Toward Unicorns

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***Abstract*—We present a fully autonomous modular robot system that can perform complex reactive high-level tasks (requiring reconfiguration) in an unknown environment without external sensing or control. TODO: Describe system capabilities in detail here.**

I. Introduction

Modular self-reconfigurable robot (MSRR) systems are composed of a number of simple repeated robot elements (called *modules*) that connect together to form larger robotic structures. These systems can *self-reconfigure*, changing their shape (*i.e.* the connective structure of the modules) to meet the needs of the task at hand. In principal, these systems can address a wide variety of tasks by transforming into a wide variety of morphologies. The traditional approach to achieving flexible robots is to build monolithic systems that are highly capable, but also highly complex (*e.g.* large humanoids). Self-reconfigurability is an elegant, scalable alternative: since the shape of the robot is not fixed, each individual task can be solved with a morphology that is only as complicated as it needs to be.

Over the past three decades, dozens of modular robot systems have been built **TODO: cite** . Existing literature provides ample evidence of the ability of MSRR hardware to reconfigure, algorithms for reconfiguration planning with hundreds of modules, a number of interesting morphologies suited to object manipulation and locomotion over varying terrain, methods and interfaces for programming, controlling, and simulating modular robots, and recently, systems that select appropriate configurations and behaviors for an MSRR automatically given a high-level specification of a task **TODO: cite** .

These capabilities are impressive, and each represents a significant research accomplishment in its own right. However, in order to truly live up to their promise of flexible capability in the real world, MSRR systems must demonstrate autonomy: moving, navigating, interacting with objects, and self-reconfiguring, all in unknown environments and without external localization or control. To our knowledge, this paper represents the first example of a truly autonomous MSRR system accomplishing tasks in an unknown environment.

Traditional robotics literature provides numerous examples of robots operating autonomously in unknown environments **TODO: cite** . Our system goes beyond this existing work because it has the unique ability to recognize and act on situations in which reconfiguration is needed to complete a task. Through hardware experiments, we demonstrate that autonomous self-reconfiguration allows our system to complete tasks that would have otherwise been impossible.

The remainder of the paper is structured as follows. **TODO: complete paper structure paragraph**

A. Related Work

TODO: coming soon .

II. SMORES-EP Modular Robot

Our system is built around the SMORES-EP robot, but could easily be adapted to work with other hardware platforms. In this section, we provide a brief introduction to the technical capabilities of SMORES-EP.

Each module is about the size of an *80mm cube*, and has four actuated DoF - three continuously rotating faces (left, right, and pan) and one central hinge (tilt) with a 180° range of motion (Fig. 1). The DoF marked left, right, and tilt have axes of rotation that are parallel and coincident. A single module can use its left and right wheels to drive around as a two-wheel differential drive robot. All four faces of the SMORES-EP module have electro-permanent (EP) magnets that serve as a high-strength, low-energy connector for self-reconfiguration [1]. Any face of one module can connect to any face of another.

The magnetic connectors can also attach to objects made of ferromagnetic materials (such as steel). By taking advantage of this capability, SMORES-EP modules can use their magnets to attract, lift, and carry metal objects. Provided the attachment surface is flat and smooth, the attachment force between a SMORES-EP face and a strongly ferromagnetic object can be as high as 90N [1].

Some of the motions a SMORES-EP cluster can perform are limited by the strength of the magnetic connectors, which can support the weight of at most three modules cantilevered horizontally against gravity. This limitation is alleviated in some cases by using rigid connector plates, which are screwed into the faces of two modules to create a strong permanent connection between them. Using connector plates, up to four modules can be cantilevered before exceeding the torque limits of the motors. However, because the connector plates must be manually screwed into place, modules with connector plates cannot self-reconfigure.

Each module has an onboard battery, microcontroller, and 802.11b wireless module to send and receive UDP packets. In this work, clusters of SMORES modules were controlled by a central computer running a Python program that sends wireless commands to control the four DoF and magnets of each module. Battery life is about one hour (depending on motor, magnet, and radio usage), and commands to a single module can be received at a rate of about 20hz. Wireless networking was provided by a standard off-the-shelf router, with a range of about 100 feet.

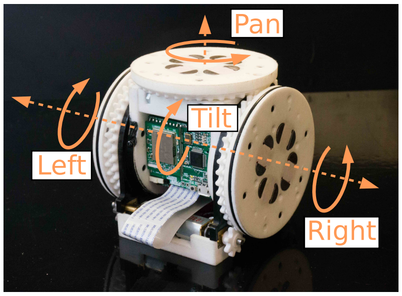

Fig. 1: SMORES-EP module

Acknowledgments

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References

[1] Tarik Tosun, Jay Davey, Chao Liu, and Mark Yim. Design and characterization of the ep-face connector. In *IROS*. IEEE, 2016.