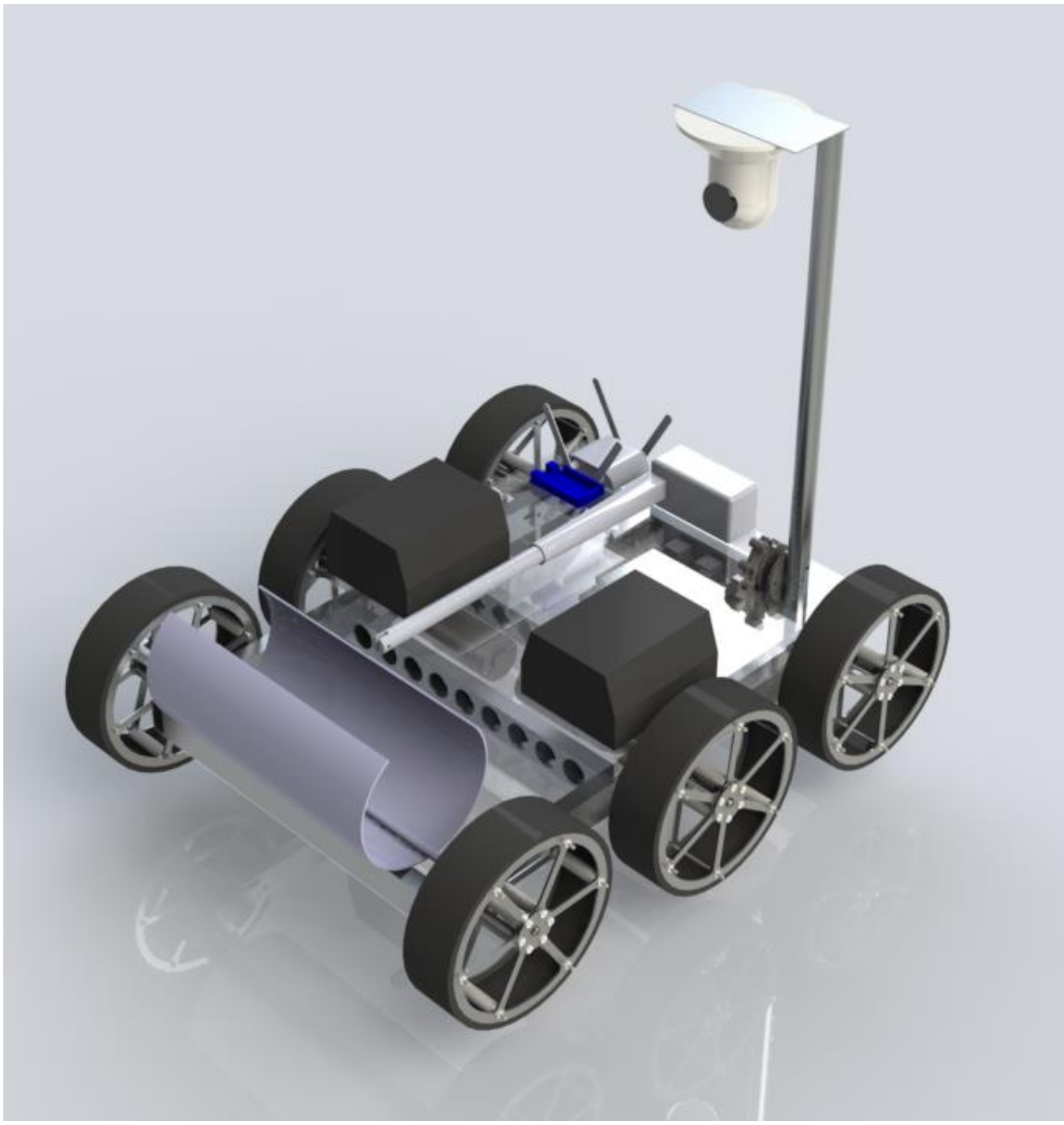
ASU RoboDevil Mk1: A Planetary Exploration Concept



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I. Introduction

Figure 1: Electrical and Mechanical team meeting

Presented henceforth is the final design of Arizona State University's RoboDevil Mk1 for the 2013 RASC-AL Exploration Robo-Ops competition. The students who comprise the RoboDevils team come from many different fields of study, interests, and experiences to bring together a creative and powerful system to compete in the planetary exploration and sample collection tasks that comprise Robo-Ops. The team consists of eight undergraduate students, comprising a collaborative effort of engineering students, planetary scientists, astrobiology, astrophysics, and systems design all working through a Senior Design Capstone project.

Members have been tasked with designing an experimental planetary exploring robot capable of remotely traversing very dynamic terrain, and collecting samples along the way. The team utilizes the diverse creative backgrounds of the members to explore many ways to complete the objectives, and what is presented further is the culmination of those efforts. A robot capable of clearing over 10 cm objects, climbing hill grades of 33%, and collecting samples in various environmental compositions. The robot is remotely operated via cameras and cellular signal modems, and basic microcontroller hardware.

The design draws from a fundamentally simple and static configuration that focuses on maneuverability and stability in construction and operation. This project has permitted the team to practice an iterative design method for the challenges that have arisen over the course of the last five months. RoboDevil has become a configuration of simple mechanical elements and electrical components that have formed a scientific sample collection test-bed. Whether it is a loss of traction while on inclines, or sifting too much sand traversing pits, the team used these opportunities to find simple solutions to complex problems.

II. System Description

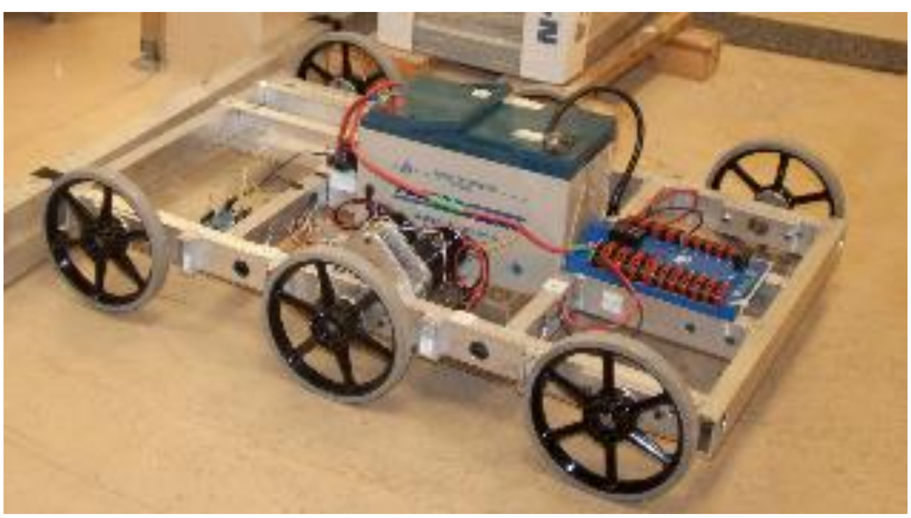

Figure 2: Initial Proto-Bot configuration

Initial design and testing has taken place on a prototype chassis created of 2 inch by 1 inch rectangular tube stock, and utilized all mechanical subsystems found in the competition ready rover currently in the testing and practice stages. The initial chassis size was 0.95 meters by 0.75 meters and permitted room for growth in the development and replacement of components to fit our needs. This proto-bot was used to test a full battery of terrain evaluation, as well as serve as the flight-testing and debug platform for all onboard communication and electronics for the robot.

The final iteration of RoboDevil pays respect to fundamentals from this prototype frame, but has grown in its own respects. The robot operates from a primary CIM motor and DeWalt XRP gearbox that direct-drive each respective center wheel. The overall dimension in stowed configuration is 0.782 meters by 0.943 meters by 0.365 meters. The robot is driven by roller chain with each wheel independently chained from the center axle. This center axle is dropped an eighth of an inch from the plane the other two wheels operate in, and permits a pivot point for increased mobility with the distributed frame. The rover is remotely operated across the Verizon Wireless cellular network utilizing a CradlePoint corporate modem. All onboard operations are managed through network protocols and an Arduino microcontroller. The deployable mast utilized on RoboDevil measures approximately 0.61 meters above the frame at greatest height and provides the operator navigation and telemetry determination. Sample collection is managed with a linearly actuated polycarbonate scoop, formed to deploy in front of the robot, and collect a general sampling while targeting the specific scientific objectives.

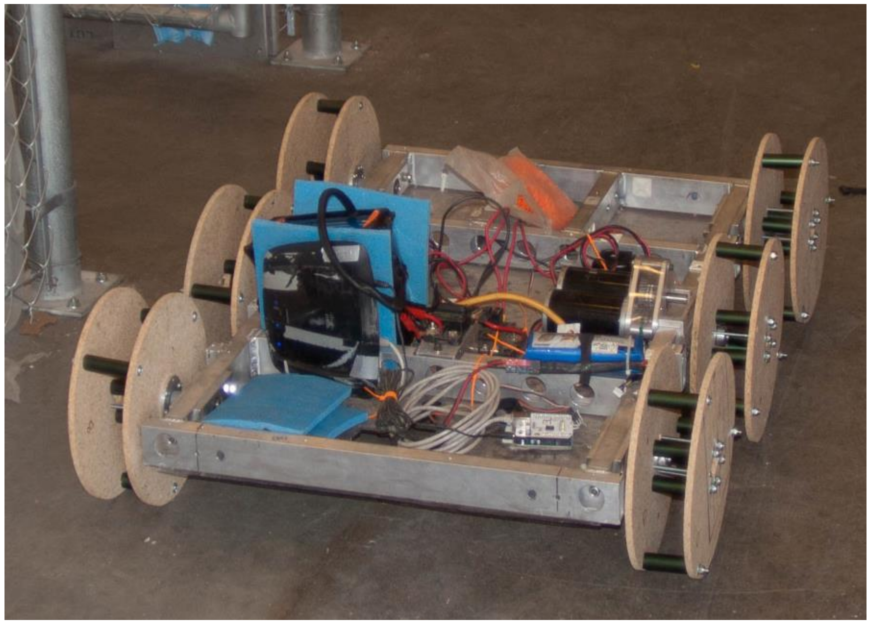

Figure 3: Wooden wheel 10 inch prototype

Figure 4: Progression of wheel design

A. Chassis and Drive System Design

There are 6 wheels on the rover. Originally the wheels were .2032 meter diameter, .0254 meter wide wheels, but the low surface area was deemed unsuitable for sand and other loose materials. The prototype robot was still maneuverable when tested with the original wheels, but the rover began to dig itself into the test site. New wheel designs have changed the dimensions to 0.273 meter diameter and .0762 meter width. Overall progression of wheel design can be seen in Figure 4. Once the final wheel design was agreed upon, prototypes were made out of wood to test for any potential issues with the design before metal copies were made.

The final wheel design uses ⅛ inch aluminum plate that was water jetted for the hubs and then is bolted together with 3 inch bolts. PVC pipe was used as spacers for the wheel to help it hold its shape. The center hub was machined out of aluminum and is the strongest segment of the wheel. The wheel also uses heat treated 1/16 inch polycarbonate for the outer mounting surface which is riveted to conveyor belt tread for added traction. The wheel

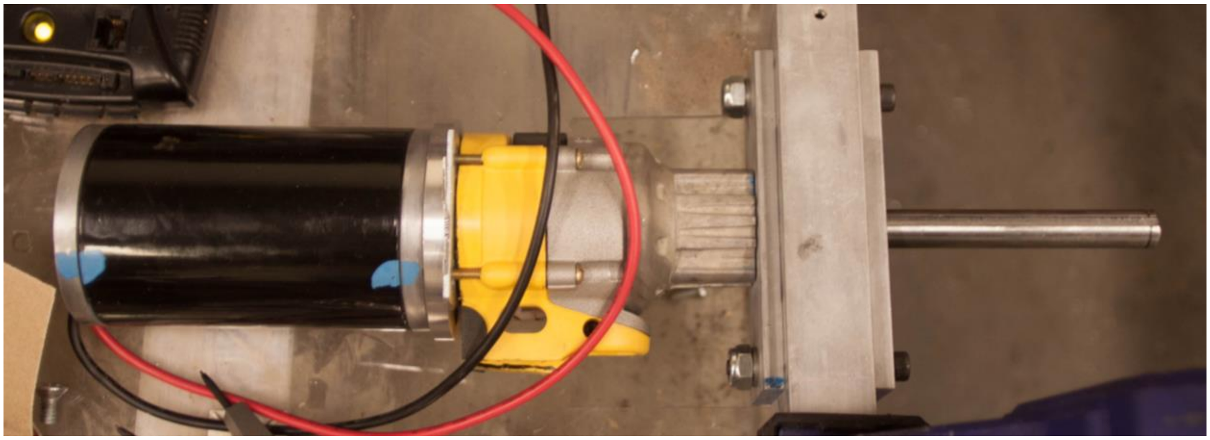

Figure 5: CIM motor and DeWalt XRP gearbox assembly

design has been selected as an open face with the intention that any dirt or debris that could enter would have the same accessibility to leave the system.

The drive system utilizes a pivot system that allows the rover to pivot on its center wheels and these center wheels are direct driven off of the motors. From the center the chain drive system extends to the front and rear wheels. The pivot system allows the rover to turn in tight maneuvers despite its size and reduces the need for dynamic suspension. This system has been tested extensively over large and small rocks, sand and loose soil, and has permitted great control and motion. The chain drive is fit inlay to the 2 inch by 1 inch aluminum 6061 tube stock, protecting both the chain and operators from debris.

The CIM motors which power RoboDevil are fed through a shift-able DeWalt XRP drill gearbox modified for the purpose of variable torque output to the system. The gearboxes permit 4:1 and 16:1 gear ratios through a sealed planetary gear system. The full system assembly can be seen in Figure 5.

B. Camera and Manipulator

Figure 6: Panasonic BB-HCM581A

The camera mast is .6096 meters in length, it spans the length of the robot and stores in the collector scoop upon initial delivery. Once the robot is cleared for the deployment stage of the competition the mast will pivot 90 degrees about its base from a horizontal position to a vertical position. The mast camera is mounted in a fashion similar to a ceiling-mounted orientation, where the support member is above the camera's base plate. The team opted for this configuration to give the remote driver the most viewing positions on and around the robot. The mast camera was chosen due to its operator interface, 21x optical zoom, simultaneous output resolutions, SD card recording and its overall robust design. The Panasonic BB-HCM581A seen in Figure 6 also features remote I/O connections and analog video-out support.

The system is only using one manipulator and that is a linear actuator that moves the scoop for sample collection as demonstrated in Figure 7. An automotive Denso window motor will be utilized for raising and holding the mast in place. The camera has 300 degree rotational axis for pan and is capable of 270 degrees for tilt. These feature are built directly into the enclosed housing of the camera

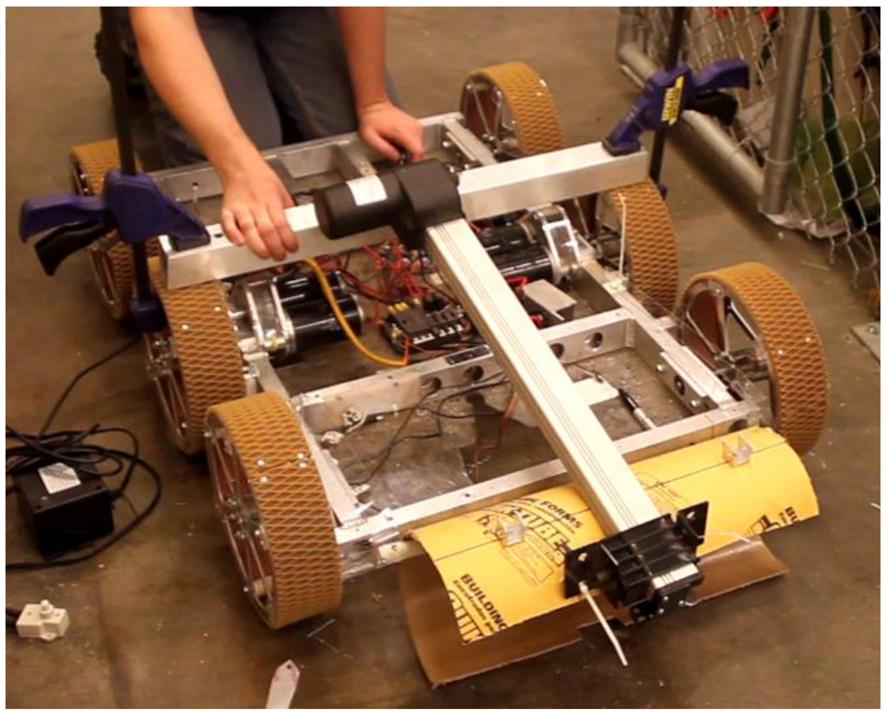

Figure 7: Scoop actuation prototype

C. Control and Communication Systems

The rover uses a CradlePoint 3G/4G industrial modem as seen in Figure 8. These modems communicate over Verizon Wireless' 4G network. In testing an average download speed of 30 Mbps and an average upload speed of 10-12 Mbps have been seen. These measurements were taken with a computer plugged directly in. The Panasonic camera will stream live video across the VPN connection RoboDevil operates through to the drivers located at Arizona State University in Tempe. There the video will be buffered and upload to Ustream for the public to view, as well as video of the control and operation station. This will reduce the load on the rover's network systems. The camera will provide visual telemetry for the drivers to use for navigation and sample identification. The camera also possesses an onboard flash memory card for physical backup of the video feed. Tunneling directly to ASU and then to the onboard modem is how latency has been simulated thus far. As far as tests have shown, the latency is only about 208 milliseconds. This may not be accurate due to only localized testing, yet to fully test the integrated systems farther distances must be evaluated. The Arduino microcontroller onboard the rover will manage the mechanical inputs for the motor controllers, servos on the mast, and servos on the scoop mechanism. The Arduino will plug directly into the modems via an Ethernet shield to minimize connection latency for commands. One of the largest difficulties the team has faced with utilizing Verizon's network is the internal IP addresses provided by the Verizon network are non-internet routable addresses usually in the 10.x.x.x range. This initially proved very difficult, because instead of the ground station connecting directly to a

Figure 8: CradlePoint Modem

remote IP address, ie the robot's address; the robot needed to create an outbound VPN request back to base station servers. Once the robot creates a VPN tunnel, then the ground station team can send and receive data through the VPN tunnel. In the case where the robot's Internet connection is dropped or lost, or the tunnel becomes disconnected, the main router will reboot to re-establish the VPN tunnel with the ground station; the main router checks for a valid tunnel every 60 seconds independent of other systems on the rover.

As of right now testing the rover's drive systems have managed with an upwards of about 300 pounds or 136 kg of mass on it with the motors set to 25% of maximum output power. The rover was still capable of driving, although it was very slow. The 136 kg mass was tested in bursts over a period of 8 hours during E/PO events on March 1st and 2nd. During the events the same battery lasted the entire 8 hour period and the robot is designed to operate as a two-battery system. Current batteries specifications are as follows: two 24-Volt, 15-Amp-Hour Lithium-Iron Phosphate ($LiFePO_4$) batteries. The batteries are configured for parallel operation to allow for a 24V, 30AH power system. This system will use DC to DC switching converters to reduce the 24V supply voltage to 12V and 5V respectively. The CradlePoint modem and network cameras operate at 12V, while the Arduino microcontroller, Ethernet Shield, and router operate a 5V.

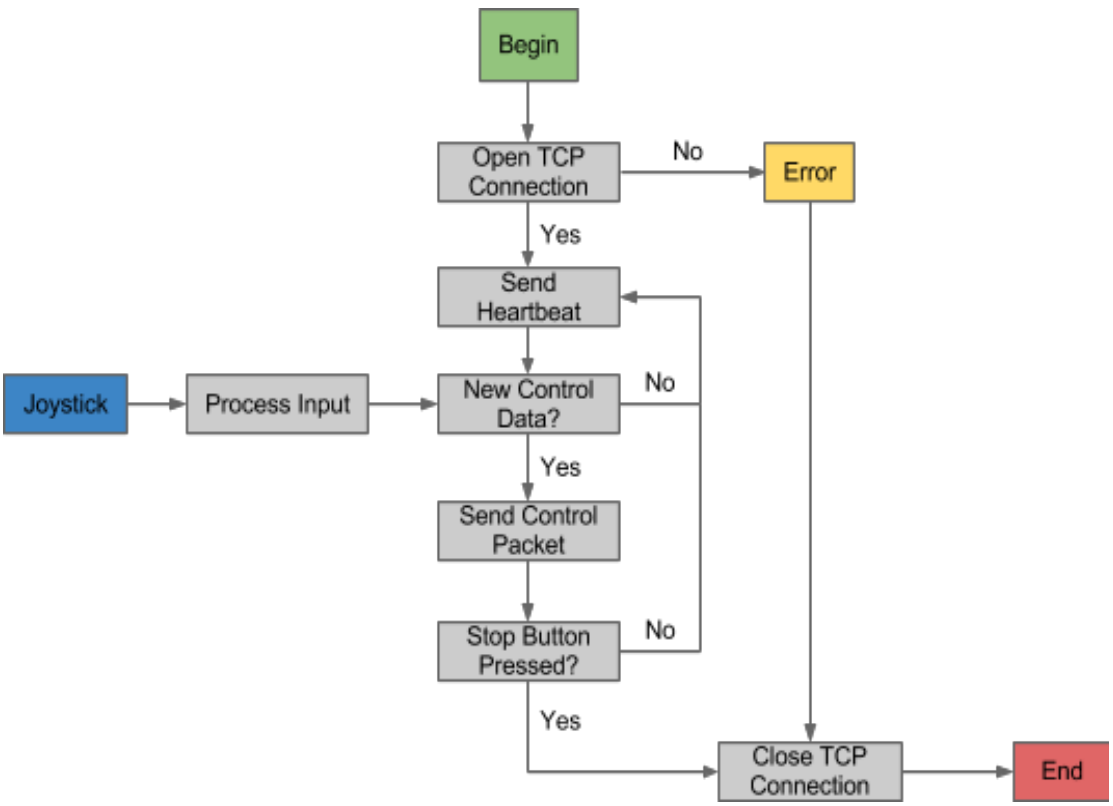

Figure 9: Overview for LabView Code

The software use a combination of Arduino code and LabView code to interpret positioning of joysticks on an Xbox 360 controller and interpret it as drive commands. The LabView code determines the value associated with the positioning and converts it to a command that the arduino can read. The arduino then sends commands to the motor controllers saying forward, reverse, or stop. The magnitude of forward or reverse is determined by the degree of tilt on the joysticks. There is also a heartbeat code included onboard our rover to ensure that if it loses contact with home base it doesn't operation, rather it stops and awaits further instructions. This is highlighted in the logic diagram provided in Figure 9. Testing showed there was a need for this when the command loop continued and the rover began driving away after it lost contact with the driving station. In early tests the rover operated at a max speed of about 15 mph, but by changing motor output and the gearbox ratios the speed has been decreased in favor of torque. The rover is capable of clearing approximately 12 cm obstacles with its current wheel diameter.

III. Testing and Operation

Testing has taken the rover to a sand volleyball pit on campus and operated through the environment at high speeds. An excess of sand and debris were sent into the chassis, which became a major concern for use. The new wheels have shown great promise, but further testing in sand is necessary. The rover has successfully climbed gravel hills of about 30 degrees incline with the original wheel design. Testing is still needed with the final wheel design, and is expected to take place in the weeks. The rover handles regular dirt and grass with ease. Gravel is tricky like sand because the rover kicks gravel into the chassis, which is a danger for some of the onboard components, most specifically the gear boxes and motor controllers. Addressing the gear box problem, a closed system sealed with a rubber gasket has been implemented at the mate between the gearbox and

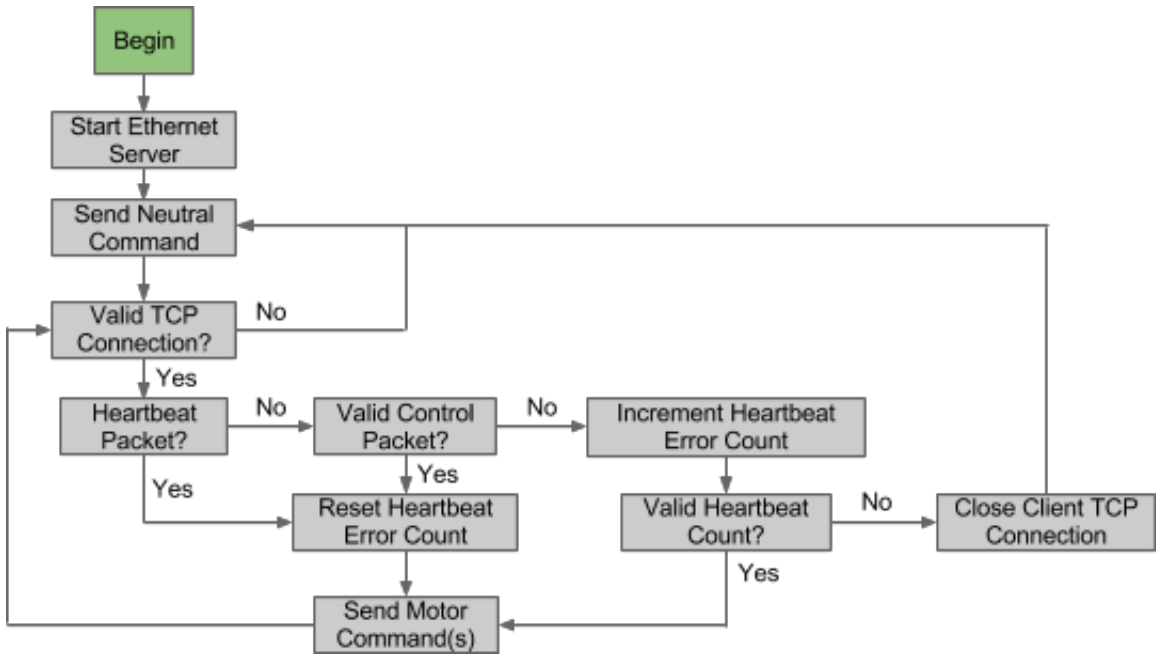

Figure 11: Overview for Arduino Code

Figure 10: Proto-Bot sifting sand rather than driving

motor. The matter of dirt, sand, dust, etc getting sucked into either the computer or motor controllers will be mitigated with a poly-carb cover that will rest over top of the rover's onboard components. The changes for addressing these problems are being implemented this week and are on the testing schedule for following weeks.

The current strategy is to use the rover's clearance to drive over most obstacles and to take advantage of the pivot system for climbing/driving over rockier terrain. The gearbox set up allows for a high torque in 1st gear and high speed transit in 2nd gear. The power system provides a surplus of power to allow the motors to draw a higher current if necessary when in high torque mode. The only time the high torque mode should be necessary is when climbing hills and if we find we are having trouble in either the sand or gravel. The rover system will transmit video back in real time for the drivers to use, but there will be a slight delay where the video is buffered from home base to Ustream for the public to view. This will minimize latency and prevent lag due to multiple hosts connecting directly to the rover. The wheel design came from a need to dissipate our mass across a larger area for terrains like sand and gravel. The chassis was designed as a rectangle to allow pivot turning and to accommodate our chain drive system. The chain drive system direct drives to the pivot center wheels, which have 2 chains that run independently to the front and rear wheels. This allows the rover to continue even if the use of a wheel is lost.

Mass Budget

Subsystem	Part	Total Mass (kg)
Mechanical		
	Motor (2)	1.23
	Gearboxes (2)	2.2
	Wheels (6)	4.38
	Chassis	15
	Scoop	1.5
	Mast w/motor	2
Electrical		
	Camera	0.78
	Battery (2)	9
	Network Switch	1.72
	Arduino w/ Shield	0.08
	Wires	0.5
	Motor Controllers (4)	1
Total		39.39
Over/Under		5.61 under

Power Budget

Subsystem	Part	Power (W)
Mechanical	Drive Motors	no-load (70W,16:1) (110W, 4:1)
Mechanical	Scoop Linear Actuator	93
Mechanical	Mast motor	50
Electrical	CradlePoint Network Router Panasonic Network Camera Arduino Microcontroller & Ethernet Shield	13

The rover received funding from NASA's ten thousand dollar competition grant. Additional funding has been provided by our project mentor Srikanth Saripalli. We received a donation/sponsorship from CradlePoint, the company we purchased our industrial modems from. They granted our project a buy 1 get 1 free deal on their $600 corporate modems. We also received a discount on our rover batteries from Headway Headquarters, who custom built both battery packs to meet our needs. The batteries cost our project $977. We also received additional services from IMS and McMaster Carr who sold our project the materials for the chassis at a discounted price. The bulk of our purchases at these 2 stores were our aluminum stock for constructing the frame and ordering drive system components for the rover. The polycarbonate for the project was purchased from Port Plastics. VEX robotics is where we purchased our motors and motor controllers, costing $543. We purchased our gyro, encoders, and arduino micro controllers from Sparkfun.com, it cost $281. The Arizona State University engineering machine shop assisted our project by handling some of the more complicated machining that we couldn't do ourselves. We also paid South West Water Jet to water jet our wheel hubs. Verizon Wireless is currently running our project approximately $50 per month and will run from March through June. Network communications will cost the project $200 for the duration of the project.

Budget

Item	Cost Each	Quantity	Total Cost
Roller Chain Sprocket	$8.45	14	$118.30
Key Stock 1/8"	$12.90	2	$25.80
Ball bearings	$7.61	12	$91.32
1/2" Keyed Drive Shaft	$46.72	1	$46.72
ANSI Roller Chain #25 10'	$37.30	1	$37.30
#25 Chain Half-links	$2.00	6	$12.00
ATC 12-position Fuse panel	$55.11	1	$55.11
Tri-Axis Gyro	$49.95	1	$49.95
Arduino Uno	$29.99	1	$29.99
Ethernet Shield	$19.99	1	$19.99
DeWalt Gearbox Parts	$254.67	1	$254.67
1/8" Polycarbonate Sheet (4'x8')	$76.50	1	$76.50
1/16" Polycarbonate Sheet (4'x8')	$44.00	1	$44.00
Industrial Metal Supply	$412.03	1	$412.03
ASU Machine Shop	$682.50	1	$682.50
Southwest Waterjet	$122.40	1	$122.40
Aluminum Keyed Hub	$10.00	12	$120.00
Cradlepoint 3G/4G Access Point	$650.00	1	$650.00
Buffalo WHR-G-N300 Router	$60.00	1	$60.00
Panasonic BB-HMC851A Network Camera	$800.00	1	$800.00
FosCam Network PTZ Camera	$430.00	1	$430.00
Treadnet IP Camera	$89.99	1	$89.99
TI Jaguar Speed Controller	$59.99	4	$239.96
2.5" CIM Motor	$25.00	2	$50.00
WedgeTop Rubber Tread 10' x 6"	$70.00	1	$70.00
Travel Expenses	$2,000.00	1	$2,000.00
Total			$6,588.53

Donations and Sponsorships

Organization or Corporation	Type of Donation/Sponsorship	amount provided	Organization or Corporation
NASA: RASC-AL Robo-Ops	Grant	$10000	NASA: RASC-AL Robo-Ops
CradlePoint	Buy 1 get 1 Free	$600	CradlePoint
Headway Headquarters	Discount on batteries	$100	Headway Headquarters
Industrial Metal Supplies (IMS)	10% discount on all products	$41	Industrial Metal Supplies (IMS)
Total Contributions		$10700	Total Contributions

IV. Education and Public Outreach

The team has taken proactive involvement within Arizona State University's outreach activities through the last semester. RoboDevil has been showcased at 4 public outreach events open primarily to middle and high school students, but public admission was encouraged. Each event showcased the robot in various aspects of the completed frame, and used the design process to show a progression to returning guests. The events that the RoboDevils participated in are as follows:

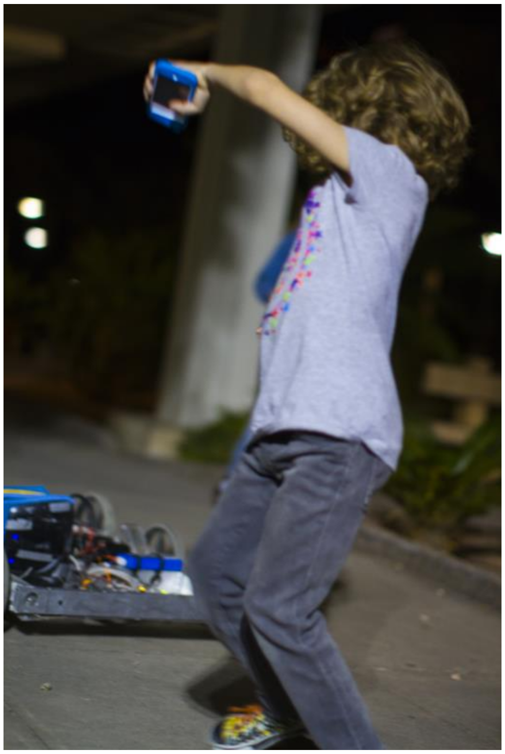

Figure 12: Night of the Open Door attendee excited about RoboDevil

1. *Astronomy Open House:*

A monthly nighttime event hosted by the School of Earth and Space Exploration. It highlights the various clubs and organizations in the school like Geology Club, Astronomy Club, Earth Scope, and NASA Space Grant. Our team sent four representatives to this open house with a poster and the rover prototype to promote the competition and the rover. The event took place in new facilities on campus, an Interdisciplinary Sciences building with the design intention of prosperous scientific research with a strong connection to planetary sciences. This permitted the attendees to see the broad scope of science being done at ASU, from soil contaminations to sub-glacial rovers, and we took honor to be able to exhibit.

2. *Engineering Open House:*

It is a yearly two day event hosted by the Ira A. Fulton Schools of Engineering. Day one of the open house is for elementary students to visit the campus and view all of the projects that different teams have been working on. The event showcases many open labs, from biology to aerospace, and activities planned at each stop. It showcases various student projects such as robotics, chemistry, biological sciences and other projects that are related to the fields of science, math, and engineering. The second day is open to the public and families to attend. The team coordinated with one another to be able to attend both days to explain using a poster and rover prototype to educate others about the project and demonstrate the capabilities of the prototype. Many children were able to help control the rover with the help of a RoboDevil teammate.

Figure 13: Engineering Open House day 1

3. *Night of the Open Door:*

A yearly nighttime event hosted by various departments at the University, which this years was on the second night of the Engineering Open House (March 2nd). The event is open to the public and university students. It shows off various projects and laboratories at the school. Our team had a table set up with the protobot available to view and ready to answer any questions that children, parents or students may have had.

Social Media:

The team set up a Facebook page, a Wordpress site, and a Google Plus page to display pictures and information about the rover and upcoming events. The team has also posted several videos to YouTube showing the Engineering Open House and various tests of the prototype. Users can "Like" the page on Facebook and gain insight to our weekly activities as well as updates about the rover and the team.

Figure 14: Elementary school student driving RoboDevil

Acknowledgements

The team would like to acknowledge the following companies for their efforts and assistance in helping us achieve our goals and complete our mission. Our wireless communication is powered by CradlePoint, without their modems our robot would not drive remotely. Headway Headquarters designed, produced, and provided our phenomenal battery packs that power the project, and without their design our power system would be infeasible. Industrial Metal Supply and Port Plastics have provided the raw materials for our construction from their will to see student groups succeed, and without them there would be no robot to drive. Lastly our entire team would like to thank our advisor Srikanth Saripalli, without his guidance, experience, and providing us just enough slack to figure this out ourselves, this project would never succeed.

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http://www.portplastics.com/
http://www.southwestwaterjet.com/
http://www.vexrobotics.com/
https://www.sparkfun.com/