MiniRHex: A Small, Open-source, Fully Programmable Walking Hexapod

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***Abstract*—Here we introduce MiniRHex, a miniature hexapod robot based on the design of RHex. The main motivation for designing MiniRHex was to create a low cost, easy to build, fully programmable robot suitable for teaching and outreach programs. The cost, just over $200 each, is critical to be able to support educational programming with a higher robot-to-student ratio than more expensive platforms. The design of the robot features a laser-cut frame, 3D printed legs, off-the-shelf actuators and control board, and an intuitive software package with fully programmable leg control. Despite its low cost, the platform is quite capable and can carry up to six times its body weight in payload.**

I. Introduction

MiniRHex was designed to be an educational and outreach tool to allow students to experiment with a fully functional walking robot at a much lower cost. Unlike many low cost small robots, which only offer differential drive control, the independent control of each leg allows for a richer range of instructional topics and greater freedom for students to explore its capabilities. The low price tag allows us to build a fleet of machines for a reasonable cost, giving each student more hands-on interaction with the hardware. Educational units planned with the platform include: 1) gait design and optimization; 2) leg materials and shape exploration; 3) mobile robot sensor feedback control; and 4) multi-robot behaviors.

The robot design, seen in Fig. 1, is available freely online[1] as open source hardware and software. In the future we plan to also post curricular materials based on this platform.

II. Design and Control

Overall the design objectives were to build a low cost robot that was easy to build, but still capable of interesting behavior. Certainly a small robot of this type could be built with higher performance or at a lower cost however this design finds a nice middle ground while placing a premium on off-the-shelf parts (instead of custom designs) and easy manufacturing. There were three main challenges in the design of this robot that we will discuss here: 1) compliant leg design; 2) actuator selection; and 3) continuous rotation control.

The robot design is based on RHex [5, 2], with six one degree-of-freedom legs. Each leg is a compliant "C" shape to better navigate rough terrain and obstacles like staircases [4]. One challenge with the design of a small and low cost RHex is the leg construction. Rather than the custom fiberglass composite legs that RHex uses, we would like to use rapid prototyping techniques so that the robot is easy to build. The initial 3D printed leg design was too stiff – animals run with a dimensionless leg stiffness of about 10 (ranging between 5 and 15) [1], and the initial legs had a stiffness of 60. Making the legs 1/6th the width would work but would be too brittle. Instead, since the stiffness of the legs roughly correlates with the square of the material thickness we were able to use legs with half the material for a final stiffness of 15. This is now within the observed range in nature, though it could be further reduced to get to the average of 10.

The continuous rotation of the legs at reasonably fast rates (at least 1 but ideally 2 or 3 rotations per second), while still requiring position feedback and control, limits the options available for actuator selection. While these properties are achievable in fully customized designs combining discrete motors, gearboxes, encoders, and motor controllers, very few off-the-shelf options exist that achieve this. The Robotis Dynamixel XL-320 was the only actuator to meet the speed,

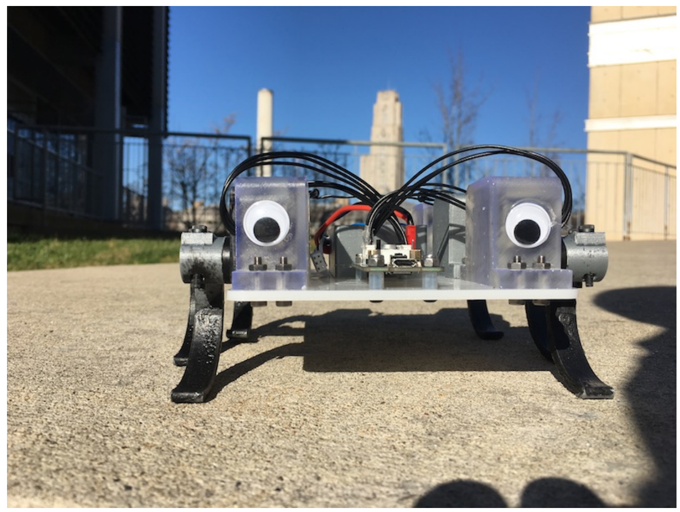

Fig. 1. The MiniRHex platform, an low cost and easy to build hexapod robot.

[1] https://robomechanics.github.io/MiniRHex/

rotation, and cost ($22) constraints of this project.

While the servo motors are capable of continuous rotation and positioning, their control code is limited from doing both simultaneously. This is because they rely on a low cost continuous potentiometer which only reports positions for 300°. Therefore a custom position tracking controller is needed to accurately track positions while the servo is in "wheel mode", with constant output effort over the remaining 60° of the rotation while the leg is in the air.

The rest of the robot design uses a laser cut baseplate and 3D printed mountings. The controller is sold by the servo manufacturer and all required cables come with the servos, meaning that the only soldering required is the two wire leads the go to the battery connector. A comparison of MiniRHex to the full-sized X-RHex is shown in Table I.

III. Results and Conclusion

Initial behaviors developed for the robot include standing, sitting, turning in place, and forward locomotion with both an alternating tripod and pronking gaits. The alternating tripod running gait can achieve a brief aerial phase, run at 1.4 strides per second, and a velocity of close to 15 cm/s with only limited hand tuning of the gait parameters (automated tuning is planned in the future [6]).

One of the advantages of the RHex morphology is that the weight of the robot is primarily supported by the legs and not the actuators. As such, the robot is able to carry (including standing up and walking forward) an additional 3 kg of payloads, or about six times its body weight, as seen in Fig. 2.

Although MiniRHex was developed as an educational tool, we have found multiple research avenues that the platform could assist in, such as: development of new gaits and behaviors; inertial data collection via visual sensors and IMU; testing of autonomous gait-tuning algorithms; and scaling comparison of control strategy and gaits with a full-scale RHex. A similar platform has also been used by the Terradynamics Lab at Johns Hopkins University to test hypotheses about insect locomotion [3].

Acknowledgments

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Specification	MiniRHex	X-RHex [2]
Mass	0.425 kg	8.6 kg
Carrying Capacity	1.8-3 kg	5-10kg
Length	19 cm	53 cm
Width	10 cm	39 cm
Leg Diameter	5.8 cm	17.5 cm
Leg Actuator	Dynamixel XL320 Servo	Maxon Brushless Motor
Processor	OpenCM9.04	Intel Atom PC104
Single Unit Price	~$200	~$20,000

TABLE I
A comparison between MiniRHex and X-RHex.

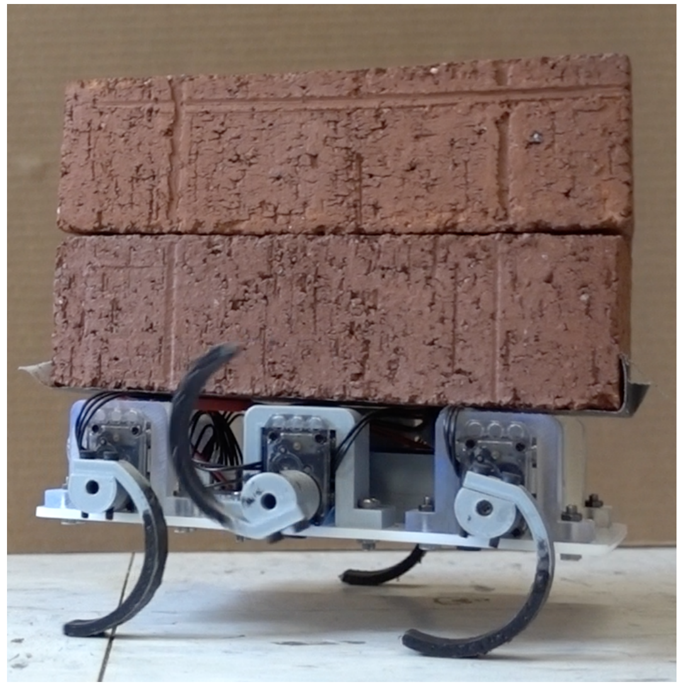

Fig. 2. MiniRHex carrying six times its body weight.

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