Guest Editorial
Special Issue on Artificial Intelligence for Autonomous Unmanned System Applications

THIS special issue of the IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING (T-ASE) focuses on how the state-of-the-art achievements and applications in the general area of artificial intelligence in automation for autonomous unmanned systems applications. As Guest Editors, we are very pleased to present the selected 16 articles, whose topics are specifically related to artificial intelligence real-time object detection, recognition, localization, control optimization, motion planning, formation control, adaptive control, and autonomous decision-making.

Artificial intelligence has become very popular in the computer, information science, and engineering community in recent years. In particular, thanks to the development of artificial intelligence factors including the brain–computer interface, information perception, interaction, and intelligent control and learning, artificial intelligence is playing an unprecedented role in modern automation systems. Nevertheless, there are many challenging issues to explore in the implementation of artificial intelligence for a practical automatic system, such as system design, security, robustness, and accessibility.

To respond to the needs and challenges for integration with new technologies, researchers are intensively investigating efficient scientific and engineering solutions, with particular attention to information technology-based modeling, analysis, control, and optimization. In particular, we observed the following major research topics in the wide area of artificial intelligence for autonomous unmanned system applications:

1) Artificial intelligence for real-time object detection, recognition, and tracking
2) Artificial intelligence for map building and localization
3) Artificial intelligence for real-time sensing
4) Artificial intelligence for autonomous control
5) Artificial intelligence for autonomous decision-making
6) Artificial intelligence for motion planning
7) Artificial intelligence for path tracking and motion control
8) Artificial intelligence for intelligence testing and verification

The proposed Special Issue is an opportunity for highly qualified researchers, academicians, and practitioners to exchange new ideas and results on artificial intelligence for autonomous unmanned system applications. A high number of papers have been submitted to this Special Issue and all manuscripts went through a peer-review process, after which 16 contributions were selected for publication.

The articles selected for this Special Issue exemplify and present the latest advances in scientific research in artificial intelligence for practical automated systems. More specifically, the included articles can be conceptually divided into the following different macro-categories.

1) Application and optimization of artificial intelligence in multiple scenarios: this class collects six articles, including contributions from topics 1) to 4) and 8).
2) On control, decision-making, and motion planning of artificial intelligence: this class collects ten articles, including contributions from topics 4) to 7).

Artificial intelligence can not only undertake some current mainstream tasks but also have a place in solid waste management. In [A1], Guo *et al.* propose the use of a material recognition method with vision-guided haptics to form a robotic system for waste sorting. Based on the experimental results, the authors demonstrate the effectiveness of the proposed robotic waste sorting system in sorting containers and packaging various materials. Distracted driving, a major challenge in improving traffic safety, is another application of artificial intelligence. In contrast to mainstream computer vision-based methods, in [A2], Li *et al.* use the temporal and spatial information of electroencephalogram (EEG) signals as model inputs. Convolutional techniques and gated recurrent units were used to map the relationship between driver distraction states and EEG signals in the time domain.

In some other articles, the authors are motivated by limited performance in existing control designs. In [A3], Liu *et al.* mainly consider a vibration control problem in the case where the initial boundary deflection may violate the bounds and some actuators may be failed. They propose a redundant fault-tolerant and boundary constraint control in the framework of the adaptive method, the neural network approximation, and the barrier Lyapunov function (BLF) with a relaxed initial condition. In [A4], Zhang *et al.* discuss cooperative control of a mobile dual flexible manipulator system with asymmetric time-varying output constraints and actuator failures, and an adaptive fault-tolerant control scheme is developed to deal with actuator failures while suppressing system vibrations and achieving cooperative operation.

In fact, the positioning accuracy will also bring challenges to the application and popularization of artificial intelligence, especially the multi-mobile robot system. In [A5], Xin *et al.* propose a multi-mobile robot co-location system

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based on ultra-wideband (UWB) sensors and GPU hardware acceleration. The experimental results in real scenarios show that the proposed multi-mobile robot co-location system using UWB technology is fast, accurate, and robust.

Collaboration among multiple connected vehicles (CVs) brings swarm intelligence to our transportation system, and fuel economy optimization of platooning swarms can deliver even greater benefits. In [A6], Bian *et al.* propose an optimization method via Distributed Economic Model Predictive Control (DEMPC). Within the DEMPC framework, each CV shares its hypothetical trajectory within the prediction horizon with its neighboring CVs in each control loop. With its neighbors and its own hypothetical trajectory, each CV first solves an open-loop control optimization problem for queuing, and then an open-loop economy optimization problem to directly improve fuel economy.

With regard to topics in macro-category 2), several papers are focused on the main problems related to path planning. In particular, in [A7], Li *et al.* consider the path planning problem of the unmanned air/ground vehicle (UAV/UGV) cooperative system for illegal urban building detection and propose a two-level memetic path planning algorithm (Two-MA). The experimental results on the synthetic data as well as the real data validated the superiority of Two-MA over the classical algorithms (Two-GA, Two-ACO, and Two-greedy) in finding the paths with minimum task execution time for the detection of nonstandard buildings in cities. In [A8], Wang *et al.* propose a local path planning algorithm based on risk assessment and mitigation according to the information of predicted trajectories of surrounding vehicles. The results show that the proposed path planning algorithm reduces risk and improves driving efficiency, especially when the speed and trajectory change abruptly, compared to the prediction methods of constant-velocity prediction and nonlinear input-output (NIO) network. In [A9], Liu *et al.* address the integrated task assignment, path planning, and coordination problem applied to large-scale robot networks with the existence of uncertainties. Their designed novel generalized conflict graph and proposed greedy solution are proven to be optimal, scalable, robust, and efficient. In addition, in [A10], Wen *et al.* present a three-layer motion planning framework to solve the autonomous navigation problem in complex environments. Through simulations and real-world tasks, the authors validate the safety, smoothness, flexibility, and efficiency of the method.

Formation control is a hot issue in multi-agent research. In [A11], Wang *et al.* aim to design a practical formation control method for multi-autonomous underwater vehicles (AUVs) and to validate the control method in the field. They propose a leader–follower formation control method for underactuated AUVs using one-way acoustic communication, which can change the formation between the one-line pattern and V pattern of three AUVs, and prove its feasibility, convergence, and stability. In [A12], Yan *et al.* propose a distributed adaptive event-triggered formation control strategy for unified nonlinear heterogeneous multi-agent systems under uncertainty and perturbation to realize time-varying formation. And the simulation and experiment of formation tracking and patrol verify the effectiveness and robustness of the proposed formation control strategy.

As the execution system of the robot, the manipulator has a decisive influence on the performance of the robot. In [A13], Kang *et al.* propose an event-triggered model predictive control (MPC) strategy with a robotic manipulator that learns terminal costs, incorporating model uncertainty and input constraints. The proposed control framework mainly consists of three parts: the prediction model, the learning terminal cost, and the triggering mechanism of the MPC solution, which realizes global steady-state optimization and transient fast convergence. And the feasibility and effectiveness have also been verified by experiments.

Finally, the Special Issue focuses on autonomous decision-making by artificial intelligence in complex interactive scenarios. In [A14], Yan *et al.* present a hybrid car following a strategy based on deep deterministic policy gradients (DDPG) and cooperative adaptive cruise control (CACC). It not only ensures the basic performance of following the car through CACC but also makes full use of the advantages of DDPG to explore complex environments. In [A15], Wang *et al.* propose a probabilistic reconstruction learning method for extracting interpretable internal states for the dynamic interaction process of highway on-ramp merging. The experimental results show that three interpretable internal states can semantically describe the interactive merging process at highway entrances. In [A16], Brittain and Wei consider high-density en-route airspace sectors with heterogeneous aircraft targets and propose a scalable autonomous separation assurance framework. The numerical experimental results on a real-time air traffic simulator demonstrate that the proposed framework can effectively ensure the safe separation of heterogeneous agents, while also optimizing the intrinsic agent objectives of high-density en-route airspace sectors.

We conclude this editorial by thanking all the authors for their high-quality contributions. We are also indebted to all associate editors and anonymous reviewers for their professional and valuable work that helped improve all manuscripts.

HONGBO GAO, *Lead Guest Editor*
Department of Automation
University of Science and Technology of China
Hefei 230022, China

MING LIU, *Guest Editor*
Department of Electronic and Computer Engineering
Department of Computer Science and Engineering
Hong Kong University of Science and Technology
Hong Kong

FEI CHEN, *Guest Editor*
Department of Advanced Robotics
Istituto Italiano di Tecnologia
16163 Genova, Italy

XIAOXIANG NA, *Guest Editor*
Department of Engineering
University of Cambridge
CB2 1PZ Cambridge, U.K.

DING ZHAO, *Guest Editor*
Robotics Institute and Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, PA 15213 USA

JINGTAO WANG
Centre for Intelligent Healthcare
Coventry University
CV1 5RW Coventry, U.K.

LINGHE KONG, *Guest Editor*
Department of Computer Science and Engineering
Shanghai Jiao Tong University
Shanghai 200240, China

KEQIANG LI, *Guest Editor*
School of Vehicle and Mobility
Tsinghua University
Beijing 100084, China

CHUN-YI SUN, *Guest Editor*
Center of Industrial Control
Concordia University
Montreal, QC H3G 1M8, Canada

APPENDIX: RELATED ARTICLES

[A1] D. Guo, H. Liu, B. Fang, F. Sun, and W. Yang, "Visual affordance guided tactile material recognition for waste recycling," *IEEE Trans. Automat. Sci. Eng.*, early access, Mar. 29, 2021, doi: 10.1109/TASE.2021.3065991.

[A2] G. Li, W. Yan, S. Li, X. Qu, W. Chu, and D. Cao, "A temporal-spatial deep learning approach for driver distraction detection based on EEG signals," *IEEE Trans. Automat. Sci. Eng.*, early access, Jun. 24, 2021, doi: 10.1109/TASE.2021.3088897.

[A3] Z. Liu, Z. Han, and W. He, "Adaptive fault-tolerant boundary control of an autonomous aerial refueling hose system with prescribed constraints," *IEEE Trans. Automat. Sci. Eng.*, early access, Apr. 12, 2021, doi: 10.1109/TASE.2021.3070140.

[A4] S. Zhang, Y. Wu, X. He, and Z. Liu, "Cooperative fault-tolerant control for a mobile dual flexible manipulator with output constraints," *IEEE Trans. Automat. Sci. Eng.*, early access, Aug. 18, 2021, doi: 10.1109/TASE.2021.3102588.

[A5] J. Xin, G. Xie, B. Yan, M. Shan, P. Li, and K. Gao, "Multimobile robot cooperative localization using ultrawideband sensor and GPU acceleration," *IEEE Trans. Automat. Sci. Eng.*, early access, Oct. 15, 2021, doi: 10.1109/TASE.2021.3117949.

[A6] Y. Bian, C. Du, M. Hu, S. E. Li, H. Liu, and C. Li, "Fuel economy optimization for platooning vehicle swarms via distributed economic model predictive control," *IEEE Trans. Automat. Sci. Eng.*, early access, Nov. 29, 2021, doi: 10.1109/TASE.2021.3128920.

[A7] J. Li *et al.*, "A memetic path planning algorithm for unmanned air/ground vehicle cooperative detection systems," *IEEE Trans. Automat. Sci. Eng.*, early access, Mar. 10, 2021, doi: 10.1109/TASE.2021.3061870.

[A8] H. Wang *et al.*, "Risk assessment and mitigation in local path planning for autonomous vehicles with LSTM based predictive model," *IEEE Trans. Automat. Sci. Eng.*, early access, May 25, 2021, doi: 10.1109/TASE.2021.3075773.

[A9] Z. Liu, H. Wei, H. Wang, H. Li, and H. Wang, "Integrated task allocation and path coordination for large-scale robot networks with uncertainties," *IEEE Trans. Automat. Sci. Eng.*, early access, Sep. 23, 2021, doi: 10.1109/TASE.2021.3111888.

[A10] J. Wen, X. Zhang, H. Gao, J. Yuan, and Y. Fang, "E^{3}MoP: Efficient motion planning based on heuristic-guided motion primitives pruning and path optimization with sparse-banded structure," *IEEE Trans. Automat. Sci. Eng.*, early access, Nov. 29, 2021, doi: 10.1109/TASE.2021.3128521.

[A11] C. Wang, W. Cai, J. Lu, X. Ding, and J. Yang, "Design, modeling, control, and experiments for multiple AUVs formation," *IEEE Trans. Automat. Sci. Eng.*, early access, Jul. 15, 2021, doi: 10.1109/TASE.2021.3094539.

[A12] B. Yan, P. Shi, and C.-C. Lim, "Robust formation control for nonlinear heterogeneous multiagent systems based on adaptive event-triggered strategy," *IEEE Trans. Automat. Sci. Eng.*, early access, Aug. 23, 2021, doi: 10.1109/TASE.2021.3103877.

[A13] E. Kang, H. Qiao, Z. Chen, and J. Gao, "Tracking of uncertain robotic manipulators using event-triggered model predictive control with learning terminal cost," *IEEE Trans. Automat. Sci. Eng.*, early access, Mar. 4, 2022, doi: 10.1109/TASE.2022.3152166.

[A14] R. Yan, R. Jiang, B. Jia, J. Huang, and D. Yang, "Hybrid car-following strategy based on deep deterministic policy gradient and cooperative adaptive cruise control," *IEEE Trans. Automat. Sci. Eng.*, early access, Aug. 12, 2021, doi: 10.1109/TASE.2021.3100709.

[A15] H. Wang, W. Wang, S. Yuan, and X. Li, "Uncovering interpretable internal states of merging tasks at highway on-ramps for autonomous driving decision-making," *IEEE Trans. Automat. Sci. Eng.*, early access, Aug. 13, 2021, doi: 10.1109/TASE.2021.3103179.

[A16] M. Brittain and P. Wei, "Scalable autonomous separation assurance with heterogeneous multi-agent reinforcement learning," *IEEE Trans. Automat. Sci. Eng.*, early access, Feb. 21, 2022, doi: 10.1109/TASE.2022.3151607.

Hongbo Gao (Member, IEEE) is currently a Professor, the Head of the Laboratory of Intelligent Driving and Cognitive Intelligence, Department of Automation, University of Science and Technology of China. His main research includes intelligent perception, planning, intelligent decision-making, and intelligent control technology of the autonomous unmanned system. He has authored over 50 academic articles published in high-quality international journals in the fields of robotics, intelligent perception, planning, intelligent decision-making, and intelligent control, including IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, IEEE TRANSACTIONS ON CYBERNETICS, etc. His ten patents have been applied/authorized as well. He is an ITSS Member, CAAI Senior Member, and CICC Senior Member. He has served on the editorial boards of several special sessions of international journals and has chaired or co-chaired several special sessions in international conferences.

Ming Liu is currently the Acting Head of the Robotics and Autonomous Systems Thrust, Hong Kong University of Science and Technology, Guangzhou, and an Associate Professor with the Department of Electronic and Computer Engineering (ECE) and the Department of Computer Science and Engineering (CSE), Hong Kong University of Science and Technology. He received various IEEE awards, including the IEEE IROS Young Professional Award in 2018 and 15 best paper awards or finalist awards. He has published over 240 papers with H-index 49 and citation 8800+. His research interests include dynamic environment modeling, 3-D mapping, machine learning, and visual control. His team developed the first autonomous vehicle in Hong Kong in 2017. During COVID-19, his autonomous vehicles served several cities and were reported by 100+ media, including IEEE Spectrum and Xinhua.

Fei Chen is currently a Senior Researcher with the Department of Advanced Robotics, Istituto Italiano di Tecnologia, and also the Director of the Active Perception and Robot Interactive Learning Laboratory. His main research interests include active perception, robot interactive learning, and motion planning. He has authored or coauthored more than 40 journal articles and four patents. He was awarded international awards in research fields of active perception and robot interactive learning. He served as a member of several international and national professional bodies and esteemed societies.

Xiaoxiang Na is currently an Associate Professor with the Department of Engineering, University of Cambridge. He also serves as the Deputy Secretary-General of the Technical Committee on Parallel Intelligence at Chinese Association of Automation, and the Deputy Secretary-General of International Parallel Driving Alliance. His main research interests include intelligent vehicle dynamics and intelligent vehicle in-service performance evaluation. He has authored or coauthored more than 30 journal articles and three patents. He has served on the editorial boards of several special sessions of international journals and has chaired or co-chaired several special sessions in international conferences.

Ding Zhao is currently an Assistant Professor with the Robotics Institute and Mechanical Engineering, Carnegie Mellon University. His main research interests include self-driving cars, intelligent transportation, and automated manufacturing. He has authored or coauthored more than 50 journal and conference papers and nine patents. He has served on the editorial boards of several special sessions of international journals and has chaired or co-chaired several special sessions in international conferences.

Jiangtao Wang (Member, IEEE) received the Ph.D. degree from Peking University, Beijing, China, in 2015. He was an Assistant Professor with the School of Computer and Communications, Lancaster University, Lancaster, U.K., from 2019 to 2020. He is currently an Associate Professor with the Centre for Intelligent Healthcare, Coventry University, Coventry, U.K. His research interests include pervasive and mobile computing, crowdsensing, digital health, the Internet of Things, and smart cities.

Linghe Kong received the bachelor's degree from Xidian University in 2005, the master's degree from TELECOM SudParis (ex. INT) in 2007, and the Ph.D. degree from Shanghai Jiao Tong University in 2013. He is currently a Full Professor with the Department of Computer Science and Engineering, Shanghai Jiao Tong University. He previously served as a Postdoctoral Researcher at Columbia University, McGill University, and Singapore University of Technology and Design. His research interests include Internet of things, 5G, big data, blockchain, and mobile computing.

Keqiang Li is a Full Professor, and the Director of State Key Laboratory of Automotive Safety and Energy, School of Vehicle and Mobility, Tsinghua University, China. His main research area is unmanned ground vehicle dynamics and control, intelligent vehicles, and intelligent transportation systems. He has authored and coauthored over 200 journal and conference papers and has more than 80 patents. He was awarded international and national awards in research fields of unmanned ground vehicle and intelligent transportation systems, including National Technology Invention Award. He is the Editor-in-Chief (EiC) of *Journal of Intelligent and Connected Vehicles* and *Journal of Automotive Safety and Energy*. He has served as the General Chair of a number of these conferences, including the General Chair of AVEC 2018. He is now an academician of the Chinese Academy of Engineering.

Chun-Yi Su is currently a Professor and occupies the Tier I Concordia University Research Chair. He is the Director of the Center of Industrial Control and Director of the Laboratory of Robot and Mechatronic Systems at Concordia University, Montreal, Canada. His main research interests are in control techniques for mechanical systems, robotic and mechatronic systems, vehicle suspension and vibration, and nonlinear control systems. He is the author or coauthor of over 500 publications, which have appeared in journals, as book chapters, and in conference proceedings. He has been identified as 2019 Highly Cited Researchers from the Web of Science Group.

Dr. Su has served as an Associate Editor for several journals, including IEEE TRANSACTIONS ON AUTOMATIC CONTROL, IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, *Mechatronics*, *Control Engineering Practice*, IEEE TRANSACTIONS ON CYBERNETICS. He has also served as Guest Editor of several special issues including IEEE TRANSACTIONS ON CONTROL SYSTEM TECHNOLOGY. He is a Distinguished Lecturer of IEEE RA Society and has also served as Chair/Co-Chair at various capacities for numerous international conferences in the area of control and automation.