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EDITORIAL

Guest Editorial introduction to the Focused section on wearable sensors, actuators, and robots for rehabilitation

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Emerging flexible and wearable sensing, actuation and robotic technologies are crucial in the design and development of novel physiotherapy rehabilitation devices and systems that safely interact with humans. The development of wearable devices for physical rehabilitation presents a number of challenges in sensing, actuation, robot mechanism design, data processing algorithms and control, which has attracted increasing attention from researchers in recent years (Jiang et al. 2018; Rehmat et al. 2018).

To disseminate current advances and identify challenges and opportunities, this "Focused section on wearable sensors, actuators, and robots for rehabilitation" of the *International Journal of Intelligent Robotics and Applications* (IJIRA) highlights recent efforts and important achievements in wearable sensors, actuators, and robots in the context of rehabilitation and biomedical applications. This focused section includes six papers out of ten submissions that represent a sample of current developments of wearable mechatronic technologies for healthcare and rehabilitation.

The paper "A survey on foot drop and functional electrical stimulation" from York and Chakrabarty presents a review on the modern technologies of the drop foot treatment. Foot drop is a common problem after stroke which will result in a decreased quality of life. This article concludes the current treatment options including fixed ankle–foot orthosis, surgical intervention, and functional electrical stimulation (FES) devices. The paper finds that FES intervention is effective for providing a non-invasive treatment in even severe cases of foot drop. The survey suggests future development of these devices can take advantage of the great strides being made in machine learning and low powered computation. A closed-loop device with dynamic feedback affecting motor output is more flexible to changes in patients' conditions, potentially encouraging recovery.

The second paper "Peripheral nerve bionic interface—a review of electrodes" from Russell et al. surveys the current landscape of extra-neural electrodes for interfacing the peripheral nervous system exploring both clinical and exploratory sciences. As the demand for sensory feedback to and from prosthetic limbs becomes increasingly desirable, implantable neural interfaces are becoming more attractive, this article explores peripheral electrode designs of the cuff type, and emphasizes the complexity of using implantable electrodes for advancing smart prostheses by highlighting many areas of research such as the power transfer and communication techniques to the choice of materials. This

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paper also addresses current commercial options of these electrodes before discussing our perspective on peripheral neural interfaces for smart prostheses.

In terms of wearable sensors for healthcare, the work from Liu et al. is on "A new IMMU-based data glove for hand motion capture with optimized sensor layout". This paper presents a low-cost and easy-to-use data glove to capture the human hand motion can be used to assess the patient's hand ability in home environment. This paper proposes a new sensor layout strategy according to the inverse kinematics hand model and designs a multi-sensor Kalman data fusion algorithm to reduce the sensors from 12 in conventional systems to 6 in their system with the hand motion accurately reconstructed. Experiment results of a continuous hand movement indicate an average error under 15% compared with the common glove with full sensors. This new set with optimized sensor layout is promising for lower-cost and residential medical applications.

In "Hammerstein model for hysteresis characteristics of pneumatic muscle actuators" from Ai et al., a kind of wearable actuators, pneumatic muscle actuator (PMA), is investigated. The PMA has actuation characteristics such as high power/weight ratio, safety and inherent compliance. This paper proposes a method for hysteresis modelling of PMA based on Hammerstein by introducing the BP neural network into the hysteretic system. An extended space input method is adapted while the Modified Prandtl-Ishlinskii model is applied to characterize the hysteretic phenomenon. The model established in this paper can provide a better basis for robot control. This paper also presents a comparison study for PMA tracking control with and without the feed-forward hysteresis compensation. Experimental results validate the effectiveness of the designed model which has the advantages of high precision and easy identification.

Wearable rehabilitation robots are explored on the basis of sensors and actuators study. The work presented in "A compact wrist rehabilitation robot with accurate force/stiffness control and misalignment adaptation" from Su et al. presents a wrist robot using a geared bearing, slider crank mechanisms, and a spherical mechanism with three degrees-of-freedom. This robot allows large torque and rotation output which can provide the complete motion assistance for the forearm. As we know, the robots need to be lightweight and compact without major performance trade-offs, linear and rotary series elastic actuators with high torque-to-weight ratios are proposed in this research to accurately measure and control the interaction force and impedance between the robot and the wrist. Finally the resulting 1.5-kg robot can be used alone or easily in combination with other robots to provide various robot-aided upper limb rehabilitation.

Most studies on rehabilitation focus on unilateral robots, while bimanual rehabilitation robots promote inter-limb coordination which is especially useful for stroke patients. The last paper "Intelligent bimanual rehabilitation robot with fuzzy logic based adaptive assistance" from Harischandra and Abeykoon proposes a novel impedance controlled bimanual robot with fuzzy logic based adaptive assistance. The robot torque is controlled using the reaction torque observer. The authors find that by using this methods the rehabilitation robot can provide low impedance or assistance when the patient is unable to work against the resistance. The proposed method could be used to seamlessly switch between the resistance and assistance modes to enhance the angle synchronization between the impaired and unimpaired limbs. The proposed method could be applied for other limbs as well, though it is tested only for human arms.

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 review of all submitted papers.

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Shane Xie received his Ph.D. degrees from Huazhong University of Science and Technology, China and University of Canterbury, New Zealand, in 1998 and 2002, respectively. He joined University of Auckland in 2003 and became a Chair Professor in (bio)mechatronics in 2011. Since 2017 he has been the Chair Professor in Robotics and Autonomous Systems at the University of Leeds. He has published 7 books, 15 book chapters, and over 400 international journal and conference papers. His current research interests are medical and rehabilitation robots, advanced robot control. Prof. Xie is an elected Fellow of The Institution of Professional Engineers New Zealand (FIPENZ). He has also served as a Technical Editor for IEEE/ASME TRANSACITONS ON MECHARTEONICS.

Samit Chakrabarty has been studying the role of spinal circuits in execution of motor tasks, their modulation by peripheral sensory and descending inputs from the brain, focussing on the plastic changes that the system undertakes during development or disease. After receiving his BSc in Zoology, Biochemistry from St Xavier's College, Mumbai he pursued a PhD in Neurophysiology of the mammalian spinal cord at the University of Cambridge, UK. This was then followed by postdoctoral training at Columbia University, NYC and University of Manitoba, Winnipeg. He has since moved to University of Leeds as an academic researcher and is active in the field of sensory and motor control, rehabilitation and use of technology to both study and better the lives of those with maladies affecting sensory and motor function.

Jen-Yuan Chang received B.S. degree in 1994 from National Central University, Taiwan and M.S. and Ph.D. degrees in 1998 and 2001, respectively from Carnegie Mellon University, USA, all in mechanical engineering. After his faculty appointments with Washington State University, USA and Massey University, New Zealand, he is currently a Professor in the Department of Power Mechanical Engineering, National Tsing Hua University, Taiwan, the Deputy Director of MOST-AIMS Research Center, and the CTO of Mechanical and Mechatronics Systems Laboratories at Industrial Technology Research Institute, Taiwan. He was an ASEE/NRC Faculty Research Fellow at US Air Force Research Laboratory in Dayton, OH, USA. He holds Visiting Scholar/Professor positions at Hiroshima University, Japan, at Data Storage Institute, A*STAR, Singapore, at Institute of Biomedical Technologies, Auckland University of Technology, New Zealand and at Yonsei University, Korea. From 2001-2006, he worked at various R&D posts for high-end magnetic disk storage devices with IBM and HGST in San Jose, California, USA. Recipient of ASME-ISPS Distinguished Institution Award, Outstanding Contribution Award, Professor Chang, an ASME Fellow, was Division Chair of ASME ISPS Division, Vice Chair of Strategic Planning Committee, and Member of Technical Committee of IEEE Magnetics Society. Professor Chang have served as TE and AE of IEEE/ASME Transactions on Mechatronics, ASME Journal of Vibration and Acoustics, and Springer Journal of Microsystems Technologies.

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Andrew McDaid leads a large internationally recognised mechatronics-based research group focusing on developing and translating novel medical devices to clinical and commercial uptake. Devices include robotics for rehabilitation (including exoskeletons and soft/smart materials), wearables, AI/ML data platforms and neural prosthetics. Andrew's research is grounded on bionics principles, clinical-evidence and the fundamental research his devices enable him to undertake. Andrew was awarded a Bachelor of Engineering in Mechatronics followed by a PhD in Mechanical Engineering by the University of Auckland in 2008 and 2011 respectively. He is the Director of the Medical Devices & Technologies Teaching and Research groups at The University of Auckland. Andrew's passion is to see his research implemented as clinical best practise in order to improve the quality of care for individuals and the health of populations at a reduced cost.