Mechanical Design and Computational Aspects for Locomotion and Reconfiguration of the ModRED Modular Robot

(Demonstration)

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ABSTRACT

In this paper we describe the mechanical construction and AI-based planning techniques for the locomotion and reconfiguration of a modular self-reconfigurable robot(MSR) called ModRED (Modular Robot for Exploration and Discovery). ModRED is a highly dexterous, chain-type MSR with 4 degrees of freedom. It can maneuver in tight spaces and is suitable for autonomous locomotion over unstructured and uneven terrain such those encountered in extraterrestrial environments like the surface of the Moon or Mars, or, in environments that are difficult to navigate for humans like the inside of a volcanic crater. ModRED uses gait tables for navigating in a fixed configuration. We have developed a fuzzy logic control based approach for dynamically adapting ModRED's gait without changing its configuration, if its goal changes or if its motion is impeded by an obstacle. We also describe our research on reconfiguration planning in ModRED using a coalition game theory based technique that allows the modules to dynamically reconfigure into a new shape while reducing the time and cost expended to achieve the new configuration.

Categories and Subject Descriptors

I.2.9 [**Robotics**]: Miscellaneous

General Terms

Algorithms, Design

Keywords

modular self-reconfigurable robot, hardware design, dynamic gait adaptation, reconfiguration planning

1. INTRODUCTION

Modular self-reconfigurable robots(MSRs) [3] are robotic systems that are composed of small modules which are capable of connecting with each other in different ways to manifest different shapes or configurations of the robot. MSRs are attractive for performing operations in unstructured environments where the robot might have to adapt its shape to navigate among obstacles or to perform different tasks. In this paper, we describe our research results in the ongoing ModRED project (`http://cmantic.unomaha.edu/projects/modred/`) including ModRED's hardware features and techniques for dynamic gait adaptation and reconfiguration. The target applications for ModRED include autonomous navigation to explore extraterrestrial environments such as the surface of the Moon or Mars, or environments that are hazardous for humans such as the inside of a volcanic crater, automated inspection of engineering structures such as bridges or turbines, automatic formation of truss-like support structures for enabling movement of other robots or humans, etc.

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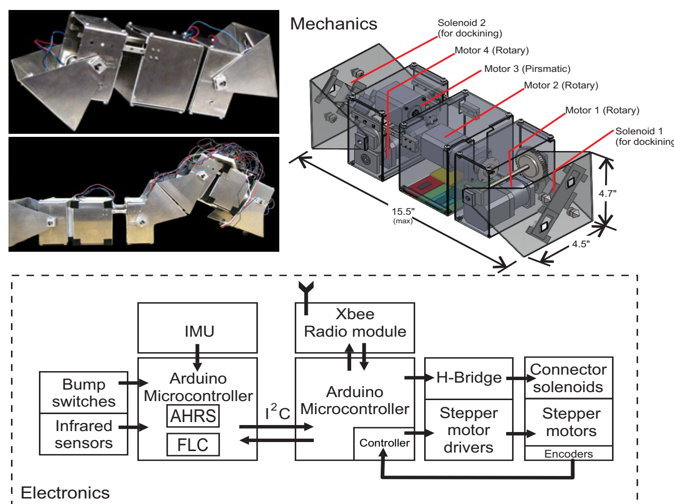

Figure 1: Mechanical construction of ModRED showing its hardware components.

2. MECHANICAL DESIGN OF MODRED

ModRED (Modular Robot for Exploration and Discovery) is a chain-type MSR that is composed of identical modules.

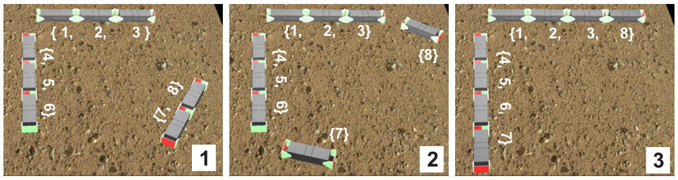

Figure 2: Reconfiguration of ModRED modules from an initial configuration (left) to a final configuration (right) within Webots simulator.

ModRED is characterized by the dexterity of its modules and by a distributed control architecture. As shown in Figure 1, each of ModRED modules has 4 degrees of freedom (DOF) - 3 rotational and 1 prismatic. Each module has five distinct segments - two end brackets containing the docking interfaces and three box-shaped segments housing the actuators, transmission, circuit components and power source [2]. A module is capable of producing pitch, yaw, and roll and one extension DOF. A unique feature of ModRED is the 4-th translational DOF on each module that enhances the module's workspace, increases its reach and helps it to dock (connect) and undock (disconnect) with other modules easily. Each module of ModRED includes an Arduino Fio processor for performing on-board computation, an inertial measurement unit including a gyro, an accelerometer and a magnetometer, Xbee-enabled wireless communication capability, IR sensors for proximity sensing and bump sensors for tactile sensing. Videos showing the different gaits of ModRED with different single module and 2-module configurations are available at `http://www.youtube.com/playlist?list=PL7C6DE7A9D15E1536&feature=plcp`.

3. DYNAMIC GAIT ADAPTATION IN FIXED CONFIGURATION

An important operation in MSRs like ModRED is to dynamically adapt the gait or movement of the MSR when it cannot continue its current movement either due to an obstacle along its path or due to a change in its current task. Reconfiguring ModRED's modules into a new configuration is a costly operation as it requires docking and undocking of several modules. In contrast, the costly reconfiguration operation can be avoided if the MSR can remedy its current impediment by adapting the way it is currently moving, without changing its current configuration. We have developed a distributed and autonomous technique for dynamic gait adaptation on ModRED using a closed loop controller. The basic locomotion types for a single module of ModRED are enabled through gait control tables (GCTs). Each GCT provides a series of rotational or translational motions for the module to effect different movements such as pivoting on its center, rotation on its axis, inchworm-like motion, etc. Our controller for dynamic gait adaptation maps the inputs from the inertial measurement unit sensors on ModRED's modules to an appropriate gait for each module, selected from the set of basic GCTs stored in a gait library, using a fuzzy logic-based approach. We have verified the operation of our controller on a simulated model of ModRED within the Webots robot simulator for aligning the robot in a desired direction while starting from any arbitrary orientation, for different configurations of the robot. A video demonstration of our technique is available at `http://www.youtube.com/watch?v=ta2rp7VXZjE`.

4. RECONFIGURATION PLANNING USING COALITION STRUCTURE GRAPH SEARCH

In MSRs, reconfiguration planning involves techniques required to change the shape or configuration of the MSR from its current configuration to a new configuration so that the MSR can continue to perform its intended operation. In uncertain environments the desirable configuration for an MSR is not known beforehand and has to be determined dynamically. We have developed a fast reconfiguration algorithm for MSRs based on a coalition game theory technique where the set of modules requring reconfiguration is represented as a coalition structure graph (CSG). To incorporate uncertainty in the modules' movements we have developed a new data structure called an uncertain CSG (UCSG) that augments the conventional CSG to handle uncertainty originating from the motion and performance of the robot. We have also developed [1] a new search algorithm called searchUCSG that intelligently prunes nodes from the UCSG using a modified branch and bound technique. We have verified our reconfiguration planning technique on a simulated model of ModRED within the Webots robot simulator and shown that our algorithm is able to find a near optimal (within 80% of the optimal) coalition structure in the UCSG while exploring only half the nodes in the UCSG. Our algorithm also runs in considerably lower time than other existing algorithms for exploring the CSG (that do not model uncertainty). Figure 2 shows an execution of the reconfiguration algorithm within Webots to find the optimal coalition structure. Initially, the MSR configuration was configured as two configurations with three modules each $(1, 2, 3)$ and $(4, 5, 6)$, and, one two module configuration $(7, 8)$. The optimal configuration was determined by our algorithm as two four module configurations given by $(1, 2, 3, 8)$ and $(4, 5, 6, 7)$. The middle and right sub-figures of Figure 2 show the intermediate and final configurations. Our demonstration will include the hardware operation of ModRED showing its different gaits with one and two modules, and videos of simulations of ModRED illustrating its operation while using our dynamic gait adaptation and fast reconfiguration algorithms. [1]

5. REFERENCES

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