CALIFORNIA STATE UNIVERSITY
LONG BEACH

NASA RASC-AL Robo-Ops 2016

Final Technical Report

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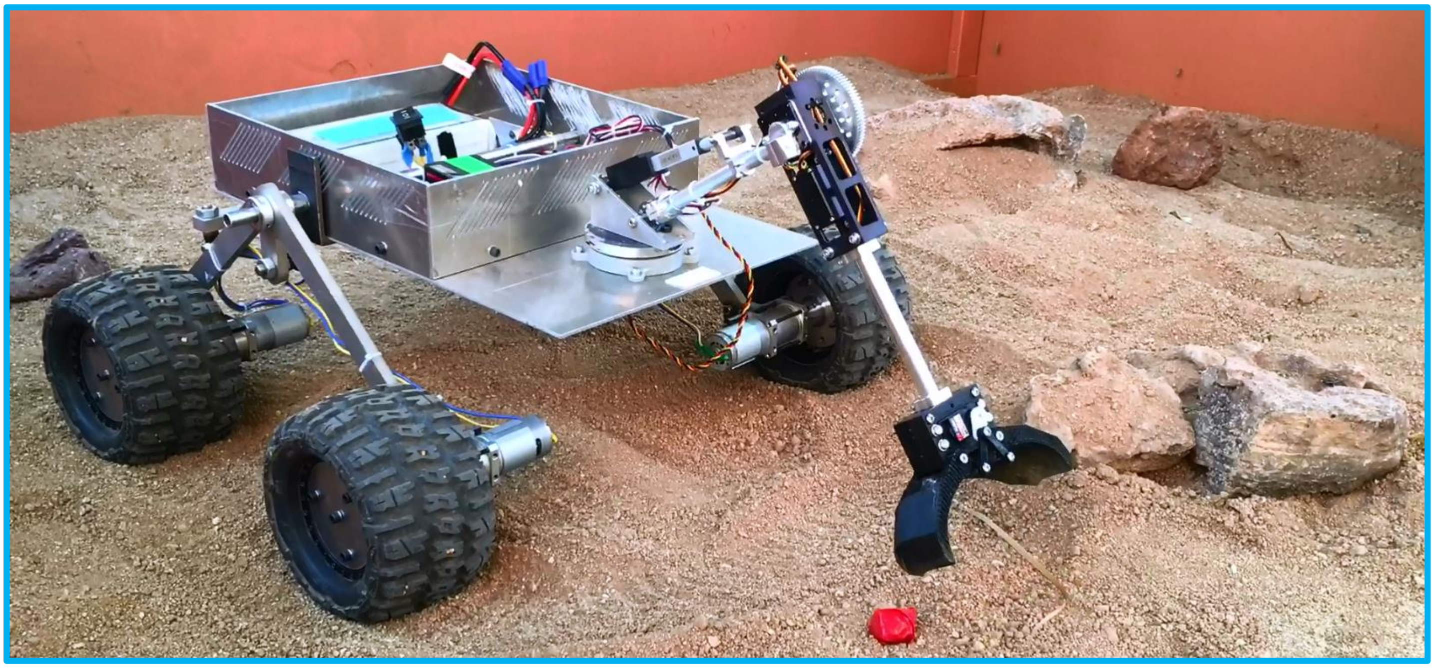


1. Introduction

The California State University; Long Beach Gemini Rover Team is very excited to compete the in RASC-AL ROBO-Ops competition at the Johnson Space Center for the second consecutive year. We will incorporate our twin rover system again this year, with each rover tailored to a general environment; either a rocky environment or a sandy one. Given our team name and the fact that they are twin rovers, our initial inclination was to name them Castor and Pollux, after the Gemini twins in the night sky constellation. However, after such frequent association of the rovers with their respective environments during the design and manufacturing process, the rovers have been affectionately renamed Rocky and Sandy.

With two members as team leads from the previous competition, our team has learned hugely about how to implement effective improvements to all aspects of our rover system this year. We have decreased the size of our team to promote task accountability, as well as increase the level of specialization each team member has in the rover system. With regard to system design, the mechanical, electrical, and communications systems have been subject to heavy re-working to improve system stability, efficiency, and ease of access and repair.

The mechanical design has been made lighter and more stable, and the electrical components bay has been made larger and easier to access. The power system has experienced improvements through the addition of serial motor drivers, which simplify wiring and programming, as well as the implementation of filtered voltage regulators to sensitive components such as the micro-computer and the motor micro-controller. The coding in the communications system, as well as the controls for the drive system and robotic arm have been entirely rewritten in a manner which simplifies controls and programming changes. In addition, the communications architecture has experienced a complete redesign which greatly reduces the amount of code and computation, as well as includes multiple redundancy measures.

2. System Description

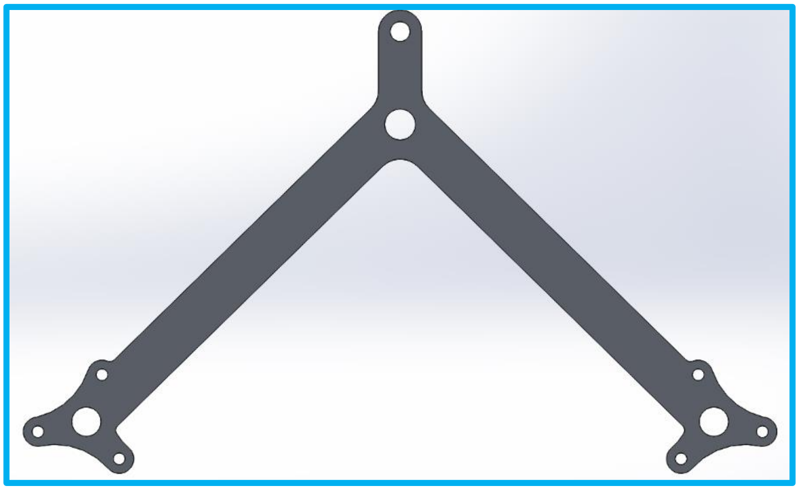
2.1: Drive System and Chassis Design

2.1.1: Drive System

Both of our rovers will employ a differential drive system for navigating the competition field this year. Each rover has four independent DC motors; one for each wheel, however the front and rear motors on each side of the rover are connected in parallel. To tailor each rover to its respective environment, the rovers employ different drive motors. Through experiencing difficulty with traversing very rocky environments due to the motors striking the rocks and preventing movement, the rock rover has been designed to use right-angle DC motors. Additionally, since the rock rover will endure a more compromising environment, its speed does not need to be high. The right-angle motors operate at 115 RPM, which translates to roughly a 2.1 mph top speed with the 6 inch diameter wheels. Since we do not anticipate the sand rover experiencing large rocks, it will utilize the same DC gear-motors that were used in the previous competition, due to their high reliability and robust construction. These motors operate at a higher speed than those on the rock rover, which at 240 RPM gives the sand rover a top speed of roughly 5 mph.

Turning maneuvers are greatly simplified by rotating the left and right side wheels in the opposite direction in a “tank style” fashion. This differential drive system for turning is highly favorable over steering wheels due to its increased simplicity in aspects of mechanical design and driving controls. Additionally, this drive system, in which the left and right side wheels are controlled, rather than all four drive wheels controlled independently, further reduces complexity in the aspect of driver control of the rover.

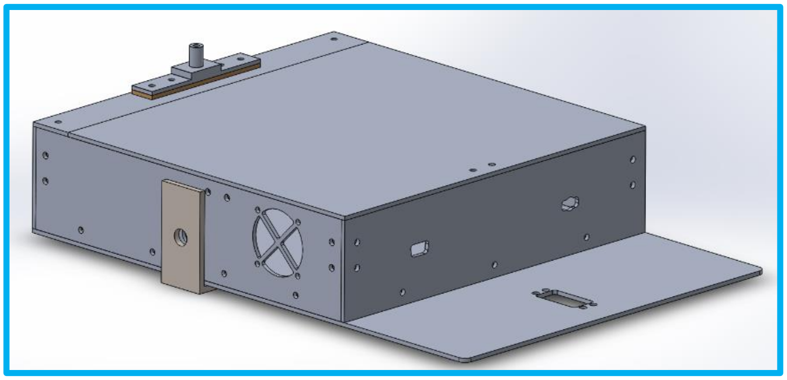
2.1.2: Suspension System



Due to its robust nature and simplified mechanics, the suspensions of our rovers will utilize a modified rocker-bogie system. In this system, a differential arm is attached at both ends to each of the suspension linkages, which we have named “Wishbones” due to their strikingly similar shapes, via push-rods. Upward movement of a front wheel will cause the differential arm to move, which translates to the suspension linkage on the opposite side. This ensures that the wheels on the left and right side of the rover are in opposite-lock; if the wheels on one side move upward when climbing over a rock, the wheels on the other side will be pushed down to maintain constant contact with the ground for maximum traction. This method ensures that the rover maintains strong contact with any obstacle and the ground, resulting in a desirable crawling motion.

2.1.3: Chassis

The dimensions of each rover is roughly 50x75x26 cm from the floor to the top of the body, and 50x76x45 cm from the floor to the top of the un-extended camera mast, and the all-up weight of each is roughly 13 kg. Both rover bodies have been designed out of 1/8-inch thick aluminum panels, arranged to create a compartment for the electrical components that is 12-inches square, with a 3-inch height. For uniformity and simplicity in assembly and disassembly, the entire body is fastened with 10-32 socket head cap screws. The previous design of the body was made entirely of 80-20 aluminum T-slots, which made it bulky and heavy, and did not allow for ease of access to the components inside. As an improvement on the previous design, the body is light and more space-efficient due to the smaller form factor of the body panels. To ensure ease of access to all electrical components and the battery inside the rover body, the top body panel is on a hinge and acts as a door which can be opened to provide access to all interior components. Additionally, with its lowly-populated design and dual cooling fans, the electronics compartment will have ample ventilation.



Approximate Body Weight of Rover is 3.5kg.

Initially, a tall prototype with an 11-inch height clearance was fabricated and tested successfully on varying terrains. While its navigability was sufficient, it was found that this height clearance may be reduced without compromising maneuverability in difficult terrain, with the intent to lower its center of gravity and to reduce the size of the sample acquisition system. The current design for both rovers has roughly an 8 inch height clearance from the ground, which was selected through iterative center of gravity calculations to ensure that the rover would not tip backward or forward when traversing steep inclines. For this purpose, the center of mass of each rover was determined from computer-aided drawings (CAD), which implement the material properties of each component on our rovers.

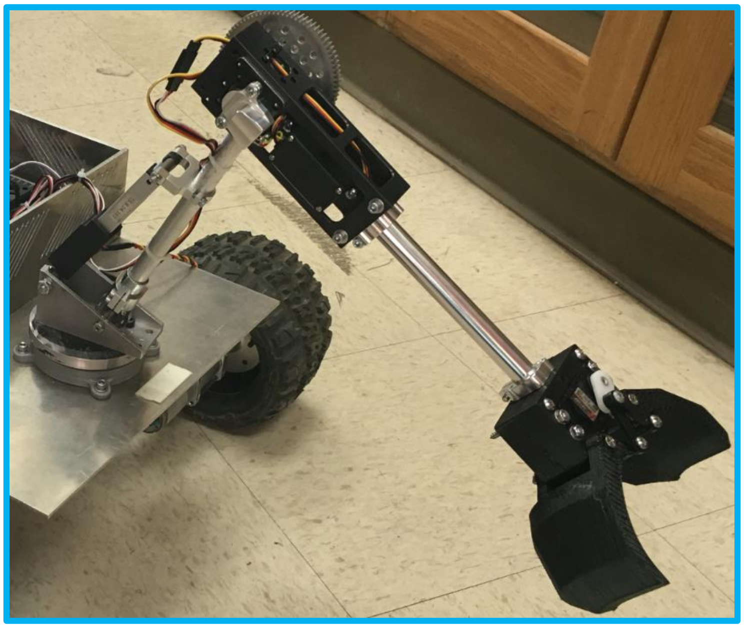
As a part of the height reduction process, the design decision was made to pass the suspension rod, which is a hollow bar that connects the wishbone suspension linkages on both sides of the rover, through the body rather than under (See Fig. 1 for comparison). In addition to reducing the height of the rover body, this measure served to reduce stress on the differential arm that translates the motion of the suspension linkages. The differential arm supports the body of the rover in a manner which prohibits the body from rotating forward and backward on the axis of the suspension rod. Since the body houses heavy components such as the battery, it was found that passing the suspension rod through the body decreased the distance between the suspension rod and the heavy components, which means that the differential arm has to resist smaller forces when the body tilts forward and back.

2.1.4: Wheels

For the rock rover, the use of commercial off-the-shelf pressurized rubber wheels, rather than the previous aluminum wheels wrapped in rubber, will allow for increased traction. From the competition last year, it was found that rubber-wrapped aluminum wheels were not ideal for climbing over rocks, due to lack of flexion. However, since we do not expect the sand rover to commonly traverse hard obstacles, the rubber-wrapped aluminum wheels from last year will be used. These wheels are favorable for this environment due to their wide profile, which will distribute the weight of the rover over a large area to prevent the wheels from sinking or digging in sand. Additionally, since our re-designed rover body is very light, the increased weight of these wheels, in comparison to commercially-purchased rubber wheels, aids with traction when climbing steep inclines that cause the front wheels of the rover to become light.

2.1.5: Sample Acquisition System

The sample acquisition system that will be used in the competition is a robotic arm which has been designed by our team, rather than purchased off-the-shelf as was done in the previous year. We found that previous robotic arm encountered issues during driving and operation, caused by motion-induced vibration and uncontrolled rocking movement. These issues were the result of an under-powered servo motor in the shoulder joint, and the arm having excessive degrees of freedom (DoF). As a remedy, the current design employs a shoulder member controlled by a linear actuator, which has a back drive lock-out feature to stably hold its position when not in actuation, and has lifting capability for samples over 300 grams. Additionally, the arm's DoFs has been reduced from five to three through the removal of a tilting wrist servo, which increases stress on the shoulder and elbow joints, and contributes to instability, as well as the elimination of a rotating base since the driving controls of the rover have been improved to include very fine turning.



The manner in which the robotic arm will deposit sample rocks for storage has been greatly simplified. The rock storage bin will lie on the top panel of the rover body, as an enclosure consisting of posts around which mesh walls are stretched to create a perimeter fence. Rather than have a rotating base turn the arm around for rock deposit, the elbow joint features a very strong servo motor capable of nearly 400 degrees of rotation, and can therefore rotate upward to deposit the rock directly behind it into the rock bin. This is a very favorable design decision, as a base introduces the possibility of complexity and instability in movement. This was found after extensive testing with a base we designed and built, as seen in the image.

The robotic arm is controlled by an Arduino mega using 3 logic pins and a ground. Each control pin is provided with a RLC circuit to damp the oscillations introduced due to interference from the induction motors. Externally geared servo motors helped in controlling the speed of movement thereby reducing vibrations in the robotic arm. These improvements helped us in making a very stable robotic arm, which is a crucial part of the sample acquisition system on the rover. The servos and the linear actuator are fed with appropriate currents at 6V to achieve the maximum torque that could be delivered by them.

Components of the Robotic Arm:

1. SPG5485A-45-360-degree rotation Servo
   Elbow Member Servo Motor
   Specifications:
   - Gear Ratio: 7:1
   - Total Rotation: 400 Degrees
   - Weight 8.45 Oz
   - Torque: 623 Oz-in
   - Speed: 60 degrees/1.19 Sec

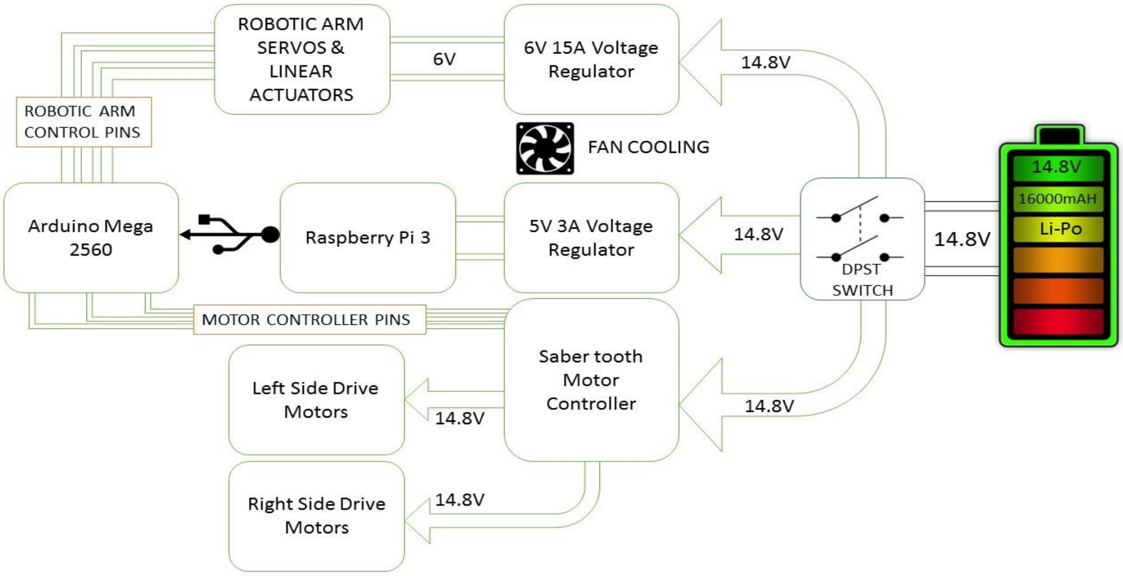
2. HS-5585MH Servo
   End-Effector (Gripper) Servo Motor
   Specifications:
   - Operating Voltage Range: 6.0-7.4 Volts
   - Operating Speed (6.0V): 0.17sec/60° at no load
   - Stall Torque (6.0V): 194 oz/in. (14 kg.cm)
   - Operating Angle: 45 Deg. one side pulse traveling 400usec
   - Direction: Clockwise/Pulse Traveling 1500 to 1900usec
   - Motor Type: Coreless
   - Bearing Type: Dual Ball Bearings
   - Gear Type: Metal Gears
   - Dimensions: 1.57” x 0.78” x 1.49” (39.8 x 19.8 x 37.8mm)
   - Weight: 2.10oz (60g)

3. Firgelli L-16 Linear Actuator
   Shoulder Member Actuator
   Specifications:
   - Max Speed (No Load): 8mm/s
   - Back Drive Force: 102N
   - Weight: 84g
   - Input Voltage: 0-15V
   - Stall Current: 250mA at 12V
   - Feedback Potentiometer: 16k ± 50%

2.2. Electrical System

2.2.1: Electrical System Overview

Through extensive testing, it was found that a single battery in each rover is more than sufficient for driving them for the duration of the competition, which has considerably reduced the weight of the system. Therefore, the driving wheel motors and the components of the robotic arm are powered by a high capacity (16000 mAH) 14.8V battery. The DC drive motors are connected to and controlled by a serial communication H-bridge in accordance with the logic signals coming from the mission control through the motherboard. Voltage regulators have been used to power components such as the robotic arm, the Raspberry Pi, and the Arduino. A brief visual description of the electrical system is shown in the figure at the right.



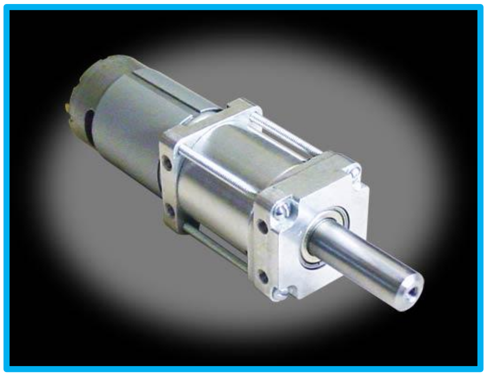
2.2.2: Drive Motors

As mentioned in the drive system section 2.1.1, each rover will have different drive motors. For the rock rover, having placed careful thought into the planetary rover's mass and approximate torque required for it to overcome various terrain impediments, the motors selected for rovers were AME 218-series 12V DC motors. Using hand calculations, a conservative torque necessary from the drive motors was found to be roughly 50 in-lbs. A specifications table for this motor is shown below.

Specification	Value
Nominal Voltage	12V DC
RPMs	116 RPM (no load)
Amps at No load	1.2 at 12V
Amps at Stall	21.3
Torque Nominal	98.235 in-lbs
Shaft	10mm dia x 22mm
Weight	2.55lbs

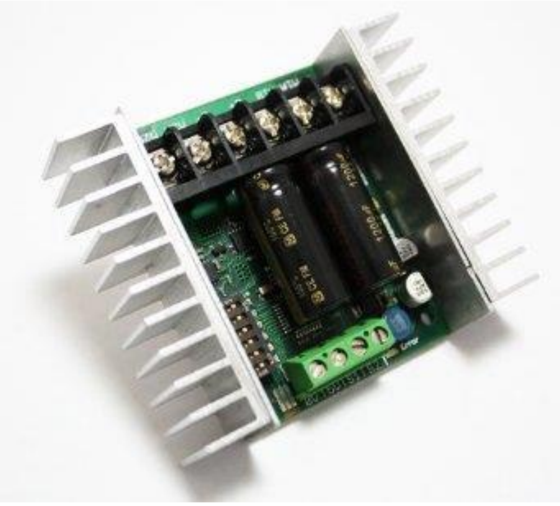
The sand rover will feature the same drive motors used in the previous competition, due to their proven strength and reliability. Comprised of a DuraTrax RS-550 motor and a BaneBots P60 104:1 gearbox, the 12V PDX104 DC motor is light, has very high torque, and consumes low current. A specification table is shown below for this motor.

Specification	Value
Nominal Voltage	12V DC
RPMs	240 RPM (no load)
Amps at No load	1.5 at 12V
Amps at Stall	148A
Torque Nominal	590 in-lbs
Shaft	0.5” shaft dia.
Weight	1.11 lbs



For both rovers, providing power to all four drive motors is accomplished with a Sabertooth motor controller. The controller chosen for each of the planetary rovers is a 25A dual-channel Motor Driver. It has a rated voltage and current of 3V-32V and 2x25A, respectively, which is more than capable of delivering power to the drive motors. These motor controllers are provided with PPM pulses from the Arduino motherboard for forward, backward, right, left operation along with speed control. These motor drivers can work with just two wires for controlling two channels, which will make the system less prone to failure. These motor drivers have a high peak current delivery, and safety cut-off features which protect the motherboard and other circuits from damage.

Sabertooth 2x25A Dual-Channel Motor Controller



Specifications:
- Output Current: 25A continuous
- Max Output Current: 50A peak per channel
- Input/Output Voltage:6-30V nominal

Drive Features:
- Synchronous regenerative drive
- Ultra-sonic switching frequency
- Thermal and overcurrent protection
- Lithium protection mode
- Input modes: Analog, R/C, simplified serial
- Size: 65 x 80 x 21 mm

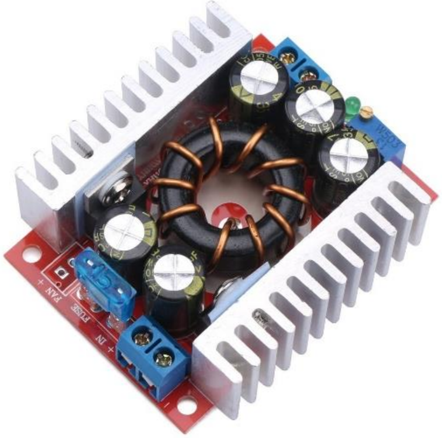
2.2.3: Power System

A 14.8 V 16000 mAh lithium-polymer battery has been used in combination with two voltage regulators to ensure proper operation of each electrical device. The DC motors are supplied with 14.8 V directly from the battery through the motor controller. A voltage regulator with an output of 6V and a current supply of up to 15A has been used to power the servos and linear actuator on the robotic arm. The voltage regulator is fitted with a heat sink and a cooling fan to lower its operating temperature whenever a high current is drawn from it. Another voltage regulator with an output of 5V and a current output of up to 3A has been used to power the electronic components such as Arduino and the Raspberry Pi. A common electrical switch for the entire system has been connected into the electrical system to turn the system on and turn off the power in case of any electrical failure. A 300W Turnigy Reaktor balance charger is used for charging at the highest safe amperage to allow the fastest charging time

Component	Current	Component	Current Consumption(mA)
Motors x 4	3000	Robotic Arm	2250
Raspberry Pi	2000	Camera Mast System	500
4G WiFi Hotspot	300		
TOTAL CURRRENT CONSUMPTION = 8050mA			

ONBOARD VOLTAGE REGULATORS

1. Buck Voltage Converter DC to DC Step-down 15A Volt Regulator



Specifications:

- Input voltage: 4-32V (36V Max)
- Output voltage: 1.2-32V (adjustable)
- Min voltage difference: 1V
- Output current: 0-15A (10A for long-term work)
- Input fuse: 15A
- Operating temperature: -40°c to +85°c
- Working frequency: 150KHz
- Conversion efficiency: up to 98%
- Module size: 60mm x 51mm x 22mm
- Installation: 4x 3mm screws

2. King Kong 5V, 3A Voltage Regulator

Features:

- Output Voltage: 5V
- Output Current: 3A
- Easy Installation
- Consistent Voltage Output

2.3. Communications System

2.3.1: Components

Earlier in the design phase, the team had been using the Radxa Rock as its main processor, however due to the recent release of the Raspberry 3, our team has switched. All the source code which the team used with Radxa Rock is compatible with raspberry pi 3. Though the Radxa rock and Raspberry Pi have similar specifications, the raspberry pi can process more data and has a better video processor and connectivity with other cameras available.

The components assembled were:

1. Raspberry Pi 3: This robust micro-computer will be used for audio-video transmission and control signals using socket communication.
2. Arduino Mega: Control driving motors, robotic arm motors, and other factors based on signal received.
3. Logitech c270: Cameras used to view the live video from the arena.

2.3.2: System Operation

Communication between the rover and mission control will be established through the use of a Verizon 4G-LTE WiFi hotspot on each rover. We have achieved the following functionalities which will be used during the competition:

1. Single server for all the rovers.

A single server system is made to control both the rovers. Each computer and each rover will act as a channel and will be connected to the server. This will provide intercommunication if there is any problem in any computer. The team can switch to another computer by connecting to the server.

2. Control signals transmission from mission control to the rover.

A control signal is the essential information for driving the rover. The team has enumerated all the tasks that are to be performed by the rover and assigned alphabetical messages for each task. A JSON file covers all the alphabets used and assigns tasks on a particular alphabet, and this alphabet value is transmitted via sockets. The Raspberry Pi 3 on the rover is the client for receiving the information from the sockets. The Raspberry Pi relays the received information to the Arduino via a UART connection.

3. Controlling various devices such as the robotic arm, drive motors and camera mast using the Arduino.

   After receiving a message, the Arduino processes the control command to the peripheral devices based on the information received. A control program in the Raspberry Pi is divided into four parts:

   - **Drive motor control**: Commands received with arrow keys are responsible for controlling the rover. Based on the command received the motors are turned on in forward or reverse and turned off in the break position respectively.

The driving control comes with 5 speed variability which will help the team to control the rover more accurately on different competition ground.

- **Robotic arm control**: Commands received from set {Q, W, E, A, S, D, Z, X, C} are responsible for the controlling of the robotic arm movements. Based on the input from the mission control, the robotic arm will move in the desired direction to set the servos on the robotic arm to the desired location. Using this method, we have successfully collected samples in our trial runs for the robotic arm system.
- **Camera mast system:** 3-D printed camera mast system actuated with a linear actuator. Similarly, commands received from numerical set {2,4,6,8} are responsible for the camera mast system. After receiving the command the camera mast will raise and pan and tilt will be engaged.
- **Camera Switch key:** There will be a toggle T key to switch from one camera view to another. This key will be monitored by the Raspberry Pi and it will change the pipeline parameters accordingly. This will help us to use one camera at a time, to reduce the data usage at one time.

4. Auto-restart mechanism

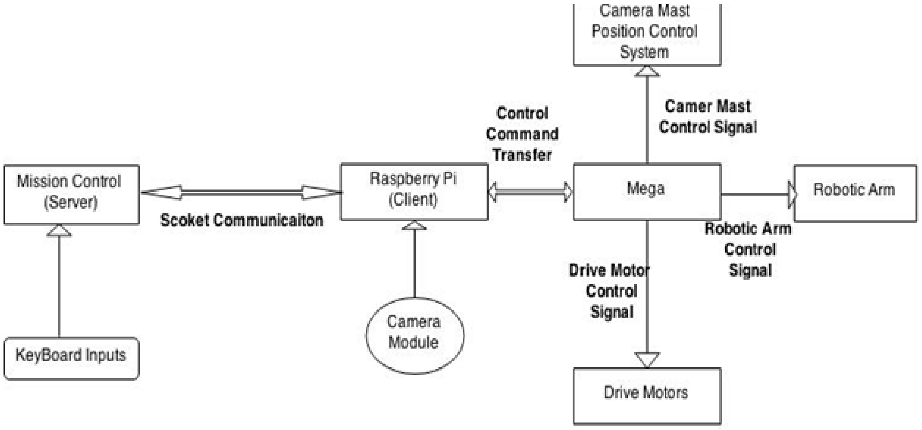
   If for some reason the communication between the server (remote computer) and client (rover) is lost, the Raspberry Pi on the client will attempt to reconnect for 30 seconds. If it does not receive any message from the server, the Raspberry Pi will restart itself to remove any issue internal issues. One the mission control, the remote computer will have constant information regarding connection status.

5. Failure check of any physical connection. For example: connection from Arduino Mega to Raspberry Pi.

   A team will see a message if there is any loose connection between the Raspberry Pi and Arduino or between the Raspberry Pi and hotspot. Having a physical check message notify mission control of any physical connection issues.
6. Receiving video feed from rover to the mission control. Switching cameras on single key press.

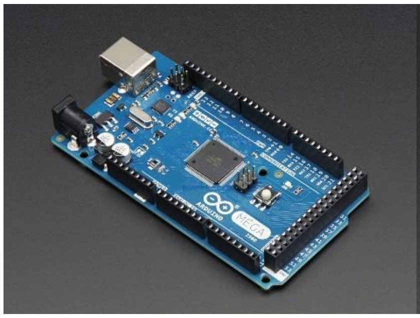
The team is using Gstreamer frameworks for streaming audio and video to the mission control with a maximum latency of 0.5 seconds, which we are attempting to further reduce. The team tested the camera stream both on TCP and UDP and found that UDP had minimum possible latency. The team then decided to use UDP protocol for real-time streaming of the video and audio.

The Logitech c270 uses H.264 video compression which provides high 720p resolution without consuming heavy data, which allows us to use 3 cameras onboard the rover. There will be a main drive camera in the front of the rover next to the robotic arm, a mast camera in the rear, and a camera in the gripper. To further reduce the amount of bandwidth consumed by the cameras, a separate key for switching cameras is assigned between the mast camera and the gripper camera, and the drive camera will have a permanent view. At the back end, the code was designed to switch the Gstreamer camera pipeline and get the live feed on a single frame. A communications system block diagram is shown below.



For controlling the rover driving motors, the robotic arm ,and the camera mast, we designed the code in C++ programming language. The socket communication code was scripted in Python programming language and some files for restarting the processor was written in shell scripting. All the codes are well implemented, and forced tested by physically disconnecting communication and reconnecting again.

Above figure shows the control and communication hardware setup for the rover. The Raspberry pi 3 has a three 720p resolution USB webcam connected to the USB hub.



The Raspberry Pi has an Arduino mega connected to it via UART. Arduino Mega receives the command signal through Raspberry Pi and based on the command received the Raspberry Pi controls the peripheral devices like main drive motors, robotic arm, etc.

3. Testing Strategy

Extensive system-by-system testing has been in effect since construction of the rovers had been taking place in early in February. The drive system, sample acquisition system, and communications system have been tested thoroughly, however it is very important to perform as much integrated systems testing as possible. The majority of our all-up systems testing is taking place in our Mars Environment which was built on campus during the previous competition. With an area of roughly 200 square feet, this area features flat dirt terrain very similar to the competition field, rocks of varying sizes to practice climbing obstacles, and loose-packed dirt in which to test navigability. For testing in looser sand and on steep inclines, multiple areas on the university campus are being utilized for testing such as hills and volleyball courts. Additionally, our first rover had been tested extensively through our many public-outreach events.

We anticipate that there are two key factors in conducting successful testing. The first is to perform extensive integrated systems testing, with both rovers navigating simultaneously to ensure no losses of communication or control. The second factor is to ensure that the drivers have had sufficient time operating the rover. Their level of comfort, fluidity, and contingency management is very important for a successful competition run.

4. Overall Strategy

The key factor in our overall strategy lies in the dual rover system. The ability to simultaneously collect rock samples on the competition field provides a large advantage to our rover system. Furthermore, each rover is tailored to one of two general environments. We have characterized the four competition terrains into two these two general environments, with the sand dunes and lunar crater being a sandy terrain, and the rock yard and Mars hill being a rocky terrain. In addition to improving navigation in their respective environments, this strategy will greatly increase the odds of our rovers receiving bonus points for collecting rock samples from all four terrains. In the case of the unplanned contingency activity, we feel that the rovers are on equal ground in the aspect of managing it wherever it may arise on the competition field, since their sample acquisition systems are identical. Further strategy involves having the rock rover depart before the sand rover. Although not significant over the timeframe of the competition run, the slower speed and farther distance of the rock yard drove our decision to have this departure order.

5. Mission Control Operation Plan

Our mission control plan stems from mistakes we had assessed from the previous competition. Upon consideration, it was found that interaction between the drivers is not necessary during the competition run given our sample acquisition strategy. Since each rover will journey through its respective terrain, it is in the best interest of our drivers to manage their competition run separately. Given how invested each driver will be in their current situation, we feel that there is no reason that another driver should influence any contingency management or strategic decisions for the other. Therefore, the drivers will be operating their vehicles in adjacent, separate rooms.

Additionally, as a part of the mission control team, we will have a third team member whose sole task is to facilitate the mission control communication system. We learned last year that having the drivers manage and monitor the communications system, as well as the live stream status and any other mission control center duties, diverted attention from their primary task of operating the rovers. This facilitating team member will also act as the liaison between the drivers in the case of a mulligan, which entails ensuring that the rovers pause and resume their competition run in synchronicity, per the competition requirements. The majority of the team members involved in the project over its course will also be present for moral support, and to represent our rover team.

6. Budget

Our project expenses are relatively straight forward, and arose from expenditures for parts of the mechanical, electrical, and communication systems, as well as for support equipment purchase, and student travel and rover system transportation. Fortunately, a portion of the cost has been reduced as a result of reuse from the previous rovers. Mainly, we have reused machined parts such as a differential arm, suspension bar, intricate differential pins, and the heavily machined wheels which are used on the sand rover. The net expenditures are shown in a cost breakdown below.

Mechanical Equipment	--	*$9500*
Electrical Equipment	--	*$2000*
Communications	--	*$1150*
Materials Transport	--	*$50*
Competition Costs		
Travel	--	*$1296*
Lodging	--	*$1273*
Registration	--	*$800*

Our overall CSULB rover project funding is a culmination of the generous stipend from NASA and the NIA, remaining previous-year funds from Chevron and AFRL, and a student travel and lodging grant from the Associated Students Inc. (ASI) organization in our university.. Below is a comprehensive funding breakdown.

NASA/NIA	--	*$10,000*
Chevron	--	*$2500*
AFRL	--	*$2500*
CSULB ASI	--	*$1537*
Total Funding		***$16,537***

There is a funding surplus of roughly $500, which is included intentionally in the case of contingencies, such as emergency materials.

7. Public/Stakeholder Engagement

This year, the CSULB rover team has made an enormous effort to engage as much as possible with students and the general public, and to promote positive publicity and education of our rover system and the exciting competition challenge. Below is a collection of the many outreach engagements our team has been involved in, as well as examples of the public interest our team has generated from the project.

Engineering Girls @ The Beach

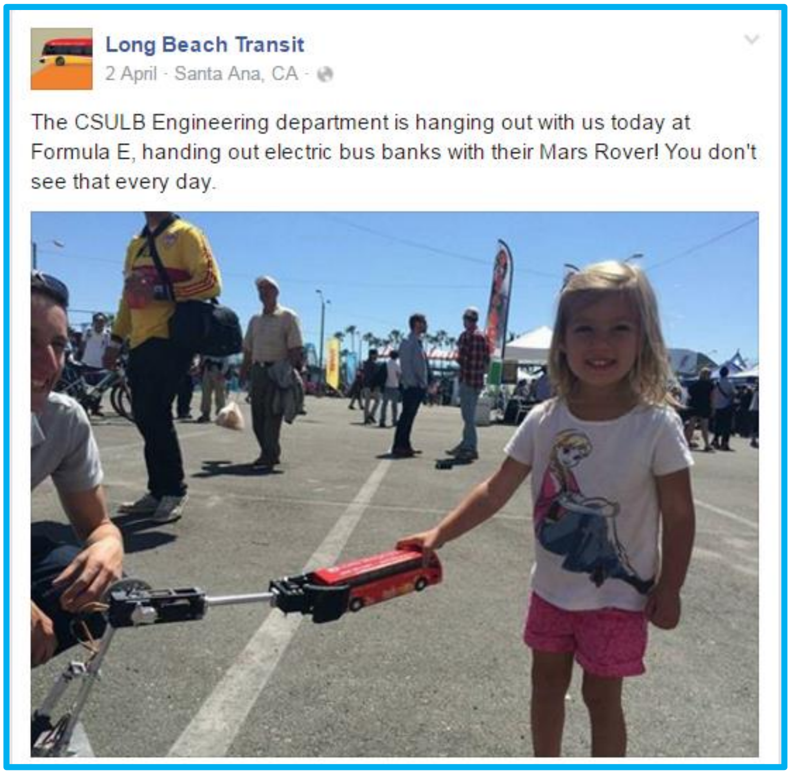
This event was aimed at generating interest in engineering among young female students through workshops in the engineering department. The girls learned about our rover system and how we prepared for the competition, as well as were given the opportunity to drive the rover in the hallway and outside in our Mars environment.

OCEC Awards Ceremony

For our efforts to further student innovation in technology and robotics, the Orange County Engineering Council (OCEC) presented our rover team with an award for an "Outstanding Student Project" at a gala event during engineering week at the end of February. This award was presented to the past and current rover team; the team leads from this year and two from previous year are pictured here. (From left: Homam Chamas, Kisalay Kumar, Jorge Vega, Javed Iqbal, Ganesh Kudlepannavar, Rahul Devikar)

Long Beach Formula-E

As an informal partnership with the Long Beach Transit office, we were given the opportunity to showcase our rover at the world’s largest formula race involving solely electric race cars. In addition to explaining our rover system and the competition to the huge number of spectators, we also drove the rover around our booth area and handed out promotional items. In addition to providing hours of enjoyment for the team members in attendance, this event provided useful metrics regarding the performance of the rover system with prolonged use in a hot environment.



Long Beach Transit
2 April · Santa Ana, CA ·

The CSULB Engineering department is hanging out with us today at Formula E, handing out electric bus banks with their Mars Rover! You don't see that every day.

Not pictured above, our team was involved in several more public outreach engagements. The annual S.T.E.A.M. carnival held by the Irvine Public Schools Foundation (IPSF), had over 3000 people in attendance with nearly 50 booths containing engaging interactive displays for children and adults alike to enjoy and learn about science, technology, arts, engineering, and mathematics. In our booth area, we were able to drive our rover around over small obstructions as well as move objects around with the robotic arm. This event provided us with a very extensive, continuous time over which the rover was being operated, nearly 3-4 hours.

Additionally, we have performed tours of our laboratory to over 150 prospective engineering students visiting the university. This gave us the opportunity to describe the nature of our rover system and the methods and strategies we had adopted for our competition preparation.

Finally, we have gained publicity through the media and journalism departments in our university. We have had a story written about our rover team competing for the second year, as well as had a journalism student make a video report on our project, which will be submitted to the 49er, our university newspaper.

8. References Cited

NIA, NASA. "Competition Rules and Regulations." Robo-Ops. NASA/NIA, n.d. Web. http://robo-ops.nianet.org/competition-basics/.