Towards a 3-DOF Mobile and Self-Reconfigurable Modular Robot

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Abstract—This paper presents early work on a new self-reconfigurable modular robot capable of independent locomotion. The prototype features three degrees of freedom, creating a spherical joint, and houses four connection surfaces allowing it to form arbitrary cubic lattice structures. The design is built around the recent HiGen connector, allowing for single-sided disconnect and enabling modules to rotate freely in place within a lattice position.

I. INTRODUCTION

Modular robotics has seen numerous advances over the past decade, with the likes of M-TRAN III [1] and ATRON [2] successfully demonstrating the self-reconfiguration and collective motion of large chain and lattice structures. Each module is simple, with typically only one or two degrees of freedom, allowing many to be produced at low cost. Unfortunately, this means that individual modules have limited or no mobility outside of a configuration. Efforts have been made to address this, with swarm systems gaining the ability to self-assemble to collaborate on a given task [3], and modular systems gaining dedicated drive mechanisms to provide efficient single module locomotion [4], [5]. Such systems demonstrate the advantages of mobile modular robots, but compromise module self-reconfigurability in favor of self-assembly. This highlights a need for modular robots that retain the reconfigurability of past successful systems, whilst also offering efficient single module locomotion.

This paper presents the first structural prototype of a new self-reconfigurable modular robot currently under development (Figure 1). Inspired by systems such as PolyBot [6] and CKbot [7], this module features a rotational hinge capable of moving $\pm 90$ degrees, and is designed to form arbitrary cubic lattice structures. Two further rotational degrees of freedom are mounted perpendicular to the hinge axis, serving the dual purpose of creating a spherical joint and enabling the module to drive around using a differential wheel setup. The arrangement of rotational axes shares similarities with the RobMAT [8] platform, and the use of reconfiguration joints as wheels has been explored on the iMobot [9], M$^3$ [10], and SMORES [11] platforms. This implementation removes the need for a separate drive mechanism for locomotion, as is the case with the modules of the Symbion / Replicator project [4].

Connections to neighboring modules are achieved using four high-speed genderless (HiGen) connectors [12], one for each wheel and two along the hinge axis. The use of HiGen connectors gives the module several advantages over other connection mechanisms, most notably the ability to independently disconnect from neighbors and rotate in place within its lattice position. This choice gave rise to the module’s spherical design, as it allows all three degrees of freedom to actuate simultaneously without risk of collision with neighboring modules.

The remainder of this paper outlines details of the prototype module (Section II) and shows a number of configurations that its design allows (Section III). Finally, Section IV concludes the paper and discusses future work.

II. MODULE DETAILS

The module is built from two mirrored halves, forming a hinge joint. Each half consists of a chassis component housing a connector, and a wheel/connector assembly at-
tached perpendicular to the hinge axis, giving a total of four HiGen connectors per module. This arrangement of structurally identical halves is common with several modular robots, such as ATRON [2], Molecubes [13] and UBot [14]. The placement of the module’s three degrees of freedom is shown in Figure 2, with all axes intersecting at the center. Figure 3 shows the ±90 degree range of motion of the hinge joint, with the module in a vertical orientation.

The current prototype consists of eight custom ABS plastic components (excluding connectors) created using 3D printing technology, and several off-the-shelf items. DC geared motors with a ratio of 154:1 and a quoted torque of 843 mNm are used to drive each degree of freedom. An additional 5:1 gear ratio is applied on top of each motor gearbox, increasing the torque of the rotational joints and allowing the motors to be offset from each drive axis.

To allow for continuous rotation of the wheels whilst passing power and communication to the connectors, slip ring components are used. This is a solution adopted by a number of past systems in the field such as ATRON [2] and Roombots [15]. Positional feedback of each wheel is achieved using photointerrupter-based optical encoders. In contrast, the module’s hinge joint makes use of a potentiometer for absolute position feedback, due to its 180 degree rotation range.

The module measures 128 mm x 128 mm x 94 mm, when the hinge is at zero degrees. This size is governed by the dimensions of the HiGen connector, the inclusion of slip rings into the design, and the chosen wheel diameter. The ground clearance for the module is 4 mm. The separation between modules in a cubic lattice is 140 mm due to the connectors extending out of their housings during connection. To take advantage of this ability the module is designed to fit within a spherical volume, allowing rotation of all three axes without risk of colliding with neighboring lattice modules [12, see Figure 4]. As such the module shares visual similarity with the Roombots [15] platform, which uses its spherical design to enable the wheel-based locomotion of metamodules, rather than to provide clearance for self-reconfiguration.

III. EXAMPLE CONFIGURATIONS

To explore the possibilities of the module design, six ½ scale models were produced, consisting of four 3D printed components each. These scale models feature all of the degrees of freedom of the full module, but lack actuators and electronics. To emulate the genderless and four times symmetric properties of HiGen at this scale, four permanent magnets are mounted on each connection surface with their magnetic fields perpendicular to the normal. This is a technique used with electro-permanent magnets on the Pebbles [16] platform, as it exposes a magnet’s north and south poles in such a way that only attractive forces are created between neighboring modules. A selection of common modular robot configurations using the scale modules is shown in Figure 4.
IV. CONCLUSIONS

This paper presented a new robotic module capable of self-reconfiguration and wheel-based locomotion, when separated from other modules. Preliminary details of the module were given and a number of example configurations shown using scale models. Future work will involve the integration of control electronics into the prototype module, to test its actuation and locomotion capabilities. Further modules will be manufactured to enable the exploration of collective locomotion and self-reconfiguration strategies.

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