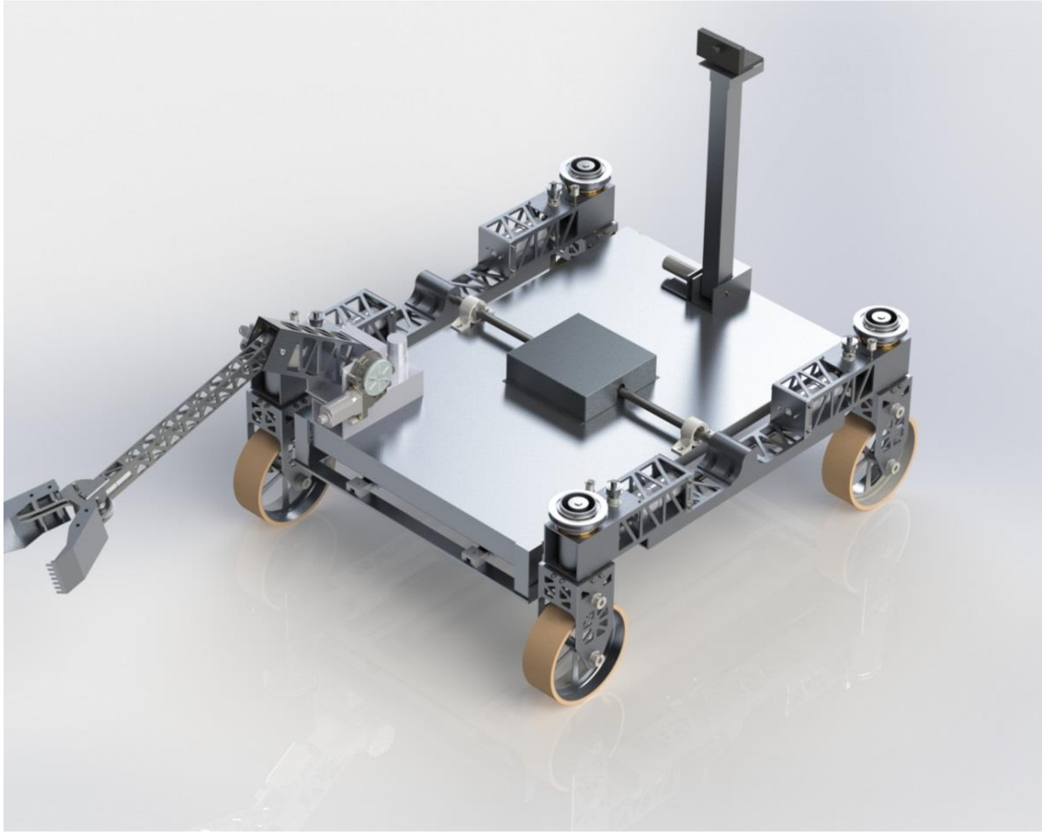
CAL-Rover Robo-Ops

2014

Final Report



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Introduction

For the past 9 months, UC Berkeley AIAA's Robo-Ops team has designed and manufactured a rover for the 2014 Robo-Ops Competition. The design utilizes swerve drives, a rocker arm suspension, and a three degree of freedom manipulator arm to fulfill every design parameter laid out for the competition. Overall, in its largest form, the rover has dimensions of .77m x .94m x .80m and weighs about 40kg.

Chassis

The chassis is made of three sections: the suspension, the frame, and the electronics box. The rocker suspension system utilized was inspired by the Mars rover Spirit's rocker bogie suspension. During the design phase, the decision to use a simple rocker suspension system over the full rocker bogie suspension was made to simplify the rocker system for easier machinability. Despite its simplicity, the suspension will effectively traverse the varied terrain found at the Johnson Space Center. Simplicity not only drove the rocker suspension decision, but also dictated suspension design. The suspension consists of two 6061-T6 aluminum rocker arms and the differential, made of steel axles, gears, and bearings. The swerve drive modules are attached to the rocker arms which are in turn attached to the differential. The differential consists of four gears oriented such that rotation of one of the gears creates rotation in the negative direction in the gear directly opposite it. Therefore, when one wheel goes over a bump or rock, the rocker arms will move opposite of each other so that the frame will stay stable.

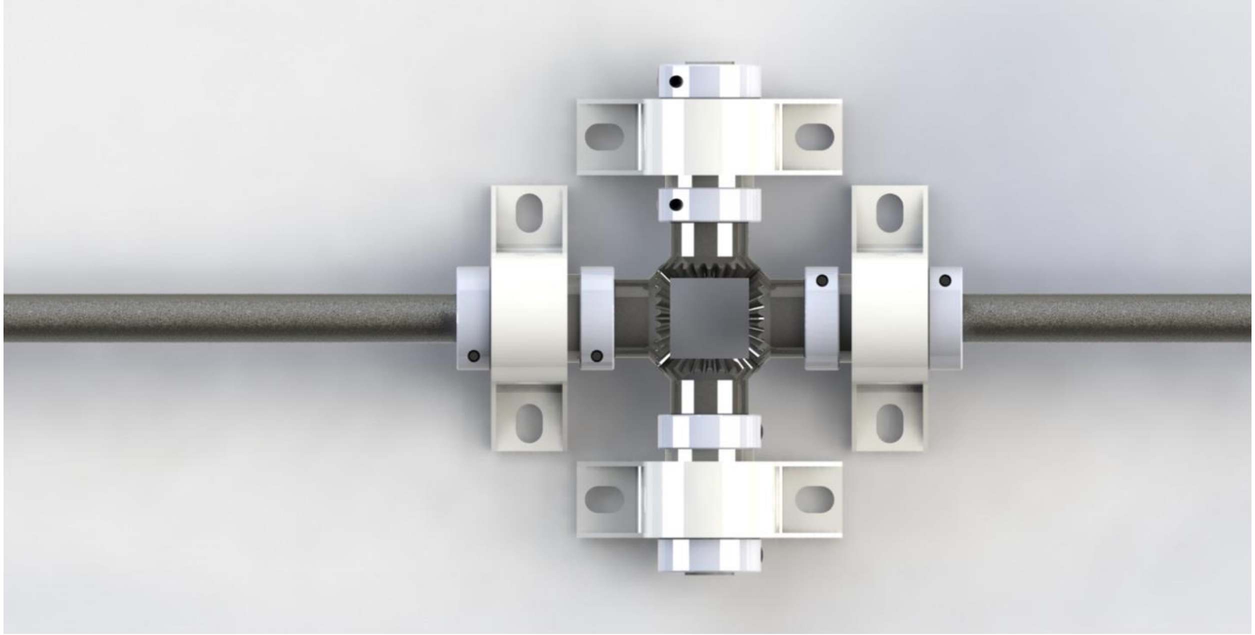

Figure 1: Top View of the Differential

When designing the main body of the chassis, an effort was made to allow for easy maintenance of the electronics that the body would house. Multiple ideas were considered with the final two being a removable box section that could be bolted on and off or a roller system to allow for the box to slide out. The latter was chosen for its structural integrity and ease of use; the designs for the roller system were able to withstand more loads while adding less overall weight to the rover. The frame is made up of 6061-T6 aluminum angle brackets and sheet welded to create the structure. Two rails were also added to add rigidity and to provide a space for the electrical box rollers. Key components including the manipulator, camera mast, and differential are attached onto the top of the frame, while the electronics box fits within the frame. Attached to the bottom are rollers which allow for easy removal of the box for quick maintenance. Overall the frame was tested to hold at least 23kg, which is enough for the electronics, manipulator, differential, and sample collection throughout the competition. The total weight of the chassis is 15kg.

Wheels

Due to the nature of the swerve drive system, the wheels were one of the more challenging parts of the rover to design and create. With the swerve module's vertically mounted drive motor and the size of the swerve module housing, our wheels were constrained to a very limited size. Wheel diameter was limited to 22.86cm in order to fit the rover into the height constraints, while the width of the wheel was constrained to 6.35cm in order to fit inside the swerve module housing. When considering different wheels, we reasoned that using the largest diameter and widest wheel possible would provide the most traction over loose sandy surfaces while also providing the ability to climb over large obstacles. After scouring the internet for wheels that met our criteria, we were unable to find any so we decided to manufacture our own.

The first design utilized two AISI 1008 steel pipe caps, with their "heads" facing outwards. An aluminum spacer with 5 lugs held the steel pipe caps together while also connecting the drive sprocket to the wheel assembly. This design proved to be both flimsy and much heavier than our target wheel weight.

Figure 2: Steel portion of the wheels, mid production

Our second design utilized one AISI 1008 steel and one AISI 3003 aluminum pipe cap, with their “heads” facing inwards. Both pipe caps were designed in a 5 lug, 5 spoke patterns to focus the force to the center of the wheel. Turning the pipe cap heads inwards added rigidity to the wheel because the force-bearing region of the wheel was distributed on both the steel and aluminum pipe caps. The steel portion of the rim was designed to be the main load bearing side, whereas the aluminum added extra reinforcement and width to the wheel. This design in theory worked well and was able to withstand a worst case scenario loading of the entire rover’s weight. In practice machining the AISI 3003 aluminum pipe cap provided difficult due to the softness of the material.

For implementation on the rover, we decided to continue to machine the steel portion of the wheel, but instead with 5 spokes, 4 lug pattern. This decision was made to continue to reduce the weight of heavier steel portion of the wheel while making the wheel easier to machine. In order to countermeasure AISI 3003’s softness, we opted to not machine the aluminum pipe cap. The extra weight gained by the aluminum is still less than an equivalent dual steel wheel.

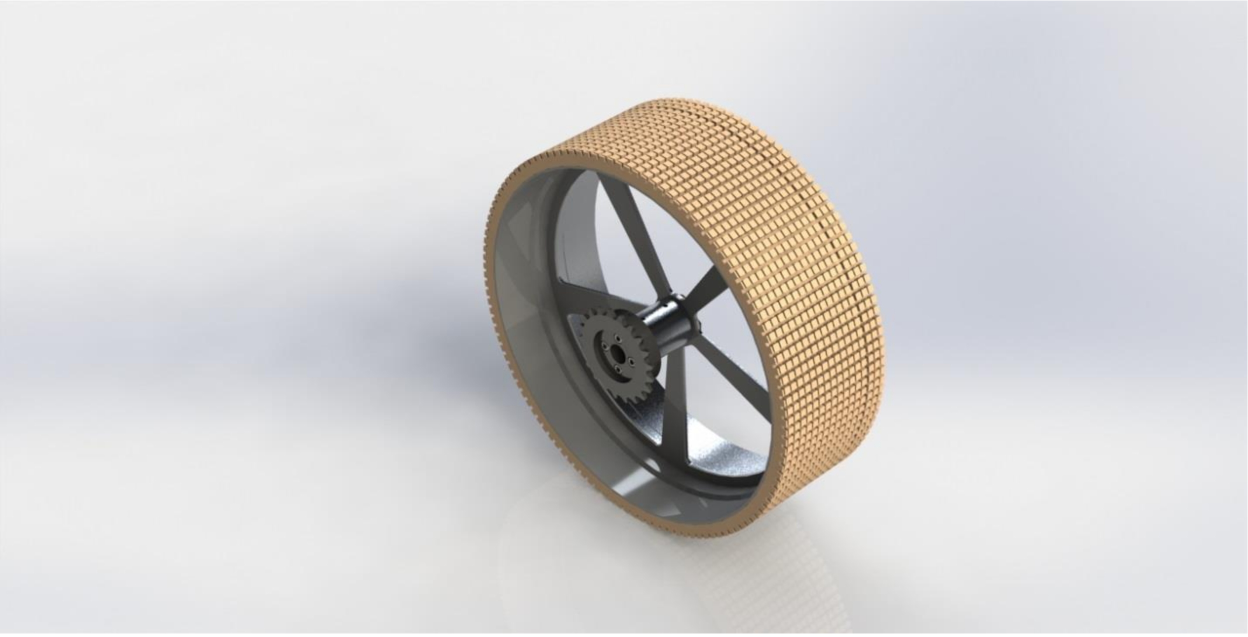

Figure 3: Final Wheel Assembly

Each wheel‘s external surface is covered in 3 ply SBR (styrene butadiene rubber) inclined conveyor belt. After researching many possible wheel materials, the conveyor belt was chosen due its ability to provide excellent grip (good for climbing over large obstacles) and also its durability. The conveyor belt provides the most grip and will also allow us to also move throughout the loose sandy portions of the field better than a solid rubber wheel would.

Manipulator

The manipulator system consists of a 3 degrees of freedom arm and a claw end effector. Two of the three degrees of freedom are located at the base of the arm (the shoulder) controlling the pitch and yaw motion of the arm, with the third located at the elbow joint .17m from the base of the arm. Overall the arm has a maximum reach of .75m.

The base of the arm is able to sweep 135° and move 110° in its yaw and pitch motion. The forearm of the manipulator can rotate 90° around its elbow joint. These rotation values are registered by potentiometers located at the pivot joints and limited through software to protect the arm from over extension.

The end effector closes and opens through a series of gears driven by an actuated worm gear. It has the capability to open up to 200° with a maximum opening of 16cm.

Due to a significant amount of load in the pitch rotation of the manipulator, the actuators at the elbow and base are worm geared to eliminate backlash. This also helps the actuator at the elbow and base, providing ample torque to move the manipulator in the vertical direction.

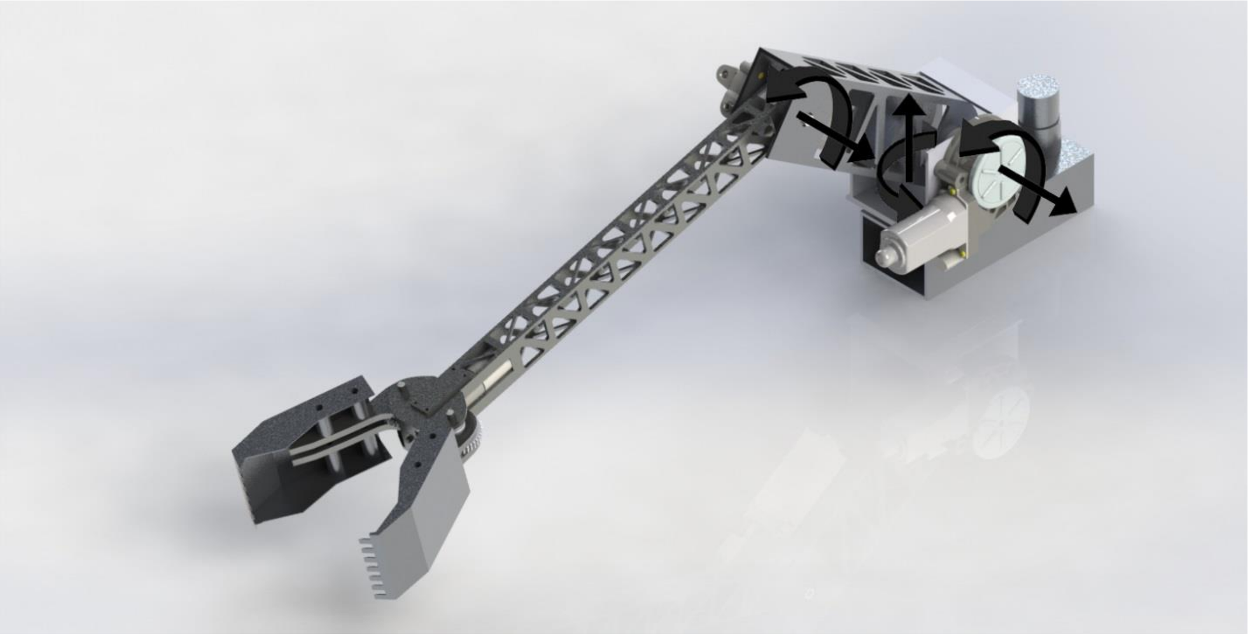

Figure 4: The Degrees of Freedom for the Manipulator

Control and Communications System

The rover's communications and control system, on a macro-scale, consists of a remote client with a control GUI that sends and receives commands from a server that running on the rover. The server in turn sends movement commands to the microcontrollers that control the physical actuators and drivetrain.

The single board computer on the rover runs two server applications: one that deals with video streaming and one that opens a socket for commands to be sent to the rover. Video streaming is accomplished through an application that initiates an HTTP server which provides a port where the video streams can be accessed. Video compression is accomplished via the MJPEG format. Essentially, this format is simply a constantly updating stream of individual JPEG frames. This format was chosen because it does not rely on interframe compression to deliver smaller file sizes, thus reducing latency. Even though this may consume more bandwidth for the level of streaming quality, frames can easily be dropped to maintain low-latency remote viewing, something that is essential for accurate control of the rover. There is no audio transmission from the rover, as there was no defined need for this feature. The control server binds a TCP socket to a specific port on the onboard computer. The client on the remote side then connects to this port and sends commands over this socket. Data privacy over the internet is maintained through the use of a private VPN. This also avoids any issues that might have arisen from forwarding ports over a cellular modem.

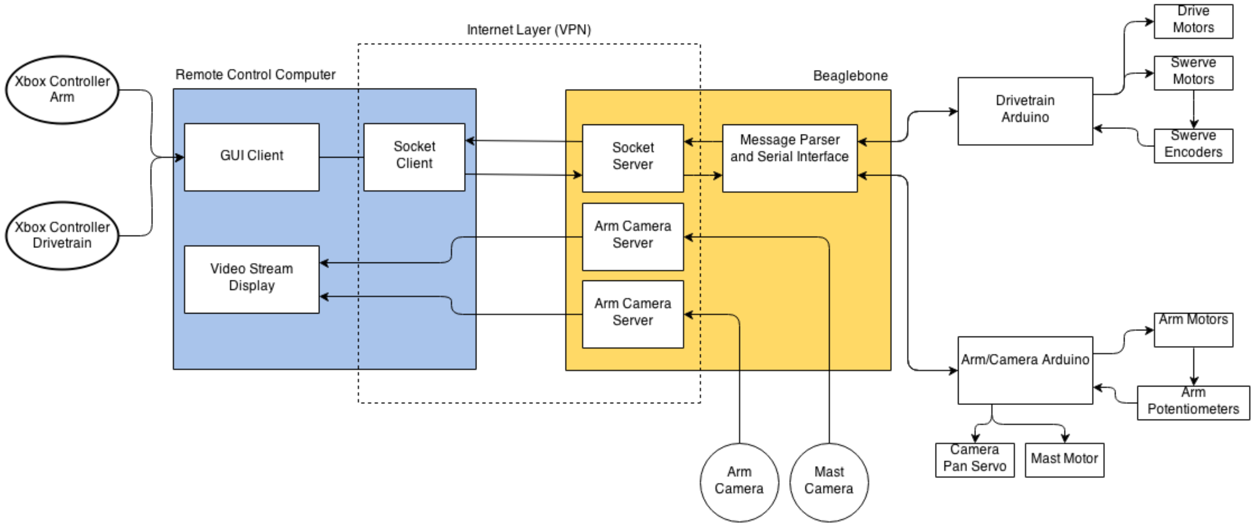

Figure 5: Control Flow Chart

The driver and manipulator arm operator can send instructions to the rover through the use of the buttons and joysticks on two Xbox 360 controllers. The GUI allows for the controller sensitivity to be tuned on the fly for maximum desired responsiveness. Also, the GUI application on the client side manages controller input and converts these readings into message objects. These message objects are then serialized and sent to the server via the TCP socket. The server program's motor manager de-serializes these messages and converts them into a simple nine-character message which can be sent to the corresponding microcontroller. In turn, the microcontroller echoes the message, notifying the remote side that the command has been received. The GUI displays these motor states.

Besides the camera, there are no sensors on the robot that send their state directly to the client side. However, potentiometers and encoders are used by each microcontroller to allow for things such as swerve drive heading angles to be accurately controlled. Additionally, potentiometer readings are used as safeguards to protect the arm from strain damage.

Communication between the robot and control center are carried out over the internet via a USB Verizon mobile broadband card. This card is capable of using Verizon's 4G LTE network, which ideally allows for a bandwidth of 15 megabits per seconds. Using an LTE capable card allows for us to deliver the bandwidth necessary for multiple concurrent video streams. Latency with this setup is low enough that our skilled operators are able to precisely control the rover remotely.

Cameras

The rover has a dual camera setup with one camera mounted on a retractable mast and one mounted on the end of the arm. The rover's camera mast is .80 meters tall when fully extended. In order to meet the transport size requirement, the mast is mounted on a motor joint that allows it to extend and retract to and from a vertical position. The top of the camera mast has a servo assembly that allows for the mounted camera to pan. In addition, the rover has a camera mounted on the manipulator that assists with control of the manipulator in difficult environments. This camera mount gives the operator a viewpoint close to the sample collection device.

The cameras used in both locations are Logitech C110 Webcams. These cameras were chosen for their reliability, affordability and simplicity. They communicate over a USB interface with the central computer and are capable of recording video at a resolution of 1024x768 pixels. They have a fixed focal point, and, as such, do not have zoom capability. However, this aids in simplicity of operation, ensuring that the operator does not need to worry about erratic focus adjustment.

Electrical System

Overview

Our electrical system provides the power required to operate the manipulator, the drive systems, the on-board microcontroller units (MCUs), and logic devices. Our power distribution network consists of power sub-circuits – each including one automatically resettable fuse with load-specific rating, and a voltage regulator to step down the power source (i.e. the Li-Po battery pack) voltage. The sub-circuit design will allow different parts of the rover to be powered independently of each other, reducing the risk of device failure chain effect. For example, if a motor draws excessive current and causes the fuse to trip, other components such as the MCUs will not shut down.

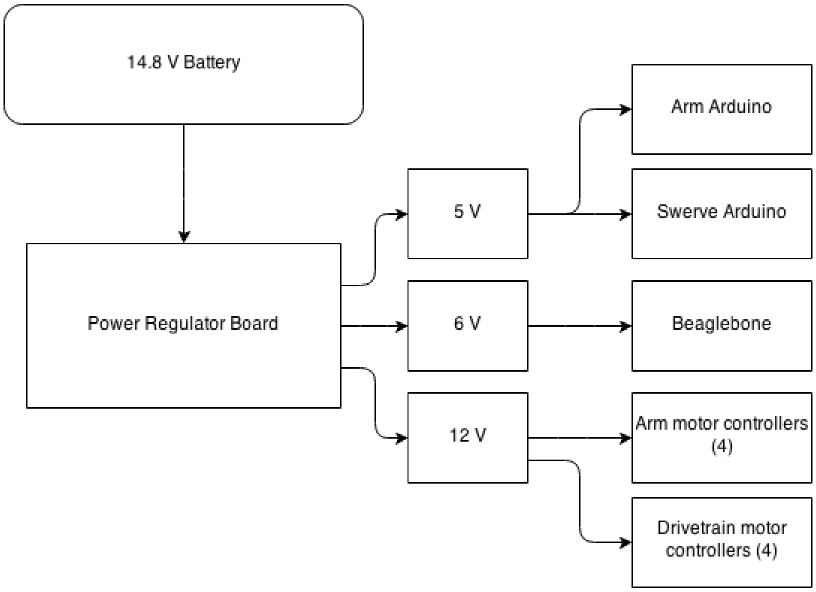

Figure 6: Power Flow Chart

Sub-circuit Voltages

Five 4s 8000mAh Lithium ion polymer batteries are used in our design (one battery for each of the four swerve modules, and one for the manipulator, MCUs, and logic devices). The available voltages for the sub-circuits are: 5V (for general logic devices, such as camera), 6V (for Beaglebone MCUs, manipulator motors), 9V (for Arduino MCU), and 14.8V (for manipulator, swerve, and drive motors). Each power sub-circuit exclusively serves one (or two in some cases, which will be discussed shortly) power device (e.g. motor, microcontroller). Table 1 shows a list of the sub-circuits, the battery power source, their rated voltage, the current rating for the fuse used, and their designated loads:

Sub-circuit #	Li-Po #	Rated Voltage (V)	Fuse Rating (A)	Loads
1	1	14.8	33	Swerve/drive system motors
2	2	14.8	33	Swerve/drive system motors
3	3	14.8	33	Swerve/drive system motors
4	4	14.8	33	Swerve/drive system motors
5	5	5	1	Logic Device x 2
6	5	6	1	Beaglebone MCUs x 2
7	5	9	1	Arduino MCU
8	5	6	27	Manipulator claw motor
9	5	6	27	Manipulator pan motor
10	5	14.8	33	Manipulator lift motor

Table 1: Voltages

Voltage Regulators

The voltage regulators chosen are the LM1084 from Texas Instrument. They supply 5A, adjustable output voltages using a feedback resistor divider network. These regulators can supply reliable 5V, 6V, and 9V voltages with enough power.

Resettable Fuses

Our main safety mechanism for over-current draw is through the use of resettable fuses. Specifically, we decide on Polyswitch fuses from TE Connectivity, which restrain the current draw to below their rated current. Although current spikes above the rated current are possible, only substantial current draw (e.g. from a short circuit) will cause the fuse to heat up and decrease conductivity.

Testing Strategy

Testing of the rover has been occurring in a modular fashion with extensive focus on the viability of the controls programming for the manipulator and swerve drive. For the manipulator, initial testing showed the manipulator has the potential to move with dangerous speeds. A PID setup was tried out, but limiting voltage directly with GUI sliders to limit the power levels for each joint proved to be more effective in controlling the arm’s speed in a predictable and safe manner. To prevent the arm from colliding with the chassis, a minimum angle is implemented into the code and measured by potentiometers throughout the arm.

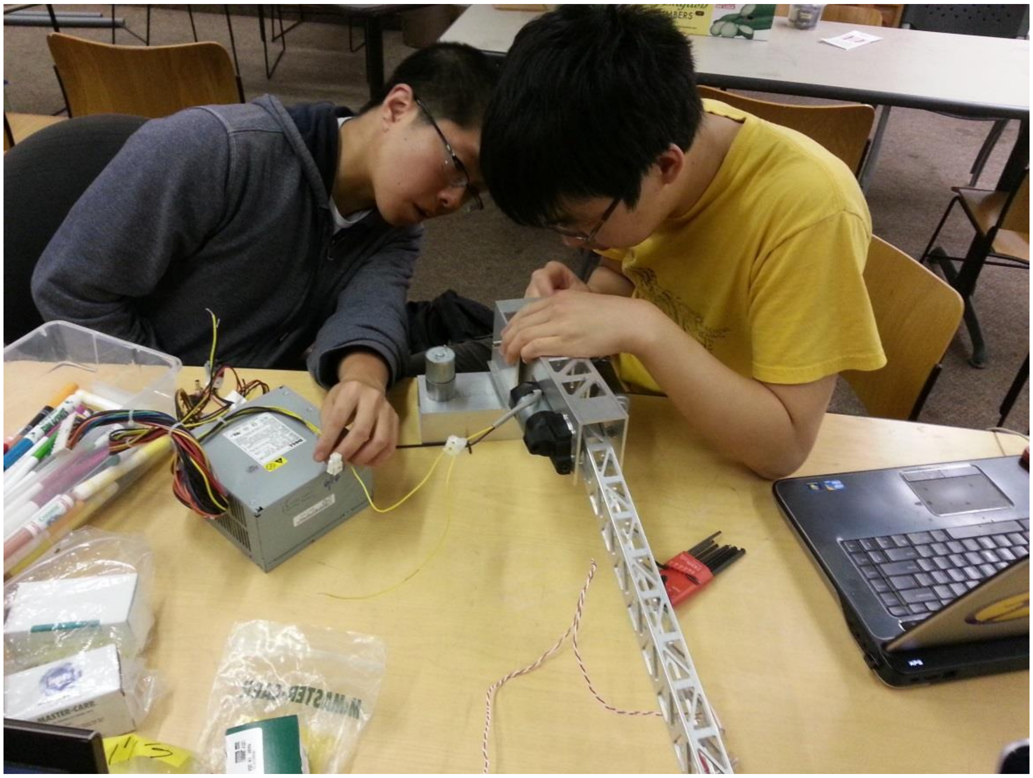

Figure 7: Early Testing of the arm

When testing the serve modules, belt tension was found to be a large problem. The solution was to create belt tensioners to prevent the belt from having slack and ensuring the full transmission of torque to rotate the modules. The swerve modules were tested in the same way for steering capability as the arm was tested. In the GUI, multiple modes have been created and tested each with the wheels in a different configuration. The three configurations are the drive configuration, rotation configuration, and the strafing configuration. For the drive configuration, the wheels all point forward so that the rover may move forward or backward. The rotation configuration has the wheels at 45 degree angles so that when powered, the rover will turn in place. The strafing configuration has the wheel facing perpendicular to the front of the rover, allowing the rover to move side to side.

Figure 8: Assembled Belt Tensioner

Communication has been tested by controlling the manipulator and swerve modules wirelessly. The communication has been shown to work with the ability to control all components.

Full integration testing will occur across the UC Berkeley campus to simulate every expected terrain. The hilly nature of campus allows for extensive testing of the rover’s ability to navigate high grades of hills. Additionally, we plan to make use of beach volleyball courts to test the rover’s mobility in sandy terrain. To simulate the rock fields, we will have to test off campus at nearby parks.

Overall Strategy for Competition

Throughout the design process, we have tried to increase the maneuverability of the rover for the competition. This led to design decision like the swerve drive, rocker suspension, and GUI control. For the competition we hope to leverage our maneuverability to traverse across the field to find the most lucrative spots for sample collection.

Budget

Our rover cost about $7800. The largest individual chunk of the expenses for the rover came from the four swerve drive which cost about $2200. The frame, machined and welded by Mun Manufacturing for a cost of $1890, consists of the next largest piece, followed by the electronics at around $1400.

Travel costs have been estimated to be $3270 for the trip to Houston.

Expenses	
Rover	7800
Rental Car	1250
Gas (Expected)	900
Hotel (2 rooms, includes travel)	1120
Total Costs	11070

Table 2: Expenses throughout the year

Our financing comes primarily from NASA’s grant for the Robo-Ops competition. However, we also received $1500 from the UC Berkeley Engineering Student Council, the organization that funds engineering clubs at the university.

Financing	
NASA	$10000
Engineering Student Council	$1500
total	$11500

Table 3: Financing Sources

Public/Stakeholder Engagements

The social media component of our public engagement is the Cal AIAA Robo-Ops page. We use this page to provide updates on our rover’s progress. With the page, we are able to advertise the competition to hundreds of students.

Our other public engagement was participation in UC Berkeley’s annual Cal Day, an event that draws tens of thousands every year. On Cal Day, we tabled in front of the Mechanical Engineering building showcasing our manipulator and swerve drive to current students, incoming high school seniors and the visiting public.