Xanthus: Self-Reconfigurable Modular Robot

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ABSTRACT

Second generation self-reconfigurable modular robotic system Xanthus developed at FIU is presented in this paper. The robot is capable of self-reconfiguring its mechanical structure for efficient walking and crawling as the previous version. In addition, the current version is able to reconfigure and roll conforming to the terrain. In both versions, changing modes is accomplished without human intervention. This work addresses mechanical design, hardware, control and software development for all-terrain navigation. Algorithms for quadruped walking, crawling and rolling are generated and tested on the prototype.

Keywords

Robotics, modular, reconfigurable, design, gait.

1. INTRODUCTION

The demand and impact of compact, versatile and intelligent mobile robots have been on a steady rise for which active research is pursued [1-5]. Mobile robots are used to access places and execute tasks that are considered hazardous or unsafe to engage the human element. The primary objective of any mobile system is efficient navigation over the terrain in its workspace. While legged robots are studied because of their agility in traversing uneven terrains [9], other concepts of mobile robots are researched to develop efficient autonomous system navigation in complex environments [10]. Most mobile robots are built for navigating specific terrains using legs, wheels or tracks. The work presented in this paper counters the fore mentioned concept by developing a system capable of executing three different modes of navigation by reconfiguring its structure depending upon the desired task. The developed system incorporates advantages established by different methods of mobile system navigation thereby overcoming drawbacks of each individual system.

There is an increasing demand for robotic systems that have the ability to perform a wide range of tasks autonomously. Over the last ten years, research efforts in the field of modular robotics have been directed towards robotic manipulations with the goal of versatility and adaptability [11-12]. Less effort has been made in the field of self-reconfigurable modular robots, which are modular robots that can autonomously change their configuration [13-14].

The design of the system developed in this work is modular in structure decreasing developmental costs and time to deploy the robot [6]. The metamorphic capabilities of modular robots greatly assist in adaptive operation in unpredictable environments. Long-life operation is possible owing to the homogeneity of the structure as a damaged module can be replaced by another module [7]. This structure prevents obsolescence of the design by allowing the designer to integrate emerging new technologies. The innate fault tolerant capability of modular systems also provides unhindered navigation under adverse circumstances.

Self-reconfigurable robotic systems present several advantages that can be exploited to enhance system capabilities. A self-reconfigurable robot changes its configuration for the desired task through a sequence of statically stable states. This is done by coordinating and optimizing motion for each individual module. Optimality for such reconfiguration strategies can be measured in different ways such as minimizing the number of module moves, minimizing time for reconfiguration or minimizing energy consumption during reconfiguration [8].

Motion planning for these systems is complex in nature and requires efficient control algorithms. Although individual modules are simple in design and easy to control, the entirety of the system allows many combinatorial configurations making the system complex to control. Gait development for such systems involves coordinating motion of each individual module, while avoiding singularities in the kinematic positions and constraints imposed by the physical design of the system.

This paper is organized as follows: An outline of the modular design of the developed system is given in Section 2. The hardware used for system fabrication is detailed in Section 3. In Section 4, gait development of the system and control algorithms are described. Finally, Section 5 summarizes conclusions and future work.

2. MODULAR DESIGN OF XANTHUS

In this work a modular self-reconfigurable robot is proposed in order to develop a system adaptable to different tasks and unknown environments.

A modular robot system consists of a set of independent modules, such as actuators, passive joints, rigid links, mobile platforms, and end-effectors that can be rapidly assembled into a complete robot with various configurations. These systems are of particular interest as they permit construction of a wide variety of specialized robots from a set of standard components. A modularly designed reconfigurable robot possesses several advantages such as decreasing cost, increasing reliability, and shortening the development cycle from design, construction to deployment [6].

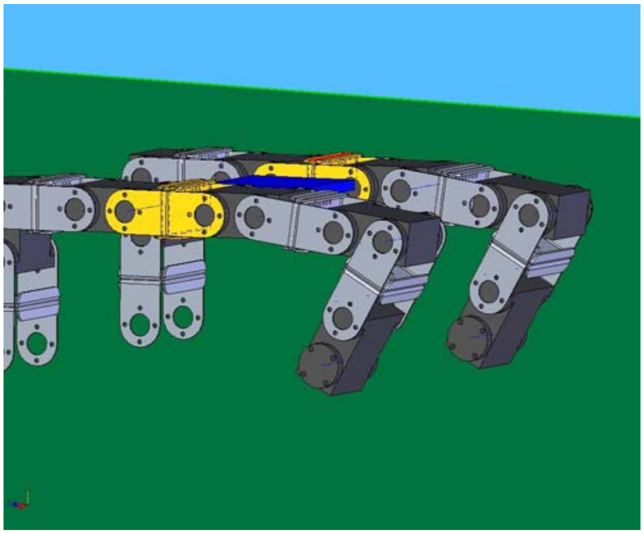

Figure 1: CAD Model of Xanthus – Walking Mode Simulation

The issue of design for controllability is important in modular robotics. A computer-aided design model shown in Figure 1 is created to study kinematic and dynamic behavior of the system before fabrication. Modularity affects the system performance parameters, such as repeatability, accuracy, singularities, and workspace which are monitored in the simulation stages of the system development.

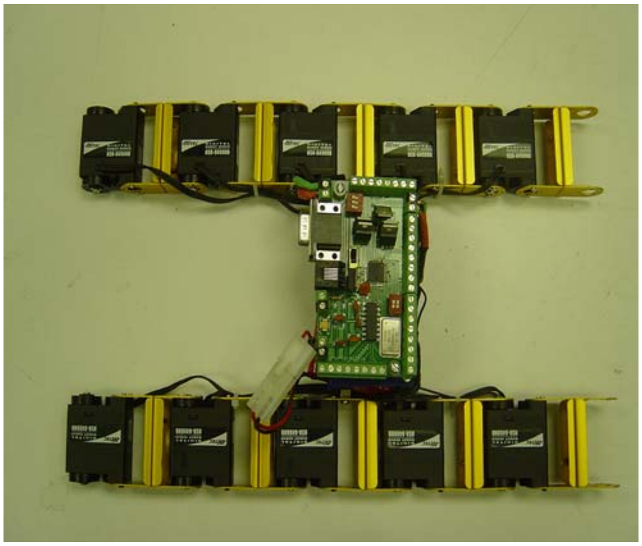

Figure 2: Constructed Model of Xanthus

To develop a modular robot system for the desired task at hand, we propose to employ standard actuators and rigid links for connecting modules whose dimensions can be custom designed and fabricated easily. The developed modular self-reconfigurable robotic system shown in Figure 1 is a bipartite system composed of two five-degree-of-freedom (DOF) serial linkages and a passive element as connector. A single 5-DOF linkage is capable of crawling and rolling but a bipartite system was designed for the system to be also capable of quadruped walking. The passive element is a square shaped plastic piece on which the control board and power supply is mounted. A novel rigid linking mechanism provides inter-module attachment and detachment to perform various tasks.

3. HARDWARE

The second generation modular robot has a total of 10 modules. Each module has two Hi-tec "U" Universal Brackets and a Hi-tec HSR-8498HB servo with Karbonite gears.

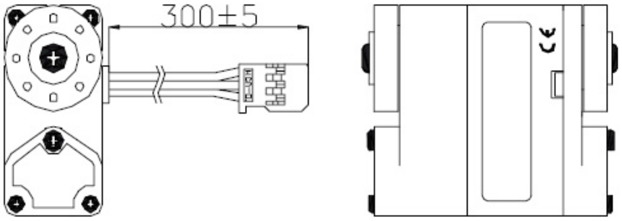

Figure 3: HSR-8498HB Hi-tec Servo

The Hi-tec HSR-8498HB servos are digital that come with the capability of being configured to form a revolute joint with the addition of links which makes for a very sleek design. The servos are relatively powerful and inexpensive. The Karbonite gear each servo encompasses is appropriate for usage under high stress circumstances for long periods of time.

Table 1: Specifications of the HSR-8498HB Servo

Interface	HMI Protocol , PWM
Operating Voltage	6 V
Max Speed	0.20sec / 60° at 6.0V
Stall Torque	10kg-cm (138.87oz.in) at 6.0V
Operating Angle	0° - 180°
Weight	55g (1.94oz)
Dimension	40 x 20 x 47mm (1.57x 0.78x 1.8 in)
Control Pulse	1500 Sec, 0~180° ±1100-1900 Sec
Pulse Cycle	12~26mSec

The "U" Universal brackets by Hi-tec, Inc. are compatible with the design specifications of the HSR-8498HB servos. These links are connected back to back to provide a very sturdy and rigid connecting mechanism between two modules on the robot.

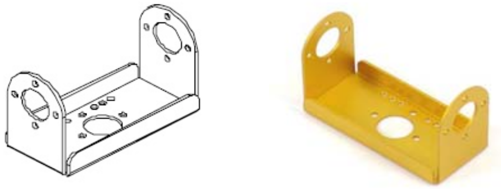

Figure 4: Hi-tec 'U' Universal Bracket

These light-weight links along with the powerful torque capabilities of the servos decrease power consumption and enhance effective navigation of the system.

The microcontroller used for the developed platform is a PIC16F877A microchip on a custom board with built-in power regulators. It includes a MAX232 chip and an ICD (In Circuit Programming / Debugging) for software control of the system.

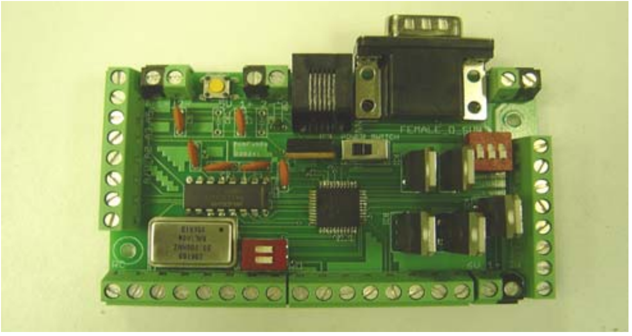

Figure 5: Custom Built Micro-Controller

The microcontroller was in house custom built. The PIC16F877a was chosen as the processor as it allows for compact packaging and possesses high speed capabilities. It has many built in features such as 256 bytes of EEPROM, 2 comparators, 8 channels of 10-bit analog-to-digital (A/D) converters and 2 capture/compare/PWM functions. The synchronous serial port can be configured either as a 3-wire Serial Peripheral Interface (SPI™) or a 2-wire Inter-Integrated Circuit (I^2C™) bus. It also features a Universal Asynchronous Receiver Transmitter (USART) and possesses 33 I/O pins. Multiple power regulation options were provided for long-term development of the system. The microcontroller is designed to distribute and regulate power requirements in addition of other peripherals in the range of 5W to 30W. A MAX232 chip which enhances the processor's capabilities by adding a buffer to its current RS232/USART connection is also included in the designed micro-controller.

The control system is designed for future addition of various sensors and peripherals depending on the task to be accomplished. Each module will include a multi-sensor system. Sensors that are to be integrated into the system are position-sensitive devices (PSD), touch sensors, accelerometers, gyros and cameras. The inclusion of the above mentioned sensors will be processed by the micro-controller onboard to configure the robot's internal and external parameters. These sensors allow the system to estimate the model's existing condition and assess its actions for efficient navigation.

4. GAITS

4.1 Walking

The benefits of the quadruped configuration is twofold: One is that the robot has superior static and dynamic stability as opposed to a biped robot, and the other is that the legs are capable of utilizing discreet footholds as opposed to continuous ground support required by wheeled and tracked mobile systems.

The developed modular robot is reconfigured to a quadruped walking gait configuration as shown in Figure 6 when activated to its walking mode. It represents a typical model of four-legged continuous walking robot with three revolute joints (3-R) in each of its limbs. The robot is capable of moving forward in a straight line with a periodic wave motion.

There are several methods of propelling forward motion in quadruped walking as experienced while developing motion sequences for the system. The system is able to move forward based on body centered forward propulsion, leg centered forward propulsion or a combination of both. In body centered gait development, the body mass of the system is moved forward initially which is compensated by the legs for forward motion. Leg centered gait development consists of actuating legs for initial forward displacement which is compensated by the body by the forward propulsion induced into the system. The combination of both of the above methods is executed by moving the body forward during intermediate stages of leg displacement. At this point some legs reach their final state while the rest are at their initial stage.

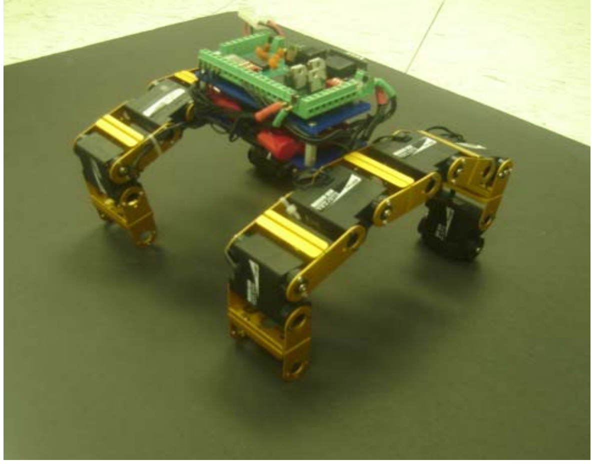

Figure 6: Walking Mode - Initial Kinematic Configuration

Stable and robust motion is achieved when a single leg is lifted off the ground and placed forward while the other legs propel the body forward. After the lifted leg completes its forward motion and touches the ground, one of the supporting legs is lifted up and placed forward while the rest assume the supporting role.

Quadruped walking requires accurate and timely coordination among all legs. For smoother and elegant walking all legs are motion sequenced to have the same horizontal and vertical strokes. Rubber layered gripping was provided at the feet to minimize sliding and slippage experienced during gait development of the system.

4.2 Crawling

Crawling motion of the developed system is limbless and solely depends on the system-terrain interaction. It occurs under the influence of dry friction and control torques at the actuators installed in each module of the robot.

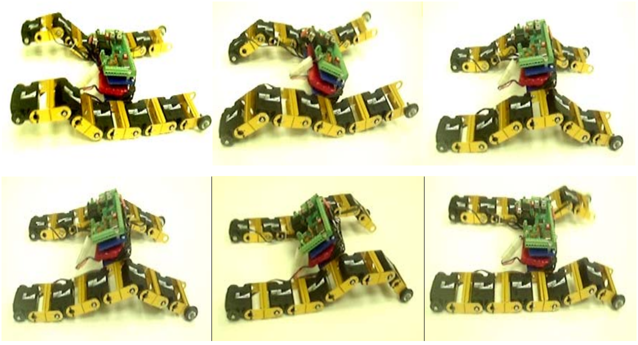

Figure 7: Wave Propagation in Crawling Gait

Forward motion is achieved by the propagation of a lateral undulatory wave from the rear to the front of the robot which deforms the shape of the system periodically [16]. Each module advances when raised, avoiding any friction with the ground. When the module is lowered and reaches the ground, its position is past its initial point of contact with the ground. The existing friction on the support modules prevent the robot from slipping due to the inertia created by the ondulatory movement [16]. The speed of system propagation was controlled by changing the phase lag between the tail and head of the system. Gait optimization for slow and fast navigation was done by modulating the actuation timing and amplitude.

4.3 Rolling

In order to develop effective navigation, the system was designed to be able to roll. The robot is able to reconfigure itself into a spherically symmetric polyhedron which permits smooth rolling on flat or inclined surfaces.

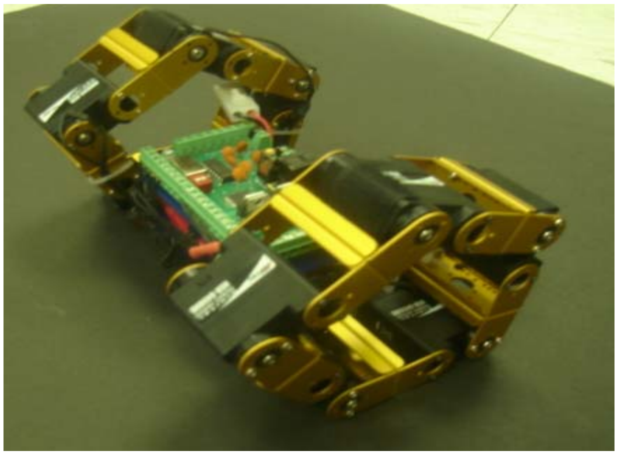

Figure 8: Crawling Mode - Initial Kinematic Configuration

The system has a single module on both links in contact with the ground at all stable states during the entire gait. Intermediate states are achieved by transitory contact of the modules with the ground until a statically stable state is achieved. Rolling is executed by actuating these modules in contact with the ground to tip over to their adjacent modules. This is done by reconfiguring all the other modules to shift the center of gravity of the system beyond the pivot point of the module in contact with the ground. This generates moment in the direction of motion allowing the robot to accelerate [17]. The motion of the robot after the first loop can be adjusted to provide motion at a constant speed or accelerate. The system configurations after the first loop are kept the same as the initial rolling configuration for a constant speed rolling gait. The robot can be accelerated by manipulating the robot configuration to displace the center of mass of the system to the farthest point with respect to the module in ground contact. The moment gained by the weight of the system displaces the robot forward providing continuous acceleration and a smoother motion.

Traversing downward inclined slopes is fast and efficient as the actuator torque utilized is minimal and system acceleration is fast after the first few loops. Light weight links and reasonable actuator mass assist in the providing optimum traction for the system to avoid slippage.

5. CONCLUSION

A reconfigurable modular robot has been presented in this paper. The design, development and testing of an all terrain navigation system was implemented in this work. Crawling, walking and rolling modes of navigation for the system were developed.

The entire unit is currently being experimentally observed to verify the range of mobility, speed and constraints in reconfiguration of the model. Singular positions and constraints in the physical design of the system were avoided while changing modes of navigation. Different gaits have been developed while optimizing gaits for minimal module movements and reducing time for reconfiguration.

Subsequent to gait development, all terrain sensing will be implemented on the system for autonomous terrain detection and adapting motion. The system allows for easy incorporation of sensor systems which will be put into effect for effective navigation to be monitored.

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