Robotics	10:00-12:00 MoBT4 Room T4 Pursuit-Evasion and Reach-Avoid Games	10:00-12:00 MoBT5 Room T5 Modeling	10:00-12:00 MoBT6 Room T6 Predictive Control	10:00-12:00 MoBT7 Room T7 Nonlinear Systems

Program at a Glance

CCTA 2021 Technical Program Tuesday August 10, 2021

Track T1	Track T2	Track T3	Track T4	Track T5	Track T6	Track T7
06:30-06:45 TuOR Room T10 Opening Remarks II						
06:45-07:45 TuPL Room T8 Tuesday Plenary Session - Using Systems and Control Theory Ideas in the Design of Quantum Amplifiers Petersen, Ian R. (Australian National University)						
07:45-07:55 TuAMBR Room T9 [Title not available]						
07:55-09:55 TuKN1 Room T8 Keynote Session 1 - A. Control of Wafer Scanners: Use the Unstable, Heertjes, Marcel; B. Modeling and Control of Digital Printing and Imaging Systems, Chiu, George T.-C				07:55-09:55 TuKN2 Room T9 Keynote Session 2 - A. Control of Floating Offshore Wind Turbines, Pao, Lucy Y.; B. Cohesive Networks Using Delayed Self-Reinforcement, Devasia, Santosh		
09:55-10:00 TuMMBR Room T9 [Title not available]						
10:00-12:00 TuBT1 Room T1 Automotive III	10:00-12:00 TuBT2 Room T2 Power Electronics and Systems	10:00-12:00 TuBT3 Room T3 Robotics Applications	10:00-12:00 TuBT4 Room T4 Kalman Filter and Fault Tolerant Control	10:00-12:00 TuBT5 Room T5 Control Technology for Critical Care Ventilators	10:00-12:00 TuBT6 Room T6 Game Theory	10:00-12:00 TuBT7 Room T7 Nonlinear Control, Sliding Mode

Program at a Glance

CCTA 2021 Technical Program Wednesday August 11, 2021

Track T1	Track T2	Track T3	Track T4	Track T5	Track T6
06:30-06:45 WeOR Room T10 Opening Remarks III					
06:45-07:45 WePL Room T8 Wednesday Plenary Session (Transition to Practice Award Lecture) - from Rotary Kilns and Paper Machines to Anesthesia and COVID-19: The Broad Reach of Control Engineering Dumont, Guy A. (Univ. of British Columbia)					
07:45-07:55 WeAMBR Room T9 [Title not available]					
07:55-09:55 WeAT1 Room T1 Control and Optimization of Vehicle Systems	07:55-09:55 WeAT2 Room T2 Automotive Batteries	07:55-09:55 WeAT3 Room T3 Mechanical Systems and MEMS	07:55-09:55 WeAT4 Room T4 Cyber Systems	07:55-09:55 WeAT5 Room T5 Control Algorithms	07:55-09:55 WeAT6 Room T6 Estimation
09:55-10:00 WeMMBR Room T9 [Title not available]					
10:00-12:00 WeBT1 Room T1 Transportation Systems	10:00-12:00 WeBT2 Room T2 PID	10:00-12:00 WeBT3 Room T3 Manufacturing & Mechanical Systems	10:00-12:00 WeBT4 Room T4 Machine Learning	10:00-12:00 WeBT5 Room T5 Control Technology	10:00-12:00 WeBT6 Room T6 Stochastic Process
12:00-12:30 WeBCR Room T10 Awards and Closing Ceremony					

Book of Abstracts of 2021 IEEE Conference on Control Technology and Applications (CCTA)

Technical Program for Sunday August 8, 2021

SuW1	Room T1
Workshop 1 - Multi-Vehicle and Assured Autonomous Control for Aerospace Applications (Workshop)	
Chair: Hull, Richard A.	Collins Aerospace
Co-Chair: Cichella, Venanzio	University of Iowa
08:30-12:30	SuW1.1
*Multi-Vehicle and Assured Autonomous Control for Aerospace Applications**	
Hull, Richard A.	Collins Aerospace
Cichella, Venanzio	University of Iowa
Hovakimyan, Naira	University of Illinois at Urbana-Champaign
Qu, Zhihua	Univ. of Central Florida
Hussain, Heather	MIT
Inalhan, Gokhan	Cranfield University

SuW2	Room T2
Workshop 2 - Motion Planning, Control, and Learning for Autonomous Driving Systems (Workshop)	
Chair: Chang, Yan	Lyft
Co-Chair: Malikopoulos, Andreas A.	University of Delaware
08:30-12:30	SuW2.1
*Motion Planning, Control, and Learning for Autonomous Driving Systems**	
Chang, Yan	Lyft
Malikopoulos, Andreas A.	University of Delaware

SuW3	Room T3
Workshop 3 - Practical Methods for Real World Control Systems (Workshop)	
Chair: Abramovitch, Daniel Y.	Agilent Technologies
08:30-12:30	SuW3.1
*Practical Methods for Real World Control Systems**	
Abramovitch, Daniel Y.	Agilent Technologies

SuW4	Room T4
Workshop 4 - Smart Control Engineering (SCE), Digital Twins, and Industrial AI (IAI) – a New Research Frontier (Workshop)	
Chair: Chen, YangQuan	University of California, Merced
Co-Chair: Viola, Jairo	University of California, Merced
08:30-17:30	SuW4.1
*Smart Control Engineering (SCE), Digital Twins, and Industrial AI (IAI) – a New Research Frontier**	
Chen, YangQuan	University of California, Merced
Viola, Jairo	University of California, Merced
Domanski, Pawel D.	Warsaw University of Technology
Wang, Jing	Beijing University of Chemical Technology

SuW5	Room T5
Workshop 5 - the Confluence of Vision and Control (Workshop)	
Chair: Gans, Nicholas	University of Texas at Arlington
Co-Chair: Bell, Zachary I.	University of Florida
08:30-17:30	SuW5.1
*The Confluence of Vision and Control II**	
Beard, Randal W.	Brigham Young Univ.
Bell, Zachary I.	University of Florida
Dani, Ashwin	University of Connecticut
Dixon, Warren E.	University of Florida
Fathian, Kaveh	MIT
Funada, Riku	Tokyo Institute of Technology
Gans, Nicholas	University of Texas at Arlington
Hu, Guoqiang	Nanyang Technological University, Singapore
Sandhu, Romeil	Stony Brook University
Tron, Roberto	Boston University
Tunstel, Edward	Johns Hopkins University Applied Physics Laboratory
Vela, Patricio A.	Georgia Institute of Technology

Technical Program for Monday August 9, 2021

MoPL Room T8

Monday Plenary Session - Prediction, Estimation, and Control of Connected and Autonomous Vehicles Sun, Jing (University of Michigan) (Plenary Session)

Chair: Moheimani, S.O. Reza — University of Texas at Dallas

Co-Chair: Tsao, Tsu-Chin — University of California, Los Angeles

06:45-07:45 MoPL.1

Prediction, Estimation, and Control of Connected and Autonomous Vehicles, pp. 1-1

Sun, Jing — University of Michigan

Connected and Automated Vehicles (CAV) have been heralded as a transformative technology, leading to the new era of transportation with unprecedented safety and mobility benefits. They also push the energy efficiency of the transportation systems at both the macro (traffic flow) and micro (vehicle) levels to the next height with abundant new opportunities for communication and optimization. While advanced sensors and hardware, such as camera, radar, and lidar and those used in V2V and V2I communications, have been featured predominantly in CAV showcases, control again is playing the role of the “unsung” hero that enables the CAV technology in the “hidden” world with algorithms and computational intelligence.

We will discuss some fundamental technical challenges for prediction, estimation, and control at the core of the CAV technology in this talk. Using the integrated power and thermal management for CAV as an example, we will show how model-based design, complemented by data-driven approaches, can lead to control and optimization solutions with a significant impact on energy efficiency and operational reliability, in addition to safety and accessibility. Several unique problem characteristics, such as multi-timescale, the highly interactive nature of subsystems involved, and the dynamic and uncertain environment that CAVs are operating within, will be illuminated. Those features call for innovative use of existing tools and the development of new solutions and tools for prediction, estimation, and control. Finally, open challenges will be highlighted to stimulate interest from our community to sing our song loudly and collectively as the control community contributes to the connected and automated transportation systems' safety, efficiency, and accessibility.

MoAT1 Room T1

Automotive Applications I (Regular Session)

Chair: Chen, Pingen — Tennessee Technological University

Co-Chair: Sun, Zongxuan — University of Minnesota

07:55-08:15 MoAT1.1

Adaptive Control and Parameter Estimation for Electric Vehicles with One-Pedal-Driving Feature in Platooning Applications, pp. 2-7

Su, Zifei — Tennessee Technological University

Yang, Shuainan — Tennessee Tech University

Chen, Pingen — Tennessee Technological University

Vehicle platooning has attracted much attention due to the significant fuel-saving potential due to the reduced aerodynamic drag force. The Battery Electric Vehicle (BEV) with One Peal Driving (OPD) feature is more suitable for platooning than traditional gasoline vehicles because of the regenerative braking. However, vehicle platooning also presents significant uncertainties in the aerodynamic drag coefficient, which is critical in vehicle spacing control and energy saving but not measurable. In this study, an adaptive controller was proposed to control the inter-vehicle space in platooning application and to estimate the aerodynamic drag coefficient simultaneously by using the embedded adaptation law. Then it was simulated on a simplified BEV with OPD model. The simulation results have demonstrated high performance of the proposed adaptive controller in spacing control, in presence of high uncertainty in drag coefficient. In addition, the real-world field tests showed promising results on spacing control.

08:15-08:35 MoAT1.2

Design and Assessment of an Eco-Driving PMP Algorithm for Optimal Deceleration and Gear Shifting in Trucks, pp. 8-13

Wingelaar, Bart — Eindhoven University of Technology

Gonçalves da Silva, Gustavo R. — Eindhoven University of Technology

Lazar, Mircea — Eindhoven University of Technology

Chen, Yutao — Fuzhou University

Kessels, J.T.B.A. — Technische Universiteit Eindhoven

In this paper, an eco-driving Pontryagin maximum principle (PMP) algorithm is designed for optimal deceleration and gear shifting in trucks based on switching among a finite set of driving modes. The PMP algorithm is implemented and assessed in the IPG TruckMaker traffic simulator as an eco-driving assistance system (EDAS). The developed EDAS strategy reduces fuel consumption with an optimized velocity profile and, in practice, allows contextual feedback incorporation from the driver for safety. Furthermore, the optimization over driving modes is computationally inexpensive, allowing the methodology to be used online, in real-time. Simulation results show that significant fuel savings can be achieved proportional to the number of velocity events and the difference between current velocity and final desired velocity for each event.

08:35-08:55 MoAT1.3

Pitch Control for Semi-Active Suspensions: Open-Loop and Closed-Loop Strategies, pp. 14-19

Savaia, Gianluca — Politecnico Di Milano

Corno, Matteo — Politecnico Di Milano

Panzani, Giulio — Politecnico Di Milano

Sinigaglia, Andrea — Automobili Lamborghini

Savaresi, Sergio M. — Politecnico Di Milano

Semi-Active suspensions can modulate the damping coefficient of the vehicle in real-time, outperforming passive systems in stability and comfort. In literature, many contributions investigate the damping of the vertical dynamics whereas the pitch motion is often disregarded. In this article, the authors present two strategies, open-loop and closed-loop, to directly tackle the pitch dynamics. Both strategies are validated experimentally on an actual vehicle in a test road which particularly excite the pitch resonance of the chassis, demonstrating how the vehicle balance, and thus the riding performance, can be drastically improved.

08:55-09:15 MoAT1.4

On the Collision Avoidance of Adaptive Cruise Controllers: Comparison of String Stability and External Positivity, pp. 20-25

Schwab, Alexander — Ruhr-Universität Bochum

Lunze, Jan — Ruhr-Universität Bochum

This paper addresses the safety of two approaches to the collision avoidance of vehicle platoons with adaptive cruise control. It has been shown that L2 string stability, which is often used in the literature to achieve safety in the platoon, is not sufficient for collision avoidance. A stricter local condition, which is external positivity of the controlled vehicles, will be applied to guarantee collision avoidance by preventing overshooting responses of the vehicles. The theoretical results are verified by experiments with a set of mobile robots.

09:15-09:35 MoAT1.5

Attitude Estimation for Ground Vehicles Using Low-Cost Sensors with In-Vehicle Calibration, pp. 26-31

Oei, Marius	University of Stuttgart
Sawodny, Oliver	University of Stuttgart

Accurate vehicle attitude estimation requires bias-calibrated sensors. The low-cost sensors typically found in industrial vehicles exhibit large time-varying biases, requiring periodic re-calibration. Thus far, the sensor needs to be removed from the vehicle to perform calibration, which is both costly and time-consuming.

In this work, we propose a ground vehicle attitude estimator based on the additive quaternion extended Kalman filter (EKF) with a simple in-vehicle accelerometer bias calibration procedure that can be performed by the end-user. Using a simple model based on wheel speeds and angular rates, accelerations of the vehicle can be estimated and compensated which increases estimation accuracy. The approach is validated through measurements on a real-world industrial vehicle and its performance compared to the state-of-the-art approaches with level-ground calibration and acceleration compensation.

09:35-09:55 MoAT1.6

An Iterative Learning Control Technique for the Kiss Point Adaption in a Dual-Clutch Transmission, pp. 32-37

Laukenmann, Michael Alexander	University of Stuttgart
Sawodny, Oliver	University of Stuttgart

In this article an iterative learning control (ILC) technique is proposed for the kiss point adaption in a dual-clutch transmission. First, the general ILC problem is introduced which is then specified as model-free phase-lead ILC. A variation of all parameters of this type of ILC is carried out in experiments with a clutch operated on a transmission test bench in order to examine performance and stability. With this, a suitable parametrization of the ILC is found that is used in combination with a Butterworth filter to improve the tracking of a prescribed clutch pressure trajectory. The kiss point adaption is done with a two-step procedure where an inner loop involves the ILC and an outer loop is used to increase the reference stepwise. A kiss point detection condition is proposed which is repeatedly checked during the inner loop. Finally, we demonstrate the performance of the adaption routine by means of experiments.

MoAT2 Room T2

Energy I (Regular Session)

Chair: Ren, Juan	Iowa State University
Co-Chair: Hara, Naoyuki	Osaka Prefecture Univ

07:55-08:15 MoAT2.1

MPC-Based Vibration Control and Energy Harvesting Using Stochastic Linearization for a New Energy Harvesting Shock Absorber, pp. 38-43

Hajidavalloo, Mohammad	Michigan State University
Gupta, Aakash	Michigan State University
Li, Zhaojian	Michigan State University
Tai, Wei-Che	Michigan State University

Existing Energy Harvesting Shock Absorbers (EHSAs) of vehicle suspensions are mainly designed based on the principle of linear resonance, thereby compromising suspension performance for high-efficiency energy harvesting and being only responsive to narrow-bandwidth vibrations. In this paper, we propose a new EHSA design -- inerter pendulum vibration absorber (IPVA) -- that integrates an electromagnetic rotary EHSA with a nonlinear pendulum vibration absorber. We show that this design simultaneously improves ride comfort and energy harvesting efficiency by virtue of the nonlinear effects of pendulum's inertia. To further improve the performance, model predictive control (MPC) is designed and evaluated in two cases. In the first case, we directly exploit the nonlinear dynamics of the proposed EHSA into a nonlinear MPC (NMPC) design. In the second case, we develop a novel stochastic linearization MPC (SL-MPC) in which we employ stochastic linearization to approximate the nonlinear dynamics of EHSA with superior accuracy compared to standard linearization. This leads to an MPC problem with bilinear dynamics, which is much more computationally efficient than the nonlinear MPC counterpart with no major performance degradation. Extensive simulations are performed to show the superiority of the proposed new nonlinear EHSA and to demonstrate the efficacy of the proposed SL-MPC.

08:15-08:35 MoAT2.2

Add-On Preview Compensator for GSPI-Based Blade Pitch Controller in Floating Offshore Wind Turbines, pp. 44-50

Tsuya, Tomoka	Osaka Prefecture University
Hara, Naoyuki	Osaka Prefecture Univ
Konishi, Keiji	Osaka Prefecture Univ

Gain-scheduled PI (GSPI) control has been widely acknowledged and used for a blade pitch controller for wind turbines. In this paper, we design an add-on H2 preview compensator for floating wind turbines with the GSPI-based blade pitch controller. The preview information of the incoming wind speed is assumed to be available by LIDAR and the preview compensator is added to the existing GSPI controller. Simulation results show that the preview compensator is effective in reducing the fatigue loads of the blades and tower as well as fluctuations of the generator speed and platform motions.

08:35-08:55 MoAT2.3

PDE Observer for All-Solid-State Batteries Via an Electrochemical Model, pp. 51-56

Zhang, Dong	University of California, Berkeley
Tang, Shuxia	Texas Tech University
Couto, Luis Daniel	Université Libre De Bruxelles
Viswanathan, Venkatasubramanian	Carnegie Mellon University

All-solid-state batteries are one of the most promising candidates for next-generation energy storage devices capable of delivering high specific energy. Significant effort has been spent on understanding the degradation mechanisms associated with dendrite formation, while energy management and model-based estimation/control for solid-state batteries has received very limited attention. This paper examines a partial differential equation (PDE) state estimation scheme for a one-dimensional electrochemical all-solid-state battery model, using voltage and current measurements only. The state estimation framework exploits the active disturbance rejection control and PDE backstepping techniques, and we rigorously prove estimation error system stability. Electrochemical model-based estimator based on PDE models identifies physical variables for all-solid-state batteries, thus enables high-fidelity monitoring and optimal control in future battery management systems.

08:55-09:15 MoAT2.4

Multi-Agent Battery Storage Management Using MPC-Based Reinforcement Learning, pp. 57-62

Bahari Kordabad, Arash	Norwegian University of Science and Technology
Cai, Wenqi	Norwegian University of Science and Technology
Gros, Sebastien	NTNU

In this paper, we present the use of Model Predictive Control (MPC) based on Reinforcement Learning (RL) to find the optimal policy for a multi-agent battery storage system. A time-varying prediction of the power price and production-demand uncertainty are considered. We focus on optimizing an economic objective cost while avoiding very low

or very high state of charge, which can damage the battery. We consider the bounded power provided by the main grid and the constraints on the power input and state of each agent. A parametrized MPC-scheme is used as a function approximator for the deterministic policy gradient method and RL optimizes the closed-loop performance by updating the parameters. Simulation results demonstrate that the proposed method is able to tackle the constraints and deliver the optimal policy.

09:15-09:35 MoAT2.5

Optimal Shaping of the Safety Factor Profile in the EAST Tokamak, pp. 63-68

Wang, Zibo	Lehigh University
Schuster, Eugenio	Lehigh University
Wang, Hexiang	Lehigh University
Luo, Zhengping	Institute of Plasma Physics, Chinese Academy of Sciences
Yuan, Quiping	Institute of Plasma Physics, Chinese Academy of Sciences
Huang, Yao	Institute of Plasma Physics, Chinese Academy of Sciences
Xiao, B. J.	Institute of Plasma Physics, Chinese Academy of Sciences
Humphreys, D.A.	General Atomics

Tokamaks, which are one of the most promising approaches to energy generation from nuclear fusion, are toroidal devices confining a very hot ionized gas, i.e. plasma, where the nuclear reactions take place. Studies have shown that the shape of the safety-factor profile, which is related to the helical pitch of the magnetic fields used for plasma confinement, is a key factor towards achieving advanced operating conditions characterized by improved confinement, magnetohydrodynamic stability, and possible steady-state operation. In this work, a first-principles-driven, control-oriented model of the safety-factor profile evolution has been used to design linear-quadratic-integral (LQI) controllers for q-profile shaping in combination, in some cases, with plasma-energy regulation. Results based on nonlinear simulations are presented together with some initial experimental results from the EAST tokamak. A general framework for real-time control of both magnetic and kinetic plasma profiles and scalars has been implemented in the EAST Plasma Control System (PCS), enabling in this way the experimental testing of the proposed controllers. These experiments are among the first experiments on safety-factor profile control ever conducted on the EAST tokamak.

09:35-09:55 MoAT2.6

A Vector Auto-Regression Based Forecast of Wind Speeds in Airborne Wind Energy Systems, pp. 69-75

Keyantuo, Patrick	University of California, Berkeley
Dunn, Laurel	University of California, Berkeley
Haydon, Benjamin	North Carolina State University
Vermillion, Christopher	North Carolina State University
Chow, Fotini Katopodes	University of California, Berkeley
Moura, Scott	University of California, Berkeley

This paper presents two wind energy forecast methods for control of an airborne wind energy system (AWE). The primary objective is to maximize the energy production of the AWE system under a spatio-temporally varying environment with uncertainty in the future wind speed. The controller for the AWE system is formulated as a model predictive controller (MPC). We employ data-driven models to generate probabilistic forecasts of the wind using vector auto-regression (VAR) and time-of-day forecasts. Bayesian optimization is employed to find the optimum of an unknown and expensive to evaluate function. Specifically, the objective function is modelled via wind speed forecasts and then Bayesian optimization optimizes the altitude trajectory while balancing exploitation and exploration of the available altitudes. The performance of the AWE system under the VAR forecast model significantly improves energy production by incorporating wind speed correlations for nearby altitudes.

MoAT3 Room T3

Multi-Agent and Multi Robot Systems (Regular Session)

Chair: Ashrafiuon, Hashem — Villanova University

Co-Chair: Xu, Hao — University of Nevada, Reno

07:55-08:15 MoAT3.1

Unifying Reactive Collision Avoidance and Control Allocation for Multi-Vehicle Systems, pp. 76-81

Matous, Josef	NTNU (Norwegian University of Science and Technology)
Basso, Erlend Andreas	Norwegian University of Science and Technology
Thyri, Emil Hjelseth	Norwegian University of Science and Technology
Pettersen, Kristin Y.	Norwegian University of Science and Technology (NTNU)

To enable autonomous vehicles to operate in cluttered and unpredictable environments with numerous obstacles, such vehicles need a collision avoidance system that can react to and handle sudden changes in the environment. In this paper, we propose an optimization-based reactive collision avoidance system that uses control barrier functions integrated into the control allocation. We demonstrate the effectiveness of our method through numerical simulations with autonomous surface vehicles. The simulated vehicles track their reference waypoints while maintaining safe distances. The proposed method can be readily implemented on vehicles that already use an optimization-based control allocation method.

08:15-08:35 MoAT3.2

Navigation of Multiple UAVs in 3D Obstacle Environments While Preserving Connectivity without Data Transmission, pp. 82-89

Nomura, Yusuke	Kyoto University
Fukushima, Hiroaki	Kyoto University of Advanced Science
Matsuno, Fumitoshi	Kyoto University

This paper presents a leader--follower navigation method for a group of unmanned aerial vehicles (UAVs) in 3D obstacle environments based on our previous method for ground robots in 2D environments. An advantage of our method is that the group's formation shape can be changed in a decentralized way so as to prevent the robots from getting stuck in narrow spaces, while preserving sensing network connectivity without data transmission between robots through a wireless communication network. Another advantage is that inequality constraints on control inputs can be explicitly considered. The effectiveness of the proposed method is evaluated in simulations and experiments using quadrotors.

08:35-08:55 MoAT3.3

Continuum Deformation Coordination of Multi-Agent Systems Using Cooperative Localization, pp. 90-96

Rastgoftar, Hossein	University of Michigan Ann Arbor
Nersesov, Sergey	Villanova University
Ashrafiuon, Hashem	Villanova University

This paper studies the problem of decentralized continuum deformation coordination of multi-agent systems aided by cooperative localization. We treat agents as particles inside a triangular continuum (deformable body) in a 2-D motion space and let the continuum deformation coordination be defined by three leaders located at vertices of a triangle, called the leading triangle. The leaders' desired trajectories are assigned as the solution of a constrained optimal control problem such that safety requirements are satisfied in the

presence of disturbance and measurement noise. Followers distributed inside the leading triangle acquire continuum deformation in a decentralized fashion by integrating cooperative localization and local communication. Specifically, cooperative localization estimates the global positions of all agents using relative position measurements based primarily on proximity of agents. Simulation results are presented for a network of ten agents.

08:55-09:15 MoAT3.4

Decentralized Optimal Multi-Agent System Tracking Control Using Mean Field Games with Heterogeneous Dynamics, pp. 97-102

Zhou, Zejian — University of Nevada, Reno
Xu, Hao — University of Nevada, Reno

In this paper, a decentralized optimal tracking control problem has been studied for a large-scale multi-agent system (MAS) with heterogeneous system dynamics. Due to the agent number of large-scale MAS, the notorious “curse of dimensionality” problem has challenged the traditional MAS algorithms for decades. The emerging mean field game (MFG) theory has recently been widely adopted to generate a decentralized control method that tackles those challenges by encoding the large-scale multi-agent systems' information into a Probability Distribution Function (PDF). However, the traditional MFG methods assume all agents are homogeneous, which is unrealistic in practical industrial applications, e.g., IoTs, etc. Therefore, a novel mean field Stackelberg game (MFSG) is formulated based on the Stackelberg game, where all the agents have been classified as two different categories where one major leader's decision dominates the other minor agents. Moreover, a hierarchical structure that treats all minor agentsasameanfieldgroupisdevelopedtotacklehomogeneous agents' assumptions. Then, the actor-actor-critic-critic-mass (A2C2M) algorithm with five neural networks is designed to learn the optimal policies by solving the MFSG. The Lyapunov theory is utilized to prove the convergence of A2C2M neural networks and the closed-loop system's stability. Finally, series of numerical simulations are conducted to demonstrate the effectiveness of the developed method.

09:15-09:35 MoAT3.5

DEC-LOS-RRT: Decentralized Path Planning for Multi-Robot Systems with Line-Of-Sight Constrained Communication, pp. 103-110

Tuck, Victoria — University of California, Berkeley
Pant, Yash Vardhan — University of California, Berkeley
Seshia, Sanjit A. — UC Berkeley
Sastry, Shankar — Univ. of California at Berkeley

Decentralized planning for multi-agent systems, such as fleets of robots in a search-and-rescue operation, is often constrained by limitations on how agents can communicate with each other. One such limitation is the case when agents can communicate with each other only when they are in line-of-sight (LOS). Developing decentralized planning methods that guarantee safety is difficult in this case, as agents that are occluded from each other might not be able to communicate until it's too late to avoid a safety violation. In this paper, we develop a decentralized planning method that explicitly avoids situations where lack of visibility of other agents would lead to an unsafe situation. Building on an existing Rapidly-exploring Random Tree (RRT)-based approach, our method guarantees safety at each iteration. Simulation studies show the effectiveness of our method and compare the degradation in performance with respect to a clairvoyant decentralized planning algorithm where agents can communicate despite not being in LOS of each other.

09:35-09:55 MoAT3.6

Decentralized Optimal Tracking Control for Large-Scale Multi-Agent Systems under Complex Environment: A Constrained Mean Field Games with Reinforcement Learning Approach, pp. 111-116

Zhou, Zejian — University of Nevada, Reno
Xu, Hao — University of Nevada, Reno

In this paper, the optimal tracking control for large-scale multi-agent systems (MAS) under constraints has been investigated. The Mean Field Game (MFG) theory is an emerging technique to solve the “curse of dimensionality” problem in large-scale multi-agent decision-making problems. Specifically, the MFG theory can calculate the optimal strategy based on one unified fix-dimension probability density function (PDF) instead of the high-dimensional large-scale MAS information collected from all the individual agents. However, the MFGtheoryhasstringentlimitationsbyassumingalltheagents operate in a predefined unlimited space, which is often too ideal for practical applications due to complex environments. In this paper, the original MFG theory has been extended by considering two practical state constraints caused by the environment, i.e., boundary and density constraints. Moreover, to solve the extended MFG type control online, the actor-critic reinforcement learning mechanism is utilized and further extended to a novel actor-critic-mass (ACM) algorithm. Finally, a series of numerical simulations are conducted to demonstrate the effectiveness of the developed schemes.

MoAT4 Room T4

Heterogeneous Multiagent Autonomous Systems (Invited Session)

Chair: Li, Tianqi — Texas A&M University
Co-Chair: Krakow, Lucas W. — Colorado State University
Organizer: Li, Tianqi — Texas A&M University
Organizer: Krakow, Lucas W. — Texas A&M
Organizer: Gopalswamy, Swaminathan — Texas A&M University

07:55-08:15 MoAT4.1

Distributed Adaptive Control for Uncertain Multiagent Systems with User-Assigned Laplacian Matrix Nullspaces (I), pp. 117-122

Dogan, Kadriye Merve — Embry-Riddle Aeronautical University
Yucelen, Tansel — University of South Florida

An important practical problem in the distributed control of multiagent systems is the ability of the closed-loop system to guarantee stability and performance with respect to uncertainties. While there are a wide array of distributed adaptive control architectures that address this problem, they are developed based on a specific Laplacian matrix that has the nullspace generally spanning the vector of ones. The contribution of this paper is to make the first attempt in showing how to design and analyze distributed adaptive control architectures for uncertain multiagent systems with user-assigned Laplacian matrix nullspaces spanning any real vector. For this generalized class of multiagent systems, we first propose a distributed adaptive control architecture to guarantee the closed-loop system stability in the presence of uncertainties. We then utilize the low-frequency learning method in order to address high-frequency oscillations that can result from the fast performance recovery need that requires high-gain learning rates. Illustrative numerical examples are further provided to demonstrate the efficacy of the proposed distributed adaptive control architectures.

08:15-08:35 MoAT4.2

Navigation of Autonomous Cooperative Vehicles for Inference and Interactive Sensing (I), pp. 123-130

Robbiano, Christopher — Ball Aerospace & Technologies Corporation
Chong, Edwin K. P. — Colorado State University

This paper addresses the problem of autonomously choosing navigation actions while searching for targets in littoral regions. The search amounts to performing detection and classification of measurements as they are collected by a moving sensor. Spatial grids are used to capture the detection and classification states, respectively, of the littoral region, and are used to indicate if objects exist and if so, indicate their class. The navigation actions are chosen

by maximizing a recently proposed information-theoretic cost function that incorporates knowledge of the current detection and classification states captured in the spatial grids. Our prior work proposed a framework for performing this type of search with a single vehicle. Here, we propose a modified cost function appropriate for multiple cooperative vehicles capable of sharing information, and characterize the consequences as more vehicles are incorporated into the search. We examine the diminishing returns in performance as we increase the number of vehicles searching a fixed-size area.

08:35-08:55 MoAT4.3

Optimizing Consensus-Based Multi-Target Tracking with Multiagent Rollout Control Policies (I), pp. 131-137

Li, Tianqi	Texas A&M University
Krakow, Lucas W.	Texas A&M
Gopalswamy, Swaminathan	Texas A&M University

This paper considers a multiagent, connected, robotic fleet where the primary functionality of the agents is sensing. A distributed multi-sensor control strategy maximizes the value of the collective sensing capability of the fleet, using an information-driven approach. Each agent individually performs sensor processing (Kalman Filtering and Joint Probabilistic Data Association) to identify trajectories (and associated distributions). Using communication with neighbors, the agent enhances the prediction of the trajectories by a Consensus of Information approach that iteratively calculates the Kullback-Leibler average of trajectory distributions, which enables the calculation of the collective information for the fleet. The dynamics of the agents, the evolution of the identified trajectories for each agent, and the dynamics of individual observed objects are captured as a Partially Observable Markov Decision Process (POMDP). Using this POMDP and applying rollout with receding horizon control, an optimized non-myopic control policy that maximizes the collective fleet information value is synthesized. Simulations are presented for a scenario with three heterogeneous UAVs performing coordinated target tracking that illustrate the proposed methodology and compare the centralized approach with a contemporary sequential multiagent distributed decision technique.

08:55-09:15 MoAT4.4

Assessment of Coordinated Heterogeneous Exploration of Complex Environments (I), pp. 138-143

Riley, Danny	University of Colorado Boulder
Frew, Eric W.	University of Colorado, Bolder

This paper assesses coordination strategies for heterogeneous robots teams exploring complex three-dimensional communication-limited environments. A multi-agent coordination framework is presented that enables exploration of subterranean environments by teams of aerial and ground robots, designed for and deployed in the DARPA Subterranean Challenge. Various trade-offs in team strategies are investigated including deployment order, sharing map information, and marsupial operations.

09:15-09:35 MoAT4.5

Online Estimation and Coverage Control with Heterogeneous Sensing Information (I), pp. 144-149

McDonald, Andrew	Michigan State University
Wei, Lai	Michigan State University
Srivastava, Vaibhav	Michigan State University

Heterogeneous multi-robot sensing systems are able to characterize physical processes more comprehensively than homogeneous systems. Access to multiple modalities of sensory data allow such systems to fuse information between complementary sources and learn richer representations of a phenomenon of interest. Often, these data are correlated but vary in fidelity, i.e., accuracy (bias) and precision (noise). Low-fidelity data may be more plentiful, while high-fidelity data may be more trustworthy. In this paper, we address the problem of multi-robot online estimation and coverage control by combining low- and high-fidelity data to learn and cover a sensory function of interest. We propose two algorithms for this task of heterogeneous learning and coverage---namely Stochastic Sequencing of Multi-fidelity Learning and Coverage (SMLC) and Deterministic Sequencing of Multi-fidelity Learning and Coverage (DMLC)---and prove that they converge asymptotically. In addition, we demonstrate the empirical efficacy of SMLC and DMLC through numerical simulations.

MoAT5 Room T5

Biosystems (Regular Session)

Chair: Beck, Carolyn L.	Univ of Illinois, Urbana-Champaign
Co-Chair: Enyioha, Chinwendu	University of Central Florida

07:55-08:15 MoAT5.1

New Insights into a Epidemic SIR Model for Control and Public Health Intervention, pp. 150-155

Barbieri, Enrique	University of Houston
Fitzgibbon, William E.	University of Houston
Morgan, Jeff J.	University of Houston

A susceptible, infectious, removed (SIR) model for the spread of directly transmitted disease caused by pathogens such as bacteria, viruses, and fungi is considered. The nonlinear state equations are feedback linearizable resulting in second order dynamics that can be controlled to achieve constant setpoint tracking. Although the model's transmission rate is not a control input in the traditional sense, feedback control is used to synthesize a 'gold standard' to assist institutions in visualizing what could be achieved via timely implementation of public health interventions, economic and other measures which are known to influence the transmission rate and curb the spread. Control goals may be an improvement in state performance, such as a reduction in the population fraction that is removed, or minimization of the peak fraction of the population that is infected, or minimization of the quarantine window weighed against the economic cost on society, or the avoidance altogether of a second peak. The examination of limiting state behaviors gives further insight into the model and what actions to take in a pandemic. Simulations illustrate several scenarios including performance impact from a time delay in the implemented actions.

08:15-08:35 MoAT5.2

Finite Approximation Models for Age-Structured Population Dynamics with Self-Competition in Chemostat Reactor Applications, pp. 156-161

Kurth, Anna-Carina	Institute for System Dynamics, University of Stuttgart
Schmidt, Kevin	University of Stuttgart
Sawodny, Oliver	University of Stuttgart

Microorganisms are typically cultivated in chemostat reactors. If considering self-competition, their population is described by a nonlinear hyperbolic first order integro-partial differential equation with integral boundary condition. In order to validate control algorithms for this system class a finite-time simulation model is required. To obtain such an approximated model Galerkin's method is used. The resulting system is transformed to Byrnes-Isidori normal form to decouple the internal dynamics and the input/output dynamics. In addition to the analysis of the stability of the internal dynamics, a feedforward and a feedback controller is designed. In simulations the performance is shown and the stated theoretic stability properties are validated by means of numerical results.

08:35-08:55 MoAT5.3

Deep Reinforcement Learning for Contagion Control, pp. 162-167

Benalcazar, Diego R,	University of Central Florida
Enyioha, Chinwendu	University of Central Florida

In this work, we present a networked epidemic model comprising non-identical agents and consider the problem of learning a vaccine and antidote allocation strategy to contain an outbreak. Even though spreading processes are generally described by nonlinear dynamics, most methods for control are typically based on linear approximations of the nonlinear process and assume full knowledge of the propagation model and dynamics. We propose an alternative approach based on deep reinforcement learning. We define an environment to represent a heterogeneous nonlinear model and show that this environment can be used in conjunction with a Deep Q-Network to stabilize the spreading process. We illustrate our approach using real data from an air traffic network.

08:55-09:15 MoAT5.4

Iterative Learning Pressure and Flow Control of a Bioreactor for Tissue Engineered Heart Valves, pp. 168-175

Voß, Kirsten	RWTH Aachen University
Ketelhut, Maike	RWTH Aachen University
Gesenhues, Jonas	RWTH Aachen
Werner, Maximilian Philipp	Rheinisch-Westfälische Technische Hochschule Aachen
Schmitz-Rode, Thomas	Helmholtz Institute, RWTH Aachen University & University Hospita
Abel, Dirk	RWTH Aachen University

During the in vitro maturation process of tissue engineered heart valves in a bioreactor, the pressures ahead of and behind the heart valve as well as the transvalvular flow rate strongly influence the tissue development. In this paper, a norm-optimal iterative learning control scheme for the control of these three process input variables within a new bioreactor setup is introduced and evaluated using physiological references of an aortic heart valve. A Model-in-the-Loop (MiL) setup is established for this evaluation. The results indicate that the proposed scheme yields good tracking performance for all three controlled variables: The stationary rootmean-square errors (RMSEs) of the aortic and left ventricular pressures are, respectively, 0.9 mmHg and 4.8 mmHg (pressure range: 0 - 120 mmHg). The RMSE of the transvalvular flow rate equals to 12.3 ml/s (flow rate range: 0 - 500 ml/s). Consequently, the proposed scheme is suitable for the introduced task and can therefore be investigated further.

09:15-09:35 MoAT5.5

Parameter Estimation for a Jump Diffusion Model of Type 2 Diabetic Patients in the Presence of Unannounced Meals, pp. 176-183

Al Ahdab, Mohamad	Aalborg University
Papež, Milan	Brno University of Technology, CEITEC
Knudsen, Torben	Aalborg University, Denmark
Aradóttir, Tinna Björk	Technical University of Denmark
Schmidt, Signe	Hvidovre University Hospital
Nørgaard, Kirsten	Hvidovre University Hospital
Leth, John	Aalborg University

A stochastic jump diffusion model for type 2 diabetes (T2D) patients is proposed to account for unknown meals during treatment. The model offers the chance to estimate parameters describing how often does the patient consume carbohydrates and how much is consumed. In addition, a strategy based on a Particle Markov chain Monte Carlo (PMCMC) method combined with parameter learning is proposed to estimate the stochastic parameters with continues glucose monitoring (CGM) data and injected insulin amounts only. The strategy was tested both for clinical and simulated data and was shown to be able to estimate all the stochastic parameters with various degrees of accuracy.

09:35-09:55 MoAT5.6

Analysis, Estimation, and Validation of Discrete-Time Epidemic Processes (I), pp. 184-194

Pare, Philip E.	Purdue University
Liu, Ji	Stony Brook University
Beck, Carolyn L.	Univ of Illinois, Urbana-Champaign
Kirwan, Barrett	University of Illinois at Urbana-Champaign
Basar, Tamer	Univ of Illinois, Urbana-Champaign

Models of spreading processes over nontrivial networks are commonly motivated by modeling and analysis of biological networks, computer networks, and human contact networks. However, learning the spread parameters of such models has not yet been explored in detail, and the models have not been validated by real data. In this paper, we present several different spread models from the literature and explore their relationships to each other; for one of these processes, we present a sufficient condition for asymptotic stability of the healthy equilibrium, show that the condition is necessary and sufficient for uniqueness of the healthy equilibrium, and present necessary and sufficient conditions for estimating the spread parameters. Finally, we employ two real data sets, one from John Snow's seminal work on cholera epidemics in London in the 1850s and the other one from the United States Department of Agriculture, to validate an approximation of a well-studied network-dependent susceptible-infected-susceptible model.

MoAT6 Room T6

Optimization (Regular Session)

Chair: Summers, Tyler H.	University of Texas at Dallas
Co-Chair: Lutz, Max	Kiel University

07:55-08:15 MoAT6.1

A Sensitivity-Based Distributed Model Predictive Control Algorithm for Nonlinear Continuous-Time Systems, pp. 195-201

Huber, Hartwig	Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)
Graichen, Knut	University Erlangen-Nürnberg (FAU)

Model predictive control (MPC) is a frequently used control technique. An extension of MPC is distributed MPC that can be used to meet restrictions in computation time and make flexible system reconfiguration possible. This contribution presents a DMPC algorithm, which uses sensitivities that contain information about how the control action of a subsystem affects the neighboring agents. Three different ways of calculation are presented. The algorithm itself performs local optimization and exchanges sensitivities on agent level until a convergence criterion is met. The method is applied to several examples to demonstrate its performance, including trajectories and time analysis. In particular, it is shown that the computation time on agent level can be kept almost constant for an increasing system size.

08:15-08:35 MoAT6.2

Finite-Time Stabilization and Optimal Feedback Control for Nonlinear Discrete-Time Systems, pp. 202-207

Haddad, Wassim M.	Georgia Inst. of Tech
Lee, Junsoo	Georgia Institute of Technology

Finite time stability involves dynamical systems whose trajectories converge to an equilibrium state in finite time. Sufficient conditions for finite time stability have recently been developed in the literature for discrete-time dynamical systems. In this paper, we build on these results to develop a framework for addressing the problem of optimal nonlinear analysis and feedback control for finite time stability and finite time stabilization for nonlinear discrete-time controlled dynamical systems. Finite time stability of the closed-loop nonlinear system is

guaranteed by means of a Lyapunov function that satisfies a difference inequality involving fractional powers and a minimum operator. This Lyapunov function can clearly be seen to be the solution to a difference equation that corresponds to a steady-state form of the Bellman equation, and hence, guaranteeing both finite time stability and optimality.

08:35-08:55 MoAT6.3

Investigation of Initial Data and Optimizer in Real-Time Optimization Performance Via Modifier Adaptation with Gaussian Processes, pp. 208-213

São Paulo Ruela, Victor — Universidade Federal De Minas Gerais
Bessani, Michel — Universidade Federal De Minas Gerais

In order to overcome plant-model mismatch in static real-time optimization (RTO) of uncertain processes, modifier adaptation (MA) schemes have gained much relevance recently. It applies first-order corrections to the model cost and constraint functions in order to reach plant optimality upon convergence. However, calculating the corrections relies on gradient information, which is challenging to obtain. A promising approach to overcome this limitation is to build Gaussian processes (GP) regression functions on steady-state data to represent the plant-model mismatch. The present paper investigates how the initial operating points and optimizer choice affect RTO performance under MA with GP regression. An experiment is designed to evaluate the system's sensitivity and convergence when initialized with random feasible operating points. Results are compared for a deterministic and evolutionary heuristic to solve the model-based optimization sub-problem: Sequential Quadratic Programming (SQP) and Differential Evolution (DE), respectively. For a semi-batch reactor system case study, we illustrate that SQP can fail to find the global optimum in RTO iterations. As a result, the system's convergence is degraded and becomes sensitive to the initialization phase. On the other hand, DE achieves a consistent convergence profile, thus being indifferent to the initial data points. For a 95% confidence interval, the results show that DE outperforms SQP for this case study.

08:55-09:15 MoAT6.4

Optimal Control of Induced Draft Cooling Tower Using Mixed Integer Programming, pp. 214-219

Ghawash, Faiq — Norwegian University of Science and Technology (NTNU)
Hovd, Morten — Norwegian Univ of Sci & Tech
Schofield, Brad — CERN

We address the problem of optimal operation of an induced draft cooling tower (IDCT) which can be operated in different modes (bypass, showering, ventilation) to meet the heat rejection requirement. Typically, the control design strategies focus on modulating the cooling tower fan speed to regulate the return water temperature without explicitly taking into account different operational modes. For a large scale industrial IDCT, the cooling and lubrication requirements for the mechanical assembly impede slow fan speeds, resulting in mode selection to become pivotal in the optimal operation of the IDCT. In this paper, we propose a control strategy which can account for different operational modes to ensure the optimal operation of the IDCT. A continuous time switched system representation is adopted to capture different operational modes, which is then used to formulate an optimal control problem (OCP) based on the objective of regulating the return water temperature while respecting the physical and operational constraints associated with different operational modes. The OCP is cast as a mixed-integer program (MIP) to simultaneously handle the mode selection and the optimal fan speed required to meet the heat rejection requirement. The MIP is solved in a receding horizon fashion providing robustness against disturbances and model mismatch. The efficacy of the proposed control strategy is demonstrated on an experimentally validated model of the IDCT.

09:15-09:35 MoAT6.5

When Does MAML Objective Have Benign Landscape?, pp. 220-227

Molybog, Igor — University of California, Berkeley
Lavaei, Javad — UC Berkeley

The paper studies the landscape of the optimization problem behind the Model-Agnostic Meta-Learning (MAML) algorithm. The goal of the study is to determine the global convergence of MAML on sequential decision-making tasks possessing a common structure. We investigate in what scenarios the benign optimization landscape of the underlying tasks results in a benign landscape of the corresponding MAML objective. For illustration, we analyze the landscape of the MAML objective on LQR tasks to determine what types of similarities in their structures enable the algorithm to converge to the globally optimal solution.

09:35-09:55 MoAT6.6

Efficient Formulation of Collision Avoidance Constraints in Optimization Based Trajectory Planning and Control, pp. 228-233

Lutz, Max — Kiel University
Meurer, Thomas — Kiel University

To be applicable to real world scenarios trajectory planning schemes for mobile autonomous systems must be able to efficiently deal with obstacles in the area of operation. In the context of optimization based trajectory planning and control a number of different approaches to formulate collision avoidance constraints can be found in the literature. This work presents a novel formulation building on constructive solid geometry (CSG) to describe collision avoidance constraints. It is highly efficient due to a very low number of nonlinear inequality constraints required for a given number of obstacles and sample points and in contrast to the original CSG formulation allows to consider the controlled system's shape. To allow for a comparison, popular methods to represent obstacles from the literature are summarized and characterized, namely the simple ellipsoidal representation, the original CSG method as well as a direct and an indirect implementation of a signed distance based approach. A benchmark example shows the good performance of the proposed formulation. Here, optimal trajectory planning for marine surface vessels formulated as a nonlinear programming problem is used, where the scenario is designed based on the maritime test field in Kiel, Germany.

MoAT7 — Room T7

Student Award Finalists (Regular Session)

Chair: Sawodny, Oliver — University of Stuttgart
Co-Chair: Cortes, Jorge — University of California, San Diego

07:55-08:15 MoAT7.1

Global Sensitivity Analysis of Aging Parameters for a Lithium-Ion Battery Cell Using Optimal Charging Profiles (I), pp. 234-239

Khan, Muhammad Aadil — Stanford University
Azimi, Vahid — Stanford University
Onori, Simona — Stanford Univeristy

A challenge with Lithium-ion battery (LIB) cells is to study the impact of degradation parameter variations on the model outputs. These parameters not only contribute to battery aging, but also their accurate identification is crucial to enhance battery management systems design. This paper employs a global sensitivity analysis technique to analyze the impact of kinetic, design, and solid-electrolyte interphase (SEI) aging parameters on two different outputs, i.e., cell voltage and charge capacity. The cell is modeled via a coupled nonlinear partial and ordinary differential equations, and differential algebraic equations representing the electrochemical, thermal, and aging dynamics of a LIB cell via the enhanced single particle model (ESPM). To perform the analysis, we adopt different optimal currents at three ambient temperatures to achieve fast chargingminimum degradation profiles. The analysis shows that anode active phase volume fraction, anode reaction rate constant, and solvent reduction kinetic constant are the

most sensitive parameters for both outputs.

08:15-08:35 MoAT7.2

Machine Learning-Based Anomaly Detection for Particle Accelerators, pp. 240-246

Marcato, Davide	INFN - Legnaro National Laboratories
Arena, Giovanni	INFN - Legnaro National Laboratories
Bortolato, Damiano	INFN - Legnaro National Laboratories
Gelain, Fabio	INFN - Legnaro National Laboratories
Martinelli, Valentina	INFN - Legnaro National Laboratories
Munaron, Enrico	INFN - Legnaro National Laboratories
Roetta, Marco	INFN - Legnaro National Laboratories
Savarese, Giovanni	INFN - Legnaro National Laboratories
Susto, Gian Antonio	University of Padova

Particle accelerators are complex systems composed of multiple subsystems that must work together to produce high quality beams employed for physics experiments. A fault or an anomalous behaviour in one of such subsystems can lead to expensive downtime for the whole facility. Thus, it is of paramount importance to be able to promptly detect anomalies. Given the vast amount of streaming data generated by accelerator field sensors, Machine Learning (ML)-based tools are promising candidates for efficient monitoring of such systems: an approach based on unsupervised ML techniques exploiting the data from a Radio Frequency tuning system is here proposed. Feature importance is exploited to guide the definition of the optimal windowing for feature extraction. The proposed approach is here validated on real-world data related to the ALPI accelerator at Legnaro National Laboratories in Italy.

08:35-08:55 MoAT7.3

Fractional-Order Stochastic Extremum Seeking Control with Dithering Noise for Plasma Impedance Matching, pp. 247-252

Viola, Jairo	University of California, Merced
Hollenbeck, Derek	UC Merced
Rodríguez, Carlos	CICESE
Chen, YangQuan	University of California, Merced

Impedance matching is critical to ensure the maximum power transfer on plasma etching for semiconductor manufacturing. However, it is a challenging task due to the unknown and complex plasma dynamics. In this paper, a Stochastic Perturb and Observe Fractional-Order Extremum Seeking Controller (P&O FO-SESC) is employed for plasma impedance matching. The controller uses a Fractional-Order Gaussian (dithering) Noise (fGn) as the perturbation signal and is tested for an L-type matching network with two variable capacitors. Obtained results show that the the Stochastic P&O FO-ESC controller improves the impedance matching convergence zone over the standard P&O ESC controller for different loads and initial conditions.

MoBT1 Room T1

Automotive Applications II (Regular Session)

Chair: Luo, Guihai	University of Kaiserslautern
Co-Chair: Chen, Pingen	Tennessee Technological University

10:00-10:20 MoBT1.1

Machine Learning Based Steering Control for Automated Vehicles Utilizing V2X Communication, pp. 253-258

Avedisov, Sergei S.	Toyota North America R&D InfoTech Labs
He, Chaozhe	Navistar, Inc
Takacs, Denes	Budapest University of Technology and Economics
Orosz, Gabor	University of Michigan

A neural network-based controller is trained on data collected from connected human-driven vehicles in order to steer a connected automated vehicle on multi-lane roads. The obtained controller is evaluated using model-based simulations and its performance is compared to that of a traditional nonlinear feedback controller. The comparison of the control laws obtained by the two different approaches provides information about the naturalistic nonlinearities in human steering, and this can benefit the controller development of automated vehicles. The effects of time delay emerging from vehicle-to-everything (V2X) communication, computation, and actuation are also highlighted.

10:20-10:40 MoBT1.2

Robust Inter-Vehicle Spacing Control for Battery Electric Vehicles with One-Pedal-Driving Feature, pp. 259-264

Yang, Shuainan	Tennessee Tech University
Su, Zifei	Tennessee Technological University
Chen, Pingen	Tennessee Technological University

Battery electric vehicles (BEVs) with one-pedal driving (OPD) features have demonstrated significant potentials in reducing energy consumption, improving driving comfort, and enhancing driving safety. Besides, vehicle platooning can provide dramatic energy-saving benefits for BEVs and extend electric driving ranges. This paper presents a robust sliding mode control (SMC)-based inter-vehicle distance controller for an OPD-enabled BEV to achieve the desired inter-vehicle distance in vehicle platooning applications, in presence of uncertainties such as aerodynamic drag coefficient, road grade, and rolling resistance coefficient. The proposed SMC-based controller was validated during highly dynamic driving cycles in simulation and on the test track. The simulation results and experimental results demonstrated that the proposed sliding mode controller can achieve the desired inter-vehicle distance with high robustness against various uncertainties.

10:40-11:00 MoBT1.3

G2 Smooth, Curvature Constrained, Local Motion Planning for Automated Vehicles, pp. 265-270

Oh, Sanghoon	University of Michigan
Zhang, Linjun	Ford Motor Company
Tseng, Eric	Ford Motor Company
Xu, Lu	The Ohio State Univ
Orosz, Gabor	University of Michigan

A new local motion planning method for automated vehicles in structured road scenarios is considered. Utilizing three consecutive clothoids, it is shown that real time generation of feasible trajectories for automated vehicles is possible. Separate path generation and consecutive velocity planning is considered. The path planning is reduced to a small set of nonlinear algebraic equations, while the velocity planning comprised of forward, backward and joint iteration processes. By varying some continuous parameters, multiple feasible plans can be generated and one of those can be chosen based on multiple criteria. A left turn at an intersection is used as an illustrative example.

11:00-11:20 MoBT1.4

Automatic Steering Control for Agricultural Tractors in Vineyards, pp. 271-276

Furioli, Sara — Politecnico Di Milano
Corno, Matteo — Politecnico Di Milano
Cesana, Paolo — SAME Deutz-Fahr
Savaresi, Sergio M. — Politecnico Di Milano

Advanced Driver Assistance Systems (ADAS) and autonomous driving systems are relevant in the agricultural field, since they can ease personnel of demanding and repetitive tasks while increasing precision and productivity. This is particularly true in constrained environments represented by intensive and high value cultivations, like vineyards and orchards. Anyway, these contexts present numerous challenges: positioning accuracy in the range of centimeters is required in an environment with continuously-changing vegetation, reduced maneuvering space and unstable terrain.

This paper presents an ADAS of level 3 for an agricultural tractor in a vineyard, focusing on its control system. The goal of the developed controller is to bring the vehicle at a desired distance from the crop rows and keep it aligned to them, so that the operator only has to set the tractor advancement speed and can focus on the ongoing agricultural procedures. This is achieved through a Linear Quadratic Integral (LQI) controller that relies on a control-oriented model of the system describing the dynamics of the vehicle position with respect to the vines. The system proves to be effective and easily tunable in order to obtain the desired behavior. An extensive experimental campaign validates the closed-loop system performance. In particular, the controller attains a steady state error of 5 cm, using a steering angle with Root Mean Square (RMS) of 1.05 deg.

11:20-11:40 — MoBT1.5

Optimal Preview Control with Uncertain Preview Information with Application to Active Suspension Systems, pp. 277-282

Luo, Guihai — University of Kaiserslautern
Görges, Daniel — German Research Center for Artificial Intelligence

This paper focuses on optimal preview control with uncertain preview information. Accurate preview information is required in optimal preview control. However, dealing with uncertain preview information in optimal preview control is not addressed in the literature. To handle uncertain preview information, a disturbance observer is introduced to possibly recover the optimal preview control performance. The effectiveness of the proposed approach is verified by numerical simulations with an example of an active suspension system.

11:40-12:00 — MoBT1.6

Control for Autonomous Vehicles in High Dynamics Maneuvers : LPV Modeling and Static Feedback Controller, pp. 283-288

Penco, Dario — CNRS-L2S
Davins-Valldaura, Joan — Renaut
Godoy, Emmanuel — Supelec
Kvieska, Pedro — Renault SAS
Valmorbida, Giorgio — L2S, CentraleSupelec

This article presents a state feedback control design strategy for the stabilization of a vehicle along a reference collision avoidance maneuver. The stabilization of the vehicle is achieved through a combination of steering, acceleration and braking. A Linear Parameter-Varying (LPV) model is obtained from the linearization of a non-linear model along the reference trajectory. A robust state feedback control law is computed for the LPV model. Finally, simulation results illustrate the stabilization of the vehicle along the reference trajectory.

MoBT2 — Room T2

Energy II (Regular Session)

Chair: Gatsis, Nikolaos — The University of Texas at San Antonio
Co-Chair: Yu, Nanpeng — University of California, Riverside

10:00-10:20 — MoBT2.1

Individual Pitch Control of a Large Wind Turbine Using a Fractional Order Nonlinear PI Approach with Anti-Windup Strategy, pp. 289-294

Wang, Xin — Fraunhofer IWES
Gambier, Adrian — Fraunhofer IWES

In this contribution, an individual pitch control system (IPC) for a large wind turbine by using a fractional order nonlinear PI approach (FO-NPI) is implemented and its performance compared with the standard PI controller analyzed.

A solution to the problem of the integrator wind-up in the case of the IPC is proposed, as well. It is considered that pitch actuators saturate not only in magnitude but also in rate. A 20 MW reference wind turbine, which is implemented in the simulation software OpenFAST, is used as virtual plant for the simulation experiments. Simulation results indicate that the IPC system based on the FO-NPI techniques improves the wind turbine control performance and reduces damage equivalent loads (DELs) by 7.5 percent on average when compared with classic PI control.

10:20-10:40 — MoBT2.2

Deep Neural Network Trained to Mimic Nonlinear Economic Model Predictive Control: An Application to a Pendulum Wave Energy Converter, pp. 295-300

Pasta, Edoardo — MOREnergy Lab, Politecnico Di Torino
Carapellese, Fabio — Politecnico Di Torino
Mattiazzo, Giuliana — Politecnico Di Torino

This paper introduces different Model Predictive Control (MPC) strategies aimed at optimizing the energy production of a Pendulum Wave Energy Converter (PeWEC). Due to MPC ability of dealing with system constraints and considering future behaviors in optimal control computation, the first proposed MPC is applied to PeWEC as a classical problem of set-point tracking using a linear model to propagate the system behaviour. Moreover, since the MPC application in wave energy conversion deviates significantly from traditional MPC ones, an economic version is also explored. The objective function of the MPC thus realized directly considers a measure of the absorbed power. However, this formulation, together with the use of a nonlinear model in predicting the system evolution, leads to an optimization problem to be solved that is neither fully quadratic nor can be guaranteed to be convex. This paper shows that this second approach brings better performances, demonstrating that it is potentially more suitable for wave energy applications. On the other side, such approach has a computational drawback from both a real time implementation and offline design perspectives. To avoid the potentially prohibitive computational costs that an online optimization would require, this work introduces a novel control based on a Deep Neural Network (DNN) able to mimic the nonlinear economic MPC. Results arising from simulations applying the proposed strategy demonstrate the effectiveness of the presented approach.

10:40-11:00 — MoBT2.3

Comparison of Deep Reinforcement Learning and Model Predictive Control for Real-Time Depth Optimization of a Lifting Surface Controlled Ocean Current Turbine, pp. 301-308

Hasankhani, Arezoo — Florida Atlantic University
Tang, Yufei — Florida Atlantic University
VanZwieten, James — Florida Atlantic University
Sultan, Cornel — Virginia Tech

This paper evaluates two strategies, deep reinforcement learning (DRL) and model predictive control (MPC), for maximizing harnessed power from a lifting surface controlled ocean current turbine (OCT) through depth optimization. To address spatiotemporal uncertainties in the ocean current, an online Gaussian Process (GP) is applied, where

the prediction error of the ocean current speed is also modeled. We compare the performance of the MPC-based optimization with the DRL-based algorithm (i.e., deep Q-networks (DQN)) using over one week of field collected acoustic doppler current profiler (ADCP) data. The DRL-based algorithm is almost equivalent to the MPC-based algorithm in real-time optimization when the ocean current speed prediction is perfect. However, the performance of the DQN-based algorithm surpasses the MPC-based algorithm when ocean current prediction error is considered. The importance of using the DQN in improving the error-tolerance of the proposed spatiotemporal optimization is verified through the comparative results.

11:20-11:40 MoBT2.5

On the Simultaneous Estimation of Dynamic and Algebraic States in Power Networks Via State Observer, pp. 309-314

Nugroho, Sebastian Adi	University of Michigan - Ann Arbor
Taha, Ahmad	The University of Texas at San Antonio
Gatsis, Nikolaos	The University of Texas at San Antonio
Zhao, Junbo	Mississippi State University

This paper considers the problem of estimating the dynamic and algebraic states in transmission power networks. Specifically, we leverage a linearized, differential-algebraic equation (DAE) of power networks—also called descriptor system models—consisting generator's dynamics, stator's algebraic constraints, generator's complex power, and the network's complex power balance equations. The DAE is then combined together with a phasor measurement unit-based measurement model, which assumes that bus voltages and line currents are measured, to produce a semi-explicit linear DAE which is exploited to design a linear DAE observer to estimate the dynamic and algebraic states of power networks. Numerical simulations are performed using the IEEE 9-bus transmission system to analyze the performance of the proposed observer in estimating generators' internal states and unmeasured bus voltages subject to both Gaussian and non-Gaussian noise.

11:40-12:00 MoBT2.6

Reinforcement Learning-Based Smart Inverter Control with Polar Action Space in Power Distribution Systems, pp. 315-322

Kabir, Farzana	Univeristy of California, Riverside
Gao, Yuanqi	University of California, Riverside
Yu, Nanpeng	University of California, Riverside

To tackle the challenge of voltage regulation under high solar photovoltaics (PV) penetration, the slow timescale control of conventional voltage regulating devices can be combined with fast timescale control of smart inverters. In this paper, we develop a two-timescale Volt-VAR control (VVC) framework. The slow timescale control of voltage regulating devices is achieved by a model-based approach. The fast time-scale control of smart inverters is attained with a reinforcement learning-based method. The deep deterministic policy gradient (DDPG) algorithm is adopted to control the setpoints of both real and reactive power of smart inverters. The control policy of smart inverters is learned from the historical operational data without relying on accurate distribution network secondary circuit parameters. Simulation results on the IEEE 34-bus feeder show that the proposed framework can determine near optimal set points of smart inverters in real-time operations. Compared with existing reinforcement learning based smart inverter control, our approach achieves lower line losses, voltage deviations, and active power curtailment.

MoBT3 Room T3

Aerial Robotics (Regular Session)

Chair: Vamvoudakis, Kyriakos G.	Georgia Inst. of Tech
Co-Chair: Yildiz, Yildiray	Bilkent University

10:00-10:20 MoBT3.1

Chaotic Velocity Profile for Surveillance Tasks Using a Quadrotor, pp. 323-328

Montañez, Carlos	CICESE
Pliego-Jiménez, Javier	CICESE
Cruz-Hernandez, Cesar	CICESE

This paper addresses the problem of surveillance of a confined area using an unmanned aerial vehicle with four rotors. The properties of chaotic systems have been exploited to design an unpredictable velocity profile for the quadrotor. To maintain the quadrotor within the area of interest, the mirror mapping approach is used. On the other hand, to guarantee velocity tracking a nonlinear velocity and attitude control laws are proposed. The effectiveness of the proposed surveillance approach is validated by numerical results. The numerical results were obtained by means of Matlab software and its Simulink tool.

10:20-10:40 MoBT3.2

A Simple Six Degree-Of-Freedom Aerial Vehicle Built on Quadcopters, pp. 329-334

Pi, Chen-Huan	National Chiao Tung University
Ruan, Lecheng	University of California, Los Angeles
Yu, Pengkang	University of California, Los Angeles
Su, Yao	Univeristy of California, Los Angeles (UCLA)
Cheng, Stone	National Yang Ming Chiao Tung University
Tsao, Tsu-Chin	University of California, Los Angeles

Conventional multirotors have coupling between position and attitude control due to underactuation in dynamics, and thus can not track six degree-of-freedom (DoF) trajectories in space. Previous works proposed fully actuated multirotors with modifications to mechanical structure to provide varying orientations of thrust forces without changing the attitude, but usually introduced additional actuators and mechanisms so that the complexity for design and construction was increased. This paper proposes a novel multirotor platform with the capability of six DoF control, which can be easily constructed with commercial quadcopters and simple 3D printed connectors, and effortlessly scaled. An easily implemented controller is designed, and the six DoF control is verified through simulation and real world experiments.

10:40-11:00 MoBT3.3

D-SDRE Based Soft-Landing Control of a Lunar Lander with Active Momentum Exchange Impact Dampers, pp. 335-340

Hsu, Yi-Lun	National Taiwan University
Lin, Jhih-Hong	National Space Organization
Chan, Chen-Yu	National Space Organization
Chen, Cheng-Wei	National Taiwan University

When a lunar lander touches down, a large impact force may have undesirable effects such as rebounding and overturning. To ensure a safe landing, active momentum exchange impact dampers (AMEIDs) are introduced in this work to enable soft-landing control. For the purpose of designing and evaluating different control strategies applied to the AMEIDs, a two-dimensional lunar lander model is derived using Lagrangian mechanics. The model is validated via a free-fall landing experiment. Using the lander dynamical model, we design a suboptimal control law by solving the discrete-time state-dependent Riccati equation (D-SDRE). The landing response of D-SDRE based controller is compared to that of open-loop control and PID control, respectively. The simulation results show that the D-SDRE method mitigates the landing instability and reduces the side-slip phenomenon.

11:00-11:20 MoBT3.4

A 3D Modeling Framework for the Application of Unmanned Aircraft Systems Integration, pp. 341-346

Albaba, Berat Mert	Bilkent University
Musavi, Negin	University of Illinois Urbana Champaign
Yildiz, Yildiray	Bilkent University

Predicting the outcomes of integrating Unmanned Aerial Systems (UAS) into the National Airspace System (NAS) is a complex problem that is required to be addressed by simulation studies before allowing the routine access of UAS into the NAS. This paper focuses on providing a 3-dimensional (3D) simulation framework developed using a game-theoretical methodology to evaluate integration concepts using scenarios where manned and unmanned air vehicles co-exist. In the proposed method, the human pilot interactive decision-making process is incorporated into airspace models, which can fill the gap in the literature where the pilot behavior is generally assumed to be known a priori. The proposed human pilot behavior is modeled using the dynamic level-k reasoning concept and approximate reinforcement learning. Level-k reasoning concept is a notion in game theory and is based on the assumption that humans have various decision-making levels. In this study, Neural Fitted Q Iteration, which is an approximate reinforcement learning method, is used to model time-extended decisions of pilots with 3D maneuvers. An analysis of UAS integration is conducted using an example 3D scenario in the presence of manned aircraft and fully autonomous UAS equipped with sense and avoid algorithms.

11:20-11:40 MoBT3.5

Modeling and Analysis of Platooning Control for a Leader-Follower Quadcopter Fleet System Level Study of String Stability, pp. 347-353

Srinivasan, Anshuman	Arizona State University
Rodriguez, Armando A.	Arizona State University

The objective of this paper is to model, simulate and analyze platooning (separation) control for a fleet of 6 quadcopter units. Control for 6 degrees of freedom ($x,y,z,phi,theta,psi$] is modeled for each individual quadcopter using a cascaded linear feedback control system, with the fleet modeled as leader-follower. The primary motivation of this research is to examine string instability arising from the ``accordion effect'', a phenomenon observed in leader-follower systems due to which positioning or relative spacing errors arise in follower vehicles due to sudden changes in lead vehicle velocity. First, a PID separation controller is designed for a nominal case, where communication within the system is ad-hoc. Steady state separation/positioning errors for each member of the fleet are observed and documented. Second, lead vehicle acceleration is then provided to each controller (as a feed forward term), which is used to compare controller bandwidth requirements to ensure relative string stability , within acceptable error bounds. Thus the key contribution of this work is a separation controller for a fleet of quadcopters, with quantitative analysis of the string stability, using simulation data from MATLAB Simulink.

11:40-12:00 MoBT3.6

Experimental Design and Control of a Smart Morphing Wing System Using a Q-Learning Framework, pp. 354-359

Syed, Aqib	Georgia Institute of Technology
Khamvilai, Thanakorn	King Abdullah University of Science and Technology
Kim, Yoobin	Georgia Institute of Technology
Vamvoudakis, Kyriakos G.	Georgia Inst. of Tech

A novel control and testing platform for a smart morphing wing system is introduced to obtain optimal aerodynamic properties. This paper delves into the manufacturing process for said system, from the computer-aided modeling to the assembly, and its corresponding difficulties. The issues associated with the primary rendition of the model are addressed, as well as proposed solutions to these issues. Additionally, a hardware-in-the-loop formulation is introduced, which utilizes the 3D printed airfoil model for Computational Fluid Dynamics (CFD) analysis and reinforcement learning. In particular, image processing techniques and algorithms are employed to obtain an outline for the various morphed configurations, which are converted into airfoil coordinates and analyzed using a CFD tool, before being imported into a Q-learning algorithm.

MoBT4 Room T4

Pursuit-Evasion and Reach-Avoid Games (Invited Session)

Chair: Garcia, Eloy	Air Force Research Laboratory
Co-Chair: Fuchs, Zachariah E.	University of Cincinnati
Organizer: Garcia, Eloy	Air Force Research Laboratory
Organizer: Fuchs, Zachariah E.	University of Cincinnati

10:00-10:20 MoBT4.1

The Cooperative Blocking Differential Game (I), pp. 360-365

Garcia, Eloy	Air Force Research Laboratory
Casbeer, David W.	Air Force Research Laboratory
Von Moll, Alexander	Air Force Research Laboratory
Pachter, Meir	AFIT/ENG

This paper considers a pursuit-evasion problem with two cooperative pursuers and one evader. The problem is posed as a zero-sum differential game where the evader aims at reaching a goal line which is protected by the pursuers. When reaching this goal is not possible, the evader strives to position itself as close as possible with respect to the goal line at the time of capture. The pursuers try to capture the evader as far as possible from the goal line. Leveraging differential game theory, state feedback strategies are both synthesized and verified in this paper. In addition, the Barrier surface that partitions the state space into two winning sets, one for the pursuer team and one for the evader, is obtained in analytical form. Under optimal play, the winning team is determined by evaluating the associated Barrier function.

10:20-10:40 MoBT4.2

Engagement Zone Defense of a Non-Maneuvering Evader (I), pp. 366-373

Weintraub, Isaac	Air Force Research Laboratory
Von Moll, Alexander	Air Force Research Laboratory
Casbeer, David W.	Air Force Research Laboratory
Garcia, Eloy	Air Force Research Laboratory
Pachter, Meir	AFIT/ENG

This paper considers a three agent scenario consisting of a pursuer, evader, and a defender. The pursuer's objective is to capture the non-maneuvering evader in minimum time while a defender aims at maximize contact with the pursuer by keeping the pursuer inside his circular engagement zone for as long as possible; the pursuer is considered to be faster than both the evader and the defender. Using optimal control theory, the optimal control for the defender that maximizes contact with the pursuer is posed and solved. In the event that the evader is captured by the pursuer before the pursuer escapes the engagement zone of the defender, some suboptimal strategies of the defender provide equivalent contact time. A derivation of defender's headings that maximize contact is presented along with examples that highlight the importance of the initial conditions of the engagement scenario.

10:40-11:00 MoBT4.3

Cooperative Evasion by Translating Targets with Variable Speeds (I), pp. 374-379

Bajaj, Shivam	Michigan State University

Garcia, Eloy — Air Force Research Laboratory
Bopardikar, Shaunak D. — Michigan State University

We consider a problem of cooperative evasion between a single pursuer and multiple evaders in which the evaders are constrained to move in the positive Y direction. The evaders are slower than the vehicle and can choose their speeds from a bounded interval. The pursuer aims to intercept all evaders in a given sequence by executing a Manhattan pursuit strategy of moving parallel to the X axis, followed by moving parallel to the Y axis. The aim of the evaders is to cooperatively pick their individual speeds so that the total time to intercept all evaders is maximized. We first obtain conditions under which evaders should cooperate in order to maximize the total time to intercept as opposed to each moving greedily to optimize its own intercept time. Then, we propose and analyze an algorithm that assigns evasive strategies to the evaders in two iterations as opposed to performing an exponential search over the choice of evader speeds. We also characterize a fundamental limit on the total time taken by the pursuer to capture all evaders when the number of evaders is large. Finally, we provide numerical comparisons against random sampling heuristics.

11:00-11:20 MoBT4.4

Multi-Player Reach-Avoid Game in Dynamic Environment (I), pp. 380-385

Lo, Jason King Ching — Purdue University
Garcia, Eloy — Air Force Research Laboratory
Mou, Shaoshuai — Purdue University

With autonomy gaining popularity and acceptance in various fields, humans have begun shifting to employing autonomous vehicles to perform risky tasks in hostile environment. Therefore, it is crucial that we investigate motion planning problem with safety in mind. In this sense, reach-avoid game is a good problem to analyze due to its complex nature and the fact that worst-case disturbance is considered. In this work we present an iterative open-loop formulation for a reach-avoid game with multiple attackers and defenders. We show the proposed method can find more direct paths compared to the basic open-loop formulation, and perhaps more importantly, the algorithm can find feasible paths in situation where open-loop formulation simply cannot. By solving the game with the proposed method we can guarantee the safety of the planned path, despite the dynamic environment with the presence of unpredictable obstacles, adversarial defender, as well as other attackers. In addition, we offer a practical method that ensures agents with minimum turning radius only take paths that respect the constraints. We verify the effectiveness of our method through a series of simulations.

11:20-11:40 MoBT4.5

Engage or Retreat Differential Game with N-Targets and Distributed Defensive Assets (I), pp. 386-393

Fuchs, Zachariah E. — University of Cincinnati
Von Moll, Alexander — Air Force Research Laboratory
Casbeer, David W. — Air Force Research Laboratory

A two-player, Engage or Retreat (EoR) differential game is presented in which an attacker must choose whether to capture one of N static targets or retreat across a defined retreat boundary. Throughout the engagement, a defending player is capable of activating defensive assets located at each of the target locations. These defensive assets inflict a cost on the attacker as a function of distance and allow the defender to present a deterrent in an effort to persuade the attacker to elect retreat. The solution of the game is constructed by examining two related subproblems: the Game of Engagement (GoE) and the Optimal Constrained Retreat (OCR). Each subproblem examines a different combination of attacker termination strategies, capture vs retreat, and defender strategies, resist vs cooperate. When solving for the optimal constrained retreat strategy, a value function constraint is imposed on the retreat trajectory in order to ensure that the attacker does not maneuver into an advantageous position. Several solutions are examined to illustrate the types of behaviors found in the equilibrium game solutions.

11:40-12:00 MoBT4.6

An Engage or Retreat Differential Game with a Mobile Target (I), pp. 394-401

Chandrasekar, Swathi — Wright State University
Fuchs, Zachariah E. — University of Cincinnati

This paper examines a variation of the standard one-pursuer, one-evader, pursuit-evasion problem. In this problem, the evader is capable of inflicting a cost on the attacker during the pursuit. The attacker chooses whether to continue the engagement or abandon pursuit and retreat across a defined retreat boundary. The evader strategically manipulates the attacker's cost function in order to encourage retreat. If the pursuer elects to retreat, the defender maneuvers in a way to escape to safety and prevent the pursuer from reengaging. The solution of the game is developed using analytic indirect methods and an illustrative solution is examined.

MoBT5 Room T5

Modeling (Regular Session)

Chair: Transtrum, Mark — Brigham Young University
Co-Chair: Butler, Brooks — Purdue University

10:00-10:20 MoBT5.1

Modeling Live Crowd Emotion Dynamics for State Estimation and Prediction, pp. 402-407

Butler, Brooks — Purdue University
Pare, Philip E. — Purdue University
Transtrum, Mark — Brigham Young University
Warnick, Sean — Brigham Young University

Crowd violence and the repression of free speech have become increasingly relevant concerns in recent years. This paper considers a new application of crowd control, namely, keeping the public safe during large scale demonstrations by anticipating the evolution of crowd emotion dynamics through state estimation. The general crowd control problem is difficult for a variety of reasons, including limited access to informative sensing and effective actuation mechanisms, as well as limited understanding of crowd psychology and dynamics. This paper takes a first step towards solving this problem by formulating a crowd state prediction problem in consideration of recent work involving crowd psychology and opinion modeling. We propose a nonlinear crowd behavior model incorporating parameters of agent personality, opinion, and relative position to simulate crowd emotion dynamics. This model is then linearized and used to build a state observer whose effectiveness is then tested on system outputs from both nonlinear and linearized models. We show that knowing the value of the equilibrium point for the full nonlinear system is a necessary condition for convergence of this class of estimators, but otherwise not much information about the crowd is needed to obtain good estimates. In particular, zero-error convergence is possible even when the estimator erroneously uses nominal or average personality parameters in its model for each member of the crowd.

10:20-10:40 MoBT5.2

Parametric Model Order Reduction of Variable Parameter Axial Dispersion Model, pp. 408-415

Ahmed, Elkhashap — RWTH Aachen University
Abel, Dirk — RWTH Aachen University

Axial dispersion models are capable of delivering accurate predictions of non-ideal flow behavior, where the residence time distribution (RTD) of the flowing material is estimated. Such models are crucial for analysis, monitoring, and control purposes of processes appearing in a wide spectrum of applications, e.g. chemical, pharmaceutical. In the previous contribution [1] the problem of the variability of the residence

time distribution due to its dependency on process variables is tackled using a grey-box approach. However, solving the grey-box model numerically including the varying model parameters requires a fine spatial discretization. In consequence, delivering a high-dimensional model unsuitable for control-oriented applications, e.g. model- based estimation/control, real-time monitoring. This work presents a solution to the problem by employing a projection-based Model Order Reduction (MOR) technique producing a computationally feasible Reduced Order Model (ROM) with acceptable accuracy. The exploitation of the Full Order Model (FOM) special structure along with a carefully selected input vector including the varying parameters allowed casting the model into a weak nonlinear form, i.e. bilinear. Hence permitting the investigation of two methods for parameter independent MOR, i.e. Proper Orthogonal Decomposition (POD) and bilinear $mathcal{H}_2$ optimal. The latter method requirements are considered and treated within the FOM mathematical formulation. The ROMs produced by the two methods are evaluated against the FOM for selected simulation test scenarios showing the superiority of the latter. That is for a practical test case of a random biased input concentration and varying flow parameters, the ROM could predict the concentration output with a Normalized Mean Square Error (NMSE) lying below $4%$ for all tested peclet number ranges. A computational speedup factor up to 32 is achieved using the ROM showing its potential for real-time applications even for sampling rates within milliseconds order of magnitude.

[1] A. Elkhashap, et al., “Greybox approach for the prediction of variable residence time distribution in continuous pharmaceutical manufacturing,” IFAC World Congress, 2020

10:40-11:00 MoBT5.3

Modeling Multi-Driver Interaction in Intersection Scenarios Based on a Hybrid Game Approach, pp. 416-423

Lemmer, Markus	FZI Research Center for Information Technology
Schwab, Stefan	Research Center for Information Technology
Hohmann, Soeren	KIT

In the presented work, an existing game-theoretical framework modeling intersection scenarios is extended. The framework is based on a hybrid dynamic game approach, which subdivides the motion of the vehicle into distinct maneuvers to reduce the continuous action space to a finite set of discrete actions. Therefore, the optimization problem modeling the decision process can be solved using dynamic programming. In the first step, the capability to handle situations with players driving along the same path is added. Furthermore, the approach is extended for situations with more than two players. In order to reduce the computational complexity, a method for selecting only relevant traffic participants is developed. Different simulation examples are used to verify the general functionality of the model.

11:00-11:20 MoBT5.4

Modelling of Transient Incompressible Concrete Mass Flow through a Hose, pp. 424-429

Blagojevic, Boris	University of Stuttgart
Nitsche, Alexander	University of Stuttgart
Sawodny, Oliver	University of Stuttgart

Concrete pumping is a widespread technology used in on site construction around the world. It also is a viable technology for the automized fabrication of concrete elements. This however requires precise control of the outgoing mass flow. Since measurements of the mass flow or the total conveyed mass are impractical, a feedforward control is required. This in turn requires a model of the outgoing mass flow. While the literature on concrete pumping is abundant, automation-relevant aspects, e.g. the initial time delay due to filling of the hose, have not been covered yet. This paper proposes a model to fill that gap, which shows promising results while refraining from treating the complex details of 3D-flow. This is an important aspect for both implementation on control hardware and process planning. Assuming incompressible flow, a hose can be described as a reservoir for the incoming mass flow, with an outflow function depending on the geometry. If the outlet points downward, gravitation imposes an additional dynamic behavior, for which several modeling approaches are proposed and validated by experiments.

11:20-11:40 MoBT5.5

Modelling of Ionization Current in a Flame Based on Hammerstein Models, pp. 430-434

Tacke, Julian	Vaillant Group
Dehnert, Robert	University of Wuppertal
Lerch, Sabine	University of Wuppertal
Tibken, Bernd	University of Wuppertal

Controller based on ionization current measurement are state of the art in the field of wall hung gas boilers (WHB). They are used to control the gas-air ratio of the combustion. The underlying ionization mechanism is a complex three-dimensional problem. Therefore, it is a difficult task to describe this system with a white-box model for simulation and controller design. This paper investigates a new method to model the ionization current using a nonlinear Hammerstein model. The parameters of the system are identified with real measurement data. Thereby, three different approaches of Hammerstein models are trained and compared. One model is a complete black-box model, the other two are grey-box models with known static nonlinearities. These two models have an increased model accuracy in comparison to the unknown model. The results are verified with additional data sets, which are not used for training.

11:40-12:00 MoBT5.6

Pricing Parameter Design for Electric Vehicle Charging, pp. 435-440

Santoyo, Cesar	Georgia Institute of Technology
Coogan, Samuel	Georgia Institute of Technology

Pricing models implemented at electric vehicle (EV) charging facilities provide facility operators a means to achieve desirable system-level behavior. Furthermore, a charging facility must meet resource constraints with high levels of confidence. To achieve this, a charging facility operator can tune the pricing model parameters such that resource constraints are met with high confidence. In this paper, we propose an approximate chance-constrained optimization program that enables charging facility operators to set the pricing model parameters in an anticipatory, rather than a reactionary, manner. We present a problem formulation based on two previously developed pricing models and present results from a numerical case study for setting the respective pricing model parameters.

MoBT6 Room T6

Predictive Control (Regular Session)

Chair: Sira-Ramirez, Hebertt	CINVESTAV
Co-Chair: Nghiem, Truong X.	Northern Arizona University

10:00-10:20 MoBT6.1

A Kalman Filter for Online Calibration of Optimal Controllers, pp. 441-446

Menner, Marcel	Mitsubishi Electric Research Labs
Berntorp, Karl	Mitsubishi Electric Research Labs
Di Cairano, Stefano	Mitsubishi Electric Research Labs

This paper proposes an approach for the calibration of the cost function of optimization-based controllers. The approach uses a Kalman filter that estimates the cost function parameters using data of closed-loop system operation. It adapts the parameters online and robustly, provides safety guarantees, is computationally efficient, has low data storage requirements, and is easy to implement making it appealing for many real-time applications. The approach provides a data-efficient alternative to Bayesian optimization and an automated alternative to

learning from demonstrations. Simulation results show that the approach is able to learn cost function parameters quickly (approximately 95% faster than Bayesian optimization), is able to adapt the parameters to compensate for disturbances (approximately 25% improvement on tracking precision), and is robust to noise.

10:20-10:40 MoBT6.2

Equivalence between Reduced Order Extended State Observer Based Active Disturbance Rejection Control and Disturbance Observers Based Control Schemes, pp. 447-452

Sira-Ramirez, Hebertt	CINVESTAV
Gomez-Leon, Brian Camilo	CINVESTAV
Aguilar-Orduña, Mario Andres	CINVESTAV
Zurita-Bustamante, Eric William	Cinvestav

A frequency domain approach is used to establish an equivalence between Reduced Order Extended State Observer (ROESO) based Active Disturbance Rejection Control (ADRC) and Disturbance Observer Based (DOB) control using nominal (estimated) state feedback. These robust control schemes are traditionally devised to solve automatic control problems for systems with unmeasured states and subject to unknown disturbances. The results are presented in the context of pure integration perturbed systems, which constitute a paradigmatic model of nonlinear, uncertain, SISO differentially flat systems. Application to the control of a non-trivial, nonlinear, mechanical example is presented along with computer simulations.

10:40-11:00 MoBT6.3

A Receding Horizon Approach for Simultaneous Active Learning and Control Using Gaussian Processes, pp. 453-458

Le, Viet-Anh	University of Delaware
Nghiem, Truong X.	Northern Arizona University

This paper proposes a receding horizon active learning and control problem for dynamical systems in which Gaussian processes (GPs) are utilized to model the system dynamics. The active learning objective in the optimization problem is presented by the exact conditional differential entropy of GP predictions at multiple steps ahead, which is equivalent to the log determinant of the GP posterior covariance matrix. The resulting non-convex and complex optimization problem is solved by the sequential convex programming algorithm that exploits the first-order approximations of non-convex functions. Simulation results of an autonomous car example verify that using the proposed method can significantly improve data quality for model learning.

11:00-11:20 MoBT6.4

Transient-Robust Reference Governors: An Extension to Systems with Non-Invertible Steady-State Mappings, pp. 459-465

Osorio, Joycer	University of Vermont
Ossareh, Hamid	University of Vermont

In our previous work, we presented a constraint management technique, referred to as the Transient-Robust Reference Governor (TR-RG), to enforce state, output, and control constraints in closed-loop nonlinear systems. One of the key assumptions behind the TR-RG is that the input-output mapping of the nonlinear system is available at steady-state and, furthermore, this mapping is invertible. While this assumption holds in some situations (e.g., engine control in automotive applications), it does not hold in general (e.g., inverted pendulum control problem). To overcome this limitation, this paper extends TR-RG to a wider class of nonlinear systems, namely those with non-invertible or uncertain steady-state characterizations. Theoretical guarantees of constraint enforcement using this scheme are provided. Finally, the scheme is illustrated using two practical examples.

11:20-11:40 MoBT6.5

PARODIS: One MPC Framework to Control Them All. Almost, pp. 466-471

Schmitt, Thomas	Technische Universität Darmstadt
Engel, Jens	Honda Research Institute Europe
Hoffmann, Matthias	Universität Des Saarlandes
Rodemann, Tobias	Honda Research Institute Europe

We introduce the MATLAB framework PARODIS, the Pareto optimal Model Predictive Control framework for distributed systems. It is a general-purpose, flexible and easy-to-use framework for discrete state space models. Special features are the support of distributed (hierarchical) systems, scenario-based optimization and built-in methods for determination of the Pareto front and selection of a solution. It uses the popular MATLAB framework YALMIP for the symbolic formulation of optimization problems and models.

11:40-12:00 MoBT6.6

Experimental Testing of a Preview-Enabled Model Predictive Controller for Blade Pitch Control of Wind Turbines (I), pp. 472-486

Sinner, Michael	University of Colorado Boulder
Petrović, Vlaho	Universität Oldenburg
Langidis, Apostolos	University of Oldenburg
Neuhaus, Lars	University of Oldenburg, ForWind - Institute of Physics
Hölling, Michael	Institute of Physics and ForWind, University of Oldenburg
Kühn, Martin	University of Oldenburg
Pao, Lucy Y.	University of Colorado Boulder

Model predictive control (MPC) is a control method that involves determining the input to a dynamical system as the solution to an optimization problem that is solved online. In the wind turbine research literature, MPC has received considerable attention for its ability to handle both actuator constraints and preview disturbance information about the oncoming wind, which can be provided by a lidar scanner. However, while many studies simulate the wind turbine response under MPC, very few physical tests have been carried out, likely due in part to the difficulties associated with solving the MPC problem in real time. In this work, we implement MPC on an experimental, scaled wind turbine operating in a wind tunnel testbed, using an active grid to create reproducible wind sequences and a hot-wire anemometer to generate upstream wind measurements. To our knowledge, this work presents the first physical test of MPC for blade pitch control of a scaled wind turbine. We compare two MPC strategies: one including preview disturbance information and one without. Our results provide further evidence that feedforward control can improve wind turbine performance in transition and above-rated conditions without increasing actuation requirements, which we hope will encourage industry experimentation and uptake of feedforward control methods. We also provide a high-level analysis and interpretation of the computational performance of the chosen approach. This work builds upon the results of an earlier study, which considered unconstrained optimal blade pitch control.

MoBT7 Room T7

Nonlinear Systems (Regular Session)

Chair: Zeng, Shen	Washington University in St. Louis
Co-Chair: Lee, Junsoo	Georgia Institute of Technology

10:00-10:20 MoBT7.1

Continuous Quaternion Based Almost Global Attitude Tracking, pp. 487-492

Conord, Thomas	LAAS-CNRS, Université De Toulouse
Peaucelle, Dimitri	LAAS-CNRS, Université De Toulouse

This paper considers the attitude control problem of a generic rotating

3 degrees of freedom fully actuated rigid object. The specific studied problem is the deviation control of this object around a theoretically feasible attitude trajectory. The rotation motion has an intrinsic non linear behaviour (trigonometric, periodicity) that need to build non linear and hybrid controllers to get global stability of the closed loop system. This paper considers the opportunity to use the quaternion framework to build a continuous non linear state feedback that reaches an almost global asymptotical stability. Some perspectives to enhance this result with integrators to cancel out static and drag errors are eventually proposed.

10:20-10:40 MoBT7.2

Nonlinear Optimal Control Synthesis Using Basis Functions: Algorithms and Examples, pp. 493-498

Vu, Minh	Washington University in St. Louis
Fang, Hao	Washington University in St. Louis
Zeng, Shen	Washington University in St. Louis

The ability to quickly synthesize an optimal control signal for a nonlinear system is critical for practical implementations. In previous work, we have introduced a computational procedure to iteratively synthesize an optimal control signal for a very broad class of nonlinear control systems. This paper presents an extension of the approach to allow for different parameterizations of control inputs, resulting in a substantial reduction in the number of decision variables and thus computation time. The highlighted efficiency and effectiveness of the proposed approach are illustrated and compared against other methods using various control examples.

10:40-11:00 MoBT7.3

A Thermodynamic-Based Control Architecture for Semistability and Consensus of Discrete-Time Nonlinear Network Systems, pp. 499-504

Haddad, Wassim M.	Georgia Inst. of Tech
Lee, Junsoo	Georgia Institute of Technology

Network systems involve distributed decision-making for coordination of networks of dynamic agents and address a broad area of applications including cooperative control of unmanned air vehicles, microsatellite clusters, mobile robotics, battle space management, and congestion control in communication networks. In this paper, we develop a thermodynamic-based framework for addressing consensus problems for discrete-time nonlinear multiagent dynamical systems with a fixed communication topology. The proposed controller architecture involves the exchange of state information between agents guaranteeing that the closed-loop dynamical network is semistable to an equipartitioned equilibrium representing a state of information consensus consistent with basic thermodynamic principles.

11:00-11:20 MoBT7.4

Kinematic and Dynamic Tracking of Mobile Robot Using Fractional Order Control, pp. 505-510

Singh, Padmini	IIT - Kanpur
Yogi, Subhash Chand	IIT Kanpur
Behera, Laxmidhar	Indian Inst. of Technology, Kanpur
Verma, Nishchal K	Indian Institute of Technology Kanpur

This paper proposes kinematic and dynamic tracking of mobile robot using novel fractional order control. In the proposed article two different types of control algorithms are developed. First controller is designed for kinematic model of mobile robot. The designing of kinematic control is based on Lyapunov based fractional order control. Second controller is designed for dynamic model of mobile robot. For dynamic control fractional order backstepping control has been developed. Stability analysis is given using Lyapunov stability theory for both kinematic and dynamic controllers. Simulations are done for different types of generated path and comparative study is given to show the advantage of the proposed method over existing methods.

11:20-11:40 MoBT7.5

Observer-Based Adaptive Output Feedback Stabilization of Generalized Hamiltonian Systems with Unstructured Component, pp. 511-516

Alavi, Seyedabbas	Queen's University at Kingston
Hudon, Nicolas	Queen's University

This study considers the problem of adaptive feedback controller design for output stabilization of dissipative (generalized) Hamiltonian systems with unstructured dynamic. This class of models enable one to exploit the dissipative-conservative structure of generalized Hamiltonian systems for feedback control design while relaxing the burden of deriving an exact structured model representation. Assuming that the overall system is stabilizable and observable, and under mild assumptions on the unstructured part of the dynamics, a stabilizing adaptive control law is designed to stabilize systems to the desired output of the system. To fulfill the design procedure, a full order nonlinear Luenberger observer is designed for unknown states measurements. Stability of the closed-loop system is then demonstrated using Lyapunov stability arguments. A numerical illustration of the proposed approach is presented to demonstrate the potential of the design method.

11:40-12:00 MoBT7.6

Sufficient Condition for the Existence of a Limit Cycle in Integrated Relay Output Feedback Systems, pp. 517-522

Yoon, Yongeun	Agency for Defense Development
Choi, Woojin	Agency for Defense Development

An integrated relay output feedback (IROF) system is a piecewise linear system representing many electric and/or mechanical systems. Like other piecewise linear systems IROF inherently has limit-cycle oscillation(LCO), which plays a critical role in the performance of the system, entailing the necessity of reliable analysis on the LCO. However, due to the nature of the solution trajectory of LCO, we cannot safely apply existing methods on the analysis of LCO such as describing function, Floquet theory, or piecewise linear system analysis. This research provides a new theoretical approach with which to establish the sufficient condition of an LCO in the IROF system accompanying the analysis on its stability and main parameters. We start from confirming that the switching time between each switching plane is finite. Then, by the introduction of a discrete-time nonlinear system representing the Poincar´e map and the linear phase can we establish the sufficient condition for the existence of an LCO and its stability. Finally, we demonstrate the effectiveness and efficiency of the main results with a simple numerical example.

Technical Program for Tuesday August 10, 2021

TuPL Room T8

Tuesday Plenary Session - Using Systems and Control Theory Ideas in the Design of Quantum Amplifiers Petersen, Ian R. (Australian National University) (Plenary Session)

Chair: Moheimani, S.O. Reza — University of Texas at Dallas

Co-Chair: Tsao, Tsu-Chin — University of California, Los Angeles

06:45-07:45 TuPL.1

Using Systems and Control Theory Ideas in the Design of Quantum Amplifiers, pp. 523-523

Petersen, Ian R. — Australian National University

One of the most signicant areas emerging in the area of quantum technology is that of quantum computing. Companies such as Google, IBM, and Microsoft have made significant investments in quantum computing to develop small scale quantum computers using microwave frequency technologies involving arrays of superconducting Josephson junctions operating at millikelvin temperatures. Other technologies which have been investigated for the implementation of quantum computers include quantum optics, ion trap devices and solid state quantum technologies. Quantum amplifiers play a critical role in many of these quantum computing technologies in that they are required to read out qubit states and transfer the information to the classical world.

Quantum amplifiers are examples of linear quantum systems and can be analysed using the recently developed theory of quantum linear systems. We begin with an introduction to quantum linear systems theory including the concept of physical realizability. We then present a systems theory approach to the design of quantum amplifiers minimizing the amount of quantum noise introduced by the amplifier whilst still guaranteeing desired properties of the ampli fier such as the phase-insensitive property and the non-reciprocal property. We also consider the achievable gain and bandwidth of quantum amplifiers. These methods can be applied to amplifiers implemented using a quantum optics technology or a super-conducting microwave technology. Our approach is based on a singularly perturbed quantum system involving the broadband approximation of a Bogoliubov transformation. In the case the optical implementation of a phase-insensitive amplifier it requires two squeezers and two beamsplitters. In the case of the optical implementation of a non-reciprocal and phase-insensitive quantum amplifier it requires three squeezers and two beamsplitters.

TuKN1 Room T8

Keynote Session 1 - A. Control of Wafer Scanners: Use the Unstable, Heertjes, Marcel; B. Modeling and Control of Digital Printing and Imaging Systems, Chiu, George T.-C (Keynote Session)

Chair: Borrello, Michael A. — Philips Healthcare

Co-Chair: Ren, Juan — Iowa State University

07:55-08:55 TuKN1.1

Control of Wafer Scanners: Use the Unstable, pp. 524-524

Heertjes, Marcel — Eindhoven University of Technology

Wafer scanners are complex lithography machines that are critical to the production of integrated circuits (or chips). Driven by the constant need to improve performance in terms of throughput, overlay, focus, and imaging, which can be linked directly to Moore's law, the control design of wafer scanners is pushed to the limit. In this sense, inherent design limitations in linear feedback control have provided the motivation to explore nonlinear strategies. This is exemplified by the recent developments in hybrid integrator-gain systems, abbreviated with HIGS. By operating alternately in integrator mode or in gain mode, HIGS control has properties and associated (phase) benefits like reset control, in particular the Clegg integrator. However, HIGS does not produce discontinuous control signals due to the absence of (partial) state resets, which is considered a favorable property in dealing with structural dynamics of the wafer scanner, especially in the presence of weakly damped resonances. HIGS control offers the possibility to outperform linear controls and can benefit from the unstable control design of its underlying modes of operation. In the keynote lecture, an industrial nonlinear control perspective will be discussed that includes the following aspects: (a) inherent design limitations, (b) time- and frequency-domain stability tools, (c) robust nonlinear control design, and (d) nonlinear motion control performance.

08:55-09:55 TuKN1.2

Modeling and Control of Digital Printing and Imaging Systems, pp. 525-525

Chiu, George T.-C. — Purdue University

Digital printing and imaging systems are well-recognized mechatronics devices. They are an integral part of our daily lives. Although traditional print media has been in decline, recent interests in leveraging printing as a scalable fabrication/manufacturing process has renewed the development of functional printing as an additive manufacturing process. In addition to deposit precisely controlled amount of material with the necessary spatial accuracy, interaction between material and substrate as well as material with themselves all contribute to the geometry, functionality and quality of the final product, be it an image, device or structure. In this talk, I will present our experiences in applying different mechatronic techniques to several digital printing and imaging processes as well as sharing some insights gained when translating these approaches to other applications with similar implementation and real-world constraints.

TuKN2 Room T9

Keynote Session 2 - A. Control of Floating Offshore Wind Turbines, Pao, Lucy Y.; B. Cohesive Networks Using Delayed Self-Reinforcement, Devasia, Santosh (Keynote Session)

Chair: Sun, Zongxuan — University of Minnesota

Co-Chair: Ruths, Justin — University of Texas at Dallas

07:55-08:55 TuKN2.1

Control of Floating Offshore Wind Turbines, pp. 526-526

Pao, Lucy Y. — University of Colorado Boulder

Wind energy is among the fastest-growing sources of electrical energy worldwide. Compared to land-based wind energy, offshore wind energy has the advantages of increased wind resource availability and consistency, proximity to major population centers, and enabling larger-scale turbines. As such, over the last decade, installed offshore wind power capacity has grown at a phenomenal average annual rate of 33%. Currently, more than 99% of installed offshore wind capacity consists of fixed-bottom wind turbines in shallow waters (<60m deep). Globally, however, 80% of offshore wind resources are at water depths greater than 60m. For such deep waters, floating offshore wind turbines are expected eventually to be as economically competitive as shallow-water fixed-bottom wind turbines. Basic types of floating wind substructures have been derived from platforms used in the oil and gas industry and result in safe but bulky and expensive designs. A novel Ultraflexible Smart FLoating Offshore Wind Turbine (USFLOWT) concept that better optimizes the design of the floating platform may be able to lower the cost of energy for floating offshore wind turbines. This talk will outline how, as part of a large team, we are using a control co-design approach to develop the USFLOWT concept. We describe some of the control challenges and highlight initial controllers and performance results. We close by discussing ongoing and future research avenues for the growing floating offshore wind energy area.

08:55-09:55 TuKN2.2

Cohesive Networks Using Delayed Self-Reinforcement, pp. 527-527

Devasia, Santosh — Univ of Washington

How a decentralized network gets to the goal (a consensus value) can be as important as reaching the consensus value. While prior methods focus on rapidly getting to a new consensus value, maintaining cohesion, during the transition between consensus values or during tracking, remains challenging and has not been addressed. Maintaining cohesion is important, e.g., to maintain inter-vehicle spacing in connected automated transportation systems, alignment synchronization to help maintain formations during maneuvers of flocks and swarms in nature, to avoid damage due to large deformations when transporting flexible objects and to maintain formation of engineered networks such as satellites, unmanned autonomous vehicles and collaborative robots.

The challenge to maintain cohesion arises because information about the desired response (such as the desired orientation or speed of the agents) might be available to only a few agents in a decentralized framework. The desired-response information needs to be propagated through the network to other agents, which results in response-time delays between agents that are “close to” the information source and those that are “farther away.” The talk will present a delayed self reinforcement (DSR) approach, where each individual augments its neighbor-based information update using its previously available updates, to improve cohesiveness of the response during transitions. The advantages of the proposed DSR approach are that it only requires already available information from a given network to improve the cohesion and does not require network-connectivity modifications (which might not be always feasible) nor increases in the system's overall response speed (which can require larger input). Results are presented that show substantial improvement in cohesion with DSR.

TuBT1 — Room T1

Automotive III (Industry Session)

Chair: He, Chaozhe — Plus AI INC

Co-Chair: Yu, Huan — University of California San Diego

10:00-10:20 — TuBT1.1

PDE Traffic Observer Validated on Freeway Data (I), pp. 528-540

Yu, Huan — University of California San Diego

Gan, Qijian — UC Berkeley, PATH

Bayen, Alexandre — University of California at Berkeley

Krstic, Miroslav — University of California, San Diego

This article develops a boundary observer for the estimation of congested freeway traffic states based on the Aw–Rascle–Zhang (ARZ) partial differential equations (PDEs) model. Traffic state estimation refers to the acquisition of traffic state information from partially observed traffic data. This problem is relevant for freeway due to its limited accessibility to real-time traffic information. We propose a model-driven approach in which the estimation of aggregated traffic states in a freeway segment is obtained simply from the boundary measurement of flow and velocity without knowledge of the initial states. The macroscopic traffic dynamics is represented by the ARZ model, a 2 × 2 coupled nonlinear hyperbolic PDEs for traffic density and velocity. Using the PDE backstepping method, we construct a boundary observer consisting of a copy of the nonlinear plant with output injections from boundary measurement errors. The exponential stability of the estimation error system in the L2 norm and finite-time convergence to zero is guaranteed. Numerical simulation and data validation are conducted to validate the boundary observer design with vehicle trajectory data.

10:20-10:40 — TuBT1.2

Fuel Efficient Connected Cruise Control for Heavy-Duty Trucks in Real Traffic (I), pp. 541-548

He, Chaozhe — Plus AI INC

Ge, Jin — Toyota Research Institute

Orosz, Gabor — University of Michigan

In this paper we present a systematic approach for fuel-economy optimization of a connected automated truck that utilizes motion information from multiple vehicles ahead via vehicle-to-vehicle (V2V) communication. Position and velocity data collected from a chain of human-driven vehicles is utilized to design a connected cruise controller that smoothly responds to traffic perturbations while maximizing energy efficiency. The proposed design is evaluated using a high-fidelity truck model and the robustness of the design is validated on real traffic data sets. It is shown that optimally utilizing V2V connectivity leads to around 10% fuel economy improvements compared to the best non-connected design.

10:40-11:00 — TuBT1.3

Optimal Coordination of Automated Vehicles at Intersections: Theory and Experiments (I), pp. 549-564

Hult, Robert — Chalmers University of Technology

Zanon, Mario — IMT Institute for Advanced Studies Lucca

Gros, Sebastien — NTNU

Falcone, Paolo — Chalmers University of Technology

In this paper, we present a bilevel, model predictive controller for coordination of automated vehicles at intersections. The bilevel controller consists of a coordination level, where intersection occupancy timeslots are allocated, and a vehicle level, where the control commands for the vehicles are computed. We establish persistent feasibility and stability of the bilevel controller under some mild assumptions and derive conditions under which closed-loop collision avoidance can be ensured with bounded position uncertainty. We thereafter detail an implementation of the coordination controller on a three-vehicle test bed, where the intersection-level optimization problem is solved using a distributed Sequential Quadratic Programing method. We present and discuss results from an extensive experimental campaign, where the proposed controller was validated. The experimental results indicate the practical applicability of the bilevel controller and show that safety can be ensured for large positioning uncertainties.

11:00-11:20 — TuBT1.4

Robust Path Tracking by a Dubins Ground Vehicle (I), pp. 565-572

Jha, Bhargav — Technion Israel Institute of Technology

Turetsky, Vladimir — Ort Braude College of Engineering

Shima, Tal — Technion - Israel Institute of Technology

The robust linear tracking technique is applied to a practical path tracking problem for a ground vehicle modeled as a Dubins car. The tracking control is designed based on the optimal strategy in an auxiliary linear-quadratic differential game for a linearized vehicle model. In contrast with a purified theoretic setup, the real-life problem is complicated by a non-constant speed and control saturation. Moreover, the actual path generating control can be unknown to the tracking strategy designer. These issues required additional design blocks: speed tracking loop and leading angle differentiation, both based on similar tracking algorithms. The saturation effect is considered by using command reinforcement. Numerical and experimental results are presented and compared. Robustness with respect to unknown disturbances is demonstrated. Novel analytic results on the tracking error/control effort trade-off are also presented.

11:20-11:40 — TuBT1.5

An Internal Model Control-Based Approach for Characterization and Controller Tuning of Turbocharged Gasoline Engines (I), pp. 573-582

Ossareh, Hamid — University of Vermont

Wisotzki, Sam — University of Vermont

Buckland, Julia — Ford Motor Company
Jankovic, Mrdjan — Ford Research & Advanced Engineering

This brief develops a method for system characterization and controller tuning for the boost control system of automotive turbocharged gasoline engines. The method utilizes the relay feedback technique for system characterization, followed by the internal model control (IMC) technique for controller tuning. The novelty is that instead of a high fidelity plant model, an ultra-simplified gain-integrator-delay model is employed in the IMC controller. As we show, our method leads to a time-efficient calibration process, assigns a desired closed-loop bandwidth exactly, and leads to good stability margins. A detailed and thorough analysis of the method, including its fundamental limitations, is provided. The method is experimentally applied to the boost control system of a turbocharged gasoline engine, where it is shown that the controller gains can be reliably computed at various engine operating points. The method identifies turbocharger speed as the best scheduling parameter for the controller gains, and the resulting controller is experimentally shown to yield good tracking performance.

TuBT2 — Room T2

Power Electronics and Systems (Regular Session)

Chair: Anubi, Olugbenga, M — Florida State University
Co-Chair: Abdollahi Biron, Zoleikha — University of Florida

10:00-10:20 — TuBT2.1

Katium-Power-Converter-Based Li-Ion Battery Charger for Railway Applications: Control-Oriented Modelling, pp. 583-588

Bratcu, Antoneta Iuliana — Grenoble Institute of Technology
Ihuel, François — Faiveley Transport – WABTEC
Contrepois, Alexandre — Faiveley Transport – WABTEC

This paper aims at obtaining a suitable model of a Katium-power-converter-based battery charger, to further serve for control design purpose for railway applications. The Katium converter represents a particular DC-DC power converter topology. In the considered application a Katium converter operates as a Li-ion battery charger and a low-voltage power supply for a load composed of a resistive part and a constant-power part. Starting from the bilinear nature of the system model, a family of linear parameter-varying models is obtained by linearization around successive operating points, which mainly depend on the load power to be supplied. The modeling approach further relies upon the observation that the battery current regulation problem is a disturbance-rejection problem, where both constant and periodic disturbances act on the system. The obtained state-space model is validated by MATLAB®/Simulink® numerical simulation, providing a sound starting point for control strategy design.

10:20-10:40 — TuBT2.2

Input Currents DCM Modelling of a Vienna-Based Rectifier, pp. 589-594

Darnet, Matthieu — GE Healthcare
Godoy, Emmanuel — Supelec
Karimi, Charif — Supelec
Gautrais, Stephane — GE Healthcare

The power supply of a medical imaging system deals with a wide power range pulsed load. For a Vienna-type three-phase rectifier, the input current can therefore be in Discontinuous Conduction Mode (DCM) as well as in Continuous Conduction Mode (CCM). While Vienna modelling in CCM case and stability issues for a wide range of operating point have already been studied. A proper modelling for stability study in DCM case has not been made yet. A new linearised DCM model is presented and validated in this paper. DCM is shown more stable but more sensitive according to the operating point than CCM.

10:40-11:00 — TuBT2.3

Off-Line PWM Control with a Three Phases Relaxed Symmetry Applied to a Two-Level Inverter, pp. 595-600

Bourgeade, Adrien Yvan Serge — Ecole Centrale De Nantes
Ghanes, Malek — Centrale Nantes
Fadel, Maurice — LAPLACE/CNRS/ENSEEIHT
Bouarfa, Abdelkader — Renault
Barbot, Jean Pierre — ENSEA

To control static converters, several Pulse Width Modulation (PWM) was proposed. Their aim was to achieve a specific minimisation by choosing the inverter switching angles. Optimal pulse patterns could be obtained considering classic symmetries on a single leg. Also known as Quarter Wave Symmetry (QWS) , Half Wave Symmetry or Full Wave Symmetry (FWS). By this way the angles on each leg can be easily deduced from the solution of the first leg, it is also known that the harmonics multiple of three are systematically removed. In this work, any symmetry is considered and simulation results are provided according to this new strategy based on relaxation symmetry. Evaluation is done with four objectives functions Weighted Total Harmonic Distortion (WTHD) and three types of electric motor models. According to the models, the new strategy is compared to the case where the symmetries (QWS,HWS and FWS) are considered. In the motor models is computed efficiency, which includes switching and conduction losses inside the legs of the inverter. Models and methods was evaluated in simulation with arbitrary parameters.

11:00-11:20 — TuBT2.4

Distributed Hybrid Frequency Control of Large-Scale Interconnected Power Systems Via Battery Integration, pp. 601-606

A.Biroon, Roghieh — Clemson University
Pisu, Pierluigi — Clemson University
Schoenwald, David A. — Sandia National Lab

The increasing penetration of renewable energy sources in power grids highlights the role of battery energy storage systems (BESSs) in enhancing the stability and reliability of electricity. The application of decentralized control to improve the stability of a large-scale power system is inevitable, especially in distributed energy sources (DERs). A power grid is a strongly interconnected system; thus, the impact of each area on the decentralized control design needs to be taken into account. This paper presents an optimal distributed hybrid control design for the interconnected systems to suppress the effects of small distur- bances in the power system employing utility-scale batteries. The results show that the smart scheduling of the batteries' output reduces the inter-area oscillations and improves the stability of the power systems.

11:20-11:40 — TuBT2.5

Model and Load Predictive Control for Design and Energy Management of Shipboard Power Systems, pp. 607-612

Mohammadi Bijaieh, Mehrzad — Florida State University
Vedula, Satish — Florida State University
Anubi, Olugbenga, M — Florida State University

In current Medium Voltage DC (MVDC) Shipboard Power Systems (SPSs), multiple sources exist to supply power to a common dc bus. Conventionally, the power management of such systems is performed by controlling Power Generation Modules (PGMs) which include fuel operated generators and underlying converters. Moreover, energy management is performed by the emerging single or hybrid Energy Storage Systems (ESSs). This paper presents a model and load predictive control framework for power and energy management of SPSs. Here, MPC with load prediction is used for three main objectives: (1) to request power and energy from generators and energy storage elements according to their individual State of Power (SOP) and ramp-rate limitations, (2) to consider and integrate the

generator cost and degradation, and (3) to reach a specific parking (final) State of Charge (SOC) for the ESSs at the end of the prediction horizon. The solution of the optimization problem is demonstrated using MATLAB and the functionality of the control framework is validated in real-time simulation environment.

11:40-12:00 TuBT2.6

Adaptive Compensation of Three-Phase Voltage Source Inverter Nonlinearities in Acoustic Applications, pp. 613-618

Schubert, Dominik	University of Applied Sciences Munich
Hecker, Simon	University of Applied Sciences - Munich
Angerpointner, Leonhard	MdynamiX AG
Sentpali, Stefan	University of Applied Sciences, Faculty 03, Munich
Buss, Martin	Technische Universitaet Muenchen

This paper describes the influences of a voltage source inverter (VSI) on the acoustic behavior of a permanent magnet synchronous machine (PMSM), while it is used as an acoustic actuator. Two methods for compensating the nonlinear influences of the VSI are derived from the measurement results and are tested in a real-time environment. First, a static look-up table (LUT) is used to correct the duty cycle of the generated pulse-width-modulated (PWM) signal. At increasing excitation frequencies, the compensation quality decreases using the static LUT. Therefore, a second method, based on the wellknown filtered-x least-mean-square (FxLMS) is used to generate harmonic compensation signals.

TuBT3 Room T3

Robotics Applications (Regular Session)

Chair: Satici, Aykut C	Boise State University
Co-Chair: Thomas, Matthias	University of Stuttgart

10:00-10:20 TuBT3.1

Reactive Collision Avoidance for Underactuated Surface Vehicles Using the Collision Cone Concept, pp. 619-626

Haraldsen, Aurora	Norwegian University of Science and Technology
Wiig, Martin	Norwegian Defence Research Establishment
Pettersen, Kristin Y.	Norwegian University of Science and Technology (NTNU)

Avoiding collisions is a crucial task for autonomous systems. Many strategies for avoiding obstacles have been proposed, yet the problem of having underactuated dynamics is rarely addressed in previous studies of collision avoidance algorithms. Underactuation of a system makes the collision avoidance control problem more complex, since the system then lacks the ability to directly control one or more of its degrees of freedom. Therefore, in this paper, we will consider collision avoidance for underactuated vehicles, specifically for the class of vehicles which cannot directly control their sideways speed. This is a broad class, which includes vehicles such as cars, airplanes, and marine vehicles. If the unactuated, sideways velocity component becomes sufficiently large, it can make the vehicle glide sideways rather than moving forward, which in the encounter with an obstacle may be fatal. To tackle this issue, we propose a reactive collision avoidance algorithm, based on the collision cone concept, which is specifically designed to account for the underactuated dynamics of a surface vehicle. We present a rigorous analysis of the closed-loop system, and establish explicit conditions guaranteeing vehicle safety. Simulations are included to verify the theoretical result.

10:20-10:40 TuBT3.2

Toward Phase-Variable Control of Sit-To-Stand Motion with a Powered Knee-Ankle Prosthesis, pp. 627-633

Raz, Daphna	University of Michigan
Bolívar-Nieto, Edgar	University of Michigan
Ozay, Necmiye	Univ. of Michigan
Gregg, Robert D.	University of Michigan

This paper presents a new model and phase-variable controller for sit-to-stand motion in above-knee amputees. The model captures the effect of work done by the sound side and residual limb on the prosthesis, while modeling only the prosthetic knee and ankle with a healthy hip joint that connects the thigh to the torso. The controller is parametrized by a biomechanical phase variable rather than time and is analyzed in simulation using the model. We show that this controller performs well with minimal tuning, under a range of realistic initial conditions and biological parameters such as height and body mass. The controller generates kinematic trajectories that are comparable to experimentally observed trajectories in non-amputees. Furthermore, the torques commanded by the controller are consistent with torque profiles and peak values of normative human sit-to-stand motion. Rise times measured in simulation and in non-amputee experiments are also similar. Finally, we compare the presented controller with a baseline proportional-derivative controller demonstrating the advantages of the phase-based design over a set-point based design.

10:40-11:00 TuBT3.3

Nonholonomic Cooperative Manipulation in the Plane Using Linear Complementarity Formulation, pp. 634-639

Ashenafi, Nardos Ayele	Boise State University
Satici, Aykut C	Boise State University

This paper presents a framework in which a group of nonholonomic wheeled mobile robots are cooperatively utilized to manipulate a polygonal object in the plane. In this framework, the robots are assumed to contact the object with- out friction, applying forces normal to the object's boundary. Contacts between the wheeled mobile robots and object are resolved through Moreau's time stepping algorithm with a linear complementarity problem. The robots are controlled so that the object's pose is asymptotically stabilized without the need for trajectory planning. Lastly, a recovery controller is proposed that places agents on the boundary of the object with a force closure grasp. An extensive simulation study is presented to support the proposed framework.

11:00-11:20 TuBT3.4

Force Estimation and Control of Delta Robot for Assembly, pp. 640-647

Flores Mendez, Juan de Dios	Aalborg University
Schiøler, Henrik	Aalborg University
Bai, Shaoping	Shb@m-Tech.aau.dk
Madsen, Ole	Aalborg University

Force Control in robotic manipulators generally requires the use of a relatively expensive F/T sensor to close the control loop. In recent years a trend to create low-cost robots arose and hence the need to reduce the use of expensive sensors i.e. avoid the use of a Force/Torque (F/T) sensor. In this work two disturbance observers are proposed for estimating the external forces (a disturbance) in parallel kinematic machines. In the paper, the external force is estimated through a Nonlinear Disturbance Observer and Extended Kalman Filter. The estimated force is used in a force controller with an inner position controller. It is shown that the estimated external force (contact force) can be estimated to an accuracy of 0.3 N and that it can be used for direct force control algorithms.

11:20-11:40 TuBT3.5

Nonlinear Model Predictive Control for Pneumatic Driven Quasi Continuum Manipulators, pp. 648-653

Wittmer, Kelvin	University of Stuttgart
Müller, Daniel	University of Stuttgart

Sawodny, Oliver University of Stuttgart

With the ongoing digitalization of manufacturing, an increasing amount of production steps is carried out by robots. Typically they work autonomously, however so-called soft robots allow to further increase their interactivity with human workers. Yet, the modeling and control of such soft robots is still a relatively new research field. In particular, the accuracy and speed of the existing controllers is not adequate for industrial use. Therefore, this paper proposes the application of nonlinear model predictive control (NMPC) for a continuum manipulator as a special case of soft robotics. Successful experimental results are presented using the sequential quadratic programming real-time iteration (SQP-RTI) scheme for embedded optimization. The controller performance is superior to a nonlinear PD controller, which is used as a benchmark. In addition, the proposed NMPC allows to explicitly define state and input constraints on the manipulator, which can be exploited for further controller improvement in future work.

11:40-12:00 TuBT3.6

Online Trajectory Generation and Feedforward Control for Manually-Driven Cranes with Input Constraints, pp. 654-659

Thomas, Matthias University of Stuttgart
Werner, Timothy University of Stuttgart
Sawodny, Oliver University of Stuttgart

Industrial cranes are usually driven manually by an operator setting the reference velocity of the drives using a handlever. Thereby, pendulum sway mainly occurs due to the input signal given by the operator and not due to external disturbances. In this paper, a feedforward controller based on trajectory generation for the payload velocity representing a flat output is presented. The trajectories for the flat output are calculated online using the handlever signal. Algebraic s-curve trajectories are planned in every time-step, which allows to consider velocity and acceleration limitations of the drives explicitly. The results are compared with the trajectories and feedforward control performance of a virtual model-predictive control loop. The latter is tuned such that the resulting trajectories are nearly time-optimal yielding a proper performancebenchmark. Both the flatness-based feedforward and the virtual model predictive control loop are tested in combination with a linear quadratic feedack regulator on a laboratory bridge crane.

TuBT4 Room T4

Kalman Filter and Fault Tolerant Control (Regular Session)

Chair: Verde, Cristina Universidad Nacional Autónoma De México
Co-Chair: Hovd, Morten Norwegian Univ of Sci & Tech

10:00-10:20 TuBT4.1

Identification of Electric Transmission Line Deterioration by an Adaptive Observer, pp. 660-665

Perez-Pinacho, Claudia A. CINVESTAV-IPN
Verde, Cristina Universidad Nacional Autónoma De México

In this work, an adaptive observer is designed to detect a uniform electric long transmission line failure by considering a distributed parameter's model where both voltage and current at the line ends are measurable. In particular, deterioration of the resistance R and conductivity G per-unit length are considered the parameters with abnormal conditions. To avoid numerical problems during the design and to generalize the results, the distributed system and the excitation are transformed into a dimensionless model before the estimation problem formulation. Based on this model, a distributed observer with boundary injections is designed. Thus, this observer's output errors can be used as a residual generator for the detection of the resistance and conductivity deterioration. An adaptive observer is constructed by combining the distributed observer and a set of updating rules to identify the parameter deviations. A long transmission line is adopted as a case study to show the feasibility of the proposition for transmission line monitoring with two different generator signals in simulations.

10:20-10:40 TuBT4.2

Reduced and Distributed Estimation in Sensor and Actuator Networks - Automated Design Based on Controllability and Observability, pp. 666-672

Friedrich, Ferdinand University of Augsburg
Mayer, Jonas University of Augsburg
Ament, Christoph Ilmenau University of Technology

To reduce memory and computational effort, large-scale systems are often modeled globally and divided into local models with lower system order. In previous papers, local sensor-based systems are mostly manually distributed. In our contribution, the controllability and observability of the global system is considered and an extension from sensor nodes to sensor and actuator networks is performed. Therefore, the inputs and outputs of the global system are allocated to local systems. Here, the local systems are reduced by model order reduction methods. To further reduce the memory and computational effort, the estimation method is distributed in sensor and actuator nodes. When the sensor and actuator exchange state vectors in a fully connected communiaction network, the local systems represent the global system. Finally, the global system is reconstructed by a central fusion center. These methods are experimentally evaluated on a demonstrator.

10:40-11:00 TuBT4.3

Fault-Tolerant Control for a Wave Energy Converter by Damping Injection, pp. 673-678

González-Esculpi, Alejandro Universidad Nacional Autónoma De México
Verde, Cristina Universidad Nacional Autónoma De México
Maya-Ortiz, Paul Universidad Nacional Autonoma De Mexico

This work presents an active fault-tolerant control (FTC) scheme by damping injection for a wave energy converter (WEC). The case study is an Archimedes wave swing-based WEC, where two braking subsystems for the floater play a critical role in protecting the physical structure from extreme sea conditions. In order to obtain fault-tolerant behavior in the presence of faults in the brakes, the deviation of the damping force is compensated through the force produced by the linear generator, which is controlled to maximize the energy conversion in nominal conditions. For this purpose, the force deviation is estimated from a fault detection and isolation (FDI) module by using an Utkin-based unknown input observer, which is then used for the compensation that completes the FTC. The proposed system is tested by numerical simulation under different scenarios, including faults in the damping system and others. The results demonstrate the capabilities and limitations of the proposal, which achieves the established objective. The performances of the nominal control and the proposed FTC are compared.

11:00-11:20 TuBT4.4

Fault Detection for Uncertain Nonlinear Systems Based on Moving Horizon Estimation, pp. 679-684

Meynen, Sönke Karlsruhe University of Applied Sciences
Hohmann, Soeren KIT
Feßler, Dirk Karlsruhe University of Applied Sciences

This paper presents a fault detection algorithm based on moving horizon estimation (MHE) for uncertain nonlinear systems. Interval arithmetic is used to describe the unknown-but-bounded uncertainties that are present in practical systems. Based on this, a novel MHE problem is formulated which incorporates the uncertainties.

Furthermore, an adaptive arrival cost approach is extended for the case of uncertain systems. The solution of this MHE problem provides an optimal estimate of the interval-valued states. Faults in the technical system will be detected on the basis of an intersection of the optimal interval-valued states with the uncertain measurements. Finally, the proposed fault detection algorithm is demonstrated using measured data of a nonlinear three-tank system.

11:20-11:40 TuBT4.5

Distributed H_infty Filtering for Linear and Nonlinear Systems, pp. 685-692

Abooshahab, Mohammad Ali — Norwegian University of Science and Technology
Hovd, Morten — Norwegian Univ of Sci & Tech

This paper develops a fully distributed approach for implementing H_{infty} filtering over multi-agent networked systems. This is obtained by using diffusion techniques for the fusion of local filtering operations to enforce cooperation between agents and achieve a network-wide cohesive filtering operation. More importantly, we propose a diffusion-based algorithm which uses only locally observable states. Furthermore, the work includes the information formulation of the derived filtering framework. This information formulation not only provides the basis for the establishment of observability conditions but also allows for the extension of the derived filtering framework to nonlinear systems via the use of the unscented transform. Finally, the effectiveness of the derived estimation framework is demonstrated in two simulation examples.

11:40-12:00 TuBT4.6

Industrial Control System Anomaly Detection Using Convolutional Neural Network Consensus, pp. 693-700

Sinha, Aviraj — Southern Methodist University
Taylor, Michael — Southern Methodist University
Srirama, Nathan — Southern Methodist University
Manikas, Theodore — Southern Methodist University
Larson, Eric — Southern Methodist University
Thornton, Mitchell A. — Southern Methodist University

Industrial control systems provide transportation, essential utilities, and the manufacturing of goods to the masses. It is critical that controlled processes are executed correctly and according to schedule. Monitoring the system's performance during its operation is an important approach for maintaining high levels of reliability and availability. We present a system monitoring capability that implements parallel multi-view neural networks to detect anomalous behavior in an industrial control system by predicting operational states. By deploying the prediction capability within the system, system operation can be monitored in a semi-supervised manner to ensure the actual system state lies within an appropriate region of the state space that was previously predicted by the neural networks. Furthermore, if the two predictive models diverge in their classification of state (breaking consensus), it is likely that system operation has been compromised due to faulty equipment, communication errors, or some other source of malfunction. To achieve different ``views'' of the system, one predictive model is trained to analyze the data flow of system control packets and the other model is trained to analyze gyrometric signals obtained from physical sensors in the control system. We demonstrate that this methodology can detect anomalous behavior of an example industrial control system by emulating its operation in the presence of injected anomalies. Results indicate highly accurate anomaly detection during system operation.

TuBT5 Room T5

Control Technology for Critical Care Ventilators (Tutorial Session)

Chair: Borrello, Michael A. — Philips Healthcare
Co-Chair: Li, Yufeng — Nihon Kohden OrangeMed, Inc
Organizer: Borrello, Michael A. — Philips Healthcare

10:00-11:00 TuBT5.1

The Application of Controls in Critical Care Ventilation (I), pp. 701-718

Borrello, Michael A. — Philips Healthcare

Ventilators are medical devices that provide respiratory life support for critically ill patients in the intensive care unit. While ventilators are widely addressed in the literature of critical care, the treatment of details surrounding control engineering as it applies to ventilators is significantly lacking compared to other control applications even though feedback control is the core technology empowering ventilator functionality.

Ventilators require precise and accurate control of flow, pressure, volume and gas oxygen concentration to meet all the clinical requirements to support safe and effective breath delivery. The performance of these controls depends on design and how well the design meets a challenging control imposed by nonlinear systems and constraints on how feedback is sensed and control is applied.

The purpose of this tutorial is to present the common problems ventilator control engineers need to solve and what controls are typically applied.

11:00-11:20 TuBT5.2

Linear Repetitive Control for a Nonlinear Mechanical Ventilation System Using Feedback Linearization (I), pp. 719-726

Reinders, Joey — Demcon Advanced Mechatronics
Hunnekens, Bram — Demcon Advanced Mechatronics
Oomen, Tom — Eindhoven University of Technology
Van De Wouw, Nathan — Eindhoven University of Technology

Mechanical ventilators sustain life of patients that are unable to breathe on their own. The aim of this paper is to improve pressure tracking performance of a nonlinear mechanical ventilation system using linear repetitive control, while guaranteeing stability. This is achieved by using feedback linearization and subsequently applying linear repetitive control to the linearized plant. The design procedure of this control strategy is developed in this paper. Thereafter, the controller is implemented in simulations and experiments showing superior pressure tracking performance of this control strategy compared to feedback control.

11:20-11:40 TuBT5.3

Modeling and Simulation of Respiratory System in Design of Mechanical Ventilators (I), pp. 727-727

Li, Yufeng — Nihon Kohden OrangeMed, Inc

Respiratory system modeling has been widely studied for a long time. Different types of models have been developed for different purposes. Review of the modeling literature reveals that there are two major motivations for the research in modeling of respiratory system. Physiologically based respiratory control system models get substantial academic attention in the fields of life sciences, physiology, and biomedical engineering. Those models attempt to include relevant physiological features for the purposes of study some specific aspects of the human respiratory systems. In this sense, a model that provides more details of the respiratory system related to blood gas exchange, metabolic activity, and brain neural central controller are mainly the focus.

Another motivation to model the respiratory system is driven by engineers and the developers of mechanical ventilators. In this field, the function of specific subsystems such as the lung mechanism is usually the focus, the whole respiratory system model is often reduced to its simplest configuration. For example, several models exist in the literature that commonly use an electrical circuit analogue to represent the pressure and airflow in the lung. However, these models usually lack the representation of physiological behavior of respiratory control

systems and provide inadequate information for advanced mechanical ventilator systems development.

Modelling and simulation in engineering and in physiology have some common problems, although the disciplines may be very different for these two groups. As interests in the physiological closed-loop ventilators are increasing continuously, we expect that a closed-loop ventilator will help both patient treatments and clinician's utilization of the machine. Therefore, it is interesting to bring more attention for ventilator engineers to study and integrate respiratory system models with physiological features into ventilator design and simulation. We believe this effort may bring some innovations in this field.

In this discussion, the use of MATLAB/Simulink program for modeling and simulation of the patient respiratory system and mechanical ventilation will be described.

TuBT6 Room T6

Game Theory (Regular Session)

Chair: Ishii, Hideaki — Tokyo Institute of Technology

Co-Chair: Ghasemi, Amirhossein — University of North Carolina Charlotte

10:00-10:20 TuBT6.1

Intent Negotiation in a Shared Control Paradigm with Cooperative-Competitive Game†

Izadi, Vahid — University of North Carolina Charlotte

Ghasemi, Amirhossein — University of North Carolina Charlotte

10:20-10:40 TuBT6.2

Ordinal Potential Differential Games to Model Human-Machine Interaction in Vehicle-Manipulators, pp. 728-734

Varga, Balint — Karlsruhe Institute of Technology (KIT), Campus South

Inga, Jairo — Karlsruhe Institute of Technology (KIT)

Lemmer, Markus — FZI Research Center for Information Technology

Hohmann, Soeren — KIT

Potential games have some useful characteristics related to the existence and computability of their Nash equilibria, which make their use attractive also in the context of modelling interactions. This paper presents the use of potential differential games to model human-machine interaction. We extend the definition of static ordinal potential games to differential games for modelling and analysing human-machine interaction in the control of large vehicle-manipulators. We provide sufficient and necessary conditions for the existence of a potential differential game. In addition, we present an optimization formulation finding a linear-quadratic (LQ) potential differential game to a original game. The suitability of the proposed modelling approach is verified using simulation examples.

10:40-11:00 TuBT6.3

Cluster Formation in Multiagent Consensus Via Dynamic Resilient Graph Games, pp. 735-740

Nugraha, Yurid — Tokyo Institute of Technology

Cetinkaya, Ahmet — National Institute of Informatics

Hayakawa, Tomohisa — Tokyo Institute of Technology

Ishii, Hideaki — Tokyo Institute of Technology

Zhu, Quanyan — New York University

In this paper we formulate a two-player game-theoretic problem on resilient graphs representing communication channels that are vulnerable to attacks in multiagent consensus setting. An attacker is capable to disconnect part of the edges of the graph by emitting jamming signals while, in response, the defender recovers some of them by increasing the transmission power for the communication signals over the corresponding edges. It is also possible for the attacker to emit stronger jamming signals that cannot be overcome by the defender. We consider repeated games where the utilities of players in each game depend on attack/recovery performance measured over multiple intervals. The utilities of both players are mainly related to agents' states and the cluster formation, i.e., how the agents are divided. The players' actions are constrained by their energy for transmissions, with a less strict constraint for the attacker compared to the defender. Numerical examples of dynamic games played over time are provided to demonstrate the cluster formation.

11:00-11:20 TuBT6.4

Recursive Reasoning for Bounded Rationality in Multi-Agent Non-Equilibrium Play Learning Systems, pp. 741-746

Fotiadis, Filippos — Georgia Institute of Technology

Vamvoudakis, Kyriakos G. — Georgia Inst. of Tech

In this work, and inspired by the theory of bounded rationality and recursive reasoning, we propose two frameworks for modeling players' behaviors and for choosing their policies in multi-agent dynamic stochastic game settings. In particular, we define multiple levels of rationality for each player, where at each level a player may reason about everyone else in two different ways; first, they may assume that the rest of the players have a cognitive level that is immediately lower than theirs, which is known as level-k thinking; second, they may assume that the rest of the players' cognitive level follows a Poisson distribution, which is known as cognitive hierarchy. We construct algorithms for estimating the players' policies at each level of rationality, both in a level-recursive as well as in a level-paralleled manner, and we study these algorithms' convergence properties. Simulations on a grid world are provided to illustrate the efficacy of the proposed models.

11:20-11:40 TuBT6.5

Act to Reason: A Dynamic Game Theoretical Driving Model for Highway Merging Applications, pp. 747-752

Koprulu, Cevahir — Bilkent University

Yildiz, Yildiray — Bilkent University

The focus of this paper is to propose a driver model that incorporates human reasoning levels as actions during interactions with other drivers. Different from earlier work using game theoretical human reasoning levels, we propose a dynamic approach, where the actions are the levels themselves, instead of conventional driving actions such as accelerating or braking. This results in a dynamic behavior, where the agent adapts to its environment by exploiting different behavior models as available moves to choose from, depending on the requirements of the traffic situation. The bounded rationality assumption is preserved since the selectable strategies are designed by adhering to the fact that humans are cognitively limited in their understanding and decision making. Using a highway merging application, it is demonstrated that the proposed dynamic approach produces more realistic outcomes compared to the conventional method that employs fixed human reasoning levels.

TuBT7 Room T7

Nonlinear Control, Sliding Mode (Regular Session)

Chair: Sun, Zongxuan — University of Minnesota

Co-Chair: Pan, Ya-Jun — Dalhousie University

10:00-10:20 TuBT7.1

Robust Nonlinear Control of the Minimum Safety Factor in Tokamaks, pp. 753-758

Pajares, Andres — Lehigh University
Schuster, Eugenio — Lehigh University

Tokamaks are torus-shaped devices whose goal is to produce energy by means of thermonuclear fusion reactions. This is achieved by using helical magnetic fields to confine a plasma, i.e., a very hot ionized gas, so that the necessary conditions for fusion (i.e., high pressure and confinement time) are achieved. The safety factor is a measure of the pitch of the magnetic-field lines, and plays an important role in the magnetohydrodynamic stability and confinement properties of the plasma. In particular, the minimum value of the safety factor across the plasma spatial domain is often closely related to the maximum achievable plasma pressure. In this work, a robust, nonlinear, model-based controller for the regulation of the minimum safety factor is presented. The controller is synthesized via Lyapunov theory, and robustified against model uncertainties by means of Lyapunov redesign techniques. The controller is tested, together with a controller for the plasma thermal energy, in one-dimensional simulations using COTSIM (Control Oriented Transport SIMulator) for a DIII-D scenario.

10:20-10:40 TuBT7.2

Output Feedback Based High-Order Sliding Mode Control Design of Electrohydraulic System Using an Exact Differentiator, pp. 759-764

Hao, Sun — Southeast University
Sun, Zongxuan — University of Minnesota
Li, Shihua — Southeast University

Electrohydraulic systems, which have been widely used in a broad range of applications, are a typical nonlinear system with uncertainties. The presence of nonlinearities, parameter variations degrades the performance of linear controllers, such as the PID controller. As one of the most robust control strategies, sliding mode control methods attract the attention of researchers and are applied to electrohydraulic systems. However, for many fluid power applications, only the piston position measurement information is available. Owing to the existence of the nonlinear orifice dynamics, the observer design is a challenging task and satisfactory performance is not guaranteed in the existing literature. Therefore, an output feedback based high-order sliding mode control (HOSMC) design of electrohydraulic systems is proposed in this paper. By using an exact differentiator, the derivatives of the tracking error are obtained and used to construct the HOSMC. Compared to the conventional sliding mode control (SMC), the HOSMC can achieve a finite-time convergence and improved tracking accuracy. To verify the tracking performance, a simulation is performed on a camless engine valve actuation system.

10:40-11:00 TuBT7.3

Sliding Mode Control for Over-Actuated Systems with Adaptive Control Allocation and Its Applications to Flight Control, pp. 765-770

Tohidi, Seyed Shahabaldin — Faculty of Mechanical Engineering, Bilkent University
Yildiz, Yildiray — Bilkent University
Kolmanovsky, Ilya V. — The University of Michigan

One solution to the problem of distributing the control action among redundant actuators with uncertain dynamics is employing an adaptive control allocator. This paper proposes a sliding mode controller which exploits a time-varying sliding surface to complement an adaptive control allocator in the presence of actuator saturation. The proposed approach does not require error augmentation for tracking desired references, which diminishes the computational burden. Aerodata Model in Research Environment (ADMIRE), which is an over-actuated aircraft model, is adopted to demonstrate the efficacy of the proposed controller in simulation studies.

11:00-11:20 TuBT7.4

Performance Comparison of Sliding Mode Techniques for LISA Mission, pp. 771-776

Capicchiano, Leonardo — Politecnico Di Torino
Bloise, Nicoletta — Politecnico Di Torino
Capello, Elisa — Politecnico Di Torino, CNR-IEIIT
Punta, Elisabetta — CNR-IEIIT
Grzymisch, Jonathan — European Space Agency

This paper focuses on the design of the controllers for the release phase of the Test Masses (TMs) of the LISA (Laser Interferometer Space Antenna) mission. Space gravitational observatories such as LISA will be complementary in future years to existing terrestrial laboratories for detecting low-frequency gravitational signals that cannot be measured from Earth. TMs are used as sensors in science phase for environmental measurements; their control system must therefore be able to stabilize TMs with a limited control authority in spite of uncertainties and noises. In this paper, two sliding mode techniques are analysed and compared in terms of performance metrics, considering two operative modes and strict requirements in terms of accuracy and steady-state error. Extensive simulations are performed, taking into account a wide range of cases by varying noises and disturbances affecting the systems. In addition, the critical initial conditions of LISA Pathfinder (the previous mission) and their effects are analysed by using a nonlinear spacecraft dynamics.

11:20-11:40 TuBT7.5

Application of Sliding Mode Control for the Formation of Heterogeneous Multi-Agent Systems, pp. 777-782

Adderson, Ryan — Dalhousie University
Pan, Ya-Jun — Dalhousie University
Shen, Henghua — Dalhousie University

This paper proposes a fundamental sliding mode control (SMC) method for the formation of heterogeneous multi-agent systems with fixed topology and a virtual leader consisting of quadrotor unmanned aerial vehicles (UAVs) and two wheeled mobile robot (2WMR) unmanned ground vehicles (UGVs). SMC is used to direct the agents for the purposes of achieving consensus and formation in a two-dimensional plane. The stability analysis with the resultant system shows that the errors can be driven to zero in finite time. Finally, simulation results are shown to demonstrate the effectiveness of the proposed control scheme for a team of three quadrotors and three mobile robots. Both static and dynamic formation cases are validated with extensive simulated studies.

11:40-12:00 TuBT7.6

Energy Storage in Paraffin: A PDE Backstepping Experiment (I), pp. 783-794

Koga, Shumon — University of California, San Diego
Krstic, Miroslav — University of California, San Diego

This paper proposes a novel control algorithm of a thermal phase change process and shows its experimental verification using paraffin as a phase change material (PCM). The core problem is to design a boundary feedback control for the ``Stefan system" which describes a time evolution of the temperature profile in liquid phase which is associated with a time evolution of a position of liquid-solid phase interface, for the sake of stabilizing the interface position at a chosen setpoint. First, we design the continuous-time full-state feedback control law by means of PDE backstepping method, which in the absence of a demand for accelerated convergence can also be arrived at by energy-shaping method, and rigorously prove the stability of the closed-loop system under sufficiently small heat loss. Next, the control law is refined via an observer-based output feedback under sampled-data measurements of the surface temperature and the phase interface position so that the control algorithm is practically implementable. Then, we conducted an experiment under a constant input to calibrate unknown parameters involved with the heat loss. Finally, the proposed model-based boundary feedback control algorithm is implemented in the experiment of melting paraffin. The experiment was successful: the convergence of the phase interface to the setpoint was achieved.

Technical Program for Wednesday August 11, 2021

WePL	Room T8
Wednesday Plenary Session (Transition to Practice Award Lecture) - from Rotary Kilns and Paper Machines to Anesthesia and COVID-19: The Broad Reach of Control Engineering **Dumont, Guy A. (Univ. of British Columbia)** (Plenary Session)	
Chair: Tsao, Tsu-Chin	University of California, Los Angeles
Co-Chair: Moheimani, S.O. Reza	University of Texas at Dallas

06:45-07:45 WePL.1

From Rotary Kilns and Paper Machines to Anesthesia and COVID-19: The Broad Reach of Control Engineering, pp. 795-795

Dumont, Guy A. Univ. of British Columbia

Karl Aström once famously called automatic control the hidden technology in recognition of the fact that despite its pervasiveness, it is rarely mentioned. Control is indeed a critical component of so many technologies used in industry and in our everyday life. In this talk I want to illustrate the broad reach of control engineering through applications I performed over the last forty years. In the process industries, I have developed and implemented adaptive control of rotary kilns for the production of TiO2 pigments, robust cross-directional control of paper machines, adaptive control of continuous digesters, dual adaptive control of wood-chip refiners and paper coating. I have developed a general-purpose adaptive controller based o Laguerre functions, that has been applied to the control of processes for the production of lime, glass, oil and gas, food and beverage. For the last two decades, working in close collaboration with clinicians I have focused on biomedical applications especially in critical care and automated intravenous anesthesia. Over the last year, COVID-19 has presented a challenge to the public health authorities. By representing control of COVID-19 explicitly in a feedback framework, transparent and effective public health policies can be systematically designed and rigorously analyzed, replacing ad-hoc policies. This requires us to work closely with epidemiologists and public health experts. Through this talk I want to illustrate the breadth of control applications and the sense of excitement a career in control can bring particularly when working in a multidisciplinary environment. I have been at it for some 45 years and still feel as passionate about my work as when I started, and I hope to convey this passion to our younger colleagues. We bring a unique perspective and have much to contribute to society at large, it is time to come out of hiding!

WeAT1	Room T1
Control and Optimization of Vehicle Systems (Invited Session)	
Chair: Soudbakhsh, Damoon	Temple University
Co-Chair: Pozzato, Gabriele	Politecnico Di Milano
Organizer: Siegel, Jason B.	University of Michigan
Organizer: Pozzato, Gabriele	Stanford University
Organizer: Dey, Satadru	The Pennsylvania State University
Organizer: Soudbakhsh, Damoon	Temple University
Organizer: Dadras, Soodeh	Utah State University
Organizer: Dadam, Sumanth	Ford Motor Company
Organizer: Dadras, Sara	Company
Organizer: Borhan, Hoseinali	Cummins Inc
Organizer: Amini, Mohammad Reza	University of Michigan
Organizer: Tong, Son	Siemens Digital Industries Software

07:55-08:15 WeAT1.1

Model Predictive Control of HEVs with Exhaust Aftertreatment System at Low Ambient Temperatures (I), pp. 796-801

Meier, Florian Johannes Kepler University Linz

Del Re, Luigi Johannes Kepler University Linz

Online control of hybrid electric vehicles (HEV) is mostly centered on fuel consumption and battery management while emissions are seldom considered. This is frequently correct, as warmed up exhaust aftertreatment systems show an extremely high conversion efficiency. However, HEVs typically shut off the engine during low load phases, which extends coldstart periods and prevents the aftertreatment to work at the correct temperature. Latest regulations put additional focus on real driving coldstart performance though. Against this background, this paper analyzes the potential relevance and presents a possible solution by considering it explicitly in the control approach. It is shown that an implementable model predictive control (MPC) strategy can recover a large part of the theoretical performance as computed by dynamic programming (DP). Optimal MPC parameter tuning is efficiently performed utilizing available DP solutions from comparable scenarios. A potential saving of up to 40% NOx with equal consumption is shown in this example.

08:15-08:35 WeAT1.2

Design and Implementation of a MPC-Based Rear-Wheel Steering Controller for Sports Cars (I), pp. 802-807

Lucchini, Alberto Politecnico Di Milano

Paganelli Azza, Federica Politecnico Di Milano

Corno, Matteo Politecnico Di Milano

Formentin, Simone Politecnico Di Milano

Savaresi, Sergio M. Politecnico Di Milano

Active rear-wheel steering is an effective technology to improve the cornering performance of vehicles, enhancing both handling and stability. In this study, a MPC-based rear-wheel steering controller for sport driving conditions is proposed. High performance is achieved by an accurate choice of the linear time-varying (LTV) predictive model. All the fundamental aspects of lateral dynamics, such as tire force saturation, tire relaxation, aerodynamic downforce and load transfer are taken into account. Simulation results on a multi-body vehicle simulator and the details of the real-time implementation complete the paper.

08:35-08:55 WeAT1.3

Comparison of Event-Triggered Model Predictive Control for Autonomous Vehicle Path Tracking (I), pp. 808-813

Chen, Jun Oakland University

Yi, Zonggen Idaho National Laboratory

This paper proposes two different event-triggered nonlinear model predictive controls (NMPC) for autonomous vehicle path tracking. The difference between the two event-triggered NMPCs is the determination of control action when an event is not triggered. In the first formulation, the optimal control sequence computed from last triggering event is shifted to determine control action when NMPC is not triggered, while in the second formulation, a time-triggered linear parametric varying MPC (LPV-MPC) with shorter prediction horizon is formulated and solved in between NMPC triggering events to compensate prediction error and disturbance. These two event-triggered NMPCs, together with a time-triggered LPVMPC and a time-triggered NMPC serving as benchmark, are implemented to track the vehicle path in both longitudinal and lateral directions, with axle driving torque and front steering input as the control variables. Control performance and throughput requirements of different MPCs are then measured and compared, where the advantage of event-triggered formulation is clearly demonstrated.

08:55-09:15 WeAT1.4

Mixed-Integer Programming for Centralized Coordination of Connected and Automated Vehicles in Dynamic Environment (I), pp. 814-819

Ravikumar, Shreejith	Mitsubishi Electric Research Limited
Quirynen, Rien	Mitsubishi Electric Research Laboratories (MERL)
Bhagat, Akshay	Mitsubishi Electric Automotive America, Inc
Zeino, Eyad	Mitsubishi Electric
Di Cairano, Stefano	Mitsubishi Electric Research Labs

Connected and automated vehicles (CAVs) have shown the potential to improve safety, increase throughput, and optimize energy efficiency and emissions in complicated traffic scenarios. This paper presents a mixed-integer linear programming (MILP) method for scheduling and coordination of CAVs in a highly dynamic environment that consists of multiple human-driven vehicles and multiple conflict zones, such as merging points and intersections. The proposed approach ensures safety, high throughput and energy efficiency by solving a centralized high-level decision making problem. The solution provides a feasible and optimal time schedule through road segments and conflict zones for the automated vehicles, by using information from the position, velocity, and destination of the manual vehicles, which cannot be directly controlled. The performance and computational load of the proposed method are assessed in closed-loop simulations on an illustrative scenario. Despite MILP having combinatorial complexity, the proposed formulation appears feasible for real-time implementation, e.g., in mobile edge computers (MECs).

09:15-09:35 WeAT1.5

Optimal Localized Trajectory Planning of Multiple Non-Holonomic Vehicles (I), pp. 820-825

Lukyanenko, Anton	George Mason University
Camphire, Heath	George Mason University
Austin, Avery	George Mason University
Schmidgall, Samuel	Select or Enter
Soudbakhsh, Damoon	Temple University

We present a trajectory planning method for multiple vehicles to navigate a crowded environment, such as a gridlocked intersection or a small parking area. In these scenarios, decoupled path planning techniques may not produce feasible solutions and a joint planning method is necessary to allow the vehicles to reach their destinations. We use multiple Reeds-Shepp (RS) non-holonomic dynamic models, and combine them into a single higher-dimensional non-holonomic multi-vehicle system. We then search for a simultaneous set of vehicle trajectories, represented by a single choreography curve in the higher-dimensional space, using the RRT* graph-based search method. While variants of RRT are widely used, convergence is known only for the specific cases of holonomic systems and sub-Riemannian non-holonomic systems. We prove the algorithm's convergence in a more general setting and demonstrate the effectiveness of the approach through simulation and experimental studies on multiple robots. The proposed approach with guaranteed optimality can be used to locally resolve collisions among a small subset of vehicles in a large multi-vehicle trajectory planning problem in presence of obstacles.

WeAT2 Room T2

Automotive Batteries (Invited Session)

Chair: Onori, Simona	Stanford Univeristy
Co-Chair: Pangborn, Herschel	Pennsylvania State University
Organizer: Siegel, Jason B.	University of Michigan
Organizer: Pozzato, Gabriele	Stanford University
Organizer: Dey, Satadru	University of Colorado Denver
Organizer: Soudbakhsh, Damoon	Temple University
Organizer: Dadras, Sara	Company
Organizer: Dadam, Sumanth	Ford Motor Company
Organizer: Dadras, Soodeh	Utah State University
Organizer: Borhan, Hoseinali	Cummins Inc
Organizer: Amini, Mohammad Reza	University of Michigan
Organizer: Tong, Son	Siemens Digital Industries Software

07:55-08:15 WeAT2.1

Modeling Degradation of Lithium-Ion Batteries for Second-Life Applications: Preliminary Results (I), pp. 826-831

Pozzato, Gabriele	Politecnico Di Milano
Lee, Seong Beom	Stanford University
Onori, Simona	Stanford Univeristy

This paper presents a novel battery modeling framework based on the enhanced single particle model (ESPM) to account for degradation mechanisms of retired electric vehicle batteries. While accounting for the transport and electrochemical phenomena in the battery solid and electrolyte phases, the dominant anode-related aging mechanisms, namely, solid electrolyte interphase (SEI) layer growth and lithium plating, are modeled. For the first time, the loss of active material (LAM), which describes the tendency of anode and cathode, over time, to reduce the electrode material available for intercalation and deintercalation, is introduced in the ESPM. Moreover, the coupling of the aging mechanisms with the LAM dynamics provides a comprehensive means for the prediction of both linear and non-linear capacity fade trajectories, crucial to assess the health of batteries that are considered for second-life applications. Relying on data borrowed from [13], a model parameter identification and a comprehensive sensitivity analysis are performed to prove the effectiveness of the modeling approach.

08:15-08:35 WeAT2.2

Power and Thermal Management with Battery Degradation for Hybrid Electric Vehicles (I), pp. 832-838

Park, Seho	Pennsylvania State University
Pangborn, Herschel	Pennsylvania State University

This paper develops a framework for integrated power and thermal management of hybrid electric vehicles (HEVs) that explicitly manages tradeoffs between fuel economy and battery degradation. The total ownership costs and cradle to grave sustainability of electrified vehicles is strongly impacted by the health and lifespan of their batteries. However, most strategies for power management of HEVs focus on maximizing fuel economy, without explicitly considering the impacts of control decisions on battery health. Studies that have addressed tradeoffs in power management and battery health have not also taken thermal management systems and temperature-dependent battery degradation into consideration. This paper couples models of the powertrain, thermal management system, and battery degradation to optimize tradeoffs between efficiency and battery health. Dynamic programming is performed to provide an idealized benchmark for performance. Simulation results illustrate that a more informed balance between fuel economy and battery degradation can be achieved by including thermal management in the purview of the powertrain controller. A model predictive controller is then studied as a closed-loop strategy, based on the same formulation as the open-loop dynamic program.

08:35-08:55 WeAT2.3

Multi-Layer Control for Hybrid Balancing Systems (I), pp. 839-845

De Castro, Ricardo	University of California, Merced
Pereira, Helder	FEUP
Araújo, Rui Esteves	University of Porto
Varela Barreras, Jorge	Imperial College London
Pangborn, Herschel	Pennsylvania State University

Hybrid balancing is a recently-proposed class of balancing systems that simultaneously provide capacity and thermal equalization, while enabling hybridization with supercapacitors. This integration of functions poses a challenging control problem, requiring the fulfillment of multiple objectives (e.g., reduction of charge and temperature imbalances, energy losses and battery stress) and the coordination of a large number of power converters. To tackle this challenge, we propose a multi-layer model predictive control (MPC) framework, which splits the control tasks into two layers. The first layer uses long prediction horizons and a simplified model of the energy storage system to compute the state-of-charge reference for the supercapacitors. The second layer uses module-level models of the battery pack to track this reference, while minimizing charge and temperature imbalances with a small prediction horizon. Simulation results demonstrate that the multi-layer MPC provides similar performance as single-layer MPC, but at a fraction of the computational effort.

08:55-09:15 WeAT2.4

Online Capacity Estimation for Lithium-Ion Battery Cells Via an Electrochemical Model-Based Adaptive Interconnected Observer (I), pp. 846-861

Allam, Anirudh — Stanford University
Onori, Simona — Stanford Univeristy

Battery aging is a natural process that contributes to capacity and power fade, resulting in a gradual performance degradation over time and usage. State-of-charge (SOC) and state-of-health (SOH) monitoring of an aging battery poses a challenging task to the battery management system (BMS) due to the lack of direct measurements. Estimation algorithms based on an electrochemical model that considers the impact of aging on physical battery parameters can provide accurate information on lithium concentration and cell capacity over a battery's usable lifespan. A temperature-dependent electrochemical model, the enhanced single particle model (ESPM), forms the basis for the synthesis of an adaptive interconnected observer that exploits the relationship between capacity and power fade, due to the growth of solid electrolyte interphase layer (SEI), to enable combined estimation of states (lithium concentration in both electrodes and cell capacity) and aging-sensitive transport parameters (anode diffusion coefficient and SEI layer ionic conductivity). The practical stability conditions for the adaptive observer are derived using Lyapunov's theory. Validation results against experimental data show a bounded capacity estimation error within 2% of its true value. Furthermore, the effectiveness of capacity estimation is tested for two cells at different stages of aging. Robustness of capacity estimates under measurement noise and sensor bias is studied.

WeAT3 Room T3

Mechanical Systems and MEMS (Regular Session)

Chair: M'Closkey, Robert — University of California, Los Angeles
Co-Chair: Welsh, James S. — University of Newcastle

07:55-08:15 WeAT3.1

On Stability of a Multi-Reluctance Actuation System for Precision Motion Control, pp. 862-867

Al Saaideh, Mohammad — Memorial University of Newfoundland
Alatawneh, Natheer — Cysca Technology
Al Janaideh, Mohammad — Memorial University of Newfoundland

This study presents the stability conditions of a precision motion system driven by two reluctance actuators. First, an electromechanical model is formulated based on the lumped parameter model to describe the interaction among the electrical, magnetic, and mechanical domains. The elec- tromechanical model is then used to study the steady-state operation conditions and determine the determined the critical input current for stable behavior of the reluctance actuator motion system. The feedforward controller is proposed to linearize the behavior of the reluctance actuator and improve the performance of the system. The simulation results in time- domain show that the system without feedforward controller is stable for input current less than the critical current. The results also show that using a feedforward controller improves tracking performances in the time-domain and increases bandwidth frequency in the frequency-domain.

08:15-08:35 WeAT3.2

Continuous-Time System Identification of a Flexible Cantilever Beam, pp. 868-873

Pan, Siqi — University of Newcastle
Nguyen, Quoc Chi — Ho Chi Minh City University of Technology
Nguyen, Van Thuat — Ho Chi Minh City University of Technology
Welsh, James S. — University of Newcastle

In this paper, we apply a continuous-time system identification method, known as the Simplified Refined Instrumental Variable method for Continuous-time systems (SRIVC), to estimate transfer function models of a flexible cantilever beam with measurements taken at two locations on the beam using a high-speed camera. The accuracy of the obtained models is validated against data records that are independent from the datasets used for estimation. The parameters of interest of the cantilever beam, including the natural frequencies and damping ratios of the vibration modes, are then extracted from the continuous-time transfer function coefficients. A discussion on the physical meanings of the transfer function zeros is also provided with respect to the locations of the measurements.

08:55-09:15 WeAT3.4

Frequency Domain-Based Integral Resonant Controller Design for a MEMS Nanopositioner, pp. 874-879

Nikooienejad, Nastaran — University of Texas at Dallas
Moheimani, S.O. Reza — University of Texas at Dallas

In this paper, a multivariable integral resonant controller is designed based on the measured frequency response of a 2-DOF MEMS nanopositioner with collocated sensors and actuators. The objective is to augment damping of the fundamental resonant mode of the nanopositioner by minimizing a cost function in an H2 sense. The design procedure is cast as convex optimization problem using Taylor expansion around an initial controller. Considering the plant and controller as negative imaginary (NI) and strictly NI systems, the NI stability constraint is imposed to the optimization algorithm. The performance of data-driven IRC is evaluated in closed-loop experiments with the MEMS nanopositioner.

09:15-09:35 WeAT3.5

Modeling and Control of Electrostatically Levitated MEMS, pp. 880-886

Andonian, Michael — The Aerospace Corporation
Pyle, Kenneth — University of California, Los Angeles
M'Closkey, Robert — University of California, Los Angeles

A system for electrostatically suspending a silicon disk between two sets of electrodes is reported. The electrodes exert electrostatic forces on the disk and also measure differential capacitances related to the disk position. There are no electrodes that directly exert in-plane forces on the disk sidewall, however, tilting the disk relative to the plane of the electrodes does exert lateral forces. Additional lateral-sensing electrodes are then used to determine the disk's lateral position so precise positioning of the disk is possible without any disk contact. Experimental stabilization results are reported.

09:35-09:55 WeAT3.6

Video-Rate Non-Raster AFM Imaging with Cycloid Trajectory (I), pp. 887-898

Nikooienejad, Nastaran	University of Texas at Dallas
Alipour, Afshin	University of Texas at Dallas
Maroufi, Mohammad	University of Texas at Dallas
Moheimani, S.O. Reza	University of Texas at Dallas

We demonstrate the application of the internal model principle in tracking a sequential cycloid trajectory to achieve video-rate atomic force microscope (AFM) imaging. To generate a sequential cycloid pattern, one axis of the nanopositioner traces a sinusoidal signal superimposed on a slow triangular wave. Discontinuities at turning points induce large peaks in the steady-state tracking error. To address this issue, a smooth trajectory is designed to reduce the magnitude of error by 60 nm compared with the triangular wave. This trajectory reduces the magnitude of error 10 times. The tracking controller includes the dynamics of the harmonic waveforms and the ramp signal as well as higher order harmonics of the scanning frequency, and an integrator to cope with the system nonlinearities at low frequencies. We perform experiments on a two degree of freedom microelectromechanical system nanopositioner at various scanning frequencies ranging from 500 to 2580 Hz within a scan area of 5 μm × 10 μm. The root-mean-square value of tracking error remains below 6.1 nm with a pitch size of 44.2 nm. We acquire time-lapse AFM images in contact mode at scan rates as high as 20 frames per second.

WeAT4 Room T4

Cyber Systems (Regular Session)

Chair: Mitra, Sayan	University of Illinois
Co-Chair: Vamvoudakis, Kyriakos G.	Georgia Inst. of Tech

07:55-08:15 WeAT4.1

A Human-Integrated Tool for Proactive and Reactive Security in Cyber-Physical Systems, pp. 899-904

Sequeira, Alistair	Georgia Institute of Technology
Kanellopoulos, Aris	Georgia Institute of Technology
Vamvoudakis, Kyriakos G.	Georgia Inst. of Tech

We present a comprehensive defense software for cyber-physical systems, comprising both proactive and reactive mechanisms. Specifically, the demonstrated tool allows a human operator to remain aware of the system's health and operation, while an autonomous subsystem applies a switching rule based on the principles of Moving Target Defense, rendering the system more unpredictable but stable nonetheless. Finally, the man-machine interaction implements a trust metric, that allows either the autonomous mechanism or the human agent to have more control over the system based detection and mitigation history. We describe the interface of the security software, while the case of an autonomous aircraft is used to showcase the efficacy of the software.

08:15-08:35 WeAT4.2

A Secure Learning Control Strategy Via Dynamic Camouflaging for Unknown Dynamical Systems under Attacks, pp. 905-910

Mukherjee, Sayak	Pacific Northwest National Laboratory
Adetola, Veronica	Pacific Northwest National Lab

This paper presents a secure reinforcement learning (RL) based control method for unknown linear time-invariant cyber-physical systems (CPSs) that are subjected to compositional attacks such as eavesdropping and covert attack. We consider the attack scenario where the attacker learns about the dynamic model during the exploration phase of the learning conducted by the designer to learn a linear quadratic regulator (LQR), and thereafter, use such information to conduct a covert attack on the dynamic system, which we refer to as doubly learning-based control and attack (DLCA) framework. We propose a dynamic camouflaging based attack-resilient reinforcement learning (ARRL) algorithm which can learn the desired optimal controller for the dynamic system, and at the same time, can inject sufficient misinformation in the estimation of system dynamics by the attacker. The algorithm is accompanied by theoretical guarantees and extensive numerical experiments on a consensus multi-agent system and on a benchmark power grid model.

08:35-08:55 WeAT4.3

Cyber-Attack Detection in Discrete-Time Nonlinear Multi-Agent Systems Using Neural Networks, pp. 911-916

Mousavi, Amirreza	Concordia University
Aryankia, Kiarash	Concordia University
Selmic, Rastko	Concordia University

This paper proposes a distributed cyber-attack detection method in communication channels for a class of discrete-time, nonlinear, heterogeneous, multi-agent systems controlled by the proposed formation-based controller. To detect false data injection attacks on agents communication channels, each agent exploits a residual-based detection system equipped with a neural network (NN)-based observer. Moreover, the NN weights tuning law and the attack detectability threshold are derived using a Lyapunov function. The uniform ultimate boundedness (UUB) of the formation error and detector residual are proven based on the Lyapunov stability theory. Finally, the attack detectability condition of the proposed method is analyzed, and a simulation example is provided to demonstrate the performance of the proposed detection methodology.

08:55-09:15 WeAT4.4

Neural Network-Assisted Resilient Wide-Area Control of Power Systems under Denial-Of-Service Attacks, pp. 917-922

Kar, Jishnudeep	North Carolina State University
Chakrabortty, Aranya	North Carolina State University

We propose a deep learning-assisted resilient wide-area control design for electric power systems by which grid models can be stabilized in real-time following a Denial-of-Service (DoS) attack. The benefit of using deep learning is twofold: first, the exact model of the grid does not need to be known apriori for the design, and, second, the speed of the design is improved significantly by exploiting the predictive knowledge of the deep learning module, which, in turn, helps in quick stabilization while the attack is in progress. The idea is to feed the learning module with online measurements of the pre-attack equilibrium of the states, and predict a representative small-signal model and a corresponding sparse controller that has a close sparsity structure to that caused by the attack. This predicted controller is then used as an initial guess for converging to an optimal sparse controller that can stabilize the grid. However, the representative model may not be the exact model for that operating condition, as a result of which, depending on the magnitude of the attack, in some situations, the model error may not allow closed-loop stability. To handle those situations, in the second half of the paper we present a robust version of the sparse control design. The designs are validated using a wide-area damping control example on the IEEE 68-bus, 16-machine system.

09:15-09:35 WeAT4.5

HooVer: A Framework for Verification and Parameter Synthesis in Stochastic Systems Using Optimistic Optimization, pp. 923-930

Musavi, Negin	University of Illinois Urbana Champaign
Sun, Dawei	University of Illinois at Urbana-Champaign
Mitra, Sayan	University of Illinois
Dullerud, Geir E.	Univ of Illinois, Urbana-Champaign

Shakkottai, Sanjay The University of Texas at Austin

This paper provides a new approach for probabilistic verification of control and dynamical systems in the scenario where there is a finite computational budget that must be used judiciously; it is based on leveraging multi-armed bandits theory from machine learning. We present an algorithm for formal verification and parameter synthesis of continuous state-space Markov chains, introduce our associated computational tool HooVer, and demonstrate their use on example applications. The problem class considered captures the design and analysis of a wide variety of autonomous and cyber-physical systems defined by nonlinear and black-box modules. In order to solve these problems, one has to maximize certain probabilistic objective functions over all choices of initial states and parameters. In this paper, we identify the assumptions that make it possible to view this problem as a multi-armed bandit problem. Based on this fresh perspective, we propose an algorithm Hierarchical Optimistic Optimization algorithm with Mini-batches (HOO-MB) for solving the problem that carefully instantiates an existing bandit algorithm---Hierarchical Optimistic Optimization---with appropriate parameters. As a consequence, we obtain theoretical regret bounds on sample efficiency of our solution that depends on key problem parameters like smoothness, near-optimality dimension, and batch size. The batch size parameter enables us to strike a balance between the sample efficiency and the memory usage of the algorithm. Experiments, using our open-source tool HooVer, suggest that the approach scales to realistic-sized problems and is often more sample-efficient compared to PlasmaLab---a leading tool for verification of stochastic systems. Specifically, HooVer has distinct advantages in analyzing models in which the objective function has sharp slopes. In addition, HooVer shows promising behavior in parameter synthesis for a linear quadratic regulator (LQR) example.

09:35-09:55 WeAT4.6

A Data-Based Moving Target Defense Framework for Switching Zero-Sum Games, pp. 931-936

Zhai, Lijing Georgia Institute of Technology
Vamvoudakis, Kyriakos G. Georgia Inst. of Tech

In this paper, a data-based moving target defense framework for cyber-physical systems evolving with unknown and discrete-time dynamics is proposed. Specifically, we develop a proactive mechanism to increase the attacking surface through entropy-based unpredictability measures, and a reactive mechanism to detect and mitigate sensor/actuator attacks. In order to handle worst-case disturbances, we formulate our problem as a zero-sum game, where the minimizing player is the control input and the maximizing player is the disturbance input. We amalgamate a model-free and data-based approximate dynamic programming technique that learns the saddle-point strategies with a Bellman-based intrusion detection mechanism. Switching rules that asymptotically stabilize the switched system are derived. We validate the effectiveness of our proposed framework through simulation results.

WeAT5 Room T5

Control Algorithms (Regular Session)

Chair: Chen, Cheng-Wei National Taiwan University
Co-Chair: Sulikowski, Bartlomiej University of Zielona Gora, Inst. Control and Computation

07:55-08:15 WeAT5.1

Distributed Formation and Orientation Control of Multiple Holonomic Mobile Robots Using Relative Measurements, pp. 937-941

Peng, Chunlai Kyoto University
Sakurama, Kazunori Kyoto University
Yamazumi, Mitsuhiro Mitsubishi Electric Corporation

This paper studies distributed formation and orientation control of multiple robots using relative measurements in local coordinate frames. The control objective is to achieve a desired formation with all robots facing a target for monitoring. It is assumed that each robot can only measure neighbors' relative positions to the target and relative orientations to their neighbors, and that communication among robots is unavailable. To address this issue, we introduce a unified framework of formation and orientation control, and proposed a distributed and relative control law to ensure achieving the control objective. Not only formation but also orientation control is successful because a clique-based method is employed, instead of conventional edge-based ones. Here, the cliques are complete subgraphs. Besides, the effectiveness of the proposed method is illustrated through a simulation, and the stability of the system is analyzed. Because this method is applicable regardless of the dimension of the space, the proposed method can be applied to both UGV and UAV, as well as the coordination of heterogeneous multi-robot systems in the case of cooperative monitoring and transport.

08:15-08:35 WeAT5.2

Switching Control of Linear Time-Varying Networked Control Systems with Sparse Observer-Controller Networks, pp. 942-949

Razeghi-Jahromi, Mohammed Senior Research Scientist
Seyedi, Alireza University of Central Florida

In this paper we provide a set of stability conditions for linear time-varying networked control systems with arbitrary topologies using a piecewise quadratic switching stabilization approach with multiple quadratic Lyapunov functions. We use this set of stability conditions to provide a novel iterative low-complexity algorithm that must be updated and optimized in discrete time for the design of a sparse observer-controller network, for a given plant network with an arbitrary topology. We employ distributed observers by utilizing the output of other subsystems to improve the stability of each observer. To avoid unbounded growth of controller and observer gains, we impose bounds on the norms of the gains.

08:35-08:55 WeAT5.3

Repetitive Process Based Design of Dynamic Iterative Learning Controllers, pp. 950-955

Maniarski, Robert University of Zielona Góra
Paszke, Wojciech University of Zielona Gora
Rogers, Eric University of Southampton

This paper develops a design procedure for dynamic iterative learning controllers applied to continuous-time linear time-invariant systems. By appropriately expressing the stability along the trial condition for the controlled system and use of the elimination lemma, a new linear matrix inequality-based design condition is obtained. As shown, the use of this setting simultaneously allows design to satisfy the trial-to-trial convergence and transient response specifications. Additionally, appropriate choice of the robustness filter and some scalar parameters enables different design specifications to be imposed. A simulation-based case study demonstrates the application of the new design.

08:55-09:15 WeAT5.4

Data-Driven Design of a Reference Governor Using Deep Reinforcement Learning, pp. 956-961

Taylor, Maria Angelica University of Los Andes
Giraldo, Luis Felipe University of Los Andes

Reference tracking systems involve a plant that is stabilized by a local feedback controller and a command center that indicates the reference set-point the plant should follow. Typically, these systems are subject to limitations such as disturbances, systems delays, constraints, uncertainties, underperforming controllers, and unmodeled parameters that do not allow them to achieve the desired performance. In situations where it is not possible to redesign the closed-loop system, it is usual to incorporate a reference governor that instructs the system to follow a modified reference path such that the resultant path is close to the ideal one. Typically, strategies to design the reference governor need to know a model of the system, which can be an unfeasible task. In this

paper, we propose a framework based on deep reinforcement learning that can learn a policy to generate a modified reference that improves the system's performance in a non-invasive and model-free fashion. To illustrate the effectiveness of our approach, we present two challenging cases in engineering: a flight control with a pilot model that includes human reaction delays, and a mean-field control problem for a massive number of space-heating devices. The proposed strategy successfully designs a reference signal that works even in situations that were not seen during the learning process.

09:15-09:35 WeAT5.5

The Poles Placement Based Control Design for the Subclass of Real Uncertain 2D Systems, pp. 962-967

Trzciński, Daniel — University of Zielona Góra
Sulikowski, Bartlomiej — University of Zielona Gora, Inst. Control and Computation

This paper addresses the problem of analysis and control synthesis for multi-mass systems. They are modeled in terms of the particular subclass of 2D systems, i.e. spatially interconnected systems. Hence, the resulting state space model for such plant is twodimensional, where one of indeterminates is time (continuous) and the latter is the number (location) of the node (cart) in the system considered. What's more, it is assumed that the model is uncertain and the procedure how to address the uncertainty is provided. The main result of the paper is upon presenting the control scheme design that meets the assumed goals. In this case those are: assuring the appropriate dynamics of the controlled system (by placing the poles of the closed loop system in the predefined region on the complex plane) and driving the output of the system to the reference. To prove the usefulness of the proposed method it has been experimentally evaluated on the real system.

09:35-09:55 WeAT5.6

Accelerated Convergence Interleaving Iterative Learning Control and Inverse Dynamics Identification (I), pp. 968-979

Chen, Cheng-Wei — National Taiwan University
Tsao, Tsu-Chin — University of California, Los Angeles

This work aims to quickly identify an FIR inverse dynamical model for linear time-invariant (LTI) systems. Various applications are enabled using the constructed inverse filter, as illustrated by an inversion-based iterative learning control (ILC) algorithm. With the help of interleaving inversion-based ILC and ILC-based inverse dynamics identification, accelerated convergence is obtained. The proposed method removes the numerical instability issues in the calculation of an inverse model. Hence, it is shown more robust against measurement noises. Both simulation comparison and experimental results demonstrate the efficacy and advantages of the proposed strategy.

WeAT6 Room T6

Estimation (Regular Session)

Chair: Berntorp, Karl — Mitsubishi Electric Research Labs
Co-Chair: Hovakimyan, Naira — University of Illinois at Urbana-Champaign

07:55-08:15 WeAT6.1

Relative Velocity Estimation of Semi-Active Suspension Using Production In-Vehicle Sensors†

Kim, Byungjun — KAIST
Choi, Seibum Ben — KAIST

08:15-08:35 WeAT6.2

Mixed-Integer Linear Regression Kalman Filters for GNSS Positioning, pp. 980-985

Greiff, Marcus Carl — Lund University
Berntorp, Karl — Mitsubishi Electric Research Labs
Di Cairano, Stefano — Mitsubishi Electric Research Labs
Kim, Kyeong Jin — Mitsubishi Electric Research Laboratories (MERL)

In this paper, recursive filters are formulated for the mixed-integer GNSS receiver estimation problem, where the integer variables come from the ambiguities in the carrier-phase measurements. Insights from the linear setting illustrate pitfalls in designing optimal recursive filters, motivating a relaxation of the original optimization problem and a departure from conventional methods. A set of filters are developed for se- quential nonlinear mixed-integer estimation based on statistical linearization, entertaining two estimate densities and taking the time-evolution of the ambiguities into account by adapting the process noise covariance based on a statistical model. Numerical examples illustrate the efficacy of the proposed algorithms.

08:35-08:55 WeAT6.3

Estimation of Vehicle Side-Slip Angle at Varying Road Friction Coefficients Using a Recurrent Artificial Neural Network, pp. 986-991

Ziaukas, Zygimantas — Institute of Mechatronic Systems, Leibniz Universität Hannover
Busch, Alexander — Leibniz Universität Hannover
Wielitzka, Mark — Leibniz Universität Hannover

The side-slip angle is one of several crucial states in vehicle dynamics allowing to judge the current status of stability and the ride comfort for the subsequent usage in active assistance systems. Unfortunately, the measurement of side-slip angle is very costly and therefore it is usually not provided in production vehicles. As an alternative, the side-slip angle can be estimated based on the available sensors. The most common approach is model-based state estimation using different forms of Kalman filters (KF). However, this method comprises the complex steps of system identification and robust filter design. In recent years, data-based approaches gain popularity among researchers throughout different fields of research including the state estimation in vehicle dynamics. These allow direct extraction of an estimation algorithm from recorded data. This contribution presents the utilization of recurrent artificial neural networks (RANN) to side-slip angle estimation in a Volkswagen Golf GTE Plug-In Hybrid on varying road surfaces. The inputs to the RANN are signals from sensors in serial production configuration. In comparison to the model-based approach of a sensitivity-based unscented Kalman filter (sUKF) from previous works, the data-based approach shows competitive experimental results.

08:55-09:15 WeAT6.4

Force Estimation in Electro-Mechanical Systems: Theory and Experiments, pp. 992-997

Riva, Giorgio — Politecnico Di Milano
Formentin, Simone — Politecnico Di Milano
Savaresi, Sergio M. — Politecnico Di Milano

In this paper, a purely data-driven approach for force estimation in electro-mechanical actuators is proposed. First, the contact with the surrounding environment is detected by means of an unsupervised learning procedure applied to the current measurements, then the clamping force is estimated in real-time by using a data-driven model of the interaction between the actuator and the system. The effectiveness of the proposed approach is illustrated on an experimental braking system setup, also showing to outperform the state of the art methodology.

09:15-09:35 WeAT6.5

Estimation and Planning of Exploration Over Grid Map Using a Spatiotemporal Model with Incomplete State Observations, pp. 998-1003

Yoon, Hyungjin — University of Nevada, Reno

Kim, Hunmin	University of Illinois Urbana-Champaign
Shrestha, Kripash	University of Nevada Reno
Hovakimyan, Naira	University of Illinois at Urbana-Champaign
Voulgaris, Petros G.	Univ of Nevada, Reno

Path planning over spatiotemporal models can be applied to a variety of applications such as UAVs searching for spreading wildfire in mountains or network of balloons in time-varying atmosphere deployed for inexpensive internet service. A notable aspect in such applications is the dynamically changing environment. However, path planning algorithms often assume static environments and only consider the vehicle's dynamics exploring the environment. We present a spatiotemporal model that uses a cross-correlation operator to consider spatiotemporal dependence. Also, we present an adaptive state estimator for path planning. Since the state estimation depends on the vehicle's path, the path planning needs to consider the trade-off between exploration and exploitation. We use a high-level decision-maker to choose an explorative path or an exploitative path. The overall proposed framework consists of an adaptive state estimator, a short-term path planner, and a high-level decision-maker. We tested the framework with a spatiotemporal model simulation where the state of each grid transits from normal, latent, and fire state. For the mission objective of visiting the grids with fire, the proposed framework outperformed the random walk (baseline) and the single-minded exploitation (or exploration) path.

09:35-09:55 WeAT6.6

A Nonlinear Adaptive Resilient Observer for Fouling Detection and Localization in Direct Contact Membrane Distillation Systems, pp. 1004-1010

Marani, Yasmine	King Abdullah University of Science and Technology
Touati, Tania Camelia	Ecole Nationale Polytechnique
Chakir, Messaoud	Laboratoire De Commande Des Processus Ecole Nationale Polytechni
Laleg-Kirati, Taous-Meriem	King Abdullah University of Science and Technology (KAUST)

Because freshwater source exhaustion is a growing issue, the use of seawater desalination technologies is constantly increasing. More attention is drawn to Direct Contact Membrane Distillation (DCMD), thanks to its high rejection factor and low energy consumption, which makes it a promising sustainable solution for water desalination. Nevertheless, the DCMD system is prone to membrane fouling which alters its produced water's properties, deteriorates the membrane performance, and induces huge operation and maintenance costs if not detected in early stages. Considering the above, the present paper proposes a new approach based on an adaptive resilient observer, not only to detect fouling in DCMD systems but also to localize it with high accuracy to further reduce the maintenance costs. We start by recalling the DCMD model in presence of fouling that was developed using the thermal-electrical analogy and the lumped capacitance method. Then, under Lipschitz conditions of the nonlinear terms, we present the design of the nonlinear adaptive resilient descriptor observer to estimate simultaneously the system's states and the fouling thermal resistance. The proposed observer's convergence proof is given using the Lyapunov method, from which we derive a set of linear matrix inequalities (LMI) to obtain the observer's gain. To demonstrate the effectiveness of the proposed method compared to the classical adaptive observer-based method, the states and parameter estimation are compared through numerical simulations under both observer designs. Simulation results reveal that the nonlinear adaptive resilient observer outperforms the adaptive observer.

WeBT1 Room T1

Transportation Systems (Regular Session)

Chair: Núñez, Felipe	Pontificia Universidad Catolica De Chile
Co-Chair: Enyioha, Chinwendu	University of Central Florida

10:00-10:20 WeBT1.1

G-BEAM: Graph-Based Exploration and Mapping for Autonomous Vehicles, pp. 1011-1016

Cecchin, Leonardo	Politecnico Di Milano
Saccani, Danilo	Politecnico Di Milano
Fagiano, Lorenzo	Politecnico Di Milano

A novel solution to the problem of autonomous exploration and mapping of an unknown environment by an autonomous vehicle is presented. A hierarchical control system is adopted, where a low-level reactive controller manages obstacle avoidance, and two high-level strategies are in charge of mapping and navigation tasks. The decision strategy implemented at the high-level is named G-BEAM, standing for "Graph-Based Exploration And Mapping". It builds a reachability graph used both as a trajectory planning tool and as a map. The reachability graph representation requires less storage resources with respect to a more traditional occupancy-map. It can be directly exploited to compute the system's path towards a given target or unexplored locations. The latter are ranked according to the expected information gain that is realized when they are visited. Such information gain is then used in the cost function of the navigation strategy, which is based on a receding horizon concept. The graph is updated as the autonomous vehicle moves, exploiting the sensors' measurements in a novel approach based on polyhedral under-approximations of the feasible space. The controller has been successfully tested in various simulated environments. Comparison with other approaches in state of the art shows promising performance.

10:20-10:40 WeBT1.2

Traffic Shaping for Control of Spreading Processes, pp. 1017-1023

Enyioha, Chinwendu	University of Central Florida

In this paper, we formulate and solve the problem of traffic shaping in a flow network to optimize the end-to-end flow rate, while simultaneously controlling the spread of a viral infection. Our model is based on the notion that as more traffic or flow is pushed through the network, infected nodes can pass on the virus infection to neighboring nodes via packets of information routed. Furthermore, we assume the probability of infection depends, amongst other factors, on the inter-agent routing rate. Based on this, we formulate a traffic shaping problem to contain a virus outbreak as a signomial program, and solve the problem via successive Geometric Program (GP) approximations. Via numerical examples, we illustrate the impact of the virus spreading control on the achievable flows in the network.

10:40-11:00 WeBT1.3

Design of a Parameter-Based Modeling Platform for Road Tunnel Supervisory Controllers, pp. 1024-1030

Moormann, Lars	Eindhoven University of Technology
van de Mortel-Fronczak, Joanna	Eindhoven University of Technology
Rooda, J.E.	Eindhoven University of Technology

Designing supervisory controllers for high-tech systems is a laborious and error-prone task. By using formal model-based methods, such as the supervisor synthesis method based on supervisory control theory (SCT), a correct-by-construction controller can be synthesized automatically from a model of the plant and a model of the requirements. Modeling for SCT, however, remains a cumbersome task for systems with large numbers of components. Moreover, modeling such systems requires extensive knowledge on SCT, e.g. regarding modeling formalisms and synthesis algorithms, as there exist relatively few modeling guidelines, especially when the components

have complex dependencies. This paper proposes a parameter-based modeling approach that enables a designer to automatically generate the required models for synthesis and simulation by defining the parameters of a system within a product platform. The gained benefits include more efficient modeling while requiring less knowledge on SCT. The product platform in this paper considers supervisory controllers for road tunnels. The parameter-based modeling platform is implemented as a proof-of-concept configuration tool, is validated by means of simulation, and its applicability is shown in a case study for a family of 22 tunnels in the Netherlands.

11:00-11:20 WeBT1.4

Graph-Based Distributed Lane-Change in Tight Multi-Lane Platoons, pp. 1031-1036

Pizarro, Germán	Pontificia Universidad Católica De Chile
Núñez, Felipe	Pontificia Universidad Catolica De Chile

Platooning of connected and automated vehicles (CAVs) has received extensive interest due to its potential to improve road traffic. In this context, multi-lane platoons have appear as a generalized version of the classical train-like platoon structure used since the early platoon implementations in the 80s. Multi-lane platoons add structural flexibility at the price of more intricate internal dynamics, particularly with respect to internal lane changes. This work proposes a distributed scheme for lane changes inside a platoon based on a hierarchical control scheme that makes use of a graph theoretical formulation of platoon formations for reference generation and distributed model predictive control (DMPC) for vehicle command. The effectiveness of the proposed approach is tested by simulating a variety of scenarios.

11:20-11:40 WeBT1.5

On the Impact of the Capacity Drop Phenomenon for Freeway Traffic Flow Control, pp. 1037-1042

Cao, Michael Enqi	Georgia Institute of Technology
Nilsson, Gustav	Georgia Institute of Technology
Coogan, Samuel	Georgia Institute of Technology

Capacity drop is an empirically observed phenomenon in vehicular traffic flow on freeways whereby, after a critical density is reached, a state of congestion sets in, but the freeway does not become decongested again until the density drops well below the critical density. This introduces a hysteresis effect so that it is easier to enter the congested state than to leave it. However, many existing first-order models of traffic flow, particularly those used for control design, ignore capacity drop, leading to suboptimal controllers. In this paper, we consider a cell transmission model of traffic flow that incorporates capacity drop to study the problem of optimal freeway ramp metering. We show that, if capacity drop is ignored in the control design, then the resulting controller, obtained via a convex program, may be significantly suboptimal. We then propose an alternative model predictive controller that accounts for capacity drop via a mixed integer linear program and show that, for sufficiently large rollout horizon, this controller is optimal. We also compare these approaches to a heuristic hand-crafted controller that is viewed as a modification of an integral feedback controller to account for capacity drop. This heuristic controller outperforms the controller that ignores capacity drop but underperforms compared to the proposed alternative model predictive controller. These results suggest that it is generally important to include capacity drop in the controller design process, and we demonstrate this insight on several case studies.

11:40-12:00 WeBT1.6

A Concurrent Controllers Integration Strategy to Enhance the Riding Experience in Bicycle Driveline Emulators, pp. 1043-1048

Radrizzani, Stefano	Politecnico Di Milano
Panzani, Giulio	Politecnico Di Milano
Corno, Matteo	Politecnico Di Milano
Savaresi, Sergio M.	Politecnico Di Milano

Bike emulators aim at replicating the pedaling experience by coupling a stand-alone bike with a dynamical simulator. The increasing interest toward series electric bicycles changed the traditional layout of bike emulators, leading to the virtualization of the complete bicycle driveline. Following this trend, in this work, an electric machine connected to the pedals is indeed used to enhance the virtual bike driveline emulation. One of the challenges to be faced when dealing with this task is to faithfully reproduce the effect of the freewheel. We address this issue with an electric motor control strategy based on two concurrent controllers. An ad-hoc anti-windup strategy is designed in order to manage the windup phenomenon occurring with the proposed controllers integration. The experimental validation shows the effectiveness of the proposed solution.

WeBT2 Room T2

PID (Regular Session)

Chair: Majewicz Fey, Ann	University of Texas at Austin
Co-Chair: Ye, Linqi	Tsinghua University

10:00-10:20 WeBT2.1

Evolutionary Algorithms for Multi-Objective Optimization of Drone Controller Parameters, pp. 1049-1055

Shamshirgaran, Azin	University of California, Merced
Javidi, Hamed	Cleveland State University
Simon, Dan	Cleveland State University

Drones are effective for reducing human activity and interactions by performing tasks such as exploring and inspecting new environments, monitoring resources and delivering packages. Drones need a controller to maintain stability and to reach their goal. The most well-known drone controllers are proportional-integral-derivative (PID) and proportional-derivative (PD) controllers. However, the controller parameters need to be tuned and optimized. In this paper, we introduce the use of two evolutionary algorithms, biogeography-based optimization (BBO) and particle swarm optimization (PSO), for multi-objective optimization (MOO) to tune the parameters of the PD controller of a drone. The combination of MOO, BBO, and PSO results in various methods for optimization: vector evaluated BBO and PSO, denoted as VEBBO and VEPSO; and non-dominated sorting BBO and PSO, denoted as NSBBO and NSPSO. The multi-objective cost function is based on tracking errors for the four states of the system. Two criteria for evaluating the Pareto fronts of the optimization methods, normalized hypervolume and relative coverage, are used to compare performance. Results show that NSBBO generally performs better than the other methods.

10:20-10:40 WeBT2.2

In Vivo Proof of Concept of a Pulsatile Physiologic Controller Framework for Ventricular Assist Devices, pp. 1056-1062

Salesch, Tobias	RWTH Aachen University
Gesenhues, Jonas	RWTH Aachen
Habigt, Moriz	RWTH Aachen University Hospital, Department of Anesthesiology
Mechelinck, Mare	RWTH Aachen University Hospital, Department of Anesthesiology
Hein, Marc	RWTH Aachen University Hospital, Department of Anesthesiology
Abel, Dirk	RWTH Aachen University

This paper presents a physiological ventricular assist devices controller framework. It extends a simple controller by any desired in-cycle feedforward trajectory. Two sample trajectories are investigated. The first trajectory generates a dynamic pumping during the filling phase (diastole) as a counter-pulse to the heart. In contrast, the second

trajectory allows pumping during the ejection phase (systole) as a co-pulse. The proof of the controlling concept is provided in vivo. The feedforward controllers are compared to the base controller without a feedforward trajectory. Pumping during systole leads to cardiac arrhythmia, whereas pumping during diastole leads to much better pulsation and slightly longer aortic valve opening. It also increases the mean and maximum aortic pressure.

10:40-11:00 WeBT2.3

AI-PID Control for Suppressing the Effects of Sudden Disturbances, pp. 1063-1068

Fujii, Takashi	OMRON Corporation
Abe, Yasuaki	OMRON Corporation
Inamoto, Shuji	OMRON Corporation
Sugawara, Shimon	AISing Ltd

A quality-related problem at manufacturing sites is the occurrence of sudden disturbances in the control system caused by variation and fluctuation in materials and machinery. Sudden disturbances cannot be sufficiently suppressed by the proportional–integral–differential (PID) control method that has come to be widely used at industrial sites. We therefore propose a method that extends PID control by adding compensation using a machine-learning model to suppress the effects of sudden disturbances. In an experiment using actual equipment, the proposed method reduced the convergence time of instability in the controlled variable due to a sudden disturbance by 90% on average relative to the convergence time for conventional PID control.

11:00-11:20 WeBT2.4

An Extended PID Control Framework, pp. 1069-1074

Ye, Linqi	Tsinghua University
Liang, Bin	Tsinghua University
Wang, Xueqian	Tsinghua University

Proportional-integral-derivative (PID) control is the most prevalent form of feedback control for a wide range of real physical applications. Traditional PID control theory is built on transfer function models. In this paper, we try to extend PID control to state-space models. Two formulations are presented to form an extended PID (EPID) control framework. One is the proportional-integral tracking controller (PITC), which includes a proportional and an integral part of all state errors. The other is the adaptive feedforward tracking controller (AFTC), which consists of a feedback part of state errors and a feedforward part which is obtained adaptively by using the previous sampled input. An interesting observation is that the two extended PID formulations are shown to be equivalent. EPID provides us a new perspective to view the mechanism of PID control itself as well as its relationship with other control theories such as tracking control, iterative learning control, and disturbance observer. All the points are demonstrated through a cart-pendulum example.

11:20-11:40 WeBT2.5

Next Generation Relay Autotuners – Analysis and Implementation, pp. 1075-1082

Hansson, Jonas	Lund University
Svensson, Magnus	LTH
Theorin, Alfred	ABB
Tegling, Emma	Lund University
Soltesz, Kristian	Lund University
Hagglund, Tore	Lund University
Astrom, Karl J.	Lund Inst. of Technology

In order to produce models for automatic controller tuning, this paper proposes a method that combines a short experiment with a novel scheme for approximating processes using low-order time-delayed models. The method produces models aimed to tune PI and PID controllers, but they could % and that could also be used for other model-dependent controllers like MPC. The proposed method has been evaluated in simulations on benchmark processes. It has also been implemented in an industrial controller and tested experimentally on a water-tank process. It is shown that our method is successful in estimating models for a variety of processes such as lag-dominated, delay-dominated, balanced, and integrating processes. We also demonstrate that the experiment time is both shorter and more predictable than currently used autotuners.

11:40-12:00 WeBT2.6

On Stability of a Nonlinear PID-Like Controller with Gravity Compensation for Input-Saturated Robot Manipulators, pp. 1083-1088

Jimenez-Quiroz, Marco	Instituto Politécnico Nacional - CITEDI
Moyrón Durán, Jerónimo	Instituto Politécnico Nacional - CITEDI
Moreno Valenzuela, Javier	Instituto Politécnico Nacional- CITEDI

In this note, the regulation problem of an n-link robot manipulator that is subject to input saturation is addressed. Our control strategy is based on a control law that uses gravity compensation together with a PID-like controller with bounded actions. The design is based on the usage of symmetrical hard saturation functions whose saturation levels are free to be selected by the user. As the resulting closed--loop equation is autonomous, we propose a Lyapunov function and apply an invariance principle known in the literature to prove asymptotic stability. Numerical simulations on a three degrees--of--freedom robot manipulator are presented, where the performance of our controller with respect to others reported in the literature is compared.

WeBT3 Room T3

Manufacturing & Mechanical Systems (Regular Session)

Chair: Lazar, Mircea	Eindhoven University of Technology
Co-Chair: Caverly, Ryan James	University of Minnesota

10:00-10:20 WeBT3.1

On Synchronization of Generic Lithography Machine Open-Chains Using a Novel Fine-Positioning Stage System, pp. 1089-1094

Al-Rawashdeh, Yazan Mohammad	Memorial University of Newfoundland
Al Janaideh, Mohammad	Memorial University of Newfoundland
Heertjes, Marcel	Eindhoven University of Technology

In this paper, we present an extension of our work on characterization of lithography machines. So far, the machine was approximated using three open-chains, reticle, optics and wafer chains, all sharing one common root. In general, the performance of the machine is assessed under partial or full synchronization among the chains being involved. The previously developed fine-positioning stage, or smart-material board, is utilized here to realize two types of synchronization, a partial one dealing with the synchronization error between the reticle and the wafer chains, specifically, and a modified synchronization which factors in all the chains motions. This stage provides additional degrees of freedom that can be used to regulate the tracking errors in a chain and to achieve partial or full synchronization as proposed herein without affecting the stability of the remaining stages. Therefore, in case an update is needed, the fine-positioning stage controller can be tuned either on-line or while the machine is in standstill. This feature of the fine-positioning stage makes it suitable as an add-on to exiting machines whose controllers settings are preferred to be held constant with the possibility of increasing their performance. These advantages will be illustrated by a simulation example.

10:20-10:40 WeBT3.2

Control of Penetration Rate in Distributed Parameter Rotary Drilling Systems, pp. 1095-1102

Faronov, Maksim V. Western University
Polushin, Ilia G. Western University

This paper deals with control of vertical penetration rate in a spatially distributed rotary drilling system with limited measurements at the bottom level and unknown parameters of the rock-bit interaction. Rotational dynamics of the drilling system are represented using an infinite-dimensional model. A control algorithm which allows for regulation of the vertical penetration rate to a desired constant level is presented. The proposed algorithm has a cascaded structure and consists of two parts. First, a reference signal for the rotational velocity of the drill bit is derived based on the speed gradient method. Second, an algorithm for tracking of reference velocity signal by the distributed parameters rotational dynamics is designed which involves an infinite-dimensional reference model and a disturbance observer. Stability of the closed-loop system is proved using Lyapunov method. Efficiency of the obtained results is illustrated by simulations.

11:00-11:20 WeBT3.4

Classification Tree-Based Wheel Unbalance Detection, pp. 1103-1108

Todeschini, Riccardo Politecnico Di Milano
Pozzato, Gabriele Politecnico Di Milano
Strada, Silvia Politecnico Di Milano
Savaresi, Sergio M. Politecnico Di Milano
Dambach, Gerhard BSH Hausgerate GmbH

In this paper, the problem of unbalance detection in vehicle's wheels is analyzed. Starting from accelerations and angular velocities acquired from a wheel balancer machine instrumented with Micro Electro-Mechanical Systems (MEMS) sensors, meaningful features are extracted for different conditions of unbalance, namely, 30 and 40g. Then, classification trees, for both the static and pure couple unbalance, are trained for the simultaneous detection of severity and angular position of the unbalanced masses. The performance of the proposed approach is validated against experimental data and its effectiveness is compared to a cascade algorithm, previously published by the authors.

11:20-11:40 WeBT3.5

Passivity-Based Adaptive Control of a 5-DOF Tower Crane, pp. 1109-1114

Schatz, Julia University of Minnesota
Caverly, Ryan James University of Minnesota

This paper presents a passivity-based adaptive control law for the payload trajectory tracking control of a three-dimensional tower crane with five degrees of freedom. The proposed method extends upon a two-dimensional tower crane control method in the literature by accounting for the additional nonlinearities that arise due to the rotation of the crane's jib. An adaptive control input is derived that ensures the tower crane features a passive input-output mapping. A novel approach is developed to bound the time derivative of the system's mass matrix, which is a critical part of the proof of passivity. Robust closed-loop input-output stability is proven using the Passivity Theorem. Numerical simulations are performed, showing the effectiveness of the control law on the three-dimensional tower crane.

11:40-12:00 WeBT3.6

Physics-Guided Neural Networks for Inversion-Based Feedforward Control Applied to Linear Motors, pp. 1115-1120

Bolderman, Max Eindhoven University of Technology
Lazar, Mircea Eindhoven University of Technology
Butler, Hans ASML

Ever-increasing throughput specifications in semiconductor manufacturing require operating high-precision mechatronics, such as linear motors, at higher accelerations. In turn this creates higher nonlinear parasitic forces that cannot be handled by industrial feedforward controllers. Motivated by this problem, in this paper we develop a general framework for inversion-based feedforward controller design using physics-guided neural networks (PGNNs). In contrast with black-box neural networks, the developed PGNNs embed prior physical knowledge in the input and hidden layers, which results in improved training convergence and learning of underlying physical laws. The PGNN inversion-based feedforward control framework is validated in simulation on an industrial linear motor, for which it achieves a mean average tracking error twenty times smaller than mass-acceleration feedforward in simulation.

WeBT4 Room T4

Machine Learning (Regular Session)

Chair: Sadamoto, Tomonori The University of Electro-Communications
Co-Chair: Vamvoudakis, Kyriakos G. Georgia Inst. of Tech

10:00-10:20 WeBT4.1

Combining Energy-Shaping Control of Dynamical Systems with Data-Driven Approaches, pp. 1121-1127

Sirichotiyakul, Wankun Boise State University
Satici, Aykut C Boise State University

Machine learning approaches to the problem of control design are flexible, but they demand large databases and computation time for training. Part of this central challenge is due to treating the environment as a black box, ignoring the useful geometric or algebraic structures of the control system. In this work, we propose an efficient data-driven procedure that leverages the known dynamics and techniques from nonlinear control theory in order to design swing-up controllers for underactuated robotic systems. We embed a neural network into the equations of motion of the robotic manipulator through its control input. This control function is determined by the appropriate gradients of a neural network, acting as an energy-like (Lyapunov) function. We encode the swing-up task through the use of transverse coordinates and goal sets; which provides a concise target for the neural network and drastically accelerates the rate of learning. We demonstrate the efficacy and robustness of the algorithm with numerical simulations and experiments on hardware.

10:20-10:40 WeBT4.2

Generating Constant Screw Axis Trajectories with Quintic Time Scaling for End-Effector Using Artificial Neural Network and Machine Learning, pp. 1128-1134

Malik, Aryslan Embry-Riddle Aeronautical University
Lischuk, Yevgeniy Thales Avionics Inc
Henderson, Troy Embry-Riddle Aeronautical University
Prazenica, Richard ERAU

In this work, the application of Neural Networks (NNs) and Machine Learning (ML) algorithms within the trajectory generation framework is presented. The main objective is to demonstrate that the trajectory of an end-effector of a multilink robotic system can be obtained by generating a path via the Bézier curve, imposing a finite jerk constraint, and using NN and ML algorithms to obtain the Constant Screw Axis (CSA) trajectory closest to the chosen path. These constraints are of importance because the former forces the jerk to be finite throughout the motion of an end-effector, which reduces the vibrations within the robotic arm or any other manipulator, and the latter smooths the

trajectory in Special Euclidean ($SE(3)$) space. First, a Bézier curve is chosen to define the path that an end-effector should follow. Subsequently, the finite jerk constraint is imposed. Lastly, NN and ML algorithms are used to obtain the closest CSA trajectory to the desired path. Since there are multiple CSA trajectories satisfying the initial configuration and final position, NN and ML algorithms are employed to minimize the Euclidean distance between the desired path (Bézier curve) and the actual obtained CSA trajectory.

10:40-11:00 WeBT4.3

Fast Online Reinforcement Learning of Distributed Optimal Controller for Large-Scale Network Systems, pp. 1135-1141

Hoshiya, Tomoki — The University of Electro-Communications

Sadamoto, Tomonori — The University of Electro-Communications

In this paper, we propose a fast real-time reinforcement learning (RL) control algorithm to design distributed controllers for large-scale network systems. When network size is large, existing RL-based methodologies can result in unacceptably long learning time, making them unsuitable for real-time control. The proposed approach overcomes this issue by aggregating states while keeping the aggregation error as small as possible. The aggregation matrix is constructed by a kind of sparse singular value decomposition of data. Next, a distributed controller is learned using the aggregated data by the RL method which is modified to promote sparsity of the controller by l_1-regularization. Because of the structure of the aggregation matrix, the resultant controller can have a highly sparse structure. The efficiency of the proposed method is shown through a numerical simulation of a complex network system whose graph structure is described by the Barabasi-albert model.

11:00-11:20 WeBT4.4

Model-Free Perception-Based Control Via Q-Learning with an Application to Heat-Seeking Missile Guidance, pp. 1142-1147

Kovalik, Wade — Georgia Institute of Technology

Zhai, Lijing — Georgia Institute of Technology

Vamvoudakis, Kyriakos G. — Georgia Inst. of Tech

Modern perception-based sensing schemes incorporate machine learning and high-dimensional image observations to control system states, but face issues of perception error and incomplete dynamics and state information. To address these issues, we propose a novel perception-based control strategy using model-free output feedback Q-learning that incorporates a Faster R-CNN convolutional neural network. We specifically investigate the optimal control problem of a linear time-invariant, discrete-time system given only the observation image data. We evaluate the data-driven control design process in ideal perception and degraded perception conditions. We show that the resulting controller from output feedback Q-learning is non-optimal, but the optimality loss is bounded with bounded perception error. Simulated results on a simple missile, whose seeker head observes synthetic images of the target heat source modeled as a blurry ball of light, show the efficacy of the proposed model-free perception-based control framework.

11:20-11:40 WeBT4.5

Safe Reinforcement Learning Control for Water Distribution Networks, pp. 1148-1153

Val Ledesma, Jorge — Aalborg University

Wisniewski, Rafal — Aalborg University

Kallesøe, Carsten Skovmose — Aalborg University

Reinforcement Learning (RL) is an optimal control method for regulating the behaviour of a dynamical system when the system model is unknown. This feature is a strong advantage for controlling systems, such as Water Distribution Networks, where it is difficult to have a reliable model. When learning an optimal policy with RL, the exploration phase implies high degree of uncertainty in the system operation. Large scale infrastructures such as WDN require a robust operation since they cannot afford fails during the operation. This paper presents a model-free control method which provides safety in the operation while learning an optimal policy. This method introduces a policy supervisor block in the control loop which assesses the safety of the learned policy in real-time. The safety verification consists of evaluating the trajectory on a standard linear model. In this model only the fundamental linear dynamics are represented and the system's dimensions do not require to be expressed with high accuracy. If the predicted trajectory violates the boundaries, the supervisor provides a safe control action. Simulation and experimental results prove the applicability of the proposed method.

WeBT5 — Room T5

Control Technology (Regular Session)

Chair: Heertjes, Marcel — Eindhoven University of Technology

Co-Chair: Wang, Ji — University of California, San Diego

10:00-10:20 WeBT5.1

Control Strategies Design and Comparison of DC-DC LLC Converter in V2X Mode for Electric Vehicle Charger Application, pp. 1154-1159

Al Attar, Houssein — Ecole Centrale De Nantes

Ghanes, Malek — Centrale Nantes

Hamida, Mohamed Assaad — IRCCyN, Ecole Centrale De Nantes

Taleb, Miassa — Renault Sas

Vehicle to Grid (V2G) and Vehicle to Home or Load (V2H/L) modes, in one word V2X mode, for Electric Vehicle (EV) chargers gets more attention in these days. AC-DC and DC-DC converters are usually used in an EV charger. In this paper, motivated by an industrial collaboration, the isolated bidirectional DC-DC LLC resonant converter is considered for the control purpose to improve the charger efficiency within both battery power and voltage ranges in V2X mode. For our best of knowledge, existing control solutions for this type of converter are mostly related to battery voltage or DC current regulations. The new challenge of this paper to achieve the improvements consists of input DC bus voltage control for such DC-DC converter. The main contribution leads to design the control laws based on the DC-DC LLC transfer function gain inversion. Three conventional modulation strategies based on an averaged small signal DC-DC LLC dynamic model converter with first harmonic approximation are presented. Pulse Frequency Modulation (PFM) control is firstly studied. Then, Pulse Width Modulation (PWM) and Phase Shift Modulation (PSM) based control are designed to avoid PFM drawbacks. The benefits and the limitations of each strategy are highlighted. A comparative study between the different strategies is generated with respect to control performances and converter efficiency.

10:20-10:40 WeBT5.2

Luenberger Observer-Based Flight Controller Design Using Robust Control Toolbox, pp. 1160-1165

Sato, Masayuki — Japan Aerospace Exploration Agency

Akasaka, Daisuke — MathWorks Japan

This paper presents a design example of structured H_{infty} control-based flight controller for the lateral-directional motions of JAXA's research airplane MuPAL-$alpha$ using MATLAB Robust Control Toolbox. To be more specific, the design problem of Luenberger observer-based flight controllers is addressed. Even if the controllers' structure is a priori supposed and fixed as Luenberger observer-based controllers, it does not always hold true that the controllers' states faithfully estimate the plants' states. We thus adopt two-step design approach to realize good control performance and good plants' states estimation simultaneously, viz., we first optimize H_{infty} control performance of the closed-loop system, and then

optimize H_{infty} observer performance under slightly relaxed H_{infty} control performance constraint. In the second process, systune command is used, because multiple design requirements are simultaneously imposed. The control and observer performance are both examined by the Hardware-In-the-Loop Simulation (HILS) tests using the actual MuPAL-$alpha$.

10:40-11:00 WeBT5.3

Chiller Pump Control Using Temperature Sensor Feedback, pp. 1166-1171

Nicolaisen, Mogens	Grundfos
Tsouvalas, Agisilaos	Grundfos
Kallesøe, Carsten Skovmose	Aalborg University

In commercial chilled water systems, one of the most prevalent system topology is the Primary/Secondary topology. In this topology, the primary and secondary circuits of the hydronic cooling system are hydraulically decoupled by a common pipe also referred to as the bypass. This allows the primary circuit to ensure minimum chiller flow without interfering with the secondary side. To maximize heat transfer and achieve optimal performance, the flow in the primary and secondary systems must equalize and thus leave no flow in the bypass line when the minimum chiller flow requirement is fulfilled. To achieve this goal in a robust and responsive manner a simple and cost-effective feedback method is proposed, where 3 temperature sensors constitute the control feedback for the primary pump control. Closed-loop stability is proven and automatic sensor calibration is proposed. The method is verified through lab test on a setup emulating by-pass of the Primary/Secondary topology.

11:00-11:20 WeBT5.4

IMU-Based Autonomous Solar Tracking System with Soft Actuators: A Machine Learning Approach, pp. 1172-1178

Barron, Daniel	University of Texas at San Antonio
Vugranam Chakravarthy, Praveen	University of Texas at San Antonio
Nagarkar, Rohan	University of Texas at San Antonio
Cao, Yongcan	University of Texas, San Antonio
Gao, Wei	The University of Texas at San Antonio

Increasing energy-efficiency and cost-effectiveness is an important research topic towards more economic solar panels. In this paper, we focus on developing a new data-based control design approach that adaptively adjusts the orientation of solar panels, built upon low-cost soft actuators, to increase their energy harvesting efficiency. In particular, the proposed approach is composed of four steps. First, we propose a calibration algorithm (CaA) that automatically creates a database of pneumatic input combinations with a correlating orientation for the yaw and pitch of a vertically mounted solar panel, as measured by an onboard Inertial Measurement Unit (IMU). Second, we design a machine learning algorithm that interpolates a finer granularity of the CaA output. Third, we propose a search algorithm that finds the corresponding set of data for the current Sun azimuth and elevation from the output of the machine learning algorithm. Forth, we propose a control algorithm that utilizes the output, obtained from the search algorithm, to apply the correct pneumatic input such that the solar panel can track the location of the Sun. To show the performance of the proposed approach, we conduct field tests to show that the solar panel with adaptively adjusted orientation under the proposed method can yield much higher power output. Another advantage of the proposed approach is the applicability of the approach to other solar harvesting systems, i.e., roof-mounted solar panels, because the data-based approach does not require physical models to be known or approximated.

11:20-11:40 WeBT5.5

A Solution to Gain Loss in Hybrid Integrator-Gain Systems, pp. 1179-1184

Heertjes, Marcel	Eindhoven University of Technology
van den Eijnden, Sebastiaan	Eindhoven University of Technology
Heemels, W.P.M.H.	Eindhoven University of Technology
Nijmeijer, Hendrik	Eindhoven University of Technology

Hybrid integrator-gain systems (HIGS) are nonlinear control elements that are designed to primarily operate as integrators in so-called integrator mode. Switching to gain mode occurs only when needed to keep sign equivalence between the input and output signals of the control element, thereby aiming for phase advantages. In order to guarantee the integrator mode to be the primary mode of operation, in this paper a combined pre- and post-filtering approach is studied. Such an approach offers a solution to the problem of gain loss that occurs when the HIGS switches too often between its modes. Typically, this happens in the presence of dominant high-frequency contributions in the input to the HIGS. Along the discussion on pre- and post-filtering, measurement results are presented from a high-performance industrial stage system.

11:40-12:00 WeBT5.6

Vibration Suppression for Coupled Wave PDEs in Deep-Sea Construction (I), pp. 1185-1201

Wang, Ji	University of California, San Diego
Krstic, Miroslav	University of California, San Diego

A deep-sea construction vessel (DCV) is used to install underwater parts of an offshore oil drilling platform at the designated locations on the seafloor. By using extended Hamilton's principle, a nonlinear partial differential equation (PDE) system governing the lateral-longitudinal coupled vibration dynamics of the DCV consisting of a time-varying-length cable with an attached item is derived, and it is linearized at the steady state generating a linear PDE model, which is extended to a more general system including two coupled wave PDEs connected with two interacting ordinary differential equations (ODEs) at the uncontrolled boundaries. Through a preliminary transformation, an equivalent reformulated plant is generated as a 4×4 coupled heterodirectional hyperbolic PDE-ODE system characterized by spatially varying coefficients on a time-varying domain. To stabilize such a system, an observer-based output-feedback control design is proposed, where the measurements are only placed at the actuated boundary of the PDE, namely, at the platform at the sea surface. The exponential stability of the closed-loop system, boundedness and exponential convergence of the control inputs, are proved via Lyapunov analysis. The obtained theoretical result is tested on a nonlinear model with ocean disturbances, even though the design is developed in the absence of such real-world effects.

WeBT6 Room T6

Stochastic Process (Regular Session)

Chair: Oliveira, Tiago Roux	State University of Rio De Janeiro
Co-Chair: Kallesøe, Carsten Skovmose	Aalborg University

10:00-10:20 WeBT6.1

Nonlinear Grey-Box Identification of Gravity-Driven Sewer Networks with the Backwater Effect: An Experimental Study, pp. 1202-1207

Balla, Krisztian M	Aalborg University
Knudsen, Casper Houtved	Aalborg University
Hodzic, Adis	Aalborg University
Bendtsen, Jan Dimon	Aalborg University
Kallesøe, Carsten Skovmose	Aalborg University

Real-time control of urban drainage networks requires knowledge about stored volumes and flows in order to predict overflows and

optimize system operation. However, using flow sensors inside the pipelines means prohibitively high installation and maintenance costs. In this article, we formulate two nonlinear, constrained estimation problems for identifying the open-channel flow in urban drainage networks. To this end, we distribute cost-efficient level sensors along the pipelines and formulate the estimation problems based on the spatially-discretized kinematic and diffusion wave approximations of the full Saint-Venant partial differential equations. To evaluate the capabilities of the two models, the two approaches are compared and evaluated on modeling a typical phenomenon occurring in drainage systems: the backwater effect. An extensive real-world experiment demonstrates the effectiveness of the two approaches in obtaining the model parameters on a scaled water laboratory setup, in the presence of measurement noise.

10:20-10:40 WeBT6.2

Maximum Likelihood Constraint Inference from Stochastic Demonstrations, pp. 1208-1213

McPherson, David	University of California, Berkeley
Stocking, Kaylene	University of California, Berkeley
Sastry, Shankar	Univ. of California at Berkeley

When an expert operates a safety-critical dynamic system, constraint information is tacitly contained in their demonstrated trajectories and controls. These constraints can be inferred by modeling them as a constrained Markov Decision Process and finding which constraint is most likely to generate the demonstrated controls. Prior constraint inference work has focused mainly on deterministic dynamics. Stochastic dynamics, however, can capture the uncertainty inherent to real applications and the risk tolerance that requires. This paper extends maximum likelihood constraint inference to stochastic applications by using maximum causal entropy likelihoods. Furthermore, this extension does not come at increased computational cost, as we derive an algorithm that computes constraint likelihood and risk tolerance in a unified Bellman backup, thereby keeping the same computational complexity.

10:40-11:00 WeBT6.3

Best Linear Mean Square Filter for a New Class of Markovian Jump Linear Systems with Hidden Markov Parameter, pp. 1214-1219

Vila Vergés, Fortià	Laboratório Nacional De Computação Cinetífica (LNCC)
Fragoso, Marcelo	Lncc / Mct

In this paper we derive the best linear mean square filter for a new class of Markovian jump linear systems (MJLS) with incomplete observations of Markovian jump parameter (the mechanism that model the switching/failure). Besides, we also carve out the associated stationary filter which amounts here to obtain the convergence of the innovation gain to a stationary value under the assumption of mean square stability of the MJLS and ergodicity of the Markov chain. A favorable feature of the stationary filter is that bear the advantage that it is easy to implement since the filter gain can be performed offline. Relying on Murayama's stochastic numerical method we carry out simulations to evaluate the filters performances vis-a-vis the actual Markov chain parameter.

11:00-11:20 WeBT6.4

Model-Free Neuromuscular Electrical Stimulation by Stochastic Extremum Seeking (I), pp. 1220-1235

Paz, Paulo	State University of Rio De Janeiro
Oliveira, Tiago Roux	State University of Rio De Janeiro
Pino, Alexandre Visintainer	Federal University of Rio De Janeiro (COPPE/PEB)
Fontana, Ana Paula	Federal University of Rio De Janeiro (UFRJ)

Stochastic extremum seeking (ES) approach is employed to adapt the gains of a proportional-integral-derivative (PID) control law for functional neuromuscular electrical stimulation. The proposed scheme is applied to control the position of the arm of healthy volunteers and stroke patients so that coordinated movements of flexion/extension for their elbow can be performed. This approach eliminates the initial tuning tests with patients since the controller parameters are automatically computed in real time. The PID parameters are updated by means of a discrete version of the multivariable stochastic ES in order to minimize a cost function which brings the desired performance requirements. Experimental results with healthy volunteers as well as stroke patients show the usual specifications commonly considered in physiotherapy for functional rehabilitation are eventually satisfied in terms of steady-state error, settling time, and percentage overshoot. Quantitative results show a reduction of 62.30% in terms of the root-mean-square error (from 9.02 degrees to 3.40 degrees) when comparing the tracking curves of the last cycle to the first cycle in the experiments with all subjects.

11:20-11:40 WeBT6.5

Optimal Control of Virtual Batteries Using Stochastic Linearization, pp. 1236-1242

Brahma, Sarnaduti	The University of Vermont
Almassalkhi, Mads	University of Vermont
Ossareh, Hamid	University of Vermont

Stochastic Linearization (SL) is a method of linearizing a nonlinearity that, unlike traditional Jacobian linearization that is valid only close to the operating point, uses statistical properties of the input to render the linearization fairly accurate over a wide range of inputs. In this paper, the method of SL is applied to optimally design controllers for an aggregation of distributed energy resources (DERs), called a virtual battery (VB), by taking into account the solar penetration levels, grid parameters, and the VB power limits. Analysis and simulation results show that VB performance can be greatly improved over a baseline design that ignores VB power limits, and that the controllers can be adaptively designed to effectively respond to changes in system parameters. This proves to be a new method for designing controllers to improve the participation of power-constrained VBs.

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