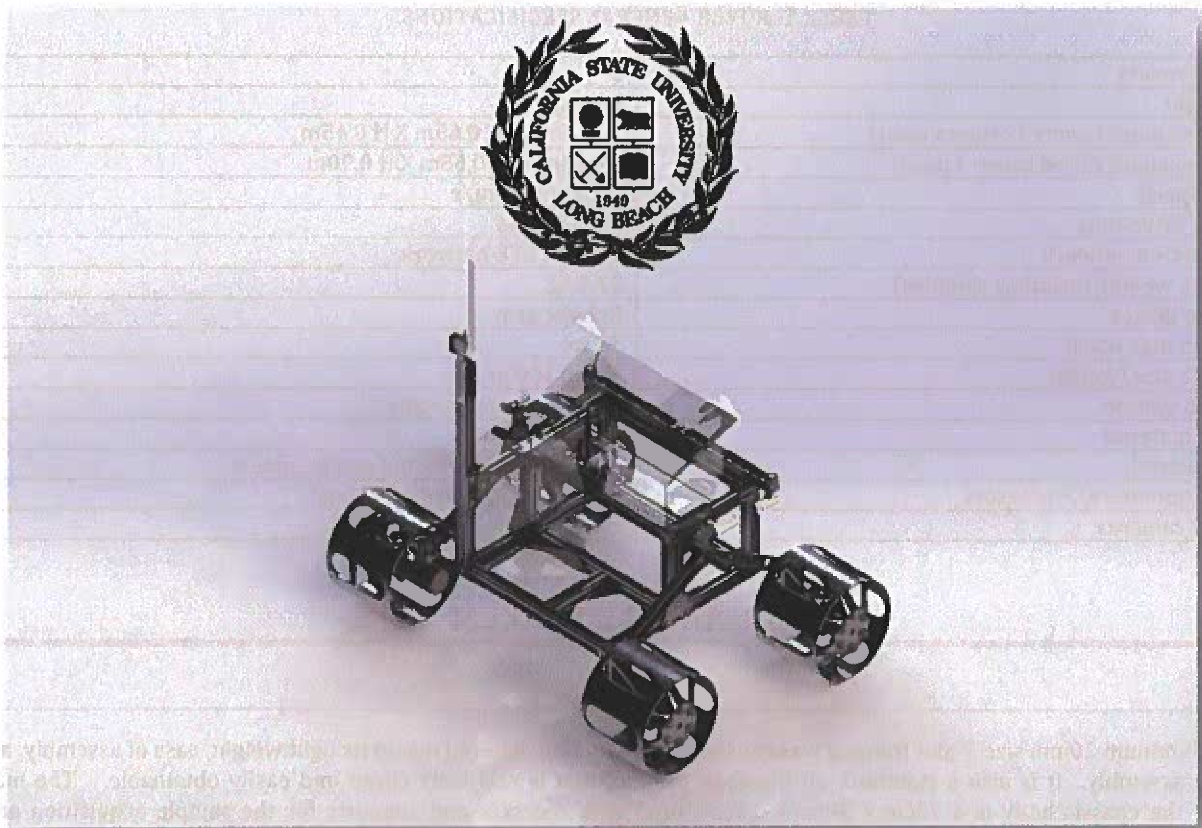
RASC-AL Robo-Ops 2015

CALIFORNIA STATE UNIVERSITY LONG BEACH



Team Leaders:
Andrew Blackney
Ganesh Kudleppanavar
Jorge Vega

Student Design and Implementation Team:
Roman Serna,Dominic Lai, Khanh Do, Brian Ngo, Jiaqi Ni, Kevin Anglim, Sinem Ergen, Brandon Ybarra, Orion Radtke, Aracely Torres, Josh Bail, Brian Zindric, Ryan Valdez, Julius Chua, Daniel Rodriguez, Enrique Manzo, Meghana Naik, Osiel Ramirez, Michael Parra, Tdanh Truc Le, Luis Moreno, Kent Hayes, George Alvarado, Javed Iqbal, Kisalay Kumar and Rahul Devikar.

Faculty Mentor: Dr. Praveen Shankar (Mechanical &Aerospace Engineering, CSULB)

INTRODUCTION

FOR THE PAST 6 MONTHS, THE CSULB TEAM HAS BEEN WORKING HARD TO GET THE GEMINI ROVERS COMPETITION READY. A PROTOTYPE ROVER WAS ASSEMBLED AND EXTENSIVE INTEGRATION AND TESTING OF THE ROVER SYSTEMS WAS COMPLETED TO DISCOVER WHAT AREAS OF THE DESIGN COULD BE IMPROVED. THE TOTAL WEIGHT OF THE PROTOTYPE ROVER WAS 18.5KG, WITH A SIZE OF .35M X .26M X .3M. THE TEAM TOOK THE LESSONS LEARNED FROM THE PROTOTYPE AND IMPROVED UPON THE DESIGN TO REDUCE WEIGHT AND INCREASE EFFICIENCY AND PERFORMANCE. ASSEMBLY OF THE TWO SISTER ROVERS IS NOW COMPLETE AND TESTING WILL CONTINUE TO TAKE PLACE IN THE WEEKS LEADING UP TO THE COMPETITION.

TABLE 1: ROVER GENERAL SPECIFICATIONS

Number of rovers	2
Rover weight	16.1 kg
Rover dimensions(lowered camera mast)	L 0.58m X W 0.65m X H 0.45m
Rover dimensions(raised camera mast)	L 0.54m X W 0.65m X H 0.90m
Max/Min Speed	.78 m/s - .6 m/s
Rover max drive time	1hr 15 mins
Communication network	Verizon LTE network
Max driving weight(including samples)	22.5 kg
Acquisition device	Robotic arm
robotic arm max reach	33 cm
Max sample size/weight	8 cm/150 grams
Suspension system	2 wheel rocker-boogie
Tire tread material	Polyurethane
Chassis material	Aluminum TSLOTS and acrylic sheets
Onboard Computers/Processors	Raspberry Pi 2, Arduino Mega
Number of cameras	2

MECHANICAL SYSTEM

CHASSIS

Aluminum 20mm size T-slot framing was chosen as the building material due to its light weight, ease of assembly, and adjustable assembly. It is also a standard, off-the-shelf product that is relatively cheap and easily obtainable. The main portion of the chassis body is a 30cm x 30cm x 15cm "box" with recesses and supports for the sample acquisition arm, collection box, batteries, and all the electronics. Additionally, there is a camera mast support beam that is 35cm tall where the camera mast assembly is attached and the camera and supporting Raspberry Pi will be located. The camera mast will be actuated by a camera mast servo that, once upright, will be locked in place with a locking mechanism and remain that way for the remainder of the competition.

FIGURE 1: ASSEMBLY OF T-SLOT FRAMING

DRIVE / STEERING SYSTEM

WHEELS

In order to provide movement for the rovers, four independent motors driving four wheels are used to provide differential speed steering, allowing each of the rover's wheels to be powered through different speeds and rotational direction. This method is beneficial because the design has built-in redundancy in the event of a motor failure, regardless of the user input or unexpected conditions. It is also more suitable for the rovers to have high maneuverability rather than high speed for the purpose of sample acquisition.

SUSPENSION SYSTEM

The suspension system utilizes a modified four-wheel Rocker-Bogie (Figure 2). This system is appealing since it is very simple and light weight, requiring only two rockers and a differential bar as opposed to using springs. By using this system, when the rovers encounter an obstacle up to 10 cm tall in its path, it will be able to overcome it by having one of the front wheels go over the object. This will cause the back wheel on the same side of the rover to push down on the ground, enabling the rover to maintain traction to the ground. This displacement of one side's rocker angle will travel through the differential bar, therefore causing the opposite motion to occur on the other rocker. Because of this translation, the wheels on the other side of the rover will also be able to remain on the ground. This type of system has been used on past NASA missions to Mars with success (institute, 2014).

When updating the design from the prototype stage to the final design stage, weight reduction features were added to areas that were deemed to be over-built. These areas include the rocker-bogie arm, the differential bar, the shaft, and the wheels. The shaft, being a solid steel bar in the prototype, was the heaviest single component in the rover. To reduce this weight by a large margin, a thin-walled steel tube, still capable of supporting the anticipated loads, was chosen to replace the bar. The wheels saw a reduction in material thickness from 3/16" to1/16", as well as larger cutouts. The rocker-bogie arms and the differential bar were made slightly smaller and circular cutouts were introduced to remove unnecessary material.

FIGURE 2: PARTIALLY ASSEMBLED PROTOTYPE (LEFT). ROCKER-BOGIE SYSTEM WITH DIFFERENTIAL BAR (RIGHT).

TREAD PATTERN

Traction will play a key role in the success or failure of our vehicles. Since the plan is to operate two separate rovers and optimize them for specific terrains, their tire treads have been designed to be optimized for the terrains. One rover will use a unique tire tread designed to navigate sand dunes and craters, while the other will use a different tire tread designed to navigate rock fields and hills. The process of custom making the tire treads required a two-part process: 1) making a mold of the tire treads, and 2) casting it. A flat mold was fabricated out of wood due to its ease of casting, its durability, its ability to be a mold for many different casting resins, as well as its ease of design and production via SolidWorks and CNC machining, respectively. Urethane rubber was chosen as the casting resin mainly for its high tear resistance property. It provides adequate traction for the rover, and yet, it is flexible enough to be wrapped around the wheel once taken from the mold.

In order to provide some measure of vibration damping, a two-layered tire tread is implemented using the tougher urethane rubber as the outer layer and a softer rubber sandwiched in between the outer layer and the wheel hub. The total wheel diameter was reduced in the final design in order to accommodate this new two-layer urethane rubber. In order to minimize the total weight of the tread, the size of the tread was reduced in width and the inner rubber layer (Figure 3.B) was designed differently to optimize damping and minimize weight.

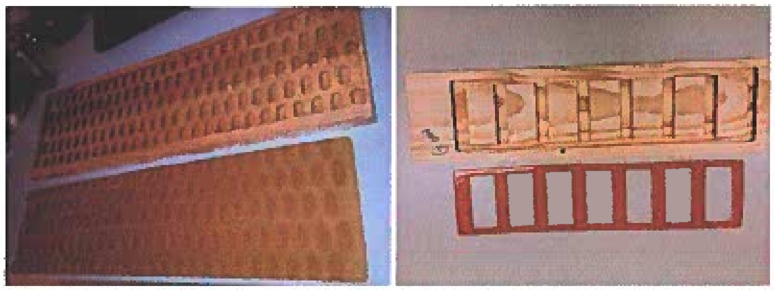


FIGURE 3 A) OUTER TREAD LAYER (LEFT) AND B) INNER TREAD LAYER (RIGHT)

MATERIALS

The wheels and rocker-bogie system's custom fabricated components are made out of machined 6061 aluminum. Aluminum was chosen due to its light weight. The wheels are attached to the chassis through the use of bearing sleeves and a stainless steel shaft. The tires were made of urethane rubber due to its high abrasive resistance properties as well as being flexible and elastic.

CAMERA

There will be two Raspberry Pi cameras mounted on each rover: one will be on the camera mast and the other will be mounted along the lowest degree of freedom on the robotic arm. These cameras will run at a 720p 60 fps video quality and are connected to the Raspberry Pi via ribbon cable. The Raspberry Pi camera is capable of automatic image control, including exposure control, white balance, band filter, 50/60 Hz luminance detection, black level calibration (mcmelectronics). The mast camera will be mounted at a two degree offset from the camera mount with two 180° servos giving the driver a full view if the area around the rover.

FIGURE 4 RASPBERRY PI CAMERA

The lower camera will be used to assist in the sample acquisition providing a second view of the sample and helping to build a 3D image of the robotic arm grabbing the sample.

MANIPULATOR SYSTEM

After careful consideration of the dimension of the rover's height and visibility, off-the-shelf five degrees-of-freedom Lynxmotion manipulator, model AL5D (Lynxmotion), was modified with longer tubing and different servos and gripper to meet desired attributes.

FIGURE 5: LYNXMOTION ROBOTIC ARM

The maximum reach of the arm is 12cm, thus it is capable of picking up objects up to 12 cm below the rover's platform. The robotic arm is an articulated five degree of freedom arm that is controlled using the Arduino. The program to control the robotic arm is written such that no inverse kinematics is used due to the computational power of the micro controller and instead trigonometric functions are utilized to control the arm. The tradeoff in using trigonometric functions is that the arm will be restrain to controlling it with two degree of freedoms but in exchange the code developed will be faster and will have one solution to its motion instead of the infinite many solutions possible if the problem was trying to be solved with five degree of freedoms at once with inverse kinematics. Even though the trigonometric functions can only solve a maximum of two degree of freedom problem the rest of the degree of problems can be solved independently or just controlled independently by a direct method through a user interface that gives the operator direct control over that specific degree of freedom. Also if the problem was attempted to be solved with five degree of freedoms at once with inverse kinematics there would be a need to make certain assumptions to restrain the arm to be able to solve the problem to a finite amount of solutions.

The robotic arm code also had to take into account that fact that there were mathematical and physical limitations that prevented the arm from moving in certain ways. The mathematical limitations included the fact that the code not to divide by zero so as to not get an error unexpectedly. Other limitations included physical limitations that needed to be programed into the code in order to not break the servos or anything in the rover that the operator of the arm could not see through the camera but that the arm may impact through its motion in the competition. The physical limitations was the one thing that was taken great care that the robotic arm obey since any deviation in this could cause damage to the servos or any of the systems in the robotic arm.

BATTERY SPECIFICATIONS

After conducting substantial research on various batteries, two Tattu 16000mAh 4S1P LiPo batteries were chosen as the power supply for the planetary rover's motors. Additionally, an 8000 mAh 2s1p Venom battery for the robotic arm (8.4V max) was utilized (atomikrc). For the microprocessors and controllers, a separate Anker 16000mAh 59.2 Wh phone charging battery bank was utilized. This battery bank has a max discharge of 3A which is above the 2A required to ensure that none of the components would "brown out" or not receive sufficient power. The servos controlling the robotic arm require a voltage range from 6V-7.4V and as much as 5A when lifting a maximum load. Originally, the team had planned to use the single Venom battery for all low-voltage components, but the demand from the robotic arm caused the voltage regulator in the Electronic Speed Controller (ESC) to provide an unsteady power supply to the microcontrollers and the microprocessors. In total, these batteries will be capable of running all components for approximately 1hour and 15 minutes.

The Thunderstorm balance charger is used for charging at the highest safe amperage to allow for the fastest charging time. This allowed the team more time for testing instead of waiting for batteries to charge. Unfortunately, this charger suffered a manufacturer defect and forced the team to purchase the first available charger as a substitute. The Skycharger 300W battery charger is used instead, although it significantly increased charge times.

FIGURE 6: THUNDERSTORM 10S. 1000W BATTERY CHARGER AND SPECIFICATIONS

FIGURE 7: 16000MAH BATTERY

TABLE 2: LIPO VOLTAGE TABLE

LiPo Cell Count	Voltage Range
2 Cell	8.4V - 7.4V
3 Cell	11.1V - 12.6V
4 Cell	16.8V - 14.8V
5 Cell	21.0V –18.5V
6 Cell	25.2V – 22.2V

FIGURE 8: 300W SKYCHARGER

FIGURE 9: 7.4V 8000MAH VENOM CHARGER

FIGURE 10: ANKER 16000MAH BATTERY

DRIVE POWER SPECIFICATIONS

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 the BaneBots RS555 Motor accompanied with the BaneBots P60 104:1 Gearboxes

FIGURE 11: BANEBOTS RS 555 MOTOR

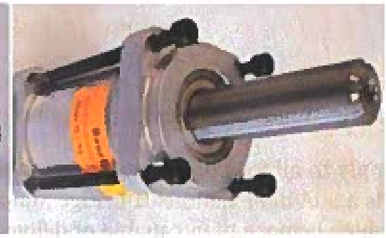


FIGURE 12: BANEBOTS P60 GEARBOX

TABLE 3: MOTOR SPECS

RS 55 Motor		P60 Gearbox	
Rated Voltage Range	5V-15V	Gear ratio	104:1
Kv rating	646 rpm/V	Stages	5:1,5:1,4:1
kT rating	1.95 oz-in/A	Gear Material	Steal
Total Motor			
Motor Max Torque		201.75 lb-in	
Max required Torque		52.6 lb-in	
Motor max rpm		99.4 rpm	
Motor Max Current Draw		10A	

As Table 3 displays, these motors, when used in conjunction with the gearboxes, are able to deliver enough torque to push the rover over steep inclines, and perform at a high enough RPM to accomplish the mission in the time limit. Additionally, the flat surface linear speed for the rover is .6 m/s.

Once the motors and gearboxes were received, an intensive process of inspection and assembly was required. Initially, the gearboxes were taken apart and each gear was inspected for irregularities or deformities and the drum was cleared of any debris.

FIGURE 13: CLEANED/INSPECTED GEARBOX

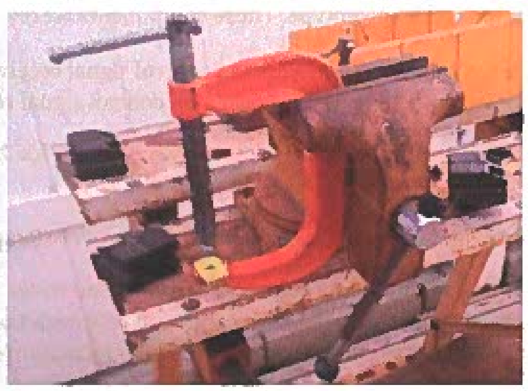


FIGURE 14: MOTOR ATTACHMENT RIG

After all the gears were found to be satisfactory, the gears were installed one level at a time, lubricated using lithium lubricant, and the gears were hand spun to assure full application of the lubricant. Next, the motor shaft and the drive gear were lubricated using white lithium grease and assembled together through the gentle use of a mallet. Once the drive gear was aligned with the motor shaft, a clamp slowly applied pressure to fit the gear onto the shaft.

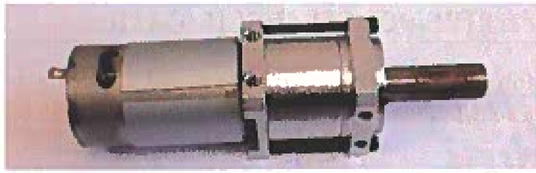


FIGURE 15: FINISHED MOTOR

The motor shaft with installed gear was then placed into the gearbox and the end cap was tightened on. Finally an electric current was applied to the motor and the entire assembly was tested.

Providing power supply to all four motors was accomplished with the help of an H-bridge. The H-bridge chosen for each of the planetary rovers is a 50A dual-channel H-bridge Motor Driver (Figure 16). It has a rated voltage and current of 3V-15V and 50A, respectively, which is more than capable of delivering power to the Banebots RS555 motors. Furthermore, the H-bridge complies with the inputs of a high value-on and a low value-off as specified by the firmware on the Arduino. The electrical component is composed of a full-bridge driver chip and MOSFET capable of enduring high current impulse. Since the 50A dual-channel H-bridge is limited to powering two motors based off a high and low input signal from the Arduino microcontroller, two 50A dual-channel H-bridges were used for each rover.

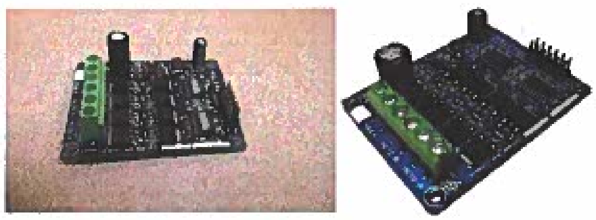


FIGURE 16: 50A DUAL-CHANNEL H-BRIDGE MOTOR DRIVER

ELECTRICAL/COMMUNICATION/CONTROL SYSTEM SPECIFICATIONS

The team had been using the raspberry pi B+ as its main processor, but due to the new release of Raspberry 2 the team has switched to using this. All the source code which the team used with Raspberry pi B+ is compatible with raspberry pi 2. The team used Raspberry Pi 2 since it has more processing capability and can process more data as compared to B+.

Implementation of the communication and control requirements for the rover was completed and the components were assembled and tested on the prototype. These components were:

1. Raspberry pi 2: for video transmission and control signal receiving using sockets.
2. Arduino Mega: for controlling devices based on control signal received.

Also tested on the prototype, the initial software design for both Raspberry Pi and Arduino includes the following functionalities:

1. Receiving control signal from mission control to the rover (Raspberry Pi).

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 a numerical value for each task. This numerical value is transmitted via sockets. The raspberry pi on the rover is the client for receiving the information from the sockets.

Once Raspberry pi receives information via sockets it then transmits the received information from socket to the Arduino via UART communication.

2. Controlling various devices, such as the Robotic Arm, Drive Motors, and Camera Mast System (Arduino Mega).

After receiving control commands from the raspberry pi Arduino processes the control command to the peripheral devices based on the information received. The program on raspberry pi is divided in three parts

- Main drive motor driving: commands received from numerical value 1to 10 are responsible for driving of the rover. Based on the command received the motors are turned on in forward or reverse and turned off in the break position respectively.
- Robotic arm controlling: commands received from 20 to 40 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 using trigonometric functions 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: Similarly commands received from 40 to 50 are responsible for the Camera mast system. After receiving the command the camera mast will raise and pan and tilt will be engaged

3. Video Streaming system:

The team has used gstreamer open source framework for transmitting the video. In initial design of the streaming of the video the team had used TCP protocol for the transmitting of the video. The trials of the TCP video transmission showed that the latency was high while using it. The team then decided to use UDP protocol for real-time streaming of the video and audio. The video is compressed using h264 format. This has resulted in significant improvement in latency and the quality of the video was not reduced so much. Video quality the is 720p using 20 frames per second. The camera and the raspberry pi are shown in Figure 178 below.

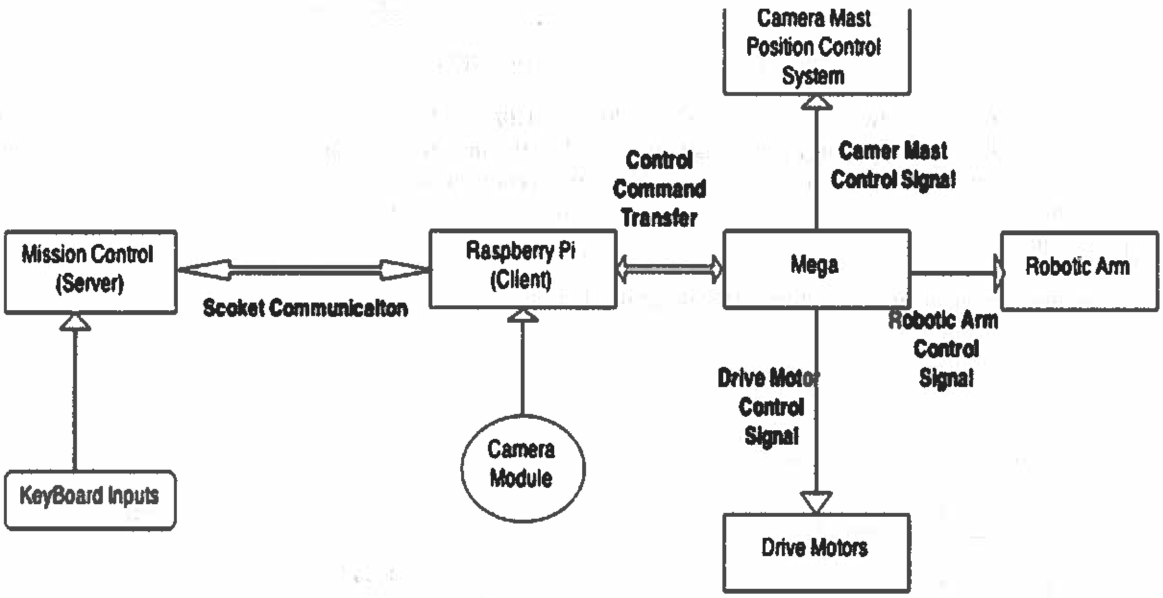


FIGURE 17: BLOCK DIAGRAM OF COMMAND AND CONTROL

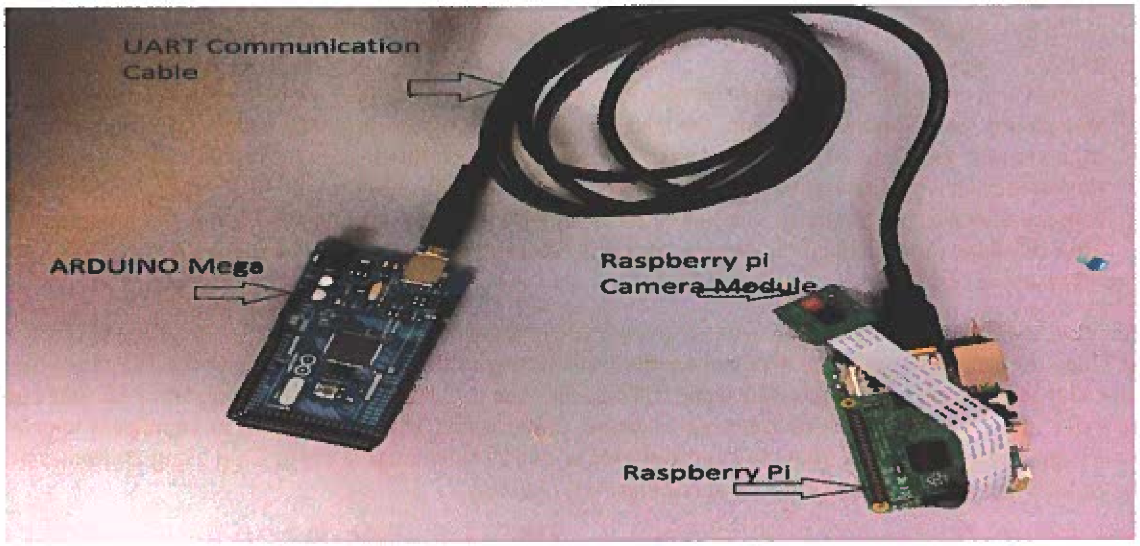
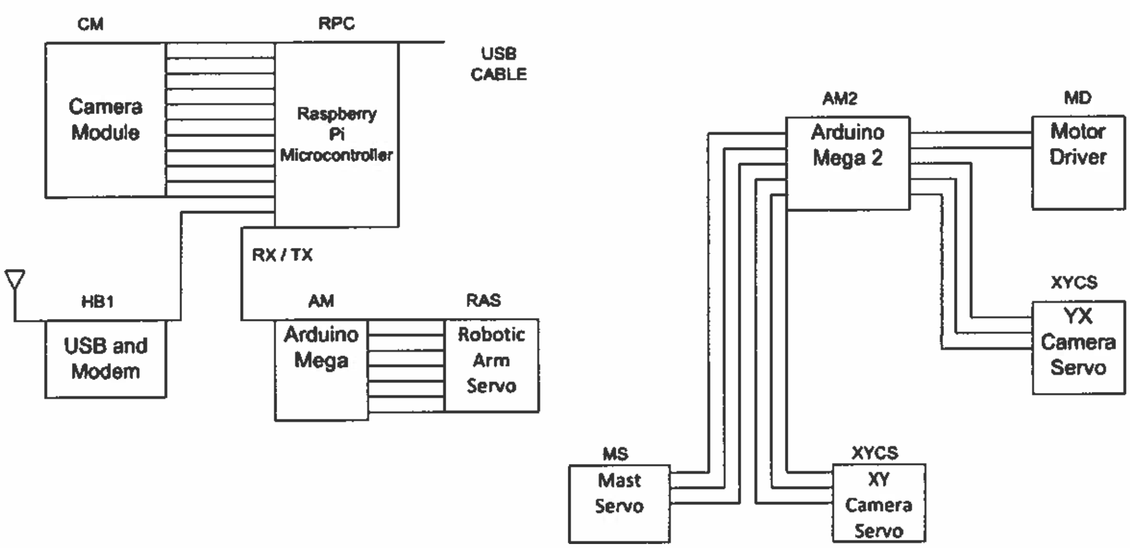


FIGURE 18: ELECTRONICS SETUP

The rover's electronic hardware set up is shown in Figure 189. The Raspberry Pi has a 5 Megapixel camera attached to it with a 15 pin CSI cable. The Raspberry Pi is also connected to the internet through wi-fi and transmits the video to the mission control. Additionally, the Raspberry Pi has an Arduino Mega connected to it via UART. The Arduino Mega receives the command signal through Raspberry Pi, and depending on the command received, the Raspberry Pi controls the peripheral devices such as the main drive motors, robotic arm, etc.

The entire electrical system can be seen in the wiring diagrams below:



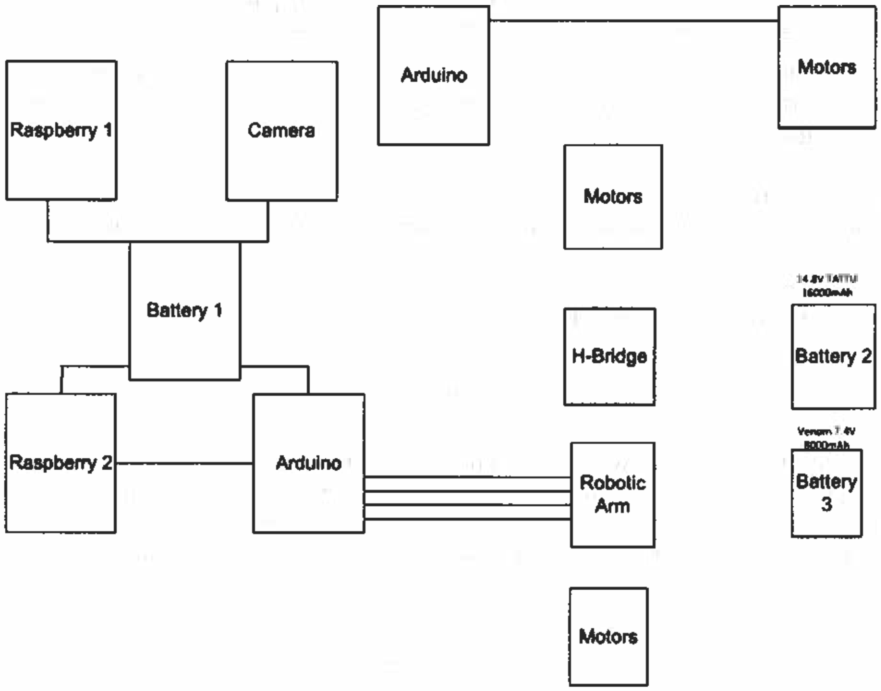


FIGURE 19: ROVER WIRING DIAGRAMS

For all batteries, an easy on/off switch was added into the loop. A single switch was made for both motor batteries and another switch for the robotic arm battery. To protect the switches from accidentally getting switched off during the competition, they were placed behind the robotic arm. This placement allowed for the easiest access while still providing the most possible protection from an accidental turn off.

TESTING STRATEGY

During the 2 weeks prior to the competition, the rover will be tested at the university's mars rover environment and around different areas of the school. These areas will include hills, sandpits, and flat terrain. On these terrains the team will place green, blue, orange, and red colored rocks for easy and difficult detection. This will give the drivers experience and practice in driving on the different environments they will experience during the competition. The spotters will also gain experience in looking for and locating rocks of different shapes, sizes, and colors for the competition. Additionally, the different terrains will give our drivers a breadth of knowledge on how to drive the rover in different terrains and the optimal distance for the robotic arm for proper operation. The team has also test failure scenarios such as a loose set screw, electrical component failure, or broken acrylic. This gives the specialist experience is the worst case scenarios situations.

OVERALL STRATEGY

During the competition we have two rovers, since there are two rovers and the arena has four parts, we are allocating one rovers for two arenas. At the start of competition the first rover would be placed ahead of the second rover. The first rover will start driving first and go to its specified arenas which it is responsible for. After the first rover is safely out of the initial area the second rover will drive off and go to is specific areas. The rovers would be directed by mission control to the areas by their mission control teams. Similarly the second rover would be driven by the mission control team to the area which the treads are designed for. After scanning for the whole arena the rovers would be driven to the initial location by the mission control team.

MISSION CONTROL CENTER

Since the team has two rovers they will have two teams at the mission control. Each team has three operators, these operators would be students who are part of team. These three operators are responsible for the overall safety and control of the rover. The three operators' responsibilities are

1. Operator 1: Driving the rover.
2. Operator 2: Spotting the rocks.
3. Operator 3: Initializing the mission control system. Looking for data from the rover and assisting Operator1 & 2 in overall operation.

The operators would be trained for specific arena and for specific rovers, so that they will get accompanied all the knowledge of the control of the rover for the competition.

STAFFING

For the mission control station there will be a group of three students for each rover, one working as the driver and the other two acting as spotters for the driver looking for rock specimens to pick up. At the competition the team will be bringing a specialist in the electrical system, mechanical system, and embedded coding to fix any problems that may arise during the competition. All other team members will be rooting on the team from a room adjoining the mission control to provide support while not crowding the driving team.

PRACTICING

For practicing before the competition, the team will be utilizing a "mars environment" developed during the past semester. Here we can mimic the environments we will experience during the competition. The team also has used other parts of the school, such as a large, steeply inclined hill, volleyball courts with very loosely packed sand, and the soccer fields. For testing of the robotic arm and camera, different colored glass rocks will be used as test objects. These rocks will range in colors from an easy to locate blue rock to much more difficult red rocks.

DECISION MAKING STRATEGY

During the competition, all decision making will be done by the individual drivers of the two rovers. They will be in charge of driving the rover in search of the samples and listening to their spotters on where rocks are located. If the rover needs to be repaired or fixed, the specialist will take the appropriate action to fix the rover. While fixing the rover the specialist will be in command of the rover. Once the problem is resolved, then the driver will be again in charge of driving the rover and making decisions.

CONTIGENCY PLAN(S) / REDUNDANCIES

In the event of a communication error between the rover and mission control, data transfer will continue through the other rover. If a mechanical failure of an external component such as acrylic, wheel, or motor occurs, replacement parts will be available and installed in the most efficient manner by the specialist. The rover has been designed with modular components, making replacement of components simple and fast.

BUDGET

TABLE 4: BUDGET FOR MARS ROVER

Items	Price
Mars Environment	$5500.00
Rover Parts	$12700.00
Rover Construction	$7225.00
Travel	$7200.00
TOTAL	$32625.00

The rover team has made plans to work with many of the existing groups and club on the university campus. Due to the heavy amount of paperwork required to take a machine such as the rover to a public high school, the idea to allow schools to remotely operate the rover was put forward and is being researched. CSULB has graciously allowed the team to develop a small test site on campus that can also be used for remote operation by local schools. In conjunction with students from the interior design department, the test site is being developed. Using material analogous with the competition sites the test site is being staged to have a Mars environment feel and to attract student's attention as they walked by. The site uses both large and small lava rocks and sand.

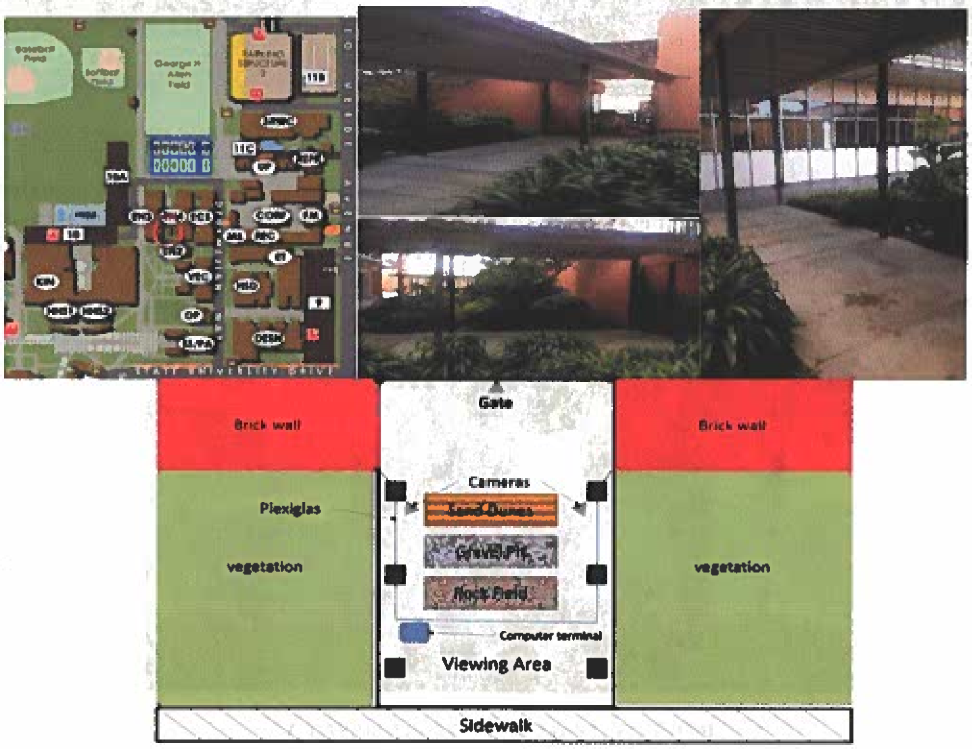


FIGURE 20: MARS ENVIORMENT

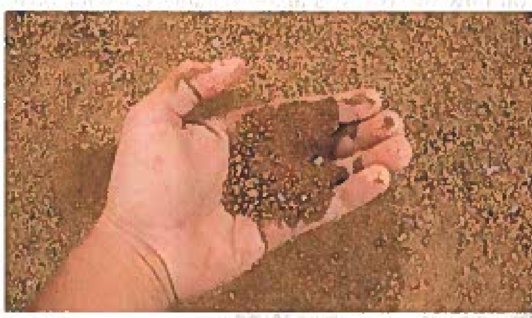


FIGURE 21: SAND IN THE MARS ENVIORMENT

FIGURE 22: LOOSE PACK SAND IN MARS ENVIORMENT

FIGURE 23:OBSTILE ROCKS IN MARS ENVIORMENT

FIGURE 24: SMALL ROCKS IN MARS ENVIORMENT

The team members were also involved in the March MESA days on campus. Middle school students competed in a variety of competitions, including robotics competitions. In their free time between competitions they were able to come and the rover and learn about the multitude of components and how they came together to make one working rover.

FIGURE 25: TEAM MEMBERS AT MESA DAY

Additionally, the team presented to Engineering Girls @ Beach on March 20th (http://www.csulbswe.org/outreach). At this event the students hosted a work show were they showed off how the rover is able to maneuver over obstacles and how it was controlled over the internet. The girls were also able to learn about how poly urethane is made and what the plastic treads increase traction for the rover giving better control.

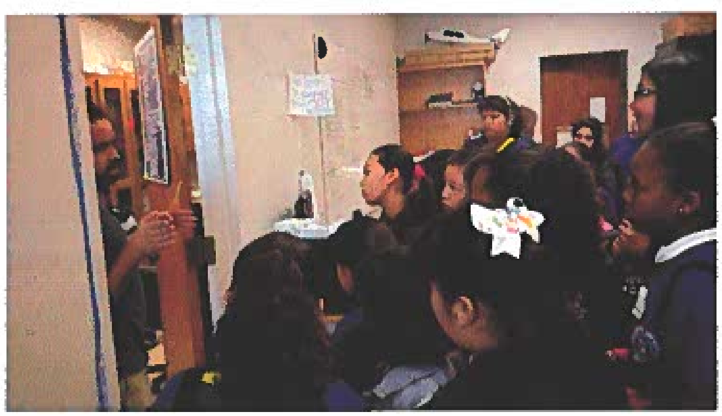


FIGURE 26: EXPLAINING DRIVE SYSTEM AT GIRLS @ THE BEACH DAY

There will be a visit to Minnie Gant Elementary School in Long Beach on May 20th where the children will be given the chance to drive the rover from the internet via a website developed for over the internet control of the rover (http://web.csulb.edu/projects/marsrover/index.htm). The primary objective of the rover website is for the Outreach program, which will enable the user to control and experience the Mars Rover. User can simply login and control the Mars Rover. Apart from the control, user can get all the information about the CASL lab and the activities done at CASL lab like MESA Day, Society for women engineers, the Minnie Gant Elementary School outreach etc. User can check the images and videos from the activities. We have also listed out our project sponsors, faculty mentor, team leaders, and team members. The front end of the website is created in HTML, JavaScript, and CSS. The backend is created in ASP.Net with C# language. Database is used to record the user registrations and to authenticate users. User must be registered to access the rover control page. Authorized users can control the rover using Keyboard and Buttons provided on the webpage. After successful login, user will be connected to the server. Every user has four controls. He or she can move the rover front, back, left, and right. Session is maintained to avoid the multiple instances of the same user.

The university and local community provided the team with a great deal of support, even getting a tweet from the CSULB University President, Dr. Jane Conoley, and article in the university news site, Inside CSULB and an article in the local Long Beach Gazette and Inside CSULB .

FIGURE 27: CSULB PRESIDENT TWITTER FEED

FIGURE 28: LONG BEACH GAZZETTE ARTICLE

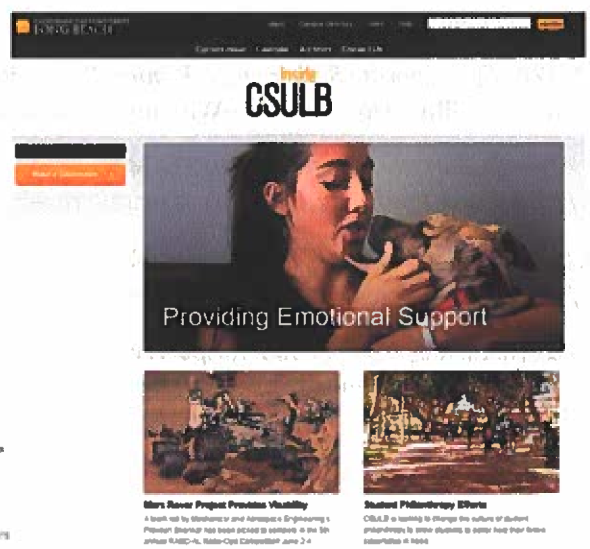


FIGURE 29: INSIDE CSULB ARCITLE

ACKNOWLEDGEMENTS

The CSULB ROBO-OPS team and faculty advisor would like to thank the following sponsors for their generous financial contributions

College of Engineering, California State University Long Beach - $10,000

Chevron - $ 5000

Air Force Research Labs Educational Outreach (Edwards Air Force Base) - $ 20,000

The team would also like to thank Mr. Kaustubh Gharpure and Mr. Saurav Chowdhary for their assistance in developing the command and control software.

REFERENCES

atomikrc. (n.d.). *Venom 20C 2S 8000mAh 7.4 Hard Case LiPO Battery with Universal Plug*. Retrieved May 2015, from atomikrc.com: http://www.atomikrc.com/products/venom-20c-2s-8000mah-7-4-hardcase-lipo-battery-with-universal-plug

BaneBots. (n.d.). *BaneBots Robot Parts: P60 Gearbox: Stock, Standard Shaft, RS-540/550 Mount, 104:1*. Retrieved 2015, from BaneBots.com: http://banebots.com/pc/P60K-S5/P60K-554-0004

Banebots. (n.d.). *Banebots RS555 Motor*. Retrieved 2015, from Banebots.com: http://banebots.com/pc/MOTOR-BRUSH/M5-RS555-12

Bourke, G. (n.d.). *2 DOF Articulated Pen Plotter*. Retrieved 2015, from Blogspot.com: http://2dofpenplotter.blogspot.com/2014/02/2-dof-articulated-pen-plotter-beng.html

company, S. B. (2015, April). Interior Design Material Company. (A. Blackney, Interviewer)

Conoley, J. (2015, Febuary). *PresConoley*. Retrieved May 2015, from Twitter: https://twitter.com/presconoley

institute, N. A. (2014). *Corporate Site Previous Wining Teams*. Retrieved 2015, from http://nia-cms.nianet.org/RoboOps/Previous-Winning-Teams.aspx

JPL, N. (n.d.). *Mars Exploration Rover Mission: The Mission*. Retrieved January 4, 2015, from nasa.gov: http://mars.nasa.gov/mer/mission/spacecraft_rover_wheels.html

Lynxmotion. (n.d.). *Lynxmotion - AL5D*. Retrieved May 2015, from Lynxmotion.com: http://www.lynxmotion.com/c-130-al5d.aspx

mcmelectronics. (n.d.). *Raspberry Pi 5MP Raspberry Pi Camera Board | 2302279 | Raspberry Pi*. Retrieved May 2015, from mcmelectronics.com: http://www.mcmelectronics.com/product/RASPBERRY-PI-2302279-/28-17733

Supply, S. C. (2015, April). Materials Company. (Andrew, Interviewer)