Guest Editorial
Special Issue on Networked Cooperative Autonomous Systems

RECENT advances in networked cooperative autonomous systems offer the potential to significantly improve quality for manufacturing and other industrial applications. Advances in embedded processor, sensor, communication and networking technology in the last few decades have accelerated interest in networked cooperative autonomous systems, multirobot systems and distributed sensor networks for applications such as manufacturing, logistics, process monitoring and enhanced situational awareness, plant safety, inspection, security, and rescue operations. The advances that have made individual autonomous systems more practical have enabled the research on and the development of cooperative systems, where capabilities are expressed by the team rather than by a super-capable individual. This is especially relevant in complex tasks that require capabilities that are varied in both quantity and difficulty, such as goods transportation, distributed assembly, vehicle coordination strategies, and infrastructure inspection. Moreover, one of the main advantages of having a cooperative system instead of a super-capable individual is in the increased reliability due to redundancy.

Subsequently, in the last few years, several research efforts have been carried out focused on networked cooperative autonomous systems. Most of the works that can be found in the literature, however, are devoted to developing basic methodologies that define the fundamentals of the multirobot systems discipline. Along these lines, most of the experimental implementations obtained so far are confined within tamed laboratory environments, and are very far from full-scale deployment in real-world application environments.

It is worth noting, however, that a few pioneering real-world applications of networked cooperative autonomous systems can be found in specific application domains. In particular, remarkable examples are given by logistics departments of a few large companies, where multirobot systems are used for goods delivery. Other preliminary successful applications can be found in the field of mining, and in precision farming applications.

The central theme of the Special Issue is the development of systems, methodologies, and new concepts for crossing the gap between laboratories and reality that will help in bringing networked cooperative autonomous systems to real-world applications.

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This theme is thus strongly interdisciplinary, involving competencies from several science fields such as: robotics, control systems, sensor networks, distributed information and control/coordination systems, and systems engineering. Articles in this Special Issue cover the following topics:

- Heterogeneous networked cooperative autonomous systems: cooperation of robots with physical and/or behavioral differences, heterogeneous cooperative sensing.
- Coordination schemes for networked cooperative autonomous systems: centralized and decentralized architectures, decentralized coordination mechanisms.
- Interaction with networked cooperative autonomous systems: human-machine interfaces (HMI) for networked cooperative robot systems, teleoperation of networked systems, coexistence of inter-robot cooperation and remote surveillance.
- Information sharing among multiple autonomous systems: cooperative data fusion, semantic representation of the environment, cooperative decision making, exploration for mapping and enhanced situational awareness, cooperative localization.
- Methodological issues for networked cooperative autonomous systems: task assignment for multirobot systems, decentralized optimization techniques.
- Applications of networked cooperative robots and autonomous systems: multivehicle systems for logistics, decentralized traffic management.
- Domain-specific networked cooperative autonomous systems: groups of autonomous aerial vehicles, groups of underwater systems.

Heterogeneity in multirobot systems is explicitly considered in three papers of this Special Issue. In particular, Nagaty *et al.* consider a team composed of ground and aerial vehicles that collaborate for cooperatively localizing a target. The collaboration scheme is implemented explicitly considering the different characteristics of the two different platforms, which then complement each other in performing the localization task.

Heterogeneity is considered in Wanasinghe *et al.* in terms of robots with different sensing and computation capabilities. In particular, the presence of a limited number of robots with higher sensor payload, higher processing power, and a larger memory capacity is exploited for developing a decentralized localization mechanism for multirobot systems.

As shown in Szwaykowska *et al.*, heterogeneity in terms of motion capabilities can be exploited for obtaining collective emergent behaviors. In particular, authors define a methodology for obtaining collective motion patterns and segregation of populations of agents with different dynamic properties, as a result of the composition of basic interaction rules.

Coordination in networked cooperative systems is considered in four papers of this Special Issue. In particular, in Cepeda-Gomez *et al.*, authors propose a coordination scheme for achieving a desired formation for a team of nonholonomic vehicles that exchange information among each other on a communication network in the presence of time delays. The proposed method, based on a consensus-like approach, ensures the desired stability performances.

Motion synchronization is considered in Shi *et al.* for high-order nonlinear multi-agent systems whose communication topology is described by means of a constant directed graph. In particular, considering a leader–follower network, authors develop a distributed adaptive neural networks-based controller that leads each follower to asymptotically synchronize with the leader, with semi-globally uniformly ultimately bounded tracking error.

Cap *et al.* consider the problem of trajectory coordination in order to avoid collisions among mobile robots. In particular, authors propose an asynchronous decentralized modification of the prioritized planning method that ensures avoidance of collisions while guaranteeing a fast solution to the trajectory planning problem.

Wallar *et al.* propose a motion-planning approach for persistent surveillance of risk-sensitive areas by a team of unmanned aerial vehicles (UAVs). The planner, termed PARCOV (Planner for Autonomous Risk-sensitive Coverage), seeks to: (i) maximize the area covered by sensors mounted on each UAV; (ii) ensure that no region in the area remains too long without being surveyed; (iii) maintain high sensor data quality; and (iv) reduce detection risk.

Interaction with human operators is considered in Lin *et al.*, where a teleoperation scheme is proposed that enables a human operator to interact with a multirobot system. In particular, robots are controlled for performing low-level cooperative operations in a semi-autonomous manner, while the human operator is able to provide additional inputs for performing high-level missions.

Information sharing in network cooperative autonomous systems is a transversal topic that is (indirectly) touched by most of the papers in this Special Issue. In particular, Dames *et al.* consider the problem of having a team of mobile robots that, equipped with appropriate sensors, are able to autonomously explore the environment for detecting and localizing an unknown number of targets. The proposed methodology is able to let robots simultaneously estimate the number of objects and their locations within the environment, without the need to explicitly consider data association, and while considering failures in individual sensors.

The problem of signal source seeking is considered in Zou *et al.* In this paper, authors develop a technique based on Particle Swarm Optimization for seeking maximum signal strength in a continuous electromagnetic signal source, with mobile robots equipped with appropriate sensors.

Two papers of the Special Issue develop methodologies for task allocation in networked cooperative autonomous systems. In particular, Luo *et al.* propose a distributed algorithm for multirobot task assignment where the tasks have to be completed within given deadlines. Authors consider battery powered mobile robots that have a limited amount of available time for performing tasks. Moreover, performing each task requires a certain amount of time, and each robot can have different payoffs for the tasks. The proposed methodology assigns tasks to the robots such that the total payoff is maximized, while respecting the task deadline constraints and the robot's battery life constraints.

Nam *et al.* model the resource contention problem as a task assignment problem. In particular, authors consider multirobot task allocation problems where the estimated costs for performing tasks are interrelated, and the overall team objective need not be a standard sum-of-costs (or utilities) model, enabling straightforward treatment of the additional costs incurred by resource contention. With the proposed methodology, a team of robots is able to choose one of a set of shared resources to perform a task, and interference is modeled when multiple robots attempt to use the same resource.

Solutions to real-world case studies are given in two papers of the Special Issue. In particular, Chen *et al.* consider a fleet of multiple vehicles exploited for creating a mobility-on-demand system. The idea is that of pushing the car sharing paradigm, exploiting autonomous vehicles. Authors propose decentralized data fusion and active sensing algorithms that lead to obtaining an accurate real-time traffic model that includes prediction mechanisms. This model is exploited for controlling the fleet of autonomous vehicles in an effective manner.

Industrial environment is considered by Digani *et al.* In particular, authors consider a fleet of multiple automated guided vehicles used for logistics in an industrial warehouse. The motion of these vehicles is constrained along a roadmap: vehicles are then coordinated to avoid conflicts while accomplishing their missions. Authors propose a comprehensive methodology in which roadmap creation and motion coordination are simultaneously considered, defining a global optimization problem whose solution leads to high efficiency and flexibility of the overall system.

Domain-specific issues for networked cooperative autonomous systems are considered in three papers of this Special Issue. In particular, Gross *et al.* consider the problem of relative positioning of multiple unmanned aerial vehicles. Authors propose a sensor fusion algorithm that merges global positioning data with local relative position measurements to provide robust and accurate relative positioning performances.

Aerial domain is considered also by Cichella *et al.* In this paper, authors define a coordination algorithm to control the motion of multiple unmanned aerial vehicles along predefined trajectories while avoiding collisions and while meeting temporal constraints on the mission execution. Information exchange is performed over a time-varying graph, and satisfactory coordination performances are obtained.

Marine domain is considered by Paulos *et al.* In this paper, authors define a methodology for achieving self-assembly of large teams of autonomous robotic boats into floating platforms. In particular, with the proposed methodology, robotic boats are able to autonomously dock together and form connected structures with controllable variable stiffness, and these structures are able to self-reconfigure into arbitrary shapes. The proposed methodology ensures reliable docking of elements in the presence of estimation and actuation errors. Moreover, local variable stiffness connections are used to control the structural properties of the larger assembled structure.

To conclude this Guest Editorial, we would like to extend our gratitude to all the Authors that gave us the opportunity of considering their valuable works, and to the Anonymous Reviewers that made the selection procedure possible. Also, we would like to thank the Editor-in-Chief K. Goldberg, and the Editor Y. Sun, for the opportunity to publish this Special Issue, and S. Jacobs for her valuable assistance.

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