Workshop I

Advanced Magneto-Mechatronics Systems: Modeling, Sensing and Control

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	Monday, July 6, 2020, 9:00 AM-12:20 PM
Location	Room W1

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

#	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.