Hexapod Robots as Folding Exploratory Rovers

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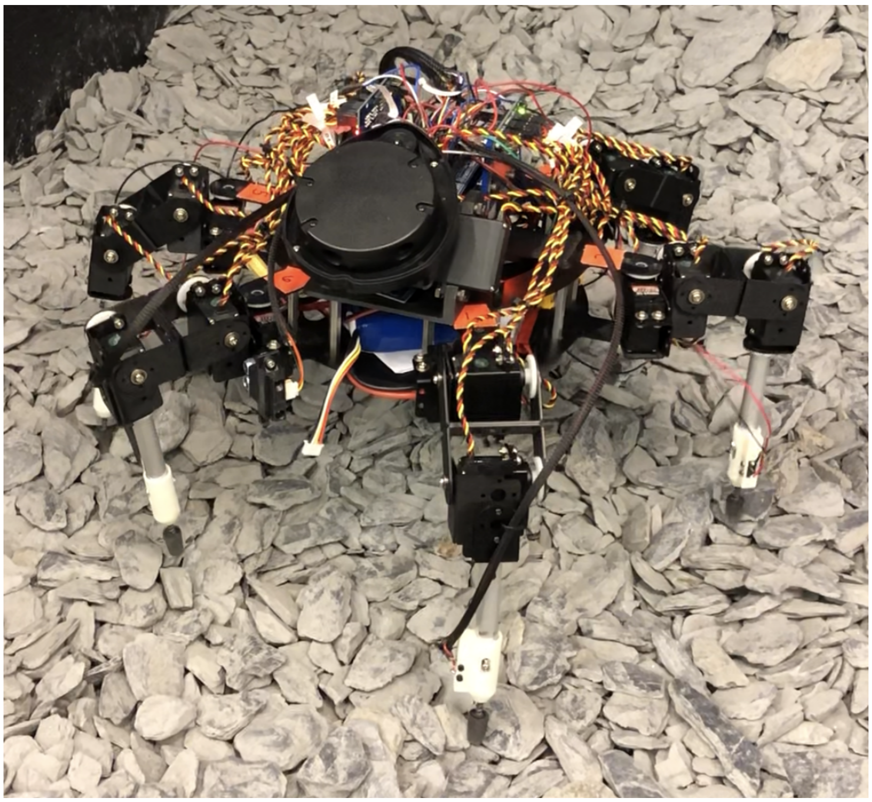
Final Report - Spring 2019



1 Overview

Walking robots have advantages over their wheeled counterparts in their ability to climb and negotiate rough terrain. This property makes such robots well-suited to exploration of rocky environments such as the surface of Mars or an asteroid. Last semester, this research project began with the goal of developing a folding autonomous hexapod rover for exploring rocky environments. While last semester was devoted to building up a basic platform, this semester we focused on adding more advanced capabilities such as rough terrain traversal, obstacle detection, and custom electronics.

2 Adaptive Gait

In order to traverse rough terrain, the hexapod adjusts the relative positions of its feet as it walks to conform to the terrain. The rover has knowledge of the positions of its feet relative to the surrounding environment through a combination of dead reckoning and external sensory feedback. The servos used to actuate the legs have built-in positional control, so the position of the feet relative to the hexapod body can be computed using inverse kinematics. Additionally, limit switches built into the feet detect when each foot hits the ground. As the hexapod takes a step, each foot is incrementally lowered until the limit switch is triggered. At that point the foot is fixed in place relative to the surrounding environment for the remainder of the step. Thus as the hexapod walks over terrain with varying height, the feet are lowered to the surface of the ground while the hexapod body remains level (Figure 1).

While this approach proved effective on level surfaces, the hexapod body tended to slowly shift up or down if there was any slope to the terrain, because the average foot height would increase or decrease while the body remained at the same

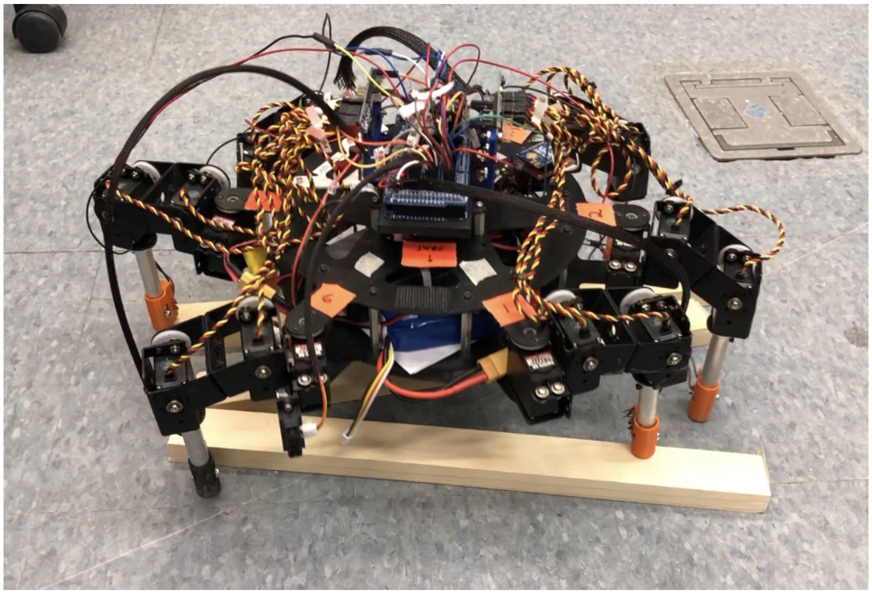


Figure 1: A controlled test of the adaptive gait algorithm on an uneven surface.

height. To address this, a corrective stage was added after each step where the hexapod raises or lowers its body relative to its feet in order to maintain a constant average foot height. A similar adaptation was also added for the angle of the body relative to the ground, so that the hexapod remains level with respect to the terrain even on a slope.

An improvement was also made to the underlying gait. While the initial gait developed last semester kept the legs parallel as they moved for simplicity, the new gait instead spaces the legs evenly around the hexapod body for greater stability. However, this gait does have a downside: while the hexapod can still detect cliffs, it can no longer react in time to step back before its momentum carries it over the edge.

3 Bio-Inspired Feet

To complement the adaptive gait algorithm, new feet were designed for greater traction and potentially the ability to climb steeper slopes. The first new design was modeled after the legs of a crab, and added curved talons to the bottom of each foot to fit between rocks and hook over objects (Figure 2). However, due to the angle between the talon and the axis of the leg the limit switches could not be reliably triggered. Each limit switch relies on its foot being able to compress along the axis of the leg, but the horizontal component of the normal force added friction that prevented easy sliding.

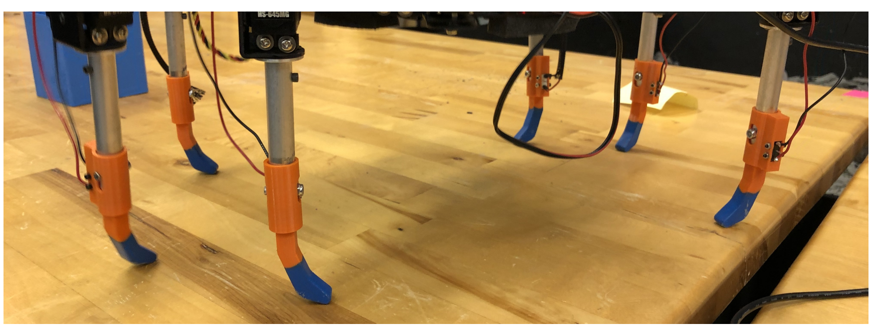


Figure 2: The hexapod outfitted with crab-inspired feet.

A second iteration of the feet replaced the curved talon with a screw, which reduces the contact area to a small point for easier pivoting and fitting between rocks (Figure 3). Because the screw is parallel to the axis of the leg, this new design also avoided the issues with triggering the limit switches. Protective plugs can also be screwed onto the ends of the feet to allow usage on tables without damage. Based on tests in the mock-up asteroid environment, the new feet have been effective at maintaining a solid purchase on uneven surfaces. The main trade-off is that the extra length added to the legs increases the amount of give in the system, causing the hexapod to wobble more severely as it walks. This issue could potentially addressed by tightening tolerances in the foot design and shortening the hexapod's legs by a corresponding amount to the increased size of the feet.

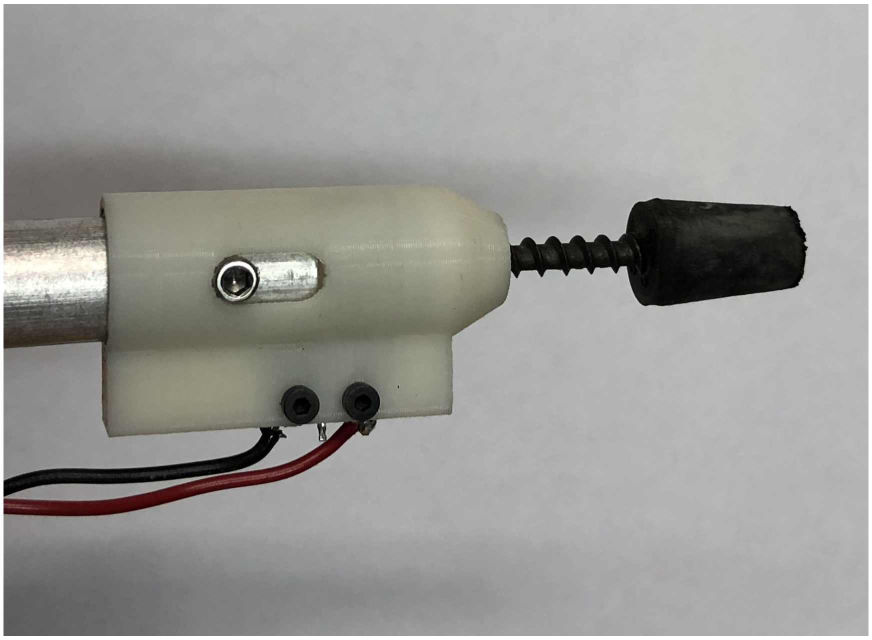


Figure 3: An updated version of the foot that integrates a screw to minimize contact area. A plug is screwed onto the end to allow testing on table tops.

4 LIDAR Integration

Despite these improvements to the robot hardware and software, there are still some obstacles and slopes that the hexapod cannot traverse. To deal with such obstructions, a LIDAR has been added to look ahead for obstacles and allow the hexapod to plan paths around them. A custom mount was designed that uses a servo to rotate the LIDAR up and down, allowing a 2-dimensional scan of the area in front of the hexapod (Figures 4 and 5). The data from the LIDAR will then be processed by an on-board Raspberry Pi, which communicates with the Arduino microcontroller over a Serial protocol. While data has been successfully collected and processed with the LIDAR, work still remains to mount the Raspberry Pi to the hexapod and then detect obstacles from the LIDAR data.

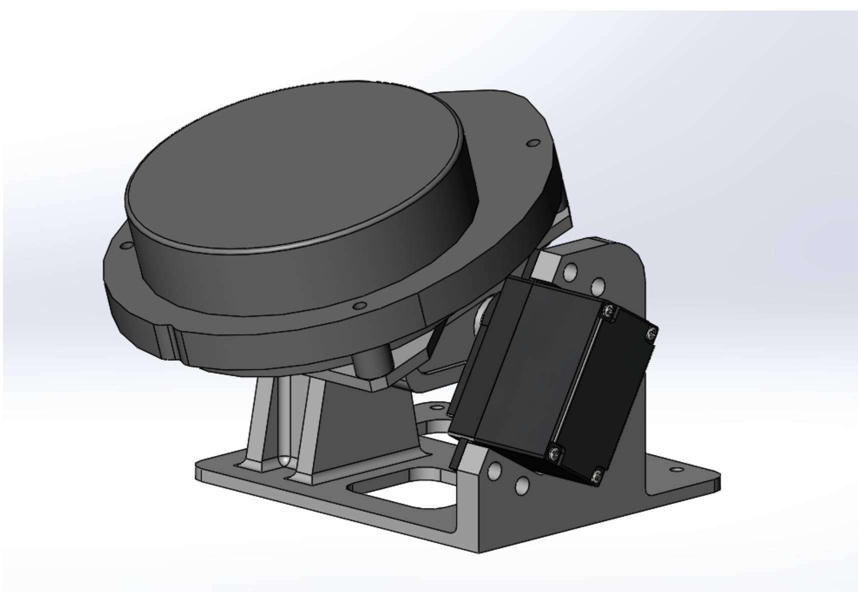


Figure 4: The CAD model of the servo-actuated LIDAR mount.

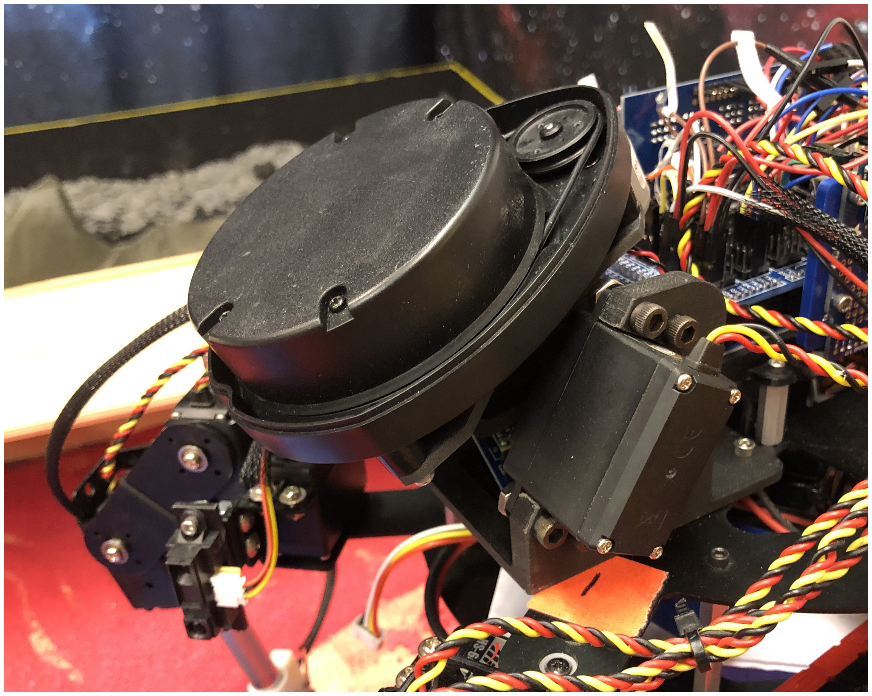


Figure 5: The 3D-printed LIDAR mount attached to the hexapod body.

5 Custom Electronics

The current hexapod electrical system is a mess of different components connected by jumper cables, so an effort was begun to unify the different boards into a single custom-designed PCB (Figure 6). This PCB will incorporate both the Arduino microcontroller and the servo drivers, and also integrates a built-in accelerometer, an XBee, a buzzer, status LEDs, and ports for connecting limit switches that include built-in pull-down resistors.

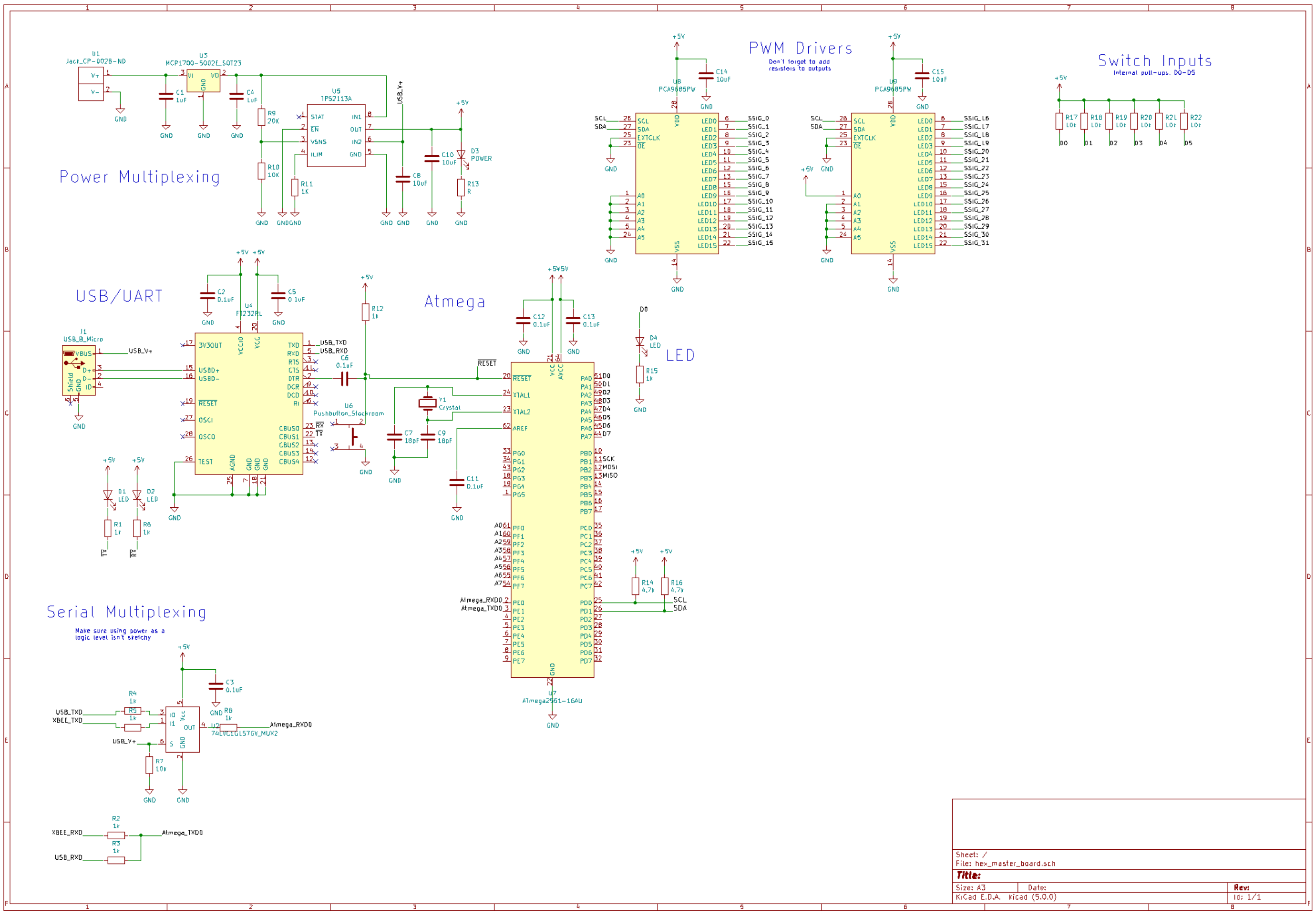


Figure 6: A wiring diagram for the custom printed circuit board, which will replace the Arduino microcontroller, servo drivers, accelerometer, and XBee with a single board.

6 Future Work

While significant progress has been made this semester, a couple key goals remain moving forward. While the LIDAR has been integrated into the system, new algorithms must still be developed to make use of it for path planning and obstacle avoidance. On the electrical side, the custom PCB design must be finalized and manufactured, and the Raspberry Pi mounted to the hexapod frame. Finally, the rough terrain traversal capabilities should be further extended to allow climbing up steeper slopes. All of these goals will hopefully be addressed in the coming fall semester.

7 Resources

All of the hexapod's code, documentation, and circuit designs are available from the Hexapods Github repository. Our CAD models are available from the Hexapods GrabCAD project.