Guest Editorial Special Issue on Artificial Intelligence in Automation for Healthcare Applications

Advancement in healthcare solutions is one of the major success stories of our times. While biomedical science and engineering has progressed significantly, increased human longevity has created huge demands on the healthcare system, such as the workforce that is struggling to meet the needs of patients. With the advent of healthcare automation, doctor offices, hospitals, and other medical facilities have streamlined the way they deal with patients with enhanced efficiency.

Healthcare automation is the technology by which a process or procedure is performed with minimal assistance from medical care personnel. It has been achieved by a variety of means including mechanical, hydraulic, pneumatic, electrical, electronic devices, and computers, usually in combination. It is worth noting that traditional automation is great for repetitive tasks that follow instructions or workflows set by individuals. In recent years, significant advancements in technology and engineering have generated numerous opportunities for innovation in healthcare automation. Such opportunities and challenges have significantly expanded the scopes of traditional automation science and engineering for healthcare applications, and a typical example is the integration of artificial intelligence (AI).

AI refers to how computational systems can use huge amounts of data to imitate human intelligence and reasoning, allowing the system to learn, predict, and recommend what to do next. AI has the potential to transform healthcare delivery, such as improved healthcare outcomes, patient experience, and access to healthcare services. When automation is combined with elements of AI such as machine learning, the result is known as intelligent healthcare automation. Such a tool is powerful because it allows us to reap both the benefits of automation—increased speed and efficiency, and ability to scale—with the insights and process power of AI.

The central theme of this Special Issue is emerging technologies and future directions in AI in automation for healthcare applications, where information technology-based modeling, analysis, control, and optimization are the focus areas. The goals are twofold: (1) to present the state-of-the-art research in science, engineering, and methodologies for intelligent healthcare automation, and (2) to provide a forum for experts to disseminate their recent advances and views on future perspectives in the relevant field. We received 40 high-quality submissions and only 18 articles were finally accepted for publication after several rounds of review. We are glad to see that the articles included in this Special Issue cover different aspects of intelligent healthcare automation. In particular, we can find several promising results using a variety of AI techniques. The accepted contributions can be divided into four parts.

The first part focuses on using AI techniques to improve robotic intelligence, including assistive walking devices (three articles), robotic prostheses (three articles), and surgical robots (two articles). Starting with the application of AI techniques in assistive robots, two of the three articles focused on robot-assisted gait rehabilitation. The article "Slope gradient adaptive gait planning for walking assistance lower limb exoskeletons" by Zou *et al*. proposed a slope gradient estimator by fusing sensor data of the exoskeleton and then constructed a slope-adaptive gait planning approach through capture point theory and dynamic gait primitives. They showed that adaptive gait trajectories can be reproduced online to adapt to slopes with different gradients after learning from demonstrated gaits sampled from healthy subjects. The article "Online gait planning of lower-limb exoskeleton robot for paraplegic rehabilitation considering weight transfer process" by Ma *et al*. proposed an online gait planning method through the integration of a finite-state machine model considering the center of gravity transfer process. Their experimental data indicated that the proposed walking gait significantly reduced arm muscle outputs. In contrast, the third study involves the use of an assistive robot to enhance human walking beyond the normal capacity human beings. The article "Effect of hip assistance modes on metabolic cost of walking with a soft exoskeleton" by Cao *et al*. developed a cable-driven exoskeleton combined with a forward model-based iterative learning algorithm for assistive force control and conducted a quantitative comparison of different hip assistance modes. The results with human users showed that the metabolic cost was reduced during loaded and unloaded conditions, and the multi-motion assistance mode has more potential in improving walking efficiency.

Three articles applied AI in automation for robotic prostheses to improve detection, control, and prediction. The first article "Maximum dorsiflexion detection based on an on-board adaptive algorithm for transtibial amputees with robotic prostheses" by Xu *et al*. proposed an on-board adaptive algorithm to detect the maximum dorsiflexion timing based on inertial measurement units and ankle angle sensors for robotic

Digital Object Identifier 10.1109/TASE.2021.3064011

transtibial prosthesis users in each gait cycle. The adaptive algorithm can realize the model updating continuously for real-time maximum dorsiflexion timing detection with collected and labeled training data. Their experimental data with three transtibial amputees indicated satisfactory adaptation for maximum dorsiflexion timing detection in different walking speeds and ramp conditions. The second article "A gait simulation and evaluation system for hip disarticulation prostheses" by Li *et al*. developed a prosthetic gait simulation system for providing a safe evaluation environment that cannot be obtained from human bodies, where reliable robotic motion control was achieved through an adaptive neural network strategy in the presence of disturbances. The third article "Environmental context prediction for lower limb prostheses with uncertainty quantification" by Zhong *et al*. developed a vision-based context prediction framework for lower limb prostheses to predict people's environmental context for multiple forecast windows. Their experimental data showed the potential of the framework in quantifying the uncertainty caused by different factors and produced a calibrated predicted probability for online decision-making by adopting Bayesian neural networks.

Two articles used AI techniques to improve the intelligence of surgical robots. The article "Feature-guided nonrigid 3-D point set registration framework for image-guided liver surgery: From isotropic positional noise to anisotropic positional noise" by Min *et al*. introduced a nonrigid registration approach (the normal vectors were used and anisotropic positional error was considered) for image-guided liver surgery. The authors have formulated the non-rigid registration as a maximum likelihood estimation problem and solved it with the expectation maximization technique, and finally validated the proposed algorithms on human liver models with improved accuracy and robustness. The article "Toward teaching by demonstration for robot-assisted minimally invasive surgery" by Su *et al*. proposed a methodology by integrating cognitive learning techniques for teaching by demonstration and the decoupled control algorithm, allowing the robot to be intelligent to learn senior surgeons' skills and perform surgical operations in a semi-autonomous manner. Experiments were performed with a KUKA robot to verify the efficiency of the proposed strategy.

The second part focuses on intelligent perception for healthcare applications (three articles), and two of them tried to recognize hand gestures. The article "Attention-based gated recurrent unit for gesture recognition" by Khodabandelou *et al*. utilized a deep neural network approach to forecast future gestures from a given sequence of hand motion using wearable capacitance sensors. The authors utilized an attention-based recurrent neural network to capture temporal features of hand motion to unveil the underlying pattern between the gesture and these sequences, and validated the efficiency of the proposed model. The article "A novel illumination-robust hand gesture recognition system with event-based neuromorphic vision sensor" by Chen *et al*. developed a novel gesture recognition system based on a biologically inspired neuromorphic vision sensor and the long-short-term-memory network. Their experimental results showed comparable recognition accuracy to the state-of-the-art methods and improved robustness than the state-of-the-art deep learning gesture recognition systems. Another study "Toward image-to-tactile cross-modal perception for visually impaired people" by Liu *et al*. used a generative adversarial network model to transform ground images into tactile signals. Their experimental data indicated that the proposed system can help visually impaired people sense the ground with a better traveling experience.

The third part focuses on the use of biological signals for pattern recognition. There were three articles involving brain–computer interfaces (BCIs) on electroencephalography (EEG) and one on electromyography (EMG), and these techniques have been generally used for intelligent control of robotic devices. The article "EEG-based volitional control of prosthetic legs for walking in different terrains" by Gao *et al*. developed an EEG-based motor imagery (EEG-MI) brain–computer interface for a powered prosthetic leg. Multiclass imaginary tasks were differentiated by leveraging the support vector machine classifier and a directed acyclic graph structure, and its effectiveness and feasibility were validated with human users. The article "EEG motor imagery classification with sparse spectrotemporal decomposition (SSD) and deep learning" by Sun *et al*. proposed a deep learning framework termed SSD-squeeze-and-excitation (SE)-convolutional neural network for EEG-MI. Their experimental results on two datasets showed that the proposed framework outperformed state-of-the-art methods in terms of classification quality and robustness. The article "Transferring subject-specific knowledge across stimulus frequencies in SSVEP-based BCIs" by Wong *et al*. investigated the feasibility of transferring model parameters, i.e., the spatial filters and the steady-state visually evoked potential (SSVEP) templates, across two different groups of visual stimuli in SSVEP-BCIs, which was motivated by the long calibration time problem. The authors then developed a transfer learning canonical correlation analysis incorporating the transferred model parameters. Experiments indicated that the spatial filter and impulse response shared commonality across neighboring stimulus frequencies and that the stimulus-to-stimulus transfer in SSVEP-BCI was feasible when the stimulus frequencies are neighboring. Another study "Ankle joint torque estimation using an EMG-driven neuromusculoskeletal model and an artificial neural network model" by Zhang *et al*. tried to estimate ankle joint torques using an EMG-driven neuromusculoskeletal model and an artificial neural network model in seven movement tasks. The authors compared the performance of the two models and found that they possess individual advantages for different conditions in predicting ankle joint torque, which could guide designing an appropriate exoskeleton rehabilitation controller.

The fourth part focuses on the intelligent diagnosis of healthcare problems (three articles). The article "Diabetic retinopathy diagnosis using multichannel generative adversarial network with semisupervision" by Wang *et al*. proposed a multichannel-based generative adversarial network with semi-supervision for intelligent medical aided diagnostic systems. Their experimental results on the public Messidor data indicated that the proposed model can grade diabetic retinopathy efficiently. The article "Automatic detection of negative symptoms in schizophrenia via acoustically measured features associated with affective flattening" by He *et al*. proposed an automatic procedure for detecting negative symptoms of schizophrenic patients based on speech signal processing with three newly presented acoustic features (the symmetric spectral difference level, quantization error and vector angle, and standard dynamic volume value). Their results indicated that the combination of these three features improved classification accuracy and robustness of schizophrenic patients and control subjects. The article "Anatomically constrained deep learning for automating dental CBCT segmentation and lesion detection" by Zheng *et al*. proposed a novel deep learning algorithm to enable automated capability for cone-beam computed tomography segmentation and lesion detection. The authors integrated oral-anatomical knowledge into the deep learning design, leading to good accuracy even under limited samples. Their experimental results demonstrated that the proposed algorithm outperformed the standard Dense U-Net in both lesion detection accuracy and dice coefficient indices in multilabel segmentation.

We would like to thank all authors who submitted and contributed to this Special Issue. Many of these submissions were of high quality but were not accepted due to limited space. We would also like to thank all reviewers who ensured that the manuscripts published in this Special Issue were of high quality by thoroughly evaluating the articles and providing plenty of constructive comments before final acceptance. Last but not least, the completion of this Special Issue would not have been possible without the strong support and guidance from the Editor-in-Chief, Prof. M. Y. Wang, and the Editorial Assistant, Rebecca Hytowitz. We would like to thank them for this great support.

MINGMING ZHANG, *Lead Guest Editor*
Department of Biomedical Engineering
Southern University of Science and Technology
Shenzhen 518055, China
e-mail: zhangmm@sustech.edu.cn

YONG HU, *Guest Editor*
Department of Orthopaedics and Traumatology
The University of Hong Kong
Hong Kong
e-mail: yhud@hku.hk

CHANDRAMOULI KRISHNAN, *Guest Editor*
Department of Physical Medicine and Rehabilitation,
Biomedical Engineering, Robotics Program
School of Kinesiology
University of Michigan at Ann Arbor
Ann Arbor, MI 48108 USA
e-mail: mouli@umich.edu

Mingming Zhang (Senior Member, IEEE) received the M.Eng. degree in mechatronics from Chongqing University, Chongqing, China, in 2012, and the Ph.D. degree in mechanical engineering from The University of Auckland, Auckland, New Zealand, in 2016.

From 2015 to 2018, he worked as a Research Fellow or a Visiting Research Fellow at The University of Auckland. Since August 2018, he has been the Principal Investigator and the Director of the Sensorimotor Rehabilitation Robotics Laboratory, Southern University of Science and Technology, Shenzhen, China, where he has been the Assistant Professor of Department of Biomedical Engineering. He has authored over 50 academic articles and one book. His research interests include medical and rehabilitation robotics, physical human–robot interaction, intelligent control, and bio-signal-based pattern recognition. He also holds over 30 patents.

Dr. Zhang has served as the invited reviewer for several high-quality international journals, including IEEE TRANSACTIONS ON MECHATRONICS, IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, and IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING.

Yong Hu (Senior Member, IEEE) received the B.Sc. and M.Sc. degrees in biomedical engineering from Tianjin University, Tianjin, China, in 1985 and 1988, respectively, and the Ph.D. degree from The University of Hong Kong, Hong Kong, in 1999.

He is currently a Principal Investigator and the Director of the Neural Engineering and Clinical Electrophysiology Laboratory, The University of Hong Kong, where he is the Tenured Associate Professor of the Department of Orthopaedics and Traumatology. His research interests include neural engineering, clinical electrophysiology, and biomedical signal measurement and processing. He has conducted more than 50 research projects with grants from Hong Kong RGC, S. K. Yee Medical Foundation, NSFC, etc. He has published ten book chapters and more than 300 journal articles.

Dr. Hu currently serves as the Council Board Member of the International Association of Neurorestoratology (IANR) and the Vice Chairman of the Chinese Committee, the Vice President of the basic science subcommittee in Chinese Association of Spine and Spinal Cord, and the Vice President of Chinese Committee of Biomedical Sensor Technology in the Chinese BME Society.

Chandramouli Krishnan received the bachelor's degree in physiotherapy from the Tamil Nadu Dr. M. G. R. Medical University, Chennai, India, in 1998, and the master's and Ph.D. degrees in physical therapy and physical therapy and rehabilitation science from the University of Iowa, Iowa City, IA, USA, in 2006 and 2009, respectively.

He then pursued a post-doctoral fellowship for three years at the Rehabilitation Institute of Chicago, Chicago, IL, USA, focusing on rehabilitation robotics and noninvasive brain stimulation. Since 2012, he is directing the Neuromuscular and Rehabilitation Robotics Laboratory (NeuRRo Lab), University of Michigan at Ann Arbor, Ann Arbor, MI, USA. He is currently an Assistant Professor with the Department of Physical Medicine and Rehabilitation, Biomedical Engineering, Robotics Institute, and the School of Kinesiology, University of Michigan at Ann Arbor. His research examines the alterations in neuromuscular function, plasticity, and movement control after an injury to the neuro-musculoskeletal system and connects how these insights can be applied to rehabilitation using robotics, motor learning, and exercise interventions. His research program is funded through intramural and extramural grants, including support from the National Institutes of Health and National Science Foundation. He has over 20 years of clinical and research experience in physical therapy and rehabilitation sciences, has published more than 50 articles in peer-reviewed journals, and has presented at over 100 national and international meetings.

Dr. Krishnan is an Associate Editor of the IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING. He is also an Associate Editor of the *Restorative Neurology and Neuroscience* and a Section Editor of the *Measurement in Physical Education and Exercise Science*. He is an ad hoc reviewer for more than 40 international journals spanning across the field of engineering, biomechanics, and rehabilitation, and a regular reviewer for the National Institutes of Health and various international grant panels.