**Workshop I** (Required Information Complete)

Advanced Magneto-Mechatronics Systems: Modeling, Sensing and Control

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| ***Organizers*** | Kun Bai, Huazhong University of Science and Technology  Shaohui Foong, Singapore University of Technology and Design  Chun-Yeon Lin, National Taiwan University  Silu Chen, Chinese Academy of Sciences  Min Li, Minnesota State University |
| ***Time*** | 9AM – 12:30PM (EDT) |
| ***Location*** | TBD |

Abstract

Magnetic fields are widely utilized as media for energy conversion and information storage. Harnessing magnetic fields for sensing and control of mechatronic systems is a reliable and efficient means as magnetic fields are invariant to environmental factors such as temperature, pressure, and light, while permitting non-contact and remote functions across multiple non-ferromagnetic mediums. Inspired by the advancements in new materials, sensor fusion technology and embedded computations, the applications of magneto-mechatronic systems are being pushed forward to a new level, advancing a wide variety of subjects being precisely measured, perceived, and manipulated at unprecedented resolution, scale, and speed. Challenges, however, are presented in modeling, sensing and control of magneto-mechatronic systems to meet the continuously increasing demands and emerging applications. The IEEE/ASME AIM2020 Workshop on Advanced Magneto-Mechatronics Systems aims at bringing mechatronic researchers and practitioners from multiple disciplines to discuss emerging fundamental issues in mechatronics from perspectives over a wide

spectrum of applications, such as smart actuators, field reconstruction and perception, medical and surgical devices. This Workshop will discuss recent advances, challenges and opportunities in modeling, sensing and control of magneto-mechatronic systems that move forward new technologies in mechatronic systems with more and more ‘smart functions’. Both hardware innovations and methodology developments will be presented, balancing theoretical analysis and modeling with experimental demonstrations and discussions. The AIM Workshop on magneto-mechatronic systems will help better understand the fundamental concepts and theories in formulating magneto problems and determine the major challenges for future magneto-mechatronic systems, as well as identify key mechatronic technologies for meeting these challenges.

Invited talks

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| **#** | **Title** | **Speaker** |
| **1** | *Magnetic Field Based Sensing and Control of Smart Actuators* | Kun Bai |
| **2** | *Passive Magnetic Field-based Sensing and Localization* | Shaohui Foong |
| **3** | *Magnetic Field Modeling and Sensors for Non-Ferrous Metallic and Biological Objects* | Chun-Yeon Lin |
| **4** | *Extending the Optimal Control to Integrated Mechatronics Design of Electromagnetic Servo Systems: Theory and Case Studies* | Silu Chen |
| **5** | *Eddy-Current Field Reconstruction and Control Based on Distributed-Parameter Models for Machine Perception and Stimulation* | Min Li |

Abstracts

*Magnetic Field Based Sensing and Control of Smart Actuators*

Smart actuators with dexterous motion and direct force/torque manipulations are central for emerging intelligent systems in a wide range of applications ranging from manufacturing to robotics. Existing actuator systems are primarily built by connecting motors and mechanical linkages to achieve complex motions and external encoders/sensors for position and force control. These systems usually have complex structures which lead to singularities in their motion (multi-DOF systems) and difficulties in direct force/torque manipulations. This talk will present smart actuator designs that can achieve complex motions and precise force/torque manipulations with compact structures and integrated field sensors for efficient low-level sensing and control. Based on the integration of actuation-sensing-control modules and driving algorithms permitting parallel computations, advanced control strategies, such as spindle load compensation, fault detection/remedy algorithms and compliant joint control can be efficiently implemented on the actuator systems. Emerging applications of these smart actuators including conformal printing of curved electronics and master-slave robots will be demonstrated.

*Passive Magnetic Field-based Sensing and Localization*

Numerous medical and surgical operations, such as minimally invasive procedures, require knowledge of the position and orientation of the target device or instrument inside the body. Currently, tethered embedded vision cameras and diagnostic imaging techniques (CT, X-Rays, MRI) are widely employed to gain instantaneous spatial feedback of the target inside the body. However, these methods can be cumbersome to deploy, limited by onboard power and potentially harmful to the patient under prolonged use. Localization using artificially generated electromagnetic fields (similar to GPS) is possible but are particular difficult to use in the clinical setting due to the need for calibrating and constricting the body with respect to fixed position of the electromagnetic field generator. Another drawback is that the target of interest, which contains the electromagnetic sensor is mechanically and electronically tethered. Here a non-invasive localization system harnessing passive magnetic tracking technology and adapted for clinical use is presented as a viable alternative to contemporary established protocols. This approach addresses the key deficiencies in current electromagnetic localization technology and retains the benefits of field-based localization such as not requiring line of sight, insensitivity to biological tissue and radiation free.

*Magnetic Field Modeling and Sensors for Non-Ferrous Metallic and Biological Objects*

Magnetic and Eddy-current (M/EC) sensing systems play important roles in a broad spectrum of applications ranging from manufacturing to biomedical engineering and have many advantages, such as long-term reliability, wide measuring range, fast response, and high resolution. The formulation of the M/EC fields is an important step to design analysis and develop these sensing systems. The distributed current source (DCS) method which formulates the axis-symmetrical and three dimensional M/EC fields of non-ferrous metallic and biological objects into first and second order systems for design analysis and development of magnetic sensor based EC and coupled differential coil systems for sensing non-ferrous metallic and biological objects will be introduced in this talk. The state-space representation of M/EC fields in DCS method provides a basis for the subsequent steady state, time dependent, and frequency analysis. One more merit of the DCS method is that this method performs better than FEA for calculations of the weak MFDs generated from the tiny ECDs induced in the biological objects to facilitate the development of low-cost coupled differential coil systems for detection of biological objects.

*Extending the Optimal Control to Integrated Mechatronics Design of Electromagnetic Servo Systems: Theory and Case Studies*

Optimal control theory has played great roles in robust controller design and state estimation for high-performance servo systems. The associate methods to efficiently solve the controller parameters provide us a potential tool to optimize the parameters in the dynamical systems, which can be from electromagnetic, mechanical parts besides controllers, if such parameters can be augmented under one single “composite feedback gain matrix”. This is named as “integrated mechatronics design”, which allows partially reconfigure the system with exchanging parts and retuning the controller parameters during production. However, unlike the problem of pure controller parameter synthesis, the formed “composite feedback gain matrix” is with the structure constraints, which cannot be solved by methods such as Riccati equation and linear matrix inequality. This talk would like to share some recent progress to solve this class of problems by extending the optimal control theory. First, the revisions of the optimal control theory on linear quadratic regulator, H\_2 and H-Infinity control are given. And the limitations of the current controller synthesizing methods when dealing with the integrated mechanical design are given subsequently. Later, the parameter optimization method toward integrated mechatronics design is given in the case that the system has an accurate model. Eventually, such method is further extended to the case that the accurate model of the system is unavailable. The case studies are accomplished to illustrate the applicability of the developed method. Last by not least, the remarks on possible future works are given.

*Eddy-Current Field Reconstruction and Control Based on Distributed-Parameter Models for Machine Perception and Stimulation*

With many outstanding characters (such as great penetration, fast response, well-defined theory, and insensitivity to oil or other media), eddy current (EC) generated inside the electrically conductive objects with the presence of the timing-varying magnetic field has been widely used in the fields of nondestructive sensing and testing, manufacturing and biomedicine. EC not only has the ability to noninvasively measure/detect object properties (machine perception), but also works as an approach of non-contact energy transmission (electromagnetic stimulation). A new machine perception method based on EC effects to reconstruct physical fields (EC field, electrical-conductivity field and hidden geometrical features) of a nonferrous material commonly encountered in intelligent manufacturing using finite magnetic flux density (MFD) measurements will be introduced. The measurement models of physical fields based on the established distributed-parameter models using discrete MFD measurements are linearly established, reducing the physical field reconstruction to a linear inverse problem for solving using Tikhonov regularization method. Based on the distributed-parameter models of the EC system, a direct field-feedback method to control 3 dimensional (3D) unmeasurable EC fields/stimulation with multiple electromagnets (EMs) using the finite MFD measurements will also be introduced. This method provides a possible approach for the controls of other unmeasurable physical fields.

Biographies

**Kun Bai**,received his B.S. degree from Zhejiang University, China in 2006 and earned his M. S. and Ph. D. degrees both from the Woodruff School of Mechanical Engineering at Georgia Institute of Technology, Atlanta, US in 2009 and 2012 respectively. Currently, he is Associate Professor with the State Key Laboratory of Digital Manufacturing Equipment and Technology and the School of Mechanical Science and Engineering at Huazhong University of Science and Technology, China. His research interests include smart actuators/sensors and their novel applications, where he has published a book and over 30 papers and also held over 10 patents from China and US. He received ASME DSCD Mechatronics TC Best Paper Award in 2019. He is Guest Editor of IEEE/ASME Trans. on Mechatronics and also Associate Editor for IEEE/ASME International Conference on Advanced Intelligent Mechatronics.

**Shaohui Foong**, is an Associate Professor in the Engineering Product Development (EPD) pillar at the Singapore University of Technology and Design (SUTD) and Visiting Academician at the Changi General Hospital, Singapore. He received his B.S., M.S. and Ph.D. degrees in Mechanical Engineering from the George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA. He is currently the principal investigator for the Aerial Innovation Research (AIR) Laboratory @ SUTD and actively pursues research in unmanned systems, robotics as well as medical devices. One of his ongoing projects is centred on developing nature inspired aerial crafts which adapts the dispersal mechanism of maple seeds to achieve efficient flight. His other research interests include system dynamics & control, nature-inspired robotics, magnetic localization, medical devices and design education & pedagogy.

**Chun-Yeon Lin**, received the B.S. degree in mechanical engineering from National Central University, Taoyuan, Taiwan, in 2003; the M.S. degree in electrical control engineering from National Chiao-Tung University, Hsinchu, Taiwan, in 2005; the M.S. degree in mechanical engineering from Stanford University, Stanford, CA, USA, in 2011; and the Ph.D. degree in mechanical engineering from George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, USA, in 2017. Currently, he is an assistant professor in the Department of Mechanical Engineering, National Taiwan University. His current research interests include mechatronics, physical field modelling, and electromagnetic system.

**Silu Chen**, received the B.Eng. and the Ph.D. degrees in Electrical Engineering from the National University of Singapore (NUS), in 2005 and 2010 respectively. From 2010 to 2011, he was with the Manufacturing Integration Technology Ltd, a Singapore-based semiconductor machine designer, as a senior engineer on motion control. From 2011 to 2017, he was a scientist in the Mechatronics group, Singapore Institute of Manufacturing Technology (SIMTech), Agency for Science, Technology and Research (A\*STAR). During this period, he also acted as co-PI of the SIMTech-NUS Joint Lab on Precision Motion Systems, adjunct assistant professor of NUS, and PhD co-advisor for A\*STAR Graduate School. Since 2017, he has been with the Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences, as a professor. His current research interests include design and optimization of high-speed motion control systems, and beyond-rigid-body control for compliant light-weight systems. He has published more than 80 technical papers, co-author one monograph on precision motion control and industrial automations. He is currently serving as Associate Editor of IEEE International Conference on Advanced Intelligent Mechatronics.

**Min Li**, received the B.S. and M.S. degrees in mechanical engineering from the Huazhong University of Science and Technology, Wuhan, China, in 2008 and 2011, respectively, and the Ph.D. degree in mechanical engineering from Georgia Institute of Technology, Atlanta, GA, USA in 2017. He is currently an Assistant Professor with the Department of Mechanical and Civil Engineering, Minnesota State University, Mankato, MN 56001 USA. His research interests include system dynamics/control, automation, and mechatronics.

**Workshop II** (Required Information Complete)

Agile Robotics for Industrial Automation Competition

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| ***Organizers*** | Anthony Downs, National Institute of Standards and Technology  William Harrison, National Institute of Standards and Technology  Craig Schlenoff, National Institute of Standards and Technology |
| ***Time*** | 9AM – 12:30PM and 1:30PM – 5PM (EDT) |
| ***Location*** | TBD |

Abstract

The Agile Robotics for Industrial Automation Competition (ARIAC) is designed to test the agility of industrial robot systems, making them more productive and autonomous, while requiring less time from shop floor workers. The goal is to promote automatic failure identification and recovery, automated planning to minimize up-front robot programming time, and ease of swapping out robots of different manufacturers without massive reprogramming. Come learn more about this competition and how to get involved in future iterations. Hear winning approaches from the top finishing teams and help guide the direction of the competition as it moves forward.

Invited talks

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| **#** | **Title** | **Speaker** |
| **1** | *ARIAC Overview* | Craig Schlenoff |
| **2** | *ARIAC Environment* | William Harrison |
| **3** | *ARIAC Metrics* | Anthony Downs |
| **4** | *Team Approach Talk I* | Attila Vidacs |
| **5** | *Team Approach Talk II* | Siwei Feng |
| **6** | *Team Approach Talk III* | Stephen Gray |
| **7** | *Industry Representative Talk I* | Philip Freeman |
| **8** | *Industry Representative Talk II* | Matthew Robinson |

Abstracts

*ARIAC Overview*

An overview of the work that NIST does in the field of Agility and how this has led to the ARIAC Competition.

*ARIAC Environment*

An overview of how the environment for the ARIAC Competition has been designed, the reasoning behind the design choices, and some of the back-end details of the competition.

*ARIAC Metrics*

A presentation on the what metrics were used and how they were determined for this year’s ARIAC competition, including discussion of what things have changed or are planned to change in future years

*Team Approach Talk I*

A presentation on how the team decided to approach the problems of this year’s ARIAC competition and unique methods of overcoming the new challenges.

*Team Approach Talk II*

A presentation on how the team decided to approach the problems of this year’s ARIAC competition and unique methods of overcoming the new challenges.

*Team Approach Talk III*

A presentation on how the team decided to approach the problems of this year’s ARIAC competition and unique methods of overcoming the new challenges.

*Industry Representative Talk I*

A presentation on the needs and thoughts of the manufacturing industry, how the competition is doing in terms of meeting those needs and helping shape the future direction of the competition.

*Industry Representative Talk II*

A presentation on the needs and thoughts of the manufacturing industry through the ROS-Industrial community, how the competition is doing in terms of meeting those needs, and helping shape the future direction of the competition.

Biographies

**Craig Schlenoff**, is the Group Leader of the Cognition and Collaboration Systems Group, the Associate Program Manager of the Measurement Science for Manufacturing Robotics Program, and the Project Leader of the Agility Performance of Robotic Systems project in the Intelligent Systems Division at the National Institute of Standards and Technology. His research interests include knowledge representation/ontologies, intention recognition, and performance evaluation of autonomous systems and industrial robotics. He has led multiple million-dollar projects addressing performance evaluation of advanced military technologies and agility performance of manufacturing robotic systems. He has published over 150 journal and conference papers, guest edited three journals, guest edited three books, and written four book chapters. He is currently the Associate Vice President for Standardization in the IEEE Robotics and Automation Society and the co-chair of the IEEE Robot Task Representation Working Group, was previously the chair of the IEEE Ontology for Robotics and Automation Working Group and has served as the Program Manager for the Process Engineering Program at NIST and the Director of Ontologies at VerticalNet. He also teaches two courses at the University of Maryland, College Park: “Calculus” and “Building a Manufacturing Robot Software System.” He received his Bachelor’s degree from the University of Maryland, his Master’s degree from Rensselaer Polytechnic Institute, and his PhD from the University of Burgundy (France).

**William Harrison**, is a mechanical research engineer in the Department of Commerce’s National Institute of Standards and Technology (NIST). Harrison’s specialty within the project is virtual fusion, which is the mix of simulated and real components for process validation and training. His interests include virtual reality, game engines, augmented reality, and CG modeling. He received his bachelor’s degree from the University of Michigan, his master’s from the University of Florida, and his PhD from the University of Michigan.

**Anthony Downs**, is a Mechanical Engineer at the National Institute of Standards and Technology, working in the Intelligent Systems Division. He is one of the designers of the Agile Robotics for Industrial Automation Competition (ARIAC) which is currently running its 4th year in 2020 and has served as one of the Judges for the ARIAC competition during the 2019 competition. He is the lead in the IEEE Standards Association (IEEE SA) Study Group on Robot Agility, which is currently in the process of becoming a Working Group under the Robotics and Automation Society (IEEE RAS) for developing standards and test metrics for Robot Agility. He is also part of the IEEE SA Robot Task Representation Working Group which is working to develop a representation of robot tasks that is independent of the nature of the task being performed. He has received awards for his efforts contributing to the testing of robots and technology, including the 2011 TARDEC Director’s Coin award for the NIST Efforts in support of the Multi Autonomous Ground-robotic International Challenge (MAGIC), the “Outstanding Information Technology Achievement in Government” from the Government Computer News (GCN) and a NIST/Department of Commerce Gold Medal for the NIST Efforts in developing and performing tests and evaluations for the DARPA Transformative Applications Project, and the 2014 NIST Edward Bennett Rosa Award for “Outstanding Achievement in or contributions to the development of meaningful and significant engineering, scientific or documentary standards either within NIST or in cooperation with other government agencies or private groups” for the work on the DHS/NIST/ASTM Standard Test Methods for Response Robots Project.

**Attila Vidacs**, received the MSc and PhD degrees from the Budapest University of Technology and Economics (BME) at the Faculty of Electrical Engineering and Informatics, in 1996 and 2000, respectively. His research interests are in the field of cloud robotics, cooperative and modular robot systems, IoT communication technologies, ad-hoc and wireless networking. Currently he is leading the Cloud Robotics Group within HSN Lab. He was involved as a researcher in many national and international research project (including EU H2020 5G-SMART, EU FP5 IST-MIND, IST-INTERMON; FP6 IST-MOME, IST-MUSE, E-NEXT; FP7 EARTH, and acted as a Management Committee Member of COST Actions 295 and IC-0806). He published more than 100 conference and journal papers in various scientific research fora. He was the deputy head of BME-TMIT (2013- 2016). He was the head of the High Speed Networks Lab (HSN Lab), a research group of more than 20 researchers and 40 PhD students at BME (2013-2018). Between 2000 and 2006 he worked as a member of Research Group for Informatics and Electronics of the Hungarian Academy of Sciences. He worked as a visiting researcher at the University of Technology, Computer Architecture and Digital Technique Lab, Delft, The Netherlands; at the Research and Development Center of the Nippon Telegraph and Telephone Corp., Tokyo; and at the Lab of Telecommunications Technology of Helsinki University of Technology, Espoo, Finland.

**Siwei Feng**, is a second year Ph.D. student studying computer science at Rutgers, supervised by Prof. Jingjin Yu with a research focus on multi-robot systems.

**Philip Freeman**, is a Senior Technical Fellow in Boeing Research and Technology (BR&T), currently focused on Advanced Production Systems, Assembly Automation, & Precision Robotics. As a Senior Technical Fellow in the area of Materials and Manufacturing Technology, Dr. Freeman has expertise in robotics, automation, and control. He works from Boeing’s Research and Technology Center in South Carolina. From 2012 to 2014, Dr. Freeman worked with BR&T South Carolina on 787 production support, helping the program meet production ramp up rate targets. Prior to that, he worked in the Assembly and Integration Technology team in St. Louis where he helped implement many of the automated drilling systems on the F/A-18 and F-15. Previously, he worked as Boeing’s liaison to the Advanced Manufacturing Research Centre in Sheffield, UK where he led the Centre’s development of an automated assembly research team, now the AMRC’s Integrated Manufacturing Group (IMG). Since joining Boeing in 1998, Dr. Freeman’s research work has been primarily focused on improving the accuracy of precision automated drilling and milling systems through accurate kinematics modeling and the use of robust machine vision. He holds over 30 patents covering a range of manufacturing technologies, and is an author on several publications in machine tool volumetric accuracy and machine vision for inspection. Currently, his research focus is in the area of automatic task and path planning for industrial automation. Dr. Freeman is a member of American Society of Mechanical Engineers (ASME) where he is on the Board of Strategic Initiatives, serves as the vice chairperson for ASME B5.TC52 standards committee on machine tool performance, and is a contributing member to the Subcommittee on Robotic Arms (Manipulators). He is also a member of the Institute of Electrical and Electronic Engineers (IEEE) where he previously served on the industrial advisory board for the Robotics and Automation Society (RAS). Dr. Freeman earned his D.Sc. in System Science and Mathematics (2012), his M.S. in Mechanical Engineering (2003), and his B.S. in Mechanical Engineering (1997) all from Washington University in St. Louis.

**Matthew Robinson**, is the Program Manager for the ROS-Industrial Consortium Americas. He is bringing his energy and passion to an exciting opportunity to make an impact and contribute to the advanced capabilities and performance of ROS-Industrial through the leadership of the ROS-Industrial Consortium, leveraging experience base to seek to bridge gap from strictly to technical development to sustainable, replicable, value realizing solutions on factory floors. During his time at Caterpillar, he led a research team in manufacturing automation applications, managed programs and projects to deliver novel validated solutions to solve difficult challenges in the areas of fabrication, planning, and process/value chain optimization. He developed initial quality system for new fabrication facility for aftertreatment components utilizing APQP methodology, developed welding technologies for the welding of aftertreatment components, procured manufacturing equipment for new fabrication facility. He developed automated inspection system and requirements for heavy fabs, led development of manufacturing line optimization tools for fabrication facilities, consulted on new manufacturing technologies as part of NPI process and incorporated lean methods for the fabrications of these new products. He led efforts regarding automation technology research and implementation.

**Workshop III** (Required Information Complete)

Challenges and Opportunities of Soft Robotics: Research, Applications, and Education

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| ***Organizers*** | Hao Su, City University of New York  Kevin Chen, Massachusetts Institute of Technology  Antonio Di Lallo, City University of New York |
| ***Time*** | 9AM – 12:30PM and 1:30PM – 5PM (EDT) |
| ***Location*** | TBD |

Abstract

During the past few years, advancement in material sciences, flexible electronics, sensors/actuators, and computation/algorithms creates new opportunities for research and development of soft robots. The paradigm shift from rigid contact towards soft interaction enables not only a safer physical human-robot interaction but also new forms of robots. The workshop brings experts in the field together to present state of the artwork and discuss the trend of enabling technologies for soft robots that are either biomimetic or for real-world applications. The workshop will also cover how to leverage soft robots to lower the barrier for STEM education.

Invited talks

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| **#** | **Title** | **Speaker** |
| **1** | *Instability-driven soft robot* | Katia Bertoldi |
| **2** | *Magnetic Soft Robots* | Xuanhe Zhao |
| **3** | *Untethered high performance soft robots for human augmentation* | Hao Su |
| **4** | *Micro-aerial robots powered by soft artificial muscles* | Kevin Chen |
| **5** | *Research and Education at the Convergence of Frontier Technologies* | Vikram Kapila |
| **6** | *Evolving the Physical Structure of Compliant, Soft, and Biological Robots* | Josh Bongard |
| **7** | *Adding Soft to Robotics: From Gecko-inspired Wall Climbing to Vine-inspired Navigation* | Elliot W. Hawkes |
| **8** | *Programming Shape Shifting and Locomotion through Anisotropy* | Shu Yang |

Abstracts

*Instability-driven soft robots*

Fluidic soft actuators are enlarging the robotics toolbox by providing flexible elements that can display highly complex deformations. Although these actuators are adaptable and inherently safe, their actuation speed is typically slow because the influx of fluid is limited by viscous forces. To overcome this limitation and realize soft actuators capable of rapid movements, we focus on spherical caps that exhibit isochoric snapping when pressurized under volume-controlled conditions. First, we note that this snap-through instability leads to both a sudden release of energy and a fast cap displacement. Inspired by these findings, we investigate the response of actuators that comprise such spherical caps as building blocks and observe the same isochoric snapping mechanism upon inflation. Last, we demonstrate that this instability can be exploited to make these actuators jump even when inflated at a slow rate. Our study provides the foundation for the design of an emerging class of fluidic soft devices that can convert a slow input signal into a fast output deformation.

*Magnetic Soft Robots*

While human tissues are mostly soft, wet and bioactive; machines are commonly hard, dry and biologically inert. Bridging human-machine interfaces is of imminent importance in addressing grand challenges in health, security, sustainability and joy of living faced by our society in the 21st century. However, designing human-machine interfaces is extremely challenging, due to the fundamentally contradictory properties of human and machine. In this talk, we will highlight MIT SAMs Lab’s recent development of soft robots that can potentially perform various tasks inside human body. The soft robots are constructed by 3D printing of a new biocompatible magneto-active polymer into various structures. Our approach is based on direct ink writing of an elastomer composite containing ferromagnetic microparticles. By applying a magnetic field on the dispensing nozzle while printing, we make the particles reoriented along the applied field to impart patterned magnetic polarity to printed filaments. This method allows us to theoretically and experimentally program ferromagnetic domains in complex 3D-printed soft robots, enabling a set of unprecedented functions including crawling, jumping, grasping and releasing objects, and transforming among various 3D shapes controlled by applied magnetic fields. The actuation speed and power density of our 3D-printed soft robots with programmed ferromagnetic domains are orders of magnitude greater than existing 3D-printed active materials and structures. We will demonstrate a set of clinically relevant applications uniquely enabled by the 3D-printed magneto-active soft robots.

*Untethered high performance soft robots for human augmentation*

Wearable robots for physical collaboration with humans are the new frontier of robotics, but they are typically bulky, obtrusive, and lack intelligence. Soft robots hold great potential to provide a conformal and unobtrusive interface to humans. However, soft robots are generally slow, suffer from low forces, and tethered to energy sources. To overcome those challenges, we develop high-torque density actuators to enable untethered soft robots with high force and high bandwidth for physical human-robot interaction. In addition, we are studying controllers for a variety of versatile wearable soft robots we have developed to augment human performance for able-bodied individuals and enhance mobility for people with lower-limb impairments, including children with cerebral palsy and people with musculoskeletal disorders. We envision our soft robots with learning-based controllers will enable a paradigm shift of wearable robots from lab-bounded rehabilitation machines to ubiquitous personal robots for workplace injury prevention, pediatric and elderly rehabilitation, and home care.

*Micro-aerial Robots Powered by Soft Artificial Muscles*

Flying insects capable of navigating in highly cluttered natural environments can withstand inflight collisions because of the combination of their low inertia and the resilience of their wings, exoskeletons, and muscles. Current insect-scale (<10 cm, <5 g) aerial robots use rigid microscale actuators, which are typically fragile under external impact. Towards improving collision robustness of micro-aerial robots, we develop the first heavier-than-air aerial robots powered by soft artificial muscles that demonstrate open-loop, passively stable ascending flight as well as closed-loop, hovering flight. First, we design and fabricate lightweight (0.1 g), power-dense (600 W/kg), and high bandwidth (500 Hz) dielectric elastomer actuators (DEA) to drive the robots. Second, we increase actuator output mechanical power and improve its control authority by addressing challenges unique to soft actuators, such as nonlinear transduction and dynamic buckling. Third, we demonstrate our robot can both achieve controlled hovering flight and passive inflight collision recovery. Our work demonstrates how soft actuators can achieve sufficient power density and bandwidth to enable controlled flight, illustrating the vast potential of developing next-generation agile soft robots.

*Research and Education at the Convergence of Frontier Technologies*

In this talk, I will lay out the evolution of research and education activities in MCRL. Slightly over two decades ago, I began by developing a hands-on control-engineering program that slowly transformed into research and education activities focused on mechatronics. A decade ago, with the arrival of smart mobile devices (smartphones and tablets), MCRL focused its efforts on mechatronics and robotics with applications to natural and intuitive human-machine interaction as well as health and wellness. More recently, having observed the rapid progress in several emerging technologies and their potential for broad societal impact, MCRL has transitioned its activities to explore and perform education and research activities at the convergence of robotics, artificial intelligence, augmented reality/virtual reality, and blockchain technologies. In this talk, in addition to sharing an overview of our education activities, I will showcase examples of our research products.

*Evolving the Physical Structure of Compliant, Soft, and Biological Robots*

In the vast majority of robotics projects (including soft robotics), it is assumed that the physical structure of the robot is designed manually or, at best, parameters of a manually-defined structure are optimized. In this talk I will survey our attempts to automate the design of soft robots from the ground up, and highlight the particular challenges and opportunities of doing so. In particular, I will describe how searching over ‘morphospace’ -- the space of all possible designs -- can have gradients that can be followed toward designs that increasingly facilitate control policy optimization, or improve simulation to reality transfer. I will draw examples from our recent work with flapping wings for ornithopters, voxel-based soft robots, and biological machines created using frog embryo cells.

*Adding Soft to Robotics: From Gecko-inspired Wall Climbing to Vine-inspired Navigation*

Natural systems, such as climbing geckos and wandering vines, are incredibly robust, adaptable, and capable of handling uncertainty in their environments. These traits are unfortunately not currently true about engineered robotic systems. I will discuss efforts to learn from nature by incorporating compliance, or softness, into robots to create new functionality. I will show results from recent work, including gecko-inspired adhesives that allow a human to climb a glass wall and vine-inspired robots that “grow” through challenging environments, such as a forest of nails or, potentially, the tortuous pathways inside the human body.

*Programming Shape Shifting and Locomotion through Anisotropy*

Conventional robots are rigid. Although robust, they are often heavy, bulky, tethered and non-adaptive to environmental changes. Soft robots are light-weight, compliant, and adaptive, and can achieve multi-degrees of freedom. However, their softness makes it difficult to control the shape change and locomotion, or lift heavy weights. To precisely and locally control the shapes and agile locomotion with considerable strains, we create thin films and filaments from liquid crystal elastomers (LCEs) and their composites. Through designs of geometric surface patterns, e.g. microchannels, we program the orientational elasticity in LCEs to direct folding of the 2D sheets into 3D shapes, which can be triggered by heat, light, and electric field. We then fabricate tendon-like filaments as high strength, dual-adaptive actuators in soft robotic applications, as well as programmable gaits to achieve different modes of locomotion.

Biographies

**Katia Bertoldi**, is the William and Ami Kuan Danoff Professor of Applied Mechanics at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS). Katia’s research contributes to the design of materials with a carefully designed meso-structure that leads to novel effective behavior at the macroscale. She investigates both mechanical and acoustic properties of such structured materials, with a particular focus on harnessing instabilities and strong geometric non-linearities to generate new modes of functionality. Since the properties of the designed architected materials are primarily governed by the geometry of the structure (as opposed to constitutive ingredients at the material level), the principles she discovers are universal and can be applied to systems over a wide range of length scales.

**Xuanhe Zhao**, is a professor at MIT. The mission of Zhao Lab is to advance science and technology on the interfaces between humans and machines for addressing grand societal challenges in health and sustainability with integrated expertise in mechanics, materials and biotechnology. A major focus of Zhao Lab's current research is the study and development of soft materials and devices for translational medicine and water treatment. For example, Zhao Lab’s invention of the hydrogel-elastomer tough hybrid is used in tissue phantoms for training doctors and researchers in medical imaging all over US. Dr. Zhao is the recipient of the NSF CAREER Award, ONR Young Investigator Award, SES Young Investigator Medal, ASME Hughes Young Investigator Award, Adhesion Society’s Young Scientist Award, Materials Today Rising Star Award, and Web of Science Highly Cited Researcher. He held the Hunt Faculty Scholar at Duke University, and the d'Arbeloff Career Development Chair and Noyce Career Development Professorship at MIT.

**Hao Su**, is Irwin Zahn Endowed assistant professor in the Department of Mechanical Engineering at the City University of New York, City College and the Director of the Lab of Biomechatronics and Intelligent Robotics (BIRO). He was a postdoctoral research fellow at Harvard University and the Wyss Institute for Biologically Inspired Engineering. Prior to this role, he was a Research Scientist at Philips Research North America where he designed robots for lung and cardiac surgery. He obtained the Ph.D. degree on Surgical Robotics from the Department of Mechanical Engineering at Worcester Polytechnic Institute. Dr. Su received NSF CAREER Award,Toyota Mobility Challenge Discover Award, the Best Medical Robotics Paper Runner-up Award in the IEEE International Conference on Robotics and Automation (ICRA) and Philips Innovation Transfer Award. He received the Advanced Simulation & Training Award from the Link Foundation and Dr. Richard Schlesinger Award from the American Society for Quality. He holds patents on surgical robotics and socially assistive robots.

**Kevin Chen**, is an assistant professor in the Department of Electrical Engineering and Computer Science (EECS) at MIT. He received his PhD in Mechanical Engineering at Harvard University under the supervision of Professor Robert J. Wood. He is a recipient of the best student paper award at the International Conference on Intelligent Robots and Systems (IROS) 2015, a Harvard Teaching Excellence Award, and he was named to the “Forbes 30 Under 30” list in the category of Science. His works have been published in top journals including Nature, Science Robotics, Nature Communications, and the Journal of Fluid Mechanics.

**Vikram Kapila**, is a Professor of Mechanical and Aerospace Engineering at the NYU Tandon School of Engineering, where he directs a Mechatronics, Controls, and Robotics Laboratory; a Research Experience for Teachers Site in Mechatronics and Entrepreneurship; a DR K-12 and an ITEST STEM education research project; all funded by NSF. He has held visiting positions with the Air Force Research Laboratories in Dayton, OH. His research interests are focused on the convergence of frontier technologies (robotics, artificial intelligence, augmented/virtual reality, and blockchain) and STEM education. He is an author or co-author of more than 240 peer-reviewed scholarly publications, including books, book chapters, journal papers, and conference articles. He is a named inventor on two awarded patents. He has received five teaching awards and a leadership award, all at NYU Tandon. Moreover, he is a recipient of 2014-2015 University Distinguished Teaching Award at NYU. He has mentored more than 50 graduate researchers and more than 60 undergraduate researchers. In addition, he has conducted significant K-12 education, training, mentoring, and outreach activities to integrate engineering concepts in science classrooms and labs of dozens of New York City public schools.

**Josh Bongard**, is the Veinott Professor of Computer Science at the University of Vermont and director of the Morphology, Evolution & Cognition Laboratory. His work involves automated design and manufacture of soft-, evolved-, and crowdsourced robots, as well as computer-designed organisms. A PECASE, TR35, and Microsoft New Faculty Fellow award recipient, he has received funding from NSF, NASA, DARPA, ARO and the Sloan Foundation. He is the author of the book How The Body Shapes the Way we Think, the instructor of a reddit-based evolutionary robotics MOOC, and director of the robotics outreach program Twitch Plays Robotics.

**Elliot Hawkes**, is an assistant professor in the Department of Mechanical Engineering at University of California, Santa Barbara. Elliot Hawkes’s research focuses on bringing together design, mechanics, and non-traditional materials to advance the vision of robust, adaptable, human-safe robots that can thrive in the uncertain, unstructured world. Current projects involve bio-inspired microstructured adhesive materials, non-linear compliant mechanisms, high-power soft actuators, soft exoskeletons, and growing robots.

**Shu Yang**, is a Professor in the Departments of Materials Science & Engineering, and Chemical & Biomolecular Engineering at University of Pennsylvania (Penn). Her group is interested in synthesis, fabrication, and assembly of polymers, liquid crystals, and colloids; investigation of the dynamic tuning of their sizes, shape and assembled structures, and use geometry to create highly flexible, super-conformable, and shape changing materials. Yang received her B.S. degree from Fudan University in 1992, and Ph. D. degree from Cornell University in 1999. She worked at Bell Laboratories, Lucent Technologies as a Member of Technical Staff before joining Penn in 2004. She received George H. Heilmeier Faculty Award for Excellence in Research from Penn Engineering (2015-2016). She is Fellow of Division of Soft Matter (DSOFT) from American Physical Society (APS), Division of Polymeric Materials: Science and Engineering from American Chemical Society (ACS) (2018), Royal Chemical Society (2017), and National Academy of Inventors (2014).

**Workshop IV** (Required Information Complete)

Flexible Mechatronics for Robotics

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| ***Organizers*** | Jiajie Guo, Huazhong University of Science and Technology  Chao-Chieh Lan, National Cheng Kung University  Qining Wang, Peking University  Guimin Chen, Xi’an Jiaotong University |
| ***Time*** | 9AM – 12:30PM (EDT) |
| ***Location*** | TBD |

Abstract

Flexible mechatronics have been critical and necessary to smart robots in unstructured environments under complicated states for they are effective in addressing the needs for adaptability to nonlinear deformations and robustness to harsh conditions. As a combination of compliant structures and stretchable electronics, flexible mechatronics has the advantages of light weights, compact sizes, zero backlashes, quick response and high energy efficiency, thus have wide applications such as human-motion sensing, health inspection, bio-inspired actuation, process state monitoring, high precision positioning/transmission, intelligent fixation and so on. With the emerging applications to robotics, this tutorial provides an opportunity to highlight the role of AIM with a focus on flexible mechatronics in the most active research areas in recent years.

As flexible mechatronics is newly developed with soft robotics and intelligent manufacturing, there exist many challenging but urgent problems unsolved in the field. Topics of interest are categorized in modeling theories, design methods, fabrication techniques, control principles and illustrative applications, which include but not limited to modeling, design and fabrication methods for flexible mechatronic systems, actuation and sensing for soft robotics, smart sensors and actuators, compliant mechanisms in automation and manufacturing, flexible electronics for human-machine interface, human-centered robotics for assistive/rehabilitative equipment, intelligent methods and algorithms for mechatronics, soft materials, analysis and control. In this way, active experts and young scholars in related fields are invited to present their new discoveries and achievements, which will be instructive and informative for students and researchers from various areas.

Besides, flexible mechatronics is an interdisciplinary research area involving researchers with diversified academic backgrounds. For example, theoretical modeling mainly requires knowledges in physics, mechanics and mathematics, while system design and control rely on mechanical, automation and electrical engineering. One the other hand, chemical engineers and material scientists develop fabrication methods and techniques, and immediate applications are usually provided by experts in biomedical and manufacturing engineering. So it is desired to have a communication and discussion platform to exchange ideas and emerging achievements for better collaborations.

Invited talks

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| **#** | **Title** | **Speaker** |
| **1** | *Distributed field sensing for human-centered robotics* | Jiajie Guo |
| **2** | *Upper limb exoskeleton design and control* | Chao-Chieh Lan |
| **3** | *Modeling large deflections in compliant mechanisms and continuum robots* | Guimin Chen |
| **4** | *Human-Centered Wearable Robotics: From Land to Underwater Applications* | Qining Wang |

Abstracts

*Distributed field sensing for human-centered robotics*

Soft robots and human musculoskeletal systems are featured with continuous nonlinear deformations. However, it is a challenge to capture distributed dynamics with typical sensing techniques due to the limitations of rigid components and nodal measurements. This talk presents recent developments on distributed field sensing for soft robots and compliant musculoskeletal structures, where the unified reconstruction method is introduced with highlights of physics-based modeling, flexible mechatronics design, and wearable device fabrication. Its application to human-centered robotics is illustrated with several examples, including articular geometry sensing with the wearable compliant mechanism, force/motion sensing for the compliant robotic hand, and the flexible curvature sensor for amphibious gait measurements.

*Upper limb exoskeleton design and control*

Powered exoskeletons can facilitate after-stroke rehabilitation of patients with upper limb disabilities. Designs using serial mechanisms usually result in complicated and bulky exoskeletons. This talk presents a new parallel actuated upper limb exoskeleton. The actuators are grounded and placed side-by-side. Thus better inertia properties can be achieved while lightweight and compactness are maintained. An adaptive mechanism with only passive joints is introduced to compensate for the exoskeleton-limb misalignment and size variation among different subjects. Linear series elastic actuators (SEAs) are proposed to obtain accurate force and impedance control at the exoskeleton-limb interface. The total number of force sensors and actuators is minimized using the adaptive mechanism and SEAs. An exoskeleton prototype will be shown to provide bidirectional actuation between the exoskeleton and upper limb, which is required for various rehabilitation processes.

*Modeling large deflections in compliant mechanisms and continuum robots*

After reviewing the fundamental beam theories, this tutorial will discuss major challenges in modeling nonlinear deflections in compliant mechanisms, recently developed methods and their use for kinetostatic modeling of compliant mechanisms, both from the vectorial and the strain energy perspectives.

*Human-Centered Wearable Robotics: From Land to Underwater Applications*

This talk will show recent progress on wearable robotics, especially the new area of underwater applications. To date, all the exoskeletons have been studied to assist human motions on land. However, regardless of the exoskeletons being rigid or soft, an exoskeleton for underwater motion assistance has not been realized thus far. This talk will discuss the challenges of using exoskeletons for underwater applications. And recent breakthrough of an underwater soft exoskeleton from my lab will be introduced in detail. Three competitive swimmers participated the experiments to evaluate the proposed soft exoskeleton. Compared with breaststroke without assistance, the peak of surface electromyography in the sweep phase with the exoskeleton assistance decreased by 49.13% (gastrocnemius) and 74.51% (soleus) on an average.

Biographies

**Jiajie Guo**, received his Ph.D. degree in mechanical engineering from Georgia Institute of Technology, Atlanta, GA, USA, in 2011, and B.S. degree in theoretical and applied mechanics, Peking University, Beijing, China, in 2006. He is currently a Professor with the State Key Laboratory of Digital Manufacturing Equipment and Technology, and the School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan, China. His research interests include flexible mechatronics, human-centered robotics, and system dynamics/control. He co-authored the book “Flexonics for Manufacturing and Robotics: modeling, design and analysis methods” by Springer Nature, and received the best paper award for IEEE/ASME Trans. on Mechatronics (2015). He recently serves on the editorial boards for two international journals, Current Chinese Engineering Science, Current Mechanics and Advanced Materials, and IEEE/ASME Int. Conf. Advanced Intelligent Mechatronics (AIM).

**Chao-Chieh Lan**, is currently a professor in the Department of Mechanical Engineering at National Cheng Kung University, Taiwan. He is currently interested in compliant actuators, robotics, multi-body dynamics, and rehabilitation devices.

**Guimin Chen**, is a full professor of Xi’an Jiaotong University. He was a visiting professor Brigham Young University (BYU CMR Lab) from December 2016 to August 2017 and from October 2007 to October 2008. He serves as an Associate Editor of ASME Journal of Mechanisms and Robotics and a Topical Editor of Mechanical Sciences (IFToMM affiliated). He is a recipient of ASME Compliant Mechanisms Award. His research interests include compliant mechanisms and their applications.

**Qining Wang**, received his Ph.D. degree in Dynamics and Control from Peking University in 2009. He serves as the Vice-Dean of the College of Engineering in Peking University, China. He has authored/coauthored over 170 scientific papers in international journals and refereed conference proceedings. His research interests include bio-inspired robots and rehabilitation robotics. He serves as an Advisor of the IEEE-RAS Technical Committee on Wearable Robotics. He was an Associate Editor for the IEEE Robotics and Automation Magazine from 2016 to 2018. He has been a Technical Editor for the IEEE/ASME Transactions on Mechatronics since 2017, and an Associate Editor for the IEEE Transactions on Medical Robotics and Bionics since 2018.

**Workshop V** (Required Information Partially Complete)

Supernumerary Robotic Devices

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| ***Organizers*** | Guy Hoffman, Cornell University  Ryder C. Winck, Rose-Hulman Institute of Technology  Vighnesh Vatsal, Cornell University |
| ***Time*** | 9AM – 12:30PM and 1:30PM – 5PM (EDT) |
| ***Location*** | TBD |

Abstract

The field of wearable robotics focuses today mostly on prostheses and exoskeletons. These devices are designed to either replace lost human capabilities or to enhance existing ones. In fact, both prostheses and exoskeletons have reached considerable maturity in terms of research and commercialization efforts over the past decades. Spurred on by recent advances in high-performance actuators and microcontrollers, as well as by increasingly inexpensive computational power, we are witnessing the advent of another class of wearable robots: supernumerary robotic (SR) devices. SR devices aim to add capacities to a human body beyond the naturally occurring and are often modeled as additional upper limbs. While SR device design is largely inspired by prostheses and exoskeletons, research into other facets of this technology beyond design, such as interaction, control systems, biomechanics, and human-robot collaboration, is still in a nascent stage. As a result, the community of SR device researchers is fairly small and insular. This workshop would provide a common forum for existing researchers who are working on aspects of SR devices to communicate their latest advances. It would also assist interested students and researchers working on other areas of robotics in getting involved with SR device research to initiate new projects.

Invited talks

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| **#** | **Title** | **Speaker** |
| **1** | *Handheld Robots: Bridging the gap between fully external and wearable robots* | Walterio Mayol-Cuevas |
| **2** | *TBD* | Masahiko Inami |
| **3** | *Playing the piano with 11 fingers – the neurobehavioural constraints of human robot augmentation* | A. Aldo Faisal |
| **4** | *TBD* | Domenico Prattichizzo |
| **5** | *TBD* | Monica Malvezzi |
| **6** | *TBD* | Hiroyasu Iwata |
| **7** | *TBD* | Mohamed Bouri |

Abstracts

*Talk 1*

*Talk 2*

*Talk 3*

*Talk 4*

*Talk 5*

*Talk 6*

*Talk 7*

Biographies

**Walterio Mayol-Cuevas**,is a Professor in Robotics, Computer Vision and Mobile Systems at the University of Bristol. His research centers around three related areas: robotics, wearable computing and computer vision.

**Masahiko Inami**,is a Professor at the Research Center for Advanced Science and Technology at the University of Tokyo.

**A. Aldo Faisal**, is Reader in Neurotechnology (US equivalent: Associate Professor, tenured) jointly at the Dept. of Bioengineering and the Dept. of Computing at Imperial College London, where he leads the Brain & Behaviour Lab. Aldo is also Director of the Behaviour Analytics Lab at the Data Science Institute. He is also Associate Investigator at the MRC London Institute of Medical Sciences and is affiliated faculty at the Gatsby Computational Neuroscience Unit (University College London).

**Domenico Prattichizzo**,is a Full Professor at the University of Siena. His research interests are in haptics, grasping, visual servoing, mobile robotics and geometric control.

**Monica Malvezzi**, is an Associate Professor of Mechanics and Mechanism Theory at the Dipartimento di Ingegneria dell'Informazione e Scienze Matematiche of the University of Siena and she has been Visiting Scientist at Istituto Italiano di Tecnologia since 2015. Her main research interests are in mechanism theory, control of mechanical systems, robotics, vehicle localization, multibody dynamics, haptics, grasping and dexterous manipulation.

**Hiroyasu Iwata**, is currently a Professor with the Department of Modern Mechanical Engineering, School of Creative Science and Engineering, Waseda University. His current research interests include advanced technology for construction machinery, robotics in medical care, rehabilitation assistive robot, and anthropomorphic dexterous hand and manipulator.

**Mohamed Bouri**, is a group leader of Rehabilitation and Assistive Robotics in LSRO and lecturer of Robotics and Industrial Robotics. Since 1997, he is at EPFL and is mainly active in the field of robot control, automation and robot design for medical and industrial applications.