Guest Editorial Special Issue on Control of Very-Large-Scale Robotic (VLSR) Networks

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FUTURE applications of autonomous systems promise to involve increasingly large numbers of collaborative robots individually equipped with onboard sensors, actuators, and wireless communications. By sharing and coordinating information, plans, and decisions, these very-large-scale robotic (VLSR) networks can dramatically improve their performance and operate over long periods of time with little or no human intervention. Controlling many collaborative agents to this day presents significant technical challenges. Besides requiring satisfactory communications, the amount of computation associated with most coordinated control algorithms increases with the number of agents. It is well known, for example, that the optimal control of N collaborative agents for path planning and obstacle avoidance is a PSPACE-hard problem. Also, while necessary for performing basic tasks such as localization and mapping, many sensing and estimation approaches suffer from the curse of dimensionality, and their performance may degrade as uncertainties from disparate sources propagate through the network.

This Special Issue of the IEEE TRANSACTIONS ON CONTROL OF NETWORK SYSTEMS (TCNS) contains original contributions that provide scalable approaches to fault-tolerant communications, data processing, optimization, planning, and control for VLSR networks. Proposed solutions leverage a broad spectrum of system theories, from random finite set (RFS) theory and finite set statistics to H-infinity and iterative linear quadratic regulation (ILQR). Box and Jenkins models and Gaussian mixture probability hypothesis density approximations are proposed to identify and model the dynamics of spatially distributed networks in terms of probability distributions or population densities. Many of the articles in this issue show that computational complexity issues associated with increasing numbers of agents can be mitigated by modeling the evolutions of the robot's spatial distribution using partial differential equations (PDEs) such as reaction-diffusion (RD) and Fokker–Planck–Kolmogorov equations.

The theoretical and computational VLSR control methods that emerged from the contributions in this issue include graphon linear quadratic regulator, RFS-based ILQR, networked Euler–Lagrange systems, Hamilton-Jacobi inequality-constrained optimization, mixed integer semi-definite programming, adaptive distributed optimal control, and constrained eigendecomposition. By these approaches, the articles in this issue analyze and solve important VLSR problems, including the following:

1) system identification of linear parameter varying state-space approximations of nonlinear RD PDEs;
2) fault tolerance in mobile networks communications;
3) runtime and safety enforcement in decentralized multiagent systems;
4) theoretical correctness guarantees for decentralized, hierarchical unmanned aerial networks;
5) real-time optimization of PDE-constrained control and estimation;
6) swarm guidance, configuration maintenance, and collision avoidance;
7) robust decentralized stochastic multirobot formation tracking;
8) global stability and asymptotic convergence guarantees for both leaderless and leader–follower networked manipulator consensus.

These original contributions propose emerging solutions that are not only scalable and grounded in sound theoretical formalisms, but are also successfully demonstrated in an impressive range of applications, such as urban air mobility, robot manipulators, biped robots, mobile wireless sensor networks, and multi-quadcopter systems, to name a few.

The articles in this Special Issue provide a unique and invaluable perspective of critical problems and applications in the field of VLSR systems. While it would not be possible to capture all approaches for swarm robotics and control, we hope that the articles selected will show the interested readers some of the important emerging trends, as well as demonstrate the incredible promise and opportunities that the future of these systems holds.

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