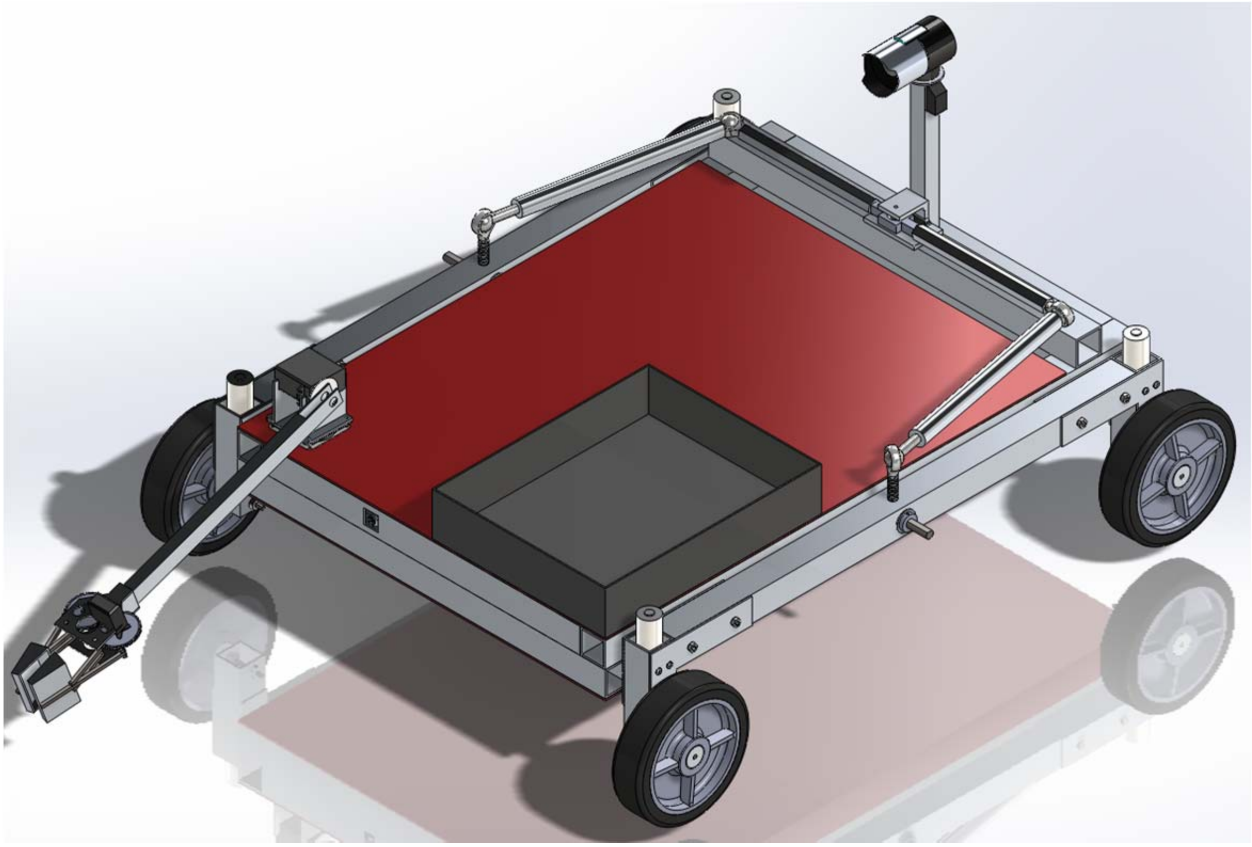
CAL-ROVER Robo-Ops 2013
Competition Proposal



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I. Introduction and Overview

CAL-Rover is the University of California-Berkeley's entry into NASA's 2013 RASC-AL Robo-Ops competition. Upon completion, its instrument suite will feature two cameras (one of which will have pan capability) and a manipulator arm with pitch and yaw control. In its stowed configuration, the rover fits within a 0.9m × 0.88m × 0.48m envelope, which is within the maximum envelope of 1m × 1m × 0.5m. Unloaded, it is estimated that it will weigh approximately 34 kg, which is well below the 45kg mass budget allotted for the rover.

The mission goal for CAL-Rover is to traverse the Johnson Space Center (JSC) Rock Yard and acquire as many colored rock samples as possible within a one-hour time frame. This document will explain the systems implemented on CAL-Rover that will help it accomplish this task and why it should be considered for the 2013 competition season.

In this report, all physical dimensions are given in MKS units, but since most part and material suppliers in the United States list their products in IPS units, these dimensions will be displayed in parenthesis where appropriate.

II. Systems

The general design philosophy for CAL-Rover is to design something that is both robust and easy to assemble. Therefore, many of the systems that will be described are made of easy-to-obtain material fastened together with bolts and nuts. The required machining is limited to just cutting lengths of metal and plastic stock and drilling in bolt holes, and welding will not be required.

(a) Chassis/Enclosure

Structurally, the design aims to be as simple and robust as possible. The chassis will be a rectangular frame of 4.445cm (1.75") square aluminum tubing bolted together in the configuration shown to the right. Because of the way the aluminum frame is assembled, this creates an internal cavity that will be used as the electronics enclosure. To ensure the enclosure is secure from dust, moisture and external electromagnetic fields, the top, bottom and sides of the chassis/enclosure frame will be covered with sheets of GPO-3 plastic that will be fastened on and ABF-300 ESD control film. This will prevent dust and moisture from affecting the electronics, while the ESD control film shields crucial circuitry from external electromagnetic fields and static charge buildup.

Fig 1: *the chassis without the plastic enclosure coverings. Dimensions are in centimeters*

(b) Suspension

To aid navigation and stabilization, the rover employs a two-rocker suspension system, where two rocking arms are connected by a central differencing arm (highlighted in blue in figure 2-a). The differencing arm is the component that ensures the rover chassis does not swing independently from the rocker arms like a seesaw. It also links the motion of each rocker to the other so that any angular displacement of one rocker arm results in an equal but opposite angular displacement in the other rocker (see figure 2-b). Thus, if the rover drives over an obstacle, it ensures that the chassis remains parallel to the ground rather than wobbling with the terrain. This improvement in stability is anticipated to make teleoperation much easier in the rough terrain expected at the JSC Rock Yard.

The materials chosen for the suspension are largely similar to the ones chosen for the chassis: overall, the structure is mostly composed of 6061-T6 aluminum. The side-mounted rockers are attached to the chassis via 1.270 cm (0.5”) diameter shafts made of 4043 steel rod.

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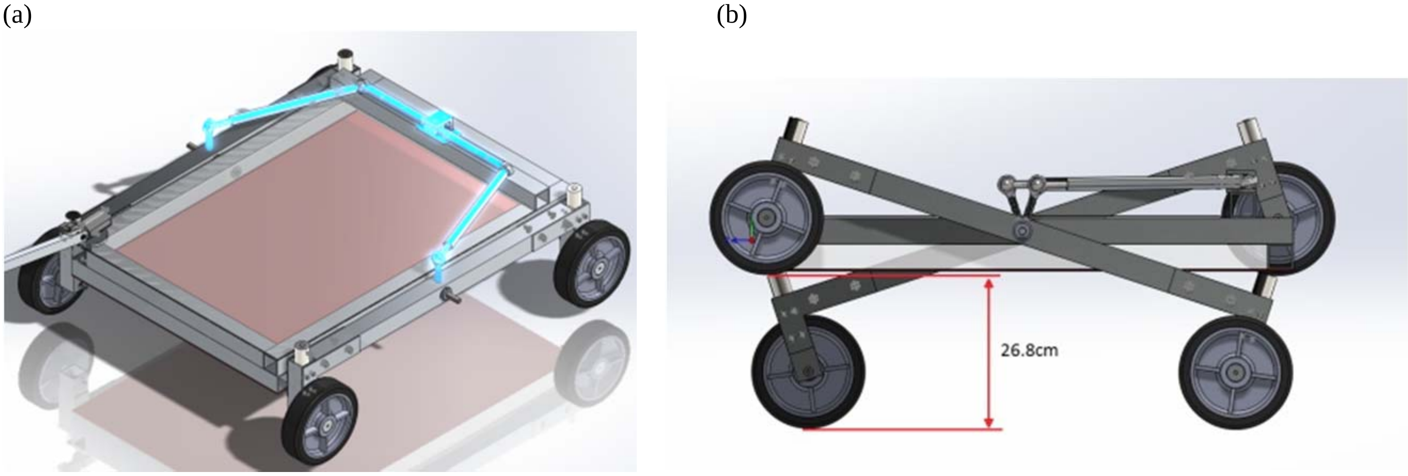

Fig 2: *Two views showing (a) an isolated view of the mobility system assembly and (b) the maximum clearance afforded by the rocker-arm suspension system*

The differencing arm will be made of cut lengths of hexagonal aluminum rod. The ends will be tapped and mounted by large-angle ball swivels that allow up to 50° of motion each. The hexagonal shape was chosen because it is easier to mount the ball swivels on, as the hexagonal cross-section gives a good gripping surface for a wrench to clamp on to while the thread is being tightened.

(c) Drive System

For propulsion, CAL-Rover will be driven by four BaneBots PDX132 gearmotors housed inside the rocker arms. These motors come with gearboxes that have a 132:1 reduction ratio, allowing for high torque in a relatively small package. While this prevents the wheels from being mounted directly to the output shafts, the protection afforded the motors by being housed inside the structure rather than being exposed to low-lying obstacles makes up for this added degree of complexity. Additionally, the internal space of the rocker arms is a 3.81cm (1.5”) square space, which is exactly the size of the gearbox on the motor. Bevel gears will interface the wheel shaft with the motor output shaft at a 1:1.3 ratio. Thus, in total, the gear reduction from the motor to the wheel is 102:1, and so the maximum torque that can be applied by the wheels to the ground is 664.2 kg·cm, which is definitely sufficient to overcome the 135 N force required to push the rover up a 33% grade.

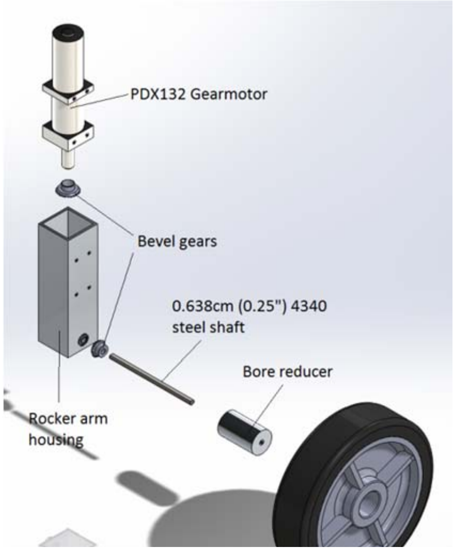

Fig. 3: *Exploded view of the drive system to illustrate placement of motor inside the rocker arm*

The wheels will be 20.32cm (8”) diameter Colson wheels. The tires for these wheels are solid rubber, and so do not require any inflation. Since the inner bore diameter of the wheel is much larger than the 0.638cm (0.25”) shaft it will be mounted to, a bore reducer made out of round aluminum stock will be press-fit into the wheel bore and fastened to the wheel shaft with a set screw.

(d) Manipulator

The manipulation subsystem of CAL-Rover employs a simple, yet agile arm and end effector to retrieve rock samples and place them inside the rover. While this minimizes the manipulator to only two degrees of freedom, it also allows for much easier control of the end effector, as there are less factors to consider when considering the end-effector position.

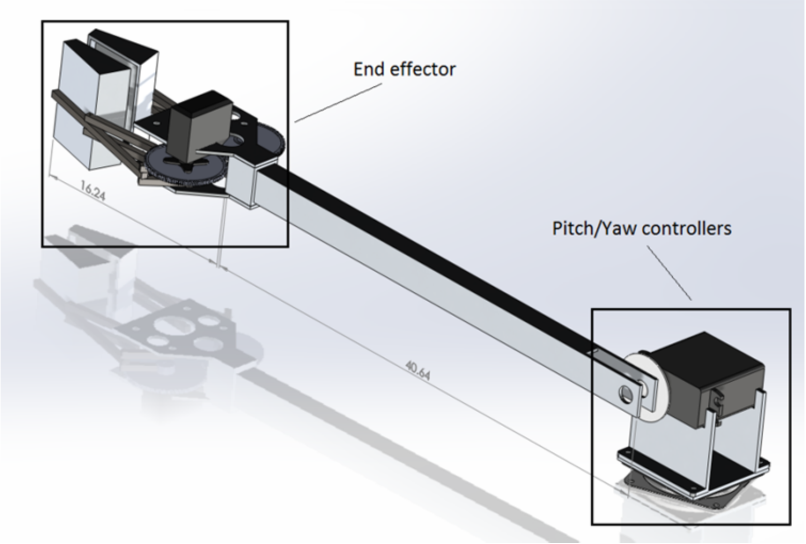

Fig. 4: *Diagram of manipulator sub-components. Included dimensions are in centimeters*

With the arm fully extended, the maximum static torque the pitch servo must overcome is 19.3 kg·cm. Thus, for the actuator, a GWS S689-2BBMG High-Torque servo will be employed, as it has a stall torque of 30 kg·cm. Because of the irregular surfaces of the rock samples CAL-Rover must acquire, the grippers must be able to provide traction on a variety of different surfaces and sample shapes. To accomplish this, CAL-Rover end effector will employ a scoop-grip hybrid that allows the grippers to partially enclose samples and thus ensure a solid hold.

To reduce the chance of foreign debris getting into the gears of the clamping mechanism, the scooping receptacle was offset from the rest of the arm, and the maximum pitch of the arm is limited to a 10° angle of elevation so that any cargo acquired is never directly over the pitch/yaw controllers or the end effector servo. Yaw control of the arm comes from an internally mounted Pololu 154:1 gearmotor at the union of the chassis and manipulator arm and is determined to be sufficiently powerful enough to rotate the arm assembly.

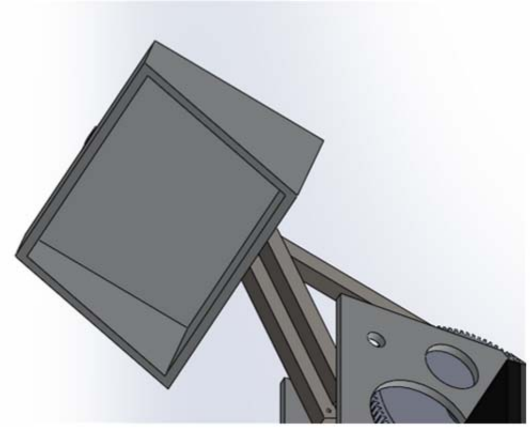

Fig 5: *Close-up of the scoop-grip hybrid. The cavities allow the grippers to enclose a variety of different sample shapes.*

(e) Cameras

To keep data rates low and allow for reliable rover navigation and sample acquisition, CAL-Rover will use two cameras: one mounted on a mast towards the rear of the rover and another mounted near the front of the rover under the manipulator arm.

The camera mast is extraordinarily simple in that it will simply be a fixed post standing straight at the rear of the rover. Mounted on top is a small table for panning the camera. The main function of this camera is to allow the team operating the rover to examine its surroundings and thus avoid large obstacles. For this application, a Microsoft Studio LifeCam was selected. It has a standard 75° field of vision along with a resolution of up to 1080p.

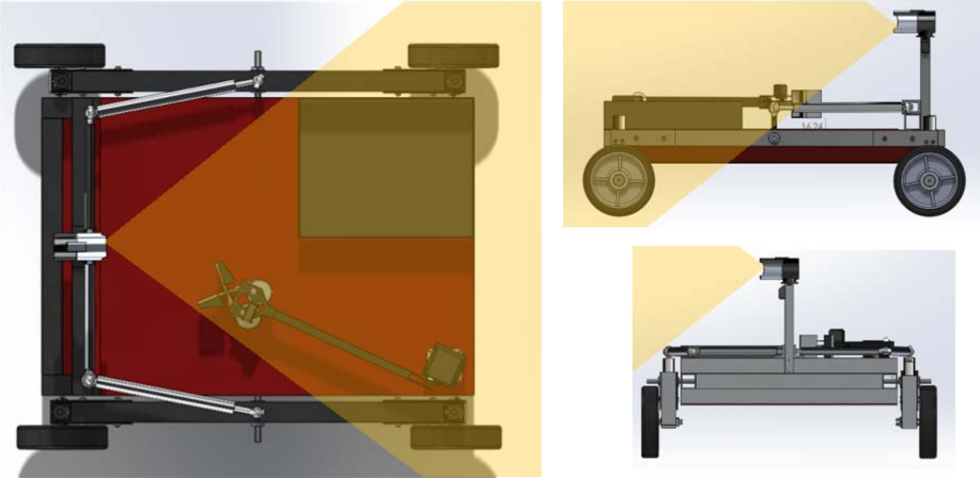

Fig. 6: *Diagram illustrating the field of view offered by the mast-mounted camera. In the forward-facing position, the manipulator and the collection box will both be visible. Panning the camera to the side allows the rover to see if there are any obstacles to its left or right.*

One beneficial feature of the camera mast is that it is short enough to fit within the envelope for the stowed configuration. From the top of the camera to the ground is 48cm. This gets rid of the need to include an extra actuator for camera mast deployment as well as another possible point of failure.

A second camera located on the front structure of the chassis gives a close-up view of the terrain near the end-effector. In order to be able to see the entire area of operation for the end-effector, an EX00 Compact 1.3MP webcam was selected. It will be modified with a fisheye lens to give a 120° viewing angle so that the end-effector would always be in sight when acquiring samples (refer to below figure).

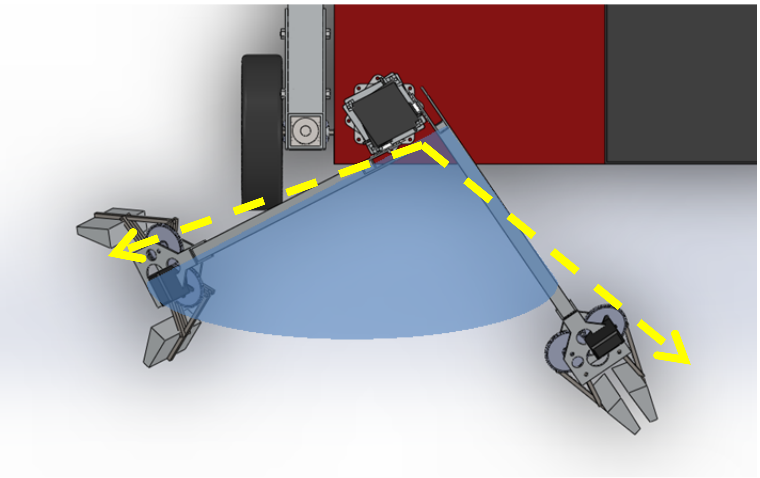

Fig. 7: *Diagram showing the end-effector range of motion and the camera field of view. The range of motion of the end effector is limited in the blue region, while the camera field of view is depicted by the yellow dashed lines. In operation, the end-effector will always be in the camera's field of vision.*

(f) Controls

Rover control will be established by linking together an Acer M5-481TG and an Arduino Mega via USB which will act as a serial connection using Python's `pyserial` module. Commands will be sent as strings of characters, which the Arduino will process and transfer the instructions to the servos and drive motors. A general view of the control scheme is below:

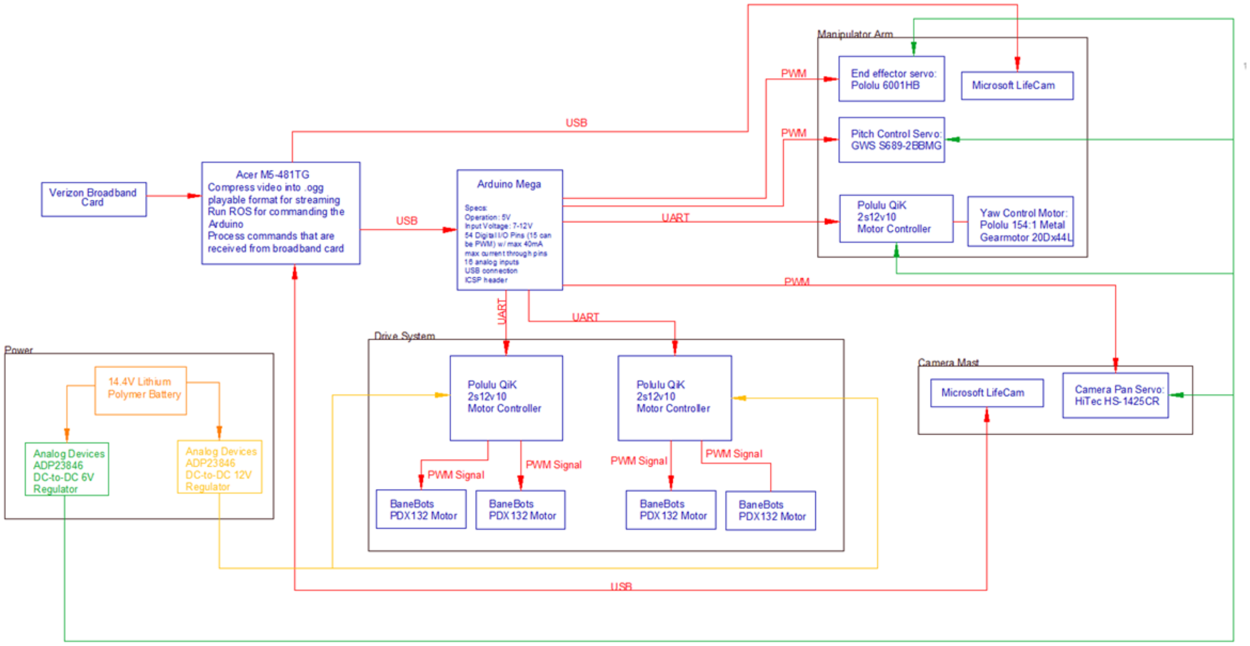

Fig. 8: *Block diagram showing the general power and control scheme of the electromechanical components of the rover as well as how all components will be connected with each other.*

The Arduino Mega has plenty of space for pulse-width modulation control; up to 14 digital I/O pins can be used for this purpose, but its maximum current draw is limited to just 50mA from the 3.3V power pin. Because of this, motor control will be done with a combination of the Arduino and three Pololu QiK 2s12v10 Dual Serial Motor Controllers. Servos will be controlled via the PWM pins on the Arduino while the drive motors will be controlled via the QiK controllers. The reason for this is because the drive motors can draw up to 140A *each* while stalled, and holding such a large current draw for any length of time could considerably damage the power system. The QiK's solve this problem because they are able to limit current to 13A per channel.

(g) Communications and Software

The conventional client-server model will be implemented to stream video and send commands between the command and onboard computers, where the onboard computer will act as the server and the command computer will act as the client. To send and receive commands, the Python `socket` module classes will be used to create TCP/IP and UDP sockets and bind them to user-defined port numbers. TCP/IP will be used to send and receive command strings, while UDP will be used for the video feed since it has lower latency and does not require error checking.

In the server script, server sockets will be created for the TCP/IP and UDP connections. Each socket will be associated with the server's host name and a user-defined port number. Additionally, the server's IP address will be established to allow connection by the client computer. The server computer must also be able to process the video feeds coming from both cameras, so OpenCV libraries implemented in Python will be used to read the image data from the USB ports and correct the fisheye lens images from the front camera.

In the client script, the socket connection will be completed by using the `socket` module to specify the IP address and the port chosen in the server script; these numbers must match exactly. Captured images from the peripheral cameras can then be sent across the network from onboard computer to the command computer. Using while loops, capture images can be sent repeatedly while specifying break intervals that define frame rate. If sufficiently small intervals are defined, this stream of images will be perceived as a live video feed, and can be tuned to optimize the balance between framerate and bandwidth.

(h) Power

The power scheme is relatively simple. The Acer has its own battery and so no further modification is needed. To power the other components, however, CAL-Rover will house a 14.4V lithium polymer battery, which was chosen for its high power-to-mass ratio. Since these batteries also tend to be volatile if mishandled, most of the design concerns are concentrated around making sure they will be charged and discharged safely. In an absolute worst-case scenario when all systems are strained to their operating limits, estimated total power draw is around 715 watts, which implies a current draw of around 50A from the battery. A battery rated for a 70A discharge was selected and is regulated by programmable voltage buck converters set for 6V and 12V. The converters selected have a maximum current draw of 6A, which is adequate for the servos. For the 12V bus connected to the drive motors, however, which can draw up to 13A each, ten converters will have to be connected in parallel for a maximum allowable current draw of 60A to compensate for the expected 52A maximum that will be drawn by the motors.

III. TimeLine

The proposed build and test schedule for CAL Rover is described below. Most action items are split into two or three phases. For mechanical components, there will usually be a machining phase, an assembly phase, and a test/quality control phase. For the electromechanical components, items are interfaced with the Arduino, and then control software is written and tested on all similar components. In case of unforeseen circumstances, buffer days have been included in case production falls behind.

Time Frame	Action Item	Description
1 Jan – 7 Jan	Manufacture rocker arms	(1 Jan – 2 Jan) machine parts (3 Jan – 5 Jan) begin assembly (6 Jan – 7 Jan) for buffer and quality control
8 Jan – 14 Jan	Manufacture chassis	(8 Jan – 9 Jan) machine parts (10 Jan – 12 Jan) begin assembly (13 Jan – 14 Jan) for buffer and quality control
22 Jan – 28 Jan	Establish servo control	(22 Jan – 23 Jan) interface servos with Arduino (24 Jan – 26 Jan) write control software for onboard computer (27 Jan – 28 Jan) test software for all servos
29 Jan – 4 Feb	Establish driver motor control	(29 Jan – 30 Jan) interface QiK's with Arduino (31 Jan – 2 Feb) write control software for onboard computer (3 Feb – 4 Feb) test software for both QiK controllers
5 Feb – 18 Feb	Program onboard computer	(5 Feb – 12 Feb) send commands to the Arduino using Pyserial (12 Feb – 18 Feb) configure socket code to receive commands from commanding computer via TCP/IP
18 Feb – 28 Feb	Program command computer	(18 Feb – 23 Feb) configure socket code to send commands to onboard computer via TCP/IP (24 Feb – 28 Feb) write Python UI

Time Frame	Action Item	Description
5 Feb – 18 Mar	Write video processing software for the onboard computer	(5 Feb – 12 Feb) research use of OpenCV with Python (13 Feb – 20 Feb) obtain image data from USB webcams (21 Feb – 28 Feb) correct fisheye lens images (1 Mar – 8 Mar) compress video for streaming (9 Mar – 18 Mar) testing and debugging
1 Mar – 11 Mar	Manufacture manipulator arm	(1 Mar – 8 Mar) manufacture all pieces (5 Mar – 10 Mar) assemble end effector (7 Mar – 11 Mar) assemble pitch/yaw controller
11 Mar – 23 Mar	Assemble rover	(11 Mar – 15 Mar) place electronics inside chassis, ESD film (16 Mar – 18 Mar) attach rocker arms and wheel assembly (18 Mar – 20 Mar) attach manipulator (20 Mar – 23 Mar) attach cameras, wire all components together
23 Mar – 1 Jun	Test driving	This section of development is left open and flexible for EP/O opportunities

IV: EP/O

To accomplish the EP/O requirement of the competition, the CAL-Rover team has multiple options it will pursue/are already pursuing. For the coming semester, we have been in contact with UC Berkeley's Academic Talent Development Program (ATDP) in order to arrange classroom visits with Bay Area schools. Throughout spring, we plan to host panels discussing and explaining our experiences as engineers, both in school and in the professional field.

Additionally, once rover development begins, we also have plans to collaborate with Pioneers in Engineering (PiE), a student organization devoted to introduce students from under-privileged schools to robotics. Two of our members are already members of this organization and will be our liaisons to PiE's outreach committee. We plan to accompany them to their spring outreach events and demonstrate our rover's capabilities to the public. This way, we hope to engage students of all grades to become interested in the engineering disciplines.

Finally, for the summer term, we will also lead a five-day course on space science for high-schoolers, again through ATDP. Topics covered will vary widely, as the course is meant to be a survey on various topics that pertain to space exploration. Proposed topics as of date are astrophysics, particle physics, general relativity and an introduction to the various models of the fundamental forces of the universe.

As a supplement to these EP/O efforts, we will also update our webpage on the CAL-AIAA website (http://aiaa.berkeley.edu) with regular news items regarding our progress on the rover, the problems we encounter, and how we solve them.

V: Team Skills and Facilities

The CAL-Rover team is fortunate to be composed of and led by highly competent individuals. The administrative team roster is as follows:

Name	Role	Relevant Experience/Skills
Jerry Allen Kim	Advisor	• Served as systems engineer for the CINEMA cube-sat • Currently serving as systems engineer for ICON. • Can use SolidWorks.
Peter Kim	Robo-Ops Lead	• Served as structural engineer for Cal Steel-Bridge team. • Can use SolidWorks, AutoCAD, and Inventor • Have machine shop training

Name	Role	Relevant Experience/Skills
Aaron Wienkers	Mechanical Lead	• Served as intern at Boeing corporation • Can use SolidWorks and AutoCAD. • Have machine shop training
Mark Jouppi	Software/Communications Advisor	• Served as intern at JPL in developing robotics software • Has extensive experience working with robotics both with electrical hardware and programming software

The CAL-Rover team will avail itself of three major facilities to complete the construction of the rover. For machining of the various parts needed, we have access to the Etcheverry student machine shop, which is equipped with milling machines, lathes, bandsaws, and drill presses, which many of our team members are trained/will be trained to use for the spring semester. For the electrical components, we have access to room 125 in Cory Hall, which is an electronics laboratory equipped with benchtop oscilloscopes, power supplies and soldering irons. Assembly of the rover is most likely to occur either in the Etcheverry machine shop or room 120AB in Bechtel hall, which is the third facility available to us.

Fig. 9: *From left to right: Etcheverry machine shop, 125 Cory Hall, room 120AB Bechtel*

VI: Statement of Preparedness and Conclusion

The CAL-Rover team believes that we are sufficiently prepared to enter and compete in the 2013 Robo-Ops competition season. This document is almost completely purely speculative, but the rover upon completion should adhere very closely to what has been described. All of the critical systems have already been fully designed, and technical drawings and bills of materials have been drafted for each subsystem. In the ideal case that all components are built and work perfectly on the first iteration, the estimated cost for one fully-functional rover is around $3000. This leaves plenty of support for creating prototypes, replacing broken and damaged components, shipping costs and reimbursing travel costs for the competition. Arrangements have also already been made to conduct EP/O opportunities, and the facilities we have are sufficient for the manufacture of the required mechanical and electronic components.

Regarding the structural integrity of the system, the rover is remarkably robust. The maximum stresses calculated at the wheel shafts and the rocker arm shafts were all determined to be well below the yield strength of the aluminum by, at the very least, two orders of magnitude. Additionally, safety requirements for the electronics systems have been taken care of: the drive motors will be current limited, all motor power supplies are voltage regulated, and all electronics will be ESD shielded.

Additional factors that will have to be closely monitored are the build schedule and regular updating of the team website and Facebook page. To limit the chance that bottlenecks will stall rover development, the proposed timeline allows for some buffering in case some components fall behind schedule. That being said, however, team leads will ensure that manufacturing remains on track as much as possible.