Guest editorial: focused section on smart mobile robotic systems in challenging environments

Xianbo Xiang¹ · Garrett M. Clayton² · Shaohui Foong³ · Francesco Maurelli⁴ · Fumin Zhang⁵

Published online: 17 June 2019
© Springer Nature Singapore Pte Ltd. 2019

Mobile robotic systems are crucial when performing diverse tasks operating in the air, on land, and above water or underwater. They are especially invaluable in highly challenging environments where human presence is dangerous, difficult or undesirable due to extreme environmental factors. In order to operate efficiently and demonstrate high intelligence and autonomy, these mobile robotic systems would need to incorporate advanced and intelligent embedded sensing, perception, actuation, control and design synthesis.

To document and disseminate current advances, challenges and opportunities in this domain, this “Focused section on smart mobile robotic systems in challenging environments” of the International Journal of Intelligent Robotics and Applications (IJIRA) highlights recent efforts and important results in smart mobile robotic systems designed and developed for challenging environments. This focused section includes eight papers that represent a glimpse into current developments of intelligent mobile robotic platforms operating in such environments.

Mobile manipulator a mobile manipulator system consists of a wheeled mobile platform and a robotic arm which has extended industrial and service applications compared with fixed base manipulators. The first paper “Learning based end effector tracking control of a mobile manipulator for

performing tasks on an uneven terrain” from Teka et al. presents a two stage Kohonen Self Organizing Maps (KSOM) based learning method to address the challenging problem of a 14 DOF mobile rover manipulator system following a desired end effector trajectory on an uneven terrain. In the first stage the KSOM performs the redundancy resolution of finding the redundant inverse kinematics, and in the second layer it corrects the error between the desired trajectory and actual tracking trajectory during motion in real time. Both the simulation and experimental results show the proposed method can be used to control a mobile manipulator to achieve desired joint angles and wheel velocities for tracking an end effector trajectory once the KSOM network is trained to learn a particular terrain. The second article “Optimization-based motion planning of mobile manipulator with high degree of kinematic redundancy” by Liao et al. proposes an integrated kinematic model to include the high degree of kinematic redundancy and embed the coupling property between the mobile platform and manipulator. Subsequently, the coordinated motion planning for mobile manipulator is developed to generate collision free trajectories which are planned for the mobile platform and manipulator simultaneously by the interior-point optimization method. The proposed algorithm is implemented on

✉ Xianbo Xiang
xbxiang@hust.edu.cn

Garrett M. Clayton
garrett.clayton@villanova.edu

Shaohui Foong
foongshaohui@sutd.edu.sg

Francesco Maurelli
f.maurelli@jacobs-university.de

Fumin Zhang
fumin@gatech.edu

¹ School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology, Luoyu Road 1037, Wuhan 430074, People's Republic of China

² Department of Mechanical Engineering, Villanova University, Tolentine Hall Rm 126C, 800 Lancaster Avenue, Villanova, PA 19085, USA

³ Engineering Product Development (EPD) Pillar, Singapore University of Technology and Design (SUTD), 8 Somapah Road, Singapore 487372, Singapore

⁴ Marine Systems and Robotics Group, Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany

⁵ School of Electrical and Computer Engineering, Georgia Institute of Technology, Technology Square Research Bldg, Room 406, 85 Fifth Street NW, Atlanta, GA 30308, USA

a KUKA Youbot wheeled mobile manipulator platform, and experimental results show the good performance of the optimization-based motion planning method.

Aerial robot the aerial domain has always been a challenging realm due to the complexities of achieving flight. External disturbances have always been an issue for traditionally designed multicopters, especially for the yaw axis due to the way the rotors are aligned on a multicopter. The paper “A novel multicopter with improved torque disturbance rejection through added angular momentum” from Bucki and Mueller presents a novel multicopter design with an additional rotating momentum wheel and accompanying feedback controller to reduce the vehicle’s sensitivity to torque disturbances caused by external effects. This controller also actively compensates for the additional angular momentum due to the spinning wheel and accelerates or decelerates the momentum wheel to gain additional control authority in yaw not possible in conventional designs. The paper found that sensitivity to torque disturbances is shown to monotonically decrease with increasing angular momentum, and the effect scales such that a greater improvement in torque disturbance sensitivity is experienced by smaller vehicles. Aerial deployment is also an important mechanism to launch robotic systems or sensors to carry out wide variety of tasks and operations. The paper “Design, modelling and control of collaborative samara autorotating wings (SAW)” by Win et al. presents a nature inspired approach to achieve such mechanism using the autorotation mechanism of maple seeds. The proposed platform takes advantage of the gyroscopic stability of a spinning mass, does not require any propulsion system on-board and is equipped with an actuator to change the angle of attack of the wing for directional control. The most unique trait of this paper is the collaborative autorotation mode whereby multiple individual systems are attached together to form a larger rotor hub that benefits from increased angular momentum and control authority which is especially important at higher altitudes where the air is less dense and more challenging for aerial operation. This proposed nonlinear control scheme enables an omni-directional guide slope, allowing SAW to be more maneuverable than parafoils or fixed-wing type of aerial deployments.

Underwater robot autonomous underwater vehicle (AUV) plays a critical role in enabling exploration and exploitation of ocean resources due to demanding and harsh underwater environments. The paper “A Data Assimilation Framework for Data-Driven Flow Models Enabled by Motion Tomography” from Chang et al. proposes a data assimilation framework for the generic environmental models (GEMs) to construct and update an environmental map by using data collected by AUVs. In order to facilitate assimilation of Lagrangian data along the AUV trajectory with time integrated flow information into the GEM, the motion tomography method is adopted to enable the unified conversion of Lagrangian data into an

Eulerian spatial map of a flow field. A filtering method is developed for estimation of the spatial and temporal characteristics of flow parameters in the GEM. The whole data assimilation framework is demonstrated through simulations using a double-gyre flow field and a flow field constructed by real ocean surface flow observations. The paper “A Multiple Autonomous Underwater Vehicles Hazard decision Based on Information Fusion” by Zhang et al. presents a fusion based accurate decisions of multiple autonomous underwater vehicles (AUVs) while facing complicated and dangerous underwater situations. A distributed decision-making structure of multiple robots is used first, and then a transferrable belief model and evidence reasoning theory are adopted to design an AUV information model. Numerical simulations verify the effectiveness of this hazard decision method which improves the survivability of multiple AUVs in accomplishing dangerous underwater missions.

Path planning and mapping path planning and mapping are fundamental problems for all types of mobile robotic systems, including wheeled, aerial and underwater robots. The paper “Real-time path planning for a robot to track a fast moving target based on improved Glasius bio-inspired neural networks” from Chen and Zhu introduces an improved Glasius Bio-inspired Neural Network (GBNN) model to address the real-time path planning for a mobile robot while tracking a fast moving target. Added local calculations with short distance cost are adopted to propagate the neuronal activities faster and an inverse function for weighting the neuronal connections is used to achieve better performance than the exponential functions. Comparative simulation and theoretical analysis show the feasibility of the improved GBNN model in the real time path planning mission in a rapidly changing environment. The paper “Mismatched image identification using histogram of loop closure error for feature-based optical mapping” by Elibol and Chong proposes to utilize closed-loop constraints for identifying mismatched image registration in optical mapping from mobile robotic platform. By exploiting the fact that images forming cycle should have an identity mapping when all the homographies are multiplied, error statistics for each matched image pair extracting several cycle bases are obtained, and image pairs are identified through a trained classifier to compare error histograms. Experimental results with both real and synthetic datasets of underwater as well as panoramic image sequences clearly show that the proposed optical mapping method is able to identify edges including some outliers in the mismatches, which can be embedded for image sequence processing in any mobile robotic application.

We would like to express our sincere thanks to all of the authors and anonymous reviewers as well as the production colleagues for their tireless efforts and dedicated contributions to this Focused Section. Our appreciation also goes to Editor-in-Chief, Professor Kok-Meng Lee, and editors and

for their wisdom and hard work in coordinating the timely and vigorous review of all submitted papers.

Xianbo Xiang is a Professor in the School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology. He received the B.E. and M.E. degrees in automatic control and marine engineering from the Huazhong University of Science and Technology, China, in 2000 and 2003, respectively, and the Ph.D. degree in System Automation and Micro-electronics from the University of Montpellier II, France, in 2011. In 2006, he was an EU Erasmus Mundus Visiting Scholar in the

SpaceMaster Project for 3 months. From 2008 to 2011, he was in the European Project FreeSubNet as an EC Marie Curie ESR Fellow with the LIRMM, CNRS UMR 5506, Montpellier, France. He has served as an International Editorial Scientific Advisory Board Member of Journal Brodogradnja/Shipbuilding, and as the guest editors for International Journal of Fuzzy Systems and Indian Journal of Geo-marine science. He was the general chair of the 2018 IEEE 8th International conference on Underwater System Technology: Theory and Applications (USYS'18). His current research interests include robotics and marine vehicle systems.

Garrett M. Clayton is an Associate Professor in the Department of Mechanical Engineering and the director of the Center for Nonlinear Dynamics and Control at Villanova University. Dr. Clayton received his Bachelor of Science in Mechanical Engineering from Seattle University in 2001 and his Masters of Science and PhD in Mechanical Engineering from the University of Washington in 2003 and 2008, respectively. His current research interests are broadly spread throughout the area of

mechatronics with specific applications in nanopositioning, remote monitoring, humanitarian technologies, and robotics.

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 in 2005, 2008 and 2010. In 2011,

he was a Visiting Assistant Professor at the Massachusetts Institute of Technology, Cambridge, USA. He has a keen interest in mechatronics, which is the synergistic integration of the multiple disciplines of mechanics, electronics, control theory and computer science, and much of his research is centred around designing and developing novel mechatronic systems for a wide spectrum of applications. His research interests include system dynamics & control, nature-inspired robotics, magnetic localization, medical devices and design education & pedagogy.

Francesco Maurelli is a Professor leading the Marine Systems and Robotics group at Jacobs University Bremen, Germany. He obtained his PhD in Electrical Engineering from Heriot-Watt University, in Edinburgh, Scotland, with a thesis focused on intelligent localization of autonomous underwater vehicles. He has worked for more than a decade in the field of autonomous marine robots. He is the Principal Investigator of the Horizon2020 MSCA project TIC-AUV, in collaboration with

Massachusetts Institute of Technology (MIT), where he spent 1 year as research scholar, and Jacobs University Bremen. He is co-coordinator the Erasmus + IMPACT project, focused on education and research in marine systems, as well as the Principal Investigator of the DAAD-funded project "Intelligence and autonomy extension for low cost freshwater inspection vehicles". He is chair of Robotics and Intelligent Systems program at Jacobs University, and co-chair of the IEEE Robotics and Automation Society Marine Robotics Technical Committee. He has been involved in several projects, funded by EU FP6, EU FP7, EU H2020 (FreeSubNet, ARROWS, PANDORA, ECHORD++, TIC-AUV), and from British, Canadian and German national fundings (MoD Competition of Ideas. Exemplar I, DRDC, DAAD).

Fumin Zhang is a Professor in the School of Electrical and Computer Engineering at the Georgia Institute of Technology. He received a PhD degree in 2004 from the University of Maryland (College Park) in Electrical Engineering, and held a postdoctoral position in Princeton University from 2004 to 2007. His research interests include mobile sensor networks, maritime robotics, control systems, and theoretical foundations for cyber-physical systems. He received the NSF CAREER Award in

September 2009 and the ONR Young Investigator Program Award in April 2010. He is currently serving as the co-chair for the IEEE RAS Technical Committee on Marine Robotics, associate editors for IEEE Journal of Oceanic Engineering, Robotics and Automation Letters, IEEE Transactions on Automatic Control, and IEEE Transactions on Control of Networked Systems, and the deputy editor-in-chief for the Cyber-Physical Systems Journal.