Editorial: Special Issue on Self-Reconfiguring Modular Robots

Mark Moll, Rice University, Houston, TX, USA
Daniela Rus, Massachusetts Institute of Technology, Cambridge, MA, USA

This Special Issue contains 13 papers that cover the most recent advances in the area of self-reconfiguring modular robots. Self-reconfiguring robots are modular robots that can change their morphology and topology. Each module is a robot by itself. These systems promise great flexibility compared to fixed-shape robots. By keeping the design of each individual module relatively simple and through mass production, self-reconfiguring robots can offer an affordable platform to perform a variety of tasks. They have the potential to perform self-diagnosis and self-repair. Moreover, a simple design lends itself well to miniaturization. Potential applications included reconnaissance missions in search and rescue operations, self-assembly (both in space and at the micro-scale), and self-replication on other planets or moons. However, the design, control, communication, and planning for such systems give rise to many challenges.

Most of the papers in this issue were presented at the Workshop on Self-Reconfiguring Modular Robots held at the 2006 "Robotics: Science & Systems" conference in Philadelphia, PA. Submissions for the workshop were reviewed by the Program Committee for this workshop, which consisted of Greg Chirikjian (Johns Hopkins), Eric Klavins (University of Washington), Hod Lipson (Cornell), Mark Moll (Rice), Daniela Rus (MIT), Behnam Salemi (ISI/USC), Wei-Min Shen (ISI/USC), and Mark Yim (University of Pennsylvania). After the workshop, workshop participants and the wider robotics community were invited to submit journal-length papers, which were submitted to another round of reviews.

As part of the workshop, a panel discussion was held to discuss the Grand Challenges for the field. The key technical difficulties that were identified were:

Scaling up: Typically, experiments are performed only on a small number of modules. As the number of modules increases, new challenges arise such as power distribution, efficient communication, and fault / noise tolerance.

Self-repairing systems: Self-repair requires modules to identify what the global arrangement of modules should be and what each individual module's role is. Even deciding whether a system requires repair is already a challenging problem. Self-assembly can be seen as the most extreme form of self-repair.

Self-replication: Although simple self-replicating systems exist, it remains a formidable challenge to design a modular robot that can assemble copies of itself from elementary parts.

Miniaturization: At the micro-/nano-scale, biological processes efficiently use stochastic motions that are robust to intrinsic noise. Most of the current robotic systems overcome uncertainty through brute force. Bridging this gap, and coming up with efficient algorithms at the nanoscale is a big challenge.

In this issue, Brener et al. analyze current designs for modular robots using results from crystallography. Campbell and Pillai describe a method for collective actuation of modules, thereby forming more powerful meta-modules. De Rosa et al. bring tools for debugging and verification for distributed software systems to the domain of modular robots. Fitch and Butler introduce a new locomotion algorithm for lattice-type modular robots that scales up to millions of modules. Gilpin et al. describe a novel approach to shape formation through self-*dis*assembly. Kurokawa et al. describe recent advances in distributed self-reconfiguration. Lee et al. introduce a formal framework to analyze the complexity of self-replicating systems and present several realizations of such systems. Park et al. address the important problem of recognizing whether a given configuration belongs to an equivalence class of configurations. Sproewitz et al. present results for the optimization of the parameters in coupled oscillators to achieve locomotion. There are two papers, one by Terada and Murata and one by Werfel and Nagpal, that describe hybrid systems of active and passive modules to build three-dimensional structures. Turetta et al. describe a distributed architecture to solve the inverse kinematics for chains of modular robots. Finally, Varshavskaya et al. apply reinforcement learning to the problem of controller design.

We thank the participants in the Workshop on Self-Reconfiguring Modular Robots held at the 2006 "Robotics: Science & Systems" conference. We are also grateful to John Hollerbach, editor of IJRR, and Jennet Batten, managing editor, for their support.