Autonomous Robots Special Issue on Heterogeneous Multi-robot Systems
Guest Editorial

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There are a number of reasons heterogeneity is an important focus of multi-robot systems research; one of the most compelling is the observation that it is nearly impossible in practice to build a truely homogeneous robot team. The realities of individual robot design, construction, and experience will inevitably cause a multi-robot system to drift to heterogeneity over time. This is recognized by experienced roboticists, who have seen that several copies of the same model of robot can vary widely in capabilities due to differences in sensor tuning, calibration, etc. Over time, even minor initial differences among robots will grow due to individual robot drift and wear-and-tear. *All* multi-robot teams are heterogeneous whether we like it or not. This means that to employ robot teams effectively we must understand diversity, predict how it will impact performance and enable robots to adapt to the diverse capabilities of their peers. In fact, it is often advantageous to build diversity explicitly into the design of a robot team.

There are a number of reasons for using heterogeneity as a design feature of a multi-robot system, including economic and engineering issues arising from the constraints of complex multi-robot applications. In many situations, for example, an application demands robotic capabilities that are difficult, if not impossible, to build into a single robot. For instance, robots cannot be both big and small at the same time, and payload limitations may restrict a robot from carrying all of the sensors needed for a particular mission. Thus, the capabilities required for the mission must at times be distributed among different robot types. Additionally, robots may specialize behaviorally due to different experiences, and more advanced learning robots may learn new behaviors that may vary due to individual experience.

This special issue includes papers that address a variety of challenges in heterogeneous multi-robot systems. Topics include: measuring diversity, individual adaptation to heterogeneous capabilities of other robot team members, communication between heterogeneous robots, modular hardware systems that enable easy configuration of robot teams with diverse capabilities and morphololgies, cooperative localization of robots with differing sensor accuracies and classification of multirobot systems within the broader multiagent domain.

An important top from the outset is how to recognize and quantify heterogeneity in multi-robot teams. The first paper, by Balch, presents the hierarchic social entropy metric that provides a continuous, quantitative measure of behavioral diversity in multi-robot teams. The utility of this metric is demonstrated in the multi-robot soccer and multi-robot foraging applications.

Heterogeneity in multi-robot teams presents a particular challenge to efficient autonomous control when overlap in team member capabilities occurs. Overlap in team member capabilities means that more than one robot may be able to perform a given task, but with different levels of efficiency. The second paper, by Parker, addresses this issue by presenting the L-ALLIANCE mechanism for generating lifelong multi-robot teams that can adapt to changes in robot team member capabilities, robot team composition, mission requirements, and the environmental state.

Most research in heterogeneous multi-robot systems assumes that robots have a common language and a common understanding of symbols in their language. Developing a common understanding of communicated symbols among robots with different physical capabilities is fundamental challenge. The third paper, by Jung and Zelinsky, describes a mechanism for engineering grounded symbolic communication between heterogeneous cooperating robots. Their approach is demonstrated in a cooperative cleaning task using a heterogeneous multi-robot team.

As the size of the individual robot team members decreases, the difficulty of carrying all the payloads required in an application is exacerbated. The paper by Grabowski, Navarro-Serment, Paredis, and Khosla presents the design of a team of modular, centimeter-scale robots applied to collaborative mapping and exploration. These Millibots are designed to enable "plug and play" of computation, communication, and sensory components to allow heterogeneous robot specialization.

Robot teams that can reconfigure to the needs of the application are a powerful method of overcoming the need to have specialized robot teams for each application. Castano, Shen, and Will address this issue in their paper by presenting the design of a CONRO module, which is a small self-sufficient module that can be connected to other modules to form a variety of complex heterogeneous robots. Prototype snake and hexapod robots are presented as two examples of their modular robots.

In collaborative mapping tasks, improved performance can sometimes be obtained by using heterogeneous robots with varying sensory capabilities. The paper by Fox, Burgard, Kruppa, and Thrun presents a statistical algorithm for collaborative mobile robot localization, and demonstrates situations in which successful localization is possible only through collaboration of heterogeneous robot teams.

From a broad perspective, heterogeneous multi-robot teams can be viewed as a sub-class of multi-agent systems. The final paper, by Stone and Veloso, examines the field of multi-agent systems as a whole from the machine learning perspective, and classified heterogeneous robot teams within this context.

This issue includes only a sampling of the research in heterogeneous multi-robot systems. The field as a whole is broader, and addresses a variety of robot platforms, including marsupial robot teams, combinations of aerial and ground vehicles, and teams of underwater robots. The intent of this issue is to raise awareness of this research, and to motivate additional researchers to explore the challenges of heterogeneous multi-robot teams.