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Special Issue on Co-operative Multi-Agent Systems with Engineering Applications


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# Editorial

# Co-operative Multi-Agent Systems with Engineering Applications

The current study of multi-agent systems is pervading many scientific disciplines, ranging from physical to biological, even to economic sciences, suggesting that its impact on modern engineering and technology is prominent and will be far-reaching. Typical co-operative behaviors of multi-agent systems include consensus, flocking, swarming, rendezvous and so on. Research on co-operative multi-agent systems has become overwhelming, which not only helps to provide a better understanding of the mechanisms of natural collective phenomena, but also benefits various applications of networked cyber-physical systems, such as robot teams and unmanned autonomous vehicles.

This Special Issue focuses on theoretical and technological achievements in co-operative multi-agent systems, specifically within the following three areas: the coordinated control of multi-agent systems and the synchronisation of complex networks; distributed estimation and control for mobile sensor networks; and applications of coordinated control of complex networked systems. It contains twenty-four papers, the contents of which are summarised below.

In the area of the coordinated control of multi-agent systems and the synchronisation of complex networks, Zhao *et al.* investigate the distributed finite-time consensus problem of networked agents described by second-order integrators in their paper entitled 'Finite-time consensus for second-order multi-agent systems with saturated control protocols'. A saturated protocol is proposed based on both relative position and relative velocity measurements to achieve finite-time consensus. A synchronised output regulation problem via exchanging information at sampled time is studied by Xiang *et al.* in their paper 'Synchronised output regulation of heterogenous networks with delayed and sampled data communications'. A necessary and sufficient condition is presented in which the sampled period should satisfy synchronised output regulation with fixed digraph and time-delay. In 'Fuzzy dynamic output-feedback control of nonlinear networked discrete-time system with missing measurements', by Li *et al.*, the challenge of $H_\infty$ dynamic output-feedback control of nonlinear networked discrete-time systems with data packet dropouts is reported, and an approach based on fuzzy Lyapunov function is developed to solve it. Wang and Yi examine the consensus problem of second-order multi-agent systems via impulsive control in their paper entitled 'Consensus in second-order multi-agent systems via impulsive control using position-only information with heterogeneous delays', using position-only information with different communication delays. A distributed impulsive consensus protocol is designed, in which only the delayed sampled relative positions to neighbors and the relative position to the last sampling state are utilised.

In 'Robustness of Cucker-Smale flocking model', Canale *et al.* present a modification of the (deterministic) flocking model introduced by Cucker and Smale. The flocking problem for a group of mobile agents with uncertain parameters is explored by Zhang *et al.* in their paper 'Adaptive flocking of nonlinear multi agents systems with uncertain parameters'. Chen *et al.* study the consensus problem for second-order multi-agent systems in their paper entitled 'Multi-consensus for second-order multi-agent systems based on sampled position information,' with only sampled position information. In 'Guaranteed-cost consensus problems for second-order multi-agent systems', Wang *et al.* study the guaranteed cost consensus for second-order multi-agent systems with fixed topologies. A paper by Li *et al.* entitled 'Continuous-time multi-agent averaging with relative-state-dependent measurement noises: matrix intensity functions' looks into the distributed averaging of higher-dimensional first-order agents with relative-state-dependent measurement noises. Aperiodic sampled-data synchronisation of complex dynamical networks is proposed by Wu *et al.*, incorporating dynamics of actuators saturation. Yazdani and Haeri's paper, titled 'Position convergence of informed agents in flocking problem with general linear dynamic agents', generalises the existing works on the flocking problem to agents with general linear dynamics, while Su and Chen study the containment control of linear multi-agent systems with input saturation on switching topologies in their paper 'Multi-agent containment control with input saturation on switching topologies'. Both state feedback and output feedback containment control protocols are proposed via a novel low gain feedback approach.

Regarding the area of distributed estimation and control for mobile sensor networks, a paper by Yang and Shi, titled 'Power allocation scheme for distributed filtering over wireless sensor networks', explores distributed filtering

over wireless sensor networks with limited energy. Several offline power scheduling strategies are introduced to distribute the power of sensors, and a sufficient condition is provided to guarantee the convergence of network estimation error covariance. In 'Distributed estimation using online semi-supervised particle filter for mobile sensor networks', Yoo *et al.* presents an improved particle filter by incorporating semi-supervised machine learning for location estimation in mobile sensor networks. In 'Periodic event/self-triggered consensus for general continuous-time linear multi-agent systems under general directed graphs', Yang *et al.* study the distributed periodic event-triggered consensus for continuous-time general linear multi-agent systems with the control cost reduced.

The final area, applications of coordinated control of complex networked systems, begins with Wang *et al.* addressing the co-operative control problem of multi-missile systems in their paper 'Cooperative control of multi-missile systems'. A two-stage control strategy, aiming at simultaneous attacks from a group of missiles on a static target is proposed for the multi-missile systems. Zhou *et al.* investigate the emergency decision-making problem in a multi-agent system in 'Multi-agent coordinated planning approach for deadline required emergency response tasks'. A novel multi-agent planning approach is proposed to coordinate for the solution among agents in the system. In the paper entitled 'Virtual line shafting control for permanent magnet synchronous motor system using sliding-mode observer', a novel observer-based electronic line-shafting control strategy, by Zhang *et al.*, is presented for permanent magnet synchronous motor systems. Fu *et al.* examine the equilibrium behavior and negotiation protocol design for a class of systems composed of multiple, non-cooperative agents in 'Concurrent multi-agent systems with temporal logic objectives: game theoretic analysis and planning through negotiation'. This work develops a negotiation protocol which ensures that, under a proper design of preferences and tasks, the mutually accepted plan is a Pareto optimal pure Nash equilibrium. A multi-agent control approach is proposed by Zhou *et al.* in 'Multi-agent model-based predictive control for large-scale urban traffic networks using a serial scheme', using a congestion-degree-based serial scheme for large-scale urban traffic networks. Liu *et al.* explore the opinion dynamics with group polarisation in their paper entitled 'Multi-agent model of group polarisation with biased assimilation of arguments'. Integrated target search, tasking and tracking using multiple fixed-wing UAVs is studied by Meng *et al.* in 'Integrated multi-agent system framework: decentralised search, tasking and tracking', in which control logic and optimise flight paths are designed for the UAVs. Finally, Wang *et al.* consider the large population dynamic games where each agent evolves according to a dynamic equation containing the input average of all agents in 'Decentralised dynamic games for large population stochastic multi-agent systems'. The Nash certainty equivalence is introduced to design decentralised controls.

Note that, although the selected topics and papers are not a comprehensive representation of the area covered by this Special Issue, they do provide some recent advances in the field of complex networked systems which could benefit current research in some way.

We would like to thank all the authors for their contributions and acknowledge all the reviewers for their time and effort in assessing the manuscripts. We also thank the Editor-in-Chief and the Editorial Office of IET Control Theory & Applications for their great support, without which the completion of this project would not be possible.

## Guest Editors

**Michael Z. Q. Chen** received a B.Eng. (1st Class Honours) degree in electrical and electronic engineering from Nanyang Technological University, Singapore, and a Ph.D. in control engineering from Cambridge University, UK. He is currently an Assistant Professor in the Department of Mechanical Engineering at The University of Hong Kong. Dr. Chen is a Fellow of the Cambridge Philosophical Society and a Life Fellow of the Cambridge Overseas Trust. He is a Guest Associate Editor for the *International Journal of Bifurcation and Chaos*. His research interests include passive network synthesis, mechanical control, complex networks and smart grids.

**Housheng Su** received a B.S. degree in automatic control and a M.S. degree in control theory and control engineering from Wuhan University of Technology, China, in 2002 and 2005, respectively. In 2008 he received a Ph.D. in control theory and control engineering from Shanghai Jiao Tong University, China. From December 2008 to January 2010, he was a postdoctoral researcher with the Department of Electronic Engineering, City University of Hong Kong. Since January 2010, he has been an Associate Professor with the Department of Control Science and Engineering, Huazhong University of Science and Technology, China. His research interests lie in the areas of multi-agent coordination control theory and its applications to autonomous robotics, and mobile sensor networks.

**Xiaofan Wang** received a Ph.D. from Southeast University, China, in 1996. He has been a Professor in the Department of Automation, Shanghai Jiao Tong University (SJTU) since 2002 and a Distinguished Professor of SJTU since 2008. He has (co)authored four books and over 70 papers, is the current Chair of the IFAC Technical Committee on Large-Scale Complex Systems, and has received the following awards: the 2002 National Science Foundation for Distinguished Young Scholars of P. R. China; the 2005 Guillemin-Cauer Best Transactions Paper Award from the IEEE Circuits and Systems Society; the 2008 Distinguished Professor of the Chang Jiang Scholars Program, Ministry of Education of P. R. China; and the 2010 Peony Prise for Natural




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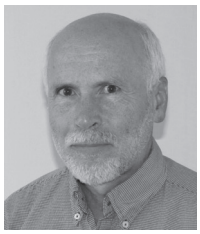
**Mario di Bernardo** is currently a Professor of Nonlinear Systems and Control at the University of Bristol, UK, and the University of Naples Federico II, Italy. He is a Fellow of the IEEE, Vice President of the IEEE Circuits and Systems Society and President of the Italian Society for Chaos and Complexity. He is the Deputy Editor-in-Chief of the *IEEE Transactions on Circuits and Systems*, and an Associate Editor of the *IEEE Transactions on Control of Network Systems and Nonlinear Analysis: Hybrid Systems*. His research interests include complex network systems; hybrid and piecewise-smooth dynamical systems; nonlinear dynamics and control with applications to engineering and computational biology.

**Guanrong (Ron) Chen** has been a Chair Professor and the Founding Director of the Centre for Chaos and Complex Networks at the City University of Hong Kong since 2000, prior to which he was a tenured Full Professor at the University of Houston, USA. Prof. Chen was elected an IEEE Fellow in 1997 and a Member of the Academia Europaea in 2014. In addition, he was conferred Honorary Doctorates by the Saint Petersburg State University of Russia in 2011 and by the University of Le Havre of France in 2014. He is a Highly Cited Researcher in Engineering as well as in Physics, was the 2011 Euler Gold Medalist named by the Euler Foundation of Russia, and recipient of the 2008 and the 2012 Chinese State Natural Science Awards, as well as 5 best journal paper awards. He is a Honorary Professor at different ranks in some 30 universities worldwide. Prof. Chen's main research pursuit is in nonlinear systems, control and dynamics, as well as complex networks. He is currently the Editor-in-Chief for the *International Journal of Bifurcation and Chaos*.



**Tamás Vicsek** is a Professor of Physics at the Biological Physics Department of Eötvös University and the Head of the Statistical and Biological Physics research group of the Hungarian Academy of Sciences. Over the past 35 years, he has been involved in computational and experimental research on fractals, pattern formation, granular materials, collective motion (bacterial colonies, flocks, crowds) and the structure and evolution of complex networks. He has had visiting positions at various research institutes and universities including Emory University, Yale University and the University of Notre Dame. Prof. Vicsek is a fellow of the American Physical Society and member of the Hungarian Academy of Sciences.

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