Guest Editorial: Special Issue on Human-Friendly Cognitive Robotics

RECENT developments in robotics and information technology have been applied to robots to improve their perception, cognition, learning, and control abilities to enhance the performance [items 1)–6) in the Appendix]. A challenging issue on robotics research is to make the robots working around with human more flexibly and safely. To address the challenge, this special issue focuses on the latest advances in the area of human-friendly cognitive robotics, particularly, the research concentrating on methodologies, computational models, and technologies to enhance the cognitive functionalities and intelligence of human–robot systems for better interaction performance. The development of these technologies aims to bring innovations into human–robot systems.

I. Scope of This Special Issue

This Special Issue on Human-Friendly Cognitive Robotics is primarily concerned with the recent demands in the development of human-friendly robots. The study of this topic aims to find methods and technologies to allow human–robot interaction in a highly intelligent and friendly manner. Cognition plays an important role for safe and dependable robots operating in close proximity to humans or directly interacting with them in a wide range of domains. These robots are also expected to characterize individuals interacting with them, such that their interactive behaviors can be personalized to maximize individual user experience. Driven by these targets, this special issue aims to promote research work on human-friendly robotics from the cognitive and developmental views.

With the development of robotic technology in various fields from the factory assembly line to healthcare and rehabilitation, it is hard for the conventional robots of low-level cognition to meet the requirements. The relationship between humans and robots has changed significantly in recent years. The transformation from conventional robots working isolated behind safety cages to collaborative robots interacting closely with human partners faces a number of challenges that should be addressed urgently. The new generation of collaborative robots is expected to be highly intelligent to learn new skills and to perform novel tasks with the partners through interaction [item 7) in the Appendix]. A promising way toward this goal is to integrate cognitive functions and developmental learning techniques into the processes of interaction between robots, humans, and the environments. This special issue serves this purpose to propose and discuss cognition-based solutions to improve the state-of-the-art human–robot friendly interaction.

The researchers from different backgrounds (such as robotics, computer science, neuroscience, and psychology) are welcome to share their methodologies, computational models, and technologies to enhance the cognitive functionalities and intelligence of human–robot systems for better interaction performance.

II. Contributions to the Special Issue

After a rigorous peer-review process, this special issue accepted 17 articles that describe work inspired by the concept of human-friendly cognitive robotics. These articles cover a wide range of topics, including human–robot interaction, skill transferring, emotion recognition, grasping, hand gesture recognition, compliant robot control, etc. Here, we briefly summarize each work.

In "An unsupervised approach for knowledge construction applied to personal robots," Russo *et al.* propose an unsupervised approach for knowledge construction based on robotic perception. The main contribution of the proposed framework is the realization of a multimedia knowledge base containing linguistic, semantic, and visual representation of general concepts, and implementation of an unsupervised approach for knowledge construction by means of self-organizing maps.

In "Learning bodily expression of emotion for social robots through human interaction," Tuyen *et al.* present a behavior selection and transformation model, enabling the robots to incrementally learn from the user's gestures and select the user's habitual behaviors, and then transform the behaviors into the robot motions. In "Computational modeling of emotion-motivated decisions for continuous control of mobile robots," Huang *et al.* investigate an emotion-motivated decision-making framework. A model-based decision-making approach with emotional intrinsic rewards is proposed to solve the continuous control problem of mobile robots. This approach can execute online model-based control with the constraint of the model-free policy and global value function, which is conducive to getting a better solution with a faster policy search.

In "Locomotion mode identification and gait phase estimation for exoskeletons during continuous multilocomotion

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tasks," Wu *et al.* design a continuous gait phase estimator based on an adaptive oscillator network. To overcome the problem that the traditional adaptive oscillator does not converge, a new structure of the gait phase estimator is designed to improve the performance of the adaptive oscillator network. In "Human-in-the-loop control strategy of unilateral exoskeleton robots for gait rehabilitation," Wei *et al.* study the human-in-the-loop control method for the gait rehabilitation of patients with hemiplegia. It utilizes a unilateral exoskeleton system that consists of a unilateral lower limb exoskeleton and a real-time robot follower, such that the affected legs can be coordinated with the healthy legs with the assistance of the exoskeleton robot.

Human walking intention estimation is critical for the active assistance control of the lower limb exoskeleton. In "Exoskeleton online learning and estimation of human walking intention based on dynamical movement primitives," Qiu *et al.* present an online learning and prediction algorithm of human joint trajectory and joint torque, to estimate a smooth personalized human joint torque profile. In "Single-layer learning-based predictive control with echo state network for pneumatic-muscle-actuators-driven exoskeleton," Cao *et al.* present a single-layer learning-based predictive control strategy for pneumatic muscle actuators (PMAs)-driven lower limb exoskeleton. In "BCI-controlled assistive manipulator: Developed architecture and experimental results," Di Lillo *et al.* propose a robot control architecture to help people performing daily-life operations using a P300-based brain–computer interface.

In "Skill learning strategy based on dynamic motion primitives for human–robot cooperative manipulation," Li *et al.* present a skill learning-based hierarchical control strategy for human–robot cooperative manipulation. The skill-learning-based hierarchical control strategy is proposed by considering both the motion modeling and the performance of the dynamic controller. In "Maxwell-model-based compliance control for human–robot friendly interaction," Fu and Zhao investigate the compliance control for safe and friendly human–robot interaction. The authors exploit the advantages of the Maxwell model in reactions to human interactions and develop a series of Maxwell-model-based compliance control methodologies, which only require kinematic control interfaces.

In "A reinforcement learning method using multifunctional principal component analysis for human-like grasping," Monforte and Ficuciello consider a problem to obtain a set of basis functions able to represent grasping movements learned from human demonstration. The authors employ a human cognition-inspired approach for generalizing and improving robot grasping skills in the motion synergies subspace by using reinforcement learning methods. In "Performance comparison of gesture recognition system based on different classifiers," Yang *et al.* investigate the hand gesture recognition problem by using sEMG signals. In "A rapid spiking neural network approach with an application on hand gesture recognition," Cheng *et al.* propose a novel spike firing time search algorithm that can narrow the search interval. Additionally, a pretrained subnet spiking neural network is designed, which makes the spiking neural network have more hidden layers. This setting of the spiking neural network can effectively improve its performance in pattern recognition tasks. The experimental results show that the spike firing time search algorithm can increase the forward propagation rate of the spiking neural network and the spiking neural network can reach a satisfactory recognition accuracy. In "A framework of hybrid force/motion skills learning for robots," Wang *et al.* present a robot learning framework based on dynamic movement primitives by considering the positional and contact force profiles in the process of human–robot skill transfer. Experiments show that the effectiveness of the proposed learning framework on real-world scenarios like cleaning a table.

In "Multimodal continual learning using online dictionary updating," Sun *et al.* consider the problem of continual learning task from the perspective of multimodal fusion. In this work, a continual learning framework is established for multimodal learning and design of an effective online dictionary updating method. In "A novel robotic guidance system with eye-gaze tracking control for needle-based interventions," Guo *et al.* develop a compact robotic guidance system which could accurately realize the needle position and orientation within the operating room. An eye-gaze tracking is proposed to control the position and orientation of the needle toward the desired location. Experimental studies based on the robot operating system are performed to evaluate the needle placement accuracy during interventional therapy. In "An ensemble net of convolutional auto-encoder and graph auto-encoder for auto-diagnosis," Li *et al.* design a diagnosis assistant to manage abundant historical inquiries between patients and doctors. The core of the auto-diagnosis system is a novel model called ensemble net of convolutional auto-encoder and graph auto-encoder which can be trained using historical data and generate a list of candidate diagnoses for a doctor to select. The experimental results show that the proposed approach outperforms the counterparts in generating more fluent and relevant diagnoses.

We would like to thank the Editor-in-Chief of IEEE TRANSACTIONS ON COGNITIVE AND DEVELOPMENTAL SYSTEMS, for his invaluable support and encouragements throughout the preparation of this special issue. In addition, we would like to express our appreciation to all the anonymous reviewers who devoted much of their precious time reviewing all the articles. Finally, we thank all authors who contributed to this special issue for their valuable and meaningful works.

III. CONCLUSION

The new generation of collaborative robots is expected to be highly intelligent to learn new skills and to perform novel tasks with their partners through interaction. A promising way toward this goal is to integrate cognitive functions and developmental learning techniques into the processes of interaction between robots, humans, and the environments. This special issue extends the concept of human-friendly robots and makes a set of contributions, from which we could draw some conclusions.

1) The robots are becoming more and more autonomous to operate in unstructured environments and facing unpredicted problems. The cognition ability of the robots allows the robot to continuously learn, to be smarter working in an unknown environment.
2) Emotion is able to trigger instinctive behaviors of animals, and modulate the decision making of humans in a social dilemma. Understanding human emotions allow the robots to serve people better in a human–robot interaction scenario.
3) Human intention estimation is important for enhancing the performance of exoskeleton robot control. By concentrating on the online learning and prediction of human walking intention during stable walking, predicting a smooth human joint trajectory can be used for both human joint torque estimation and exoskeleton active assistance control.

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APPENDIX
RELATED WORK

1) S. Jezernik, G. Colombo, and M. Morari, "Automatic gait-pattern adaptation algorithms for rehabilitation with a 4-DOF robotic orthosis," *IEEE Trans. Robot. Autom.*, vol. 20, no. 3, pp. 574–582, Jun. 2004.
2) J. F. Veneman, R. Ekkelenkamp, R. Kruidhof, F. C. van der Helm, and H. van der Kooij, "A series elastic- and bowden-cable-based actuation system for use as torque actuator in exoskeleton-type robots," *Int. J. Robot. Res.*, vol. 25, no. 3, pp. 261–281, 2006.
3) S. M. Bohte, H. La Poutré, and J. N. Kok, "Unsupervised clustering with spiking neurons by sparse temporal coding and multilayer rbf networks," *IEEE Trans. Neural Netw.*, vol. 13, no. 2, pp. 426–435, Mar. 2002.
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7) E. A. Kirchner, J. de Gea Fernandez, P. Kampmann, M. Schröer, J. H. Metzen, and F. Kirchner, "Intuitive interaction with robots–technical approaches and challenges," in *Formal Modeling and Verification of Cyber-Physical Systems*. Wiesbaden, Germany: Springer, 2015, pp. 224–248.

Chenguang Yang (Senior Member, IEEE) received the Ph.D. degree in control engineering from the National University of Singapore, Singapore, in 2010, and postdoctoral training in human robotics from Imperial College London, London, U.K.

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