Design, Control, and Applications of Real-World Multirobot Systems

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The field of multiagent robotics has recently reached a level of maturity in that systems are beginning to transition from proof-of-concept laboratory environments to deployed real-world systems. When we started planning for this special issue of *IEEE Robotics & Automation Magazine* in the early spring of 2007, we hoped to capture this exciting development trend. With a lineup of six strong articles, spanning the area from decentralized control, diagnosis, and decision making to experimental platforms, we feel that we have come very close to our original ambitions. We hope this sentiment is shared by the readers also.

The recent flurry of activities in the general area of multiagent robotics is to a large degree performance driven since multirobot systems offer a number of advantages and additional capabilities over their single-robot counterparts, including redundancy, increased spatial coverage and throughput, flexible reconfigurability, spatially diverse functionality, and the fusing of physically distributed sensors and actuators. Applications in which these capabilities constitute enabling technologies range from remote and in situ sensing to the physical manipulation of objects, and the domains for such applications include land, sea, air, and space.

Despite remarkable research developments in the area, numerous technical challenges remain that must be overcome to field cost-effective multirobot systems. These challenges include interrobot communications, relative position sensing and actuation, control paradigms appropriate to real-time multirobot systems, the fusion of distributed sensors or actuators, man-machine interfaces allowing efficient human direction or supervision of these systems, effective reconfiguration of the system's functionality, and design approaches supporting the economical production of such systems.

The six articles in this special issue present state-of-the-art work in mobile multirobot systems with an emphasis on techniques that have matured to the point of being evaluated through experimentation. The work presented ranges in scope from the coordination of motion, to the assignment of tasks, to the design considerations that are critical to development and evaluation.

Antonelli et al. describe the application of null-space-based behavioral control, a new type of behavioral control, to the control of a group of mobile rovers that are capable of entrapping or escorting a moving target. Results from both simulations and experiments using a test bed of small tabletop rovers demonstrate the effectiveness of this control approach for constituting and maintaining an escort formation. The method is also shown to be robust to failures of individual robots, with the remaining robots dynamically restructuring themselves to achieve proper coverage of the target.

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Kress-Gazit et al. present the application of hybrid feedback control to a group of automobiles that must safely navigate and park in a dynamic urban environment. These controllers combine local feedback control policies with discrete automata to satisfy high-level behavioral specifications without explicitly planning the motion of each vehicle. Through simulation, these controllers are demonstrated and show the complexity of provably correct behavior that is automatically achieved.

Bethke et al. describe the use of a task-level controller for multiple unmanned aerial vehicles that integrates vehicle health and status information into a real-time mission planning system. Using simulation and an indoor multihelicopter test bed, their experiments demonstrate significant performance improvement for response time and other metrics when such a feedback loop provides information such as payload status and fuel state to the task assignment algorithm.

Sariel et al. evaluate a distributed auction-based system for allocating tasks among a cooperative fleet of autonomous underwater vehicles for a naval mine countermeasure operation. This system, which has previously been experimentally demonstrated on a rover test bed, is evaluated in a high fidelity navy simulator capable of evaluating performance as a function of failures, limited/delayed/unreliable communications, and other real-world conditions. Through the novel integration of task scheduling and execution, their approach maintains high solution quality given the dramatic resource limitations inherent in underwater missions.

Michael et al. describe critical considerations in the design of experimental test beds for the verification and validation of large-scale multirobot control systems. In the development of their own test bed, they have focused on providing an inexpensive, flexible, scalable, and easy-to-use system to support the modeling, design, benchmarking, and validation of a wide variety of multirobot applications and control algorithms.

Bicchi et al. report on their work in developing a multiagent functional architecture for decentralized traffic management. Their platform provides a general suite of mobility and communication services that accommodates a wide variety of heterogeneous systems and that meets the critical requirements of safety, scalability, security, and reconfigurability. Their initial results in applying this architecture to a simple two or three vehicle system verify capabilities to perform accurate localization, execute collision-free motion, and manage secure communications.

As a final remark, it should be noted that this special issue (or any special issue for that matter) only represents a particular snapshot of the field, and there are undoubtedly areas and results that are not included in this issue. Although we made every effort to include most aspects of the maturing multirobot field, we cannot claim that the coverage is complete.