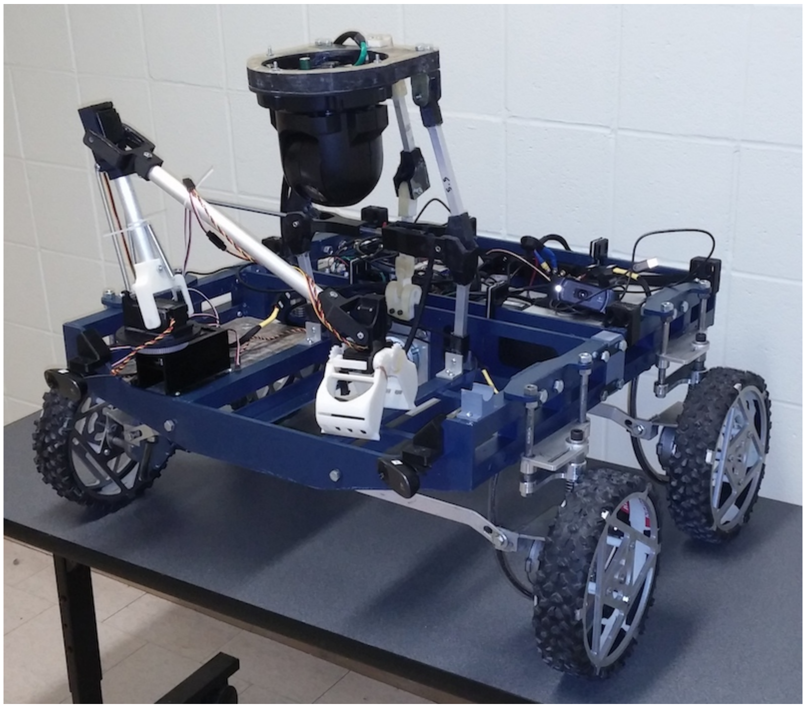
2013 - 2014 RASC-AL EXPLORATION ROBO-OPS COMPETITION

Final Technical Report

University at Buffalo, *The State University of New York*



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1 INTRODUCTION

The University at Buffalo Space Bulls Robo-Ops team has designed and realized a prototype planetary rover to compete at the NASA Johnson Space Center. Utilizing the information collected from UB student participants in the 2011-2012 competition and information gathered from ongoing testing, a new rover has been designed and built. The rover includes a larger two section chassis with a central joint for articulated movement and four wheels with independent suspension, directly driven with four high torque DC motors. This combination, along with the vertical orientation of the drive motors to avoid obstruction, will increase the mobility and maneuverability of the rover. A front-mounted, two-link arm with a two-section scoop end effector will retrieve objective rocks while requiring reduced precision. A high-resolution pan-tilt-zoom camera mounted to a mast will present the operator with a dynamic overview of the terrain. Additional cameras are mounted to view the working area of the arm and a wide-angle view of the terrain. Lightweight materials, along with a high energy density battery and more efficient electrical systems, will reduce the overall rover weight.

2 CHASSIS DESIGN AND DRIVE SYSTEM

2.1 DESCRIPTION OF CAPABILITIES

The Astraeus I, named after the Greek astrological deity and Titan-god of the dusk, is capable of traversing over rough terrain at a maximum speed of 2.20 miles per hour, ascending and descending slopes up to 60°, traversing obstacles up to 20cm in height, retrieving rock samples up to 92mm in diameter and 200g in mass, and operating for up to 1.8 hours. The team is confident that these capabilities exceed the design requirements and will enable successful completion of the roving portion of the competition.

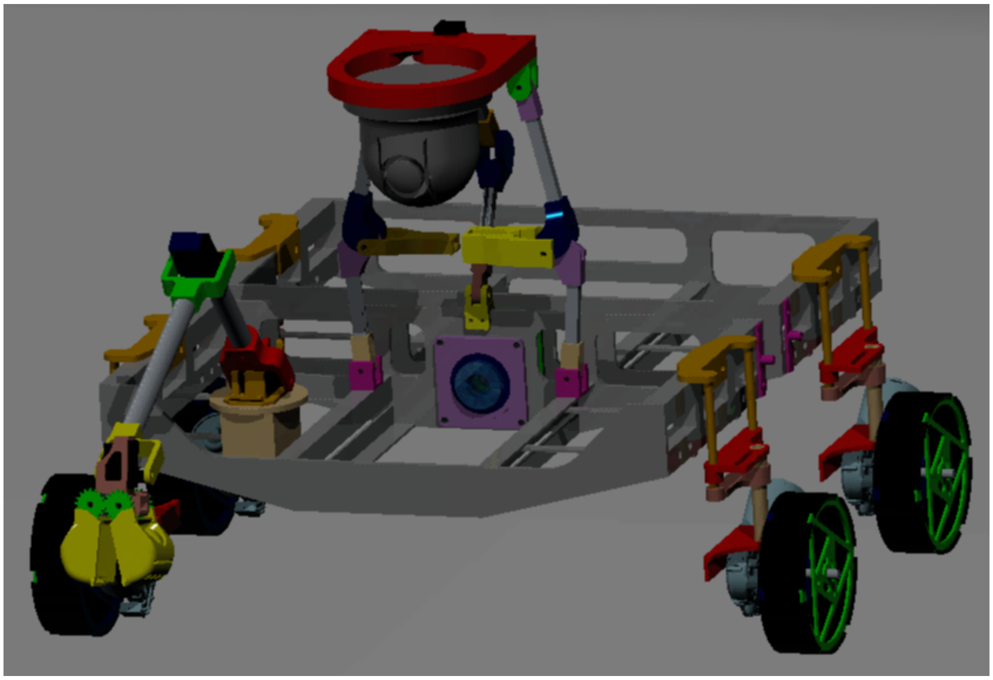


Figure 1 – 3D CAD Model of the Astraeus I

2.2 WHEELS

The four wheels have been designed to be lightweight, yet strong enough to withstand potential impact from a drop of 20cm. The interlocking triangles design, shown in Figure 2, was chosen because of its excellent ability to handle impact while requiring only a small volume of material structure. The two aluminum hub plates sandwich a 2 inch wide ring of 0.5 inch thickness PVC pipe. The PVC and aluminum have corresponding notches that hold them firmly in place. The tread utilized is a standard mountain bike tire, which is able to provide ample traction on any terrain. The tread is secured with epoxy and friction fit between the aluminum plate and PVC ring. A sliding pillar suspension system with three degrees of freedom has been designed and constructed. Each wheel has independent suspension capable of displacing up to 26mm. Figure 2 shows a suspension assembly with minimum and maximum displacement.

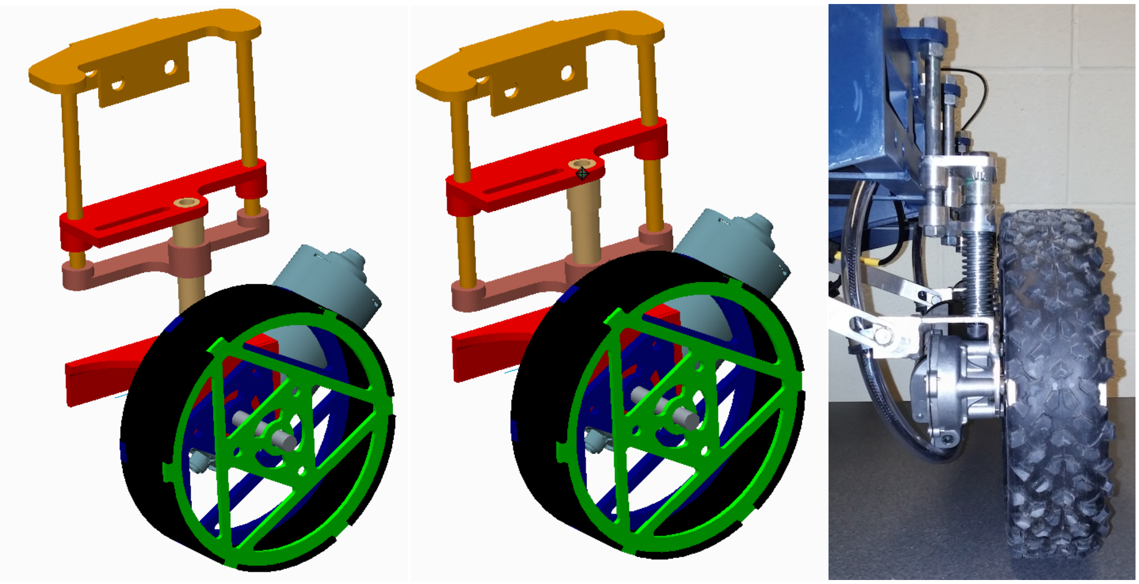


Figure 2 - Suspension Assembly Static (Left), Fully Displaced (Center), and Front View (Right)

The rover utilizes differential style steering, more commonly referred to as tank style steering. This configuration was chosen due to the simplicity of the mechanical and controls design as well as the ability for the rover to turn in place. Additionally, differential steering lends itself to a lightweight design, as there are no motors or other hardware required to provide the axis and movement for each wheel's rotation.

2.3 CHASSIS AND AXIS

The chassis is comprised of two independent sections rotating about a central axis. The chassis is fabricated from 6061-T6 aluminum due to its yield strength as well as its machinability. Each section measures 24 inches wide, 12 inches deep, and 5 inches high and weighs 3.4kg. This chassis design provides adequate space for all electrical and controls hardware in the rear section. The arm and manipulator, PTZ camera, and rock sample collection bin are in the front chassis section.

Modeling and designing the articulating pin was a challenge due to the required strength. In order to maintain a minimal weight, a 7075 aluminum pin was chosen. Finite element analysis (FEA) was used in order to determine the stress at the pin, which verified and justified the choice of aluminum. This grade of aluminum is also easy to machine, as it does not buckle under machining forces. The pin measures 4.5 inches long and 1.964 inches in diameter with a 3 inch diameter, 0.75 inch wide center lip. To further reduce the weight, a through hole of 1 inch diameter was drilled. A through hole perpendicular to the axis at each end was drilled for the placement of an end cap that prevents the pin from sliding out of the bearing housing. The end caps holding the axis are of the same material and have a 1.96 inch diameter hole to accommodate the shaft with a tight fit.

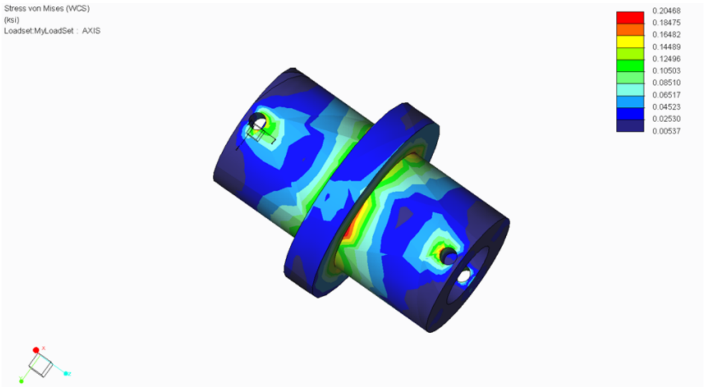


Figure 3 - FEA of Center Articulation Pin

2.4 ARM AND MANIPULATOR

The rock sample retrieval system being employed is comprised of a robotic arm with a scooping claw mechanism end effector enabling it to retrieve rock samples of varying shapes and diameters. The implemented design is constructed of parts that were designed and 3D printed to meet the specific needs of the various situations that could be encountered in the process of collecting the rock samples.

The first step in the process of fabricating the arm and manipulator was designing the individual parts and ensuring that these parts could then be assembled easily. There were a few constraints in terms of the sizes that the printer was capable of and the degree of precision that could be afforded. The use of 3D printing provided rapid prototyping and testing, supporting a low cost build-optimize design technique. The printing time and cost is significantly less than the time that would be required to machine comparable aluminum parts.

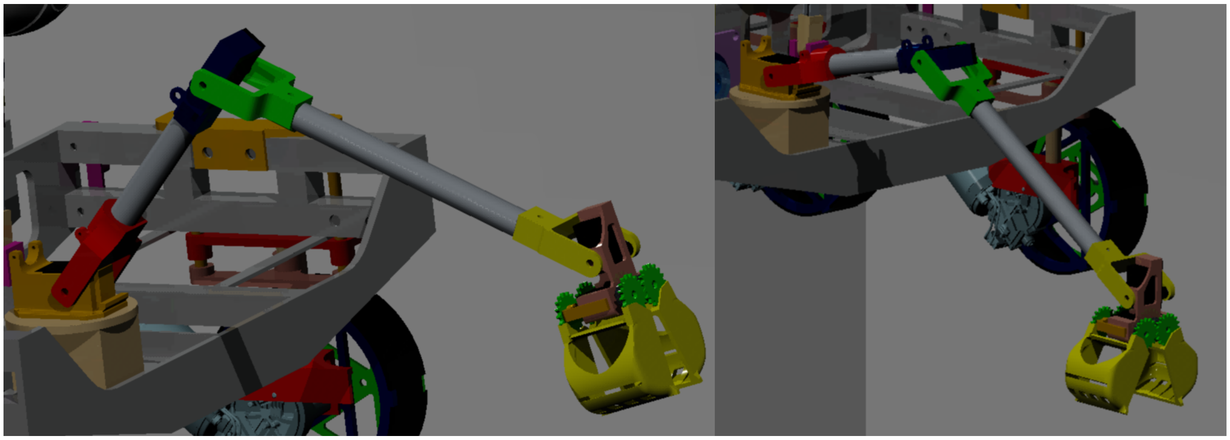


Figure 4 – 3D CAD Model of Arm and Manipulator Sample Retrieval

The arm has four degrees of freedom. It is capable of rotating about the circular base, lifting at the shoulder join, lifting at the elbow joint, and rotating about the wrist joint. Additionally, it can open and close at the gripper. Each joint is attached to a hollow circular 0.75 inch diameter aluminum rod. The 120mm long upper arm section connects the shoulder joint to the elbow joint. The 250mm long forearm section connects the elbow joint to the wrist and gripper joint. The end effector comprises two motors, one to adjust the pitch of the scoop and the second to complete the opening and closing action of the scoop. The two-piece scoop is designed to retrieve rock samples up to 92mm in diameter while filtering out unwanted sand and debris of 5mm or smaller diameter.

Table 1 - Arm and Manipulator Specifications

Servo Position	Maximum Rotation (°)	Maximum Torque (oz. – in)
Base	180	1281
Shoulder	90	500
Elbow	110	333
Wrist	180	83.3
Gripper	30	83.3

Throughout the fabrication and assembly process, the arm and manipulator designs were tested and reevaluated. Based on unfavorable results from certain tests, the 3D printed base and plate were replaced with an aluminum base that would be easier to mount to the rover chassis. This new base also incorporated a servomotor with an external gear to significantly increase the torque. This configuration also significantly increased the stability of the arm. Additionally, a single hollow rod instead of two smaller rectangular rods was chosen for the two arm sections. This was done to reduce the weight of the assembly and improve stability.

2.5 CAMERA SPECIFICATIONS

The Axis P5512 pan-tilt-zoom (PTZ) camera has been selected as the main camera. It has 180° tilt, 360° pan, and 12x optical zoom capabilities. It is mounted to a deployable camera mast that allows the PTZ camera to be raised 18 inches from the ground such that the lens will be positioned 12 inches from the ground. This pan, tilt, and zoom capability will serve as an advantage to the rover operator, as it can be used to zoom in at any place in the field and detect rocks. It also isolates the video view from the chassis position or orientation giving more control to the operator.

In addition to the main PTZ camera, two Logitech C310 USB webcams and one Logitech C910 USB webcam were selected. The C310 cameras are mounted to the left and right front sides of the rover. Their positioning provides video to aid the rover operator in retrieving the rock samples from the field. The C910, with its wide field of view, has been mounted to the very top of the camera mast. The positioning provides a wider viewing area to the operator. This will work in tandem with the PTZ camera and its narrow field of view. The C910 will be used for reconnaissance and the PTZ can be maneuvered for more detailed investigation when searching for rock samples. The resolution of each camera is dynamic and dependent upon the available 4G bandwidth.

3 CONTROL AND COMMUNICATION

3.1 CONTROL AND SENSORS

Two Roboclaw 30A dual-channel motor controllers are utilized for control of the four drive motors. These controllers have been selected due to their high output current, built-in protection, simple operation, onboard encoder inputs, and the ability for serial control inputs from a microcontroller. A Teensy 3.1 microcontroller, which employs an ARM Cortex M4 at 96MHz, communicates serially and via digital logic to control each channel of each motor controller. This device was selected due to its versatile I/O and reduced latency compared to an Arduino microcontroller. The Teensy receives two comma-separated values from a python script ranging from -127 to +127 as inputs. Each value represents the speed and direction of one channel pair. The Teensy then utilizes a linear equation before writing the corresponding values over the serial line to the motor controllers. The latency from Teensy input to motor movement is negligible.

For control of the arm and manipulator, a set of five comma-separated values is written to the Teensy serial input. Each value represents the angle to be written to each of the servos on the arm and manipulator. The Arduino Servo library is utilized on the Teensy to write the angles to each servo. Additional logic controls are utilized to control a series of relays that control the camera mast motor and power to the arm and manipulator servomotors.

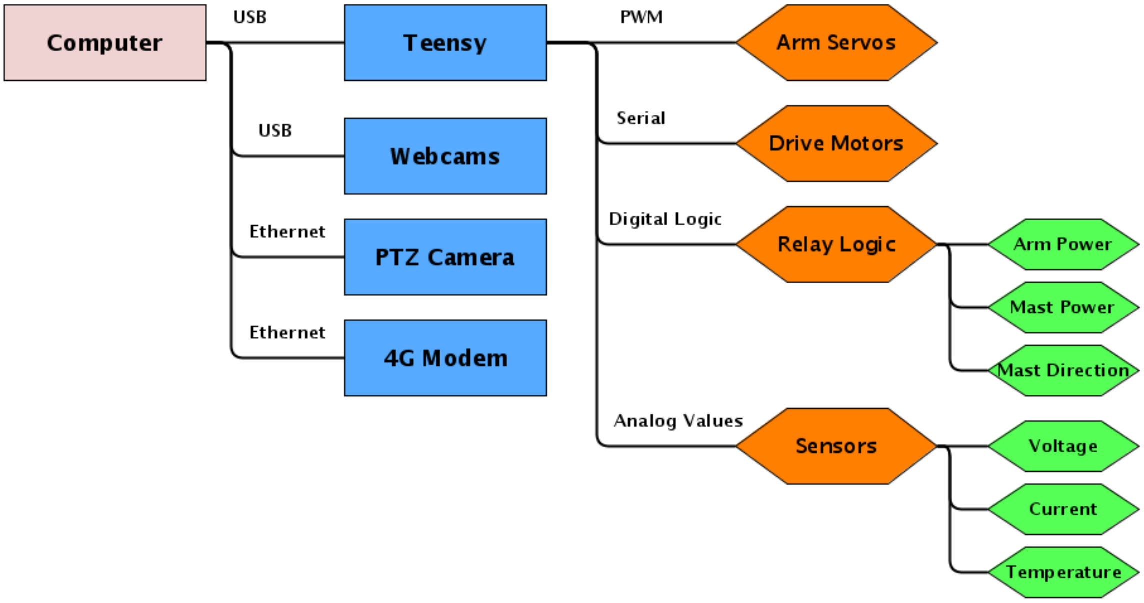


Figure 5 - Control System Flow Diagram

An onboard monitoring system measures the temperature, current, and voltage at various points throughout the rover systems. For example, the computer input voltage and current and battery case temperature are monitored carefully and reported to the operator. A one-wire temperature sensor gives an accurate value with a precision scale of 10mV/°C. Several AttoPilot 45A voltage and current sense breakout boards have been deployed. Similar to the temperature sensors, an analog voltage input is read and scaled. All measured data is then displayed on an LCD screen mounted to the rear section cover of the rover. Several groupings of values can be scrolled through and monitoring can be paused when not needed. This is programmed through the same Teensy microcontroller utilized for the drive motor and servomotor control.

3.2 SERVERS, VIDEO COMPRESSION AND BANDWIDTH

The Robot Operating System (ROS) nodes are arranged as shown in Figure 6. The `ros_project` is the TCP command listener node, which sends control signals sent from the home computer to their respective nodes. The drive motors are controlled by the `drv_control` node, which receives two speed values for left and right motors thus providing differential turning mechanism. The `arm_control` node receives angular displacement of five servos controlling the arm and manipulator. The `axis_ptz` node controls the pan, tilt and zoom of Axis PTZ camera.

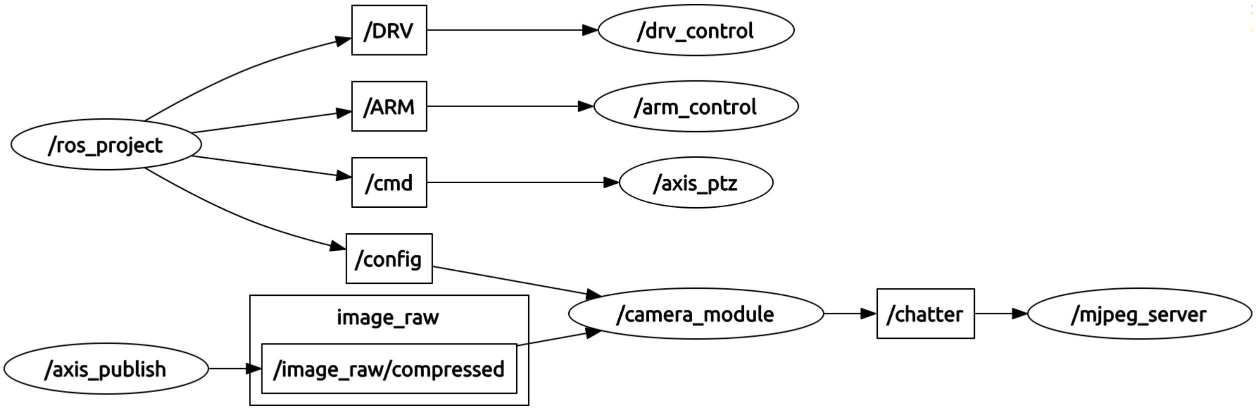
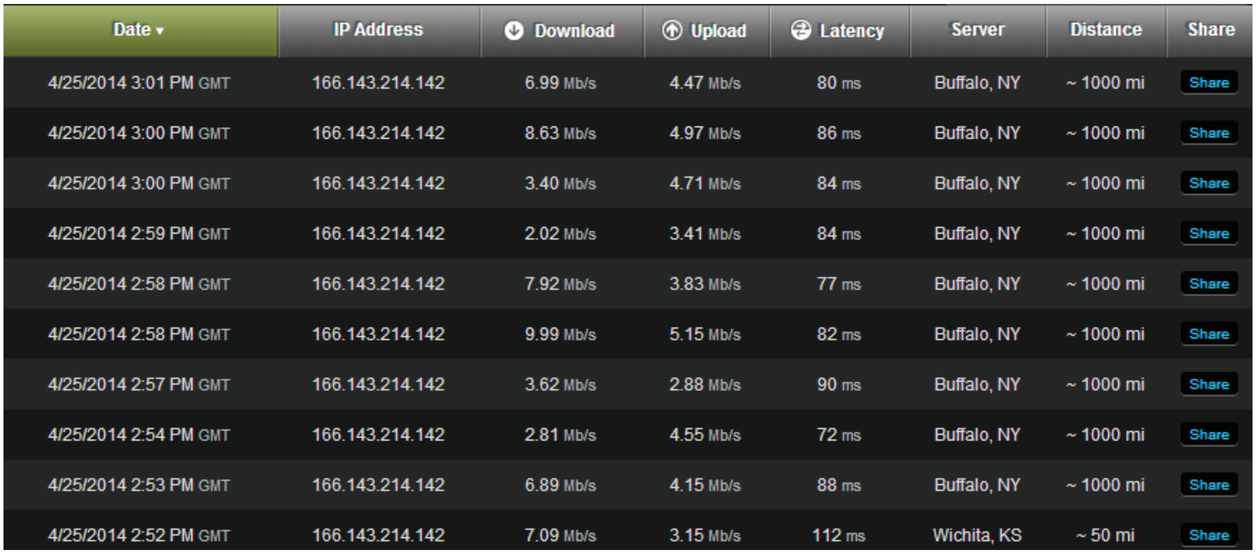


Figure 6 - ROS Nodes Configuration

A ROS MJPEG server is being used to stream the camera feeds from the rover to the control center. The MJPEG server subscribes to an image topic, which is published by the ROS node after processing the streams from the camera. The camera module node uses OpenCV to control and switch the video stream between the onboard cameras. It takes input from the PTZ via a ROS topic as well. The resolution and the frame-rate of the stream are also controlled using this node. The MJPEG server then compresses the raw image stream to the MJPEG format and streams it over HTTP. The resulting stream can be viewed in the GUI at the control center. The operator can switch between different cameras using the same GUI.

3.3 NETWORK INFORMATION, MODEMS, LATENCY, AND CONNECTION SPEED

A CradlePoint COR IBR600 4G LTE Router was chosen due to its compact design, I/O flexibility, and compatibility with Verizon's 4G LTE network. The IBR600 has a wide input voltage range and is powered directly from the battery. It is connected directly to one of two Ethernet ports on the onboard computer. Two 4G antennas are mounted externally on the rear of the rover for diversity to achieve maximum signal strength. The IBR600 is configured with a static IP address so that the control computer can connect without changing the hardcoded IP address.



Date ▾	IP Address	Download	Upload	Latency	Server	Distance	Share
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4/25/2014 3:00 PM GMT	166.143.214.142	8.63 Mb/s	4.97 Mb/s	86 ms	Buffalo, NY	~ 1000 mi	Share
4/25/2014 3:00 PM GMT	166.143.214.142	3.40 Mb/s	4.71 Mb/s	84 ms	Buffalo, NY	~ 1000 mi	Share
4/25/2014 2:59 PM GMT	166.143.214.142	2.02 Mb/s	3.41 Mb/s	84 ms	Buffalo, NY	~ 1000 mi	Share
4/25/2014 2:58 PM GMT	166.143.214.142	7.92 Mb/s	3.83 Mb/s	77 ms	Buffalo, NY	~ 1000 mi	Share
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4/25/2014 2:53 PM GMT	166.143.214.142	6.89 Mb/s	4.15 Mb/s	88 ms	Buffalo, NY	~ 1000 mi	Share
4/25/2014 2:52 PM GMT	166.143.214.142	7.09 Mb/s	3.15 Mb/s	112 ms	Wichita, KS	~ 50 mi	Share

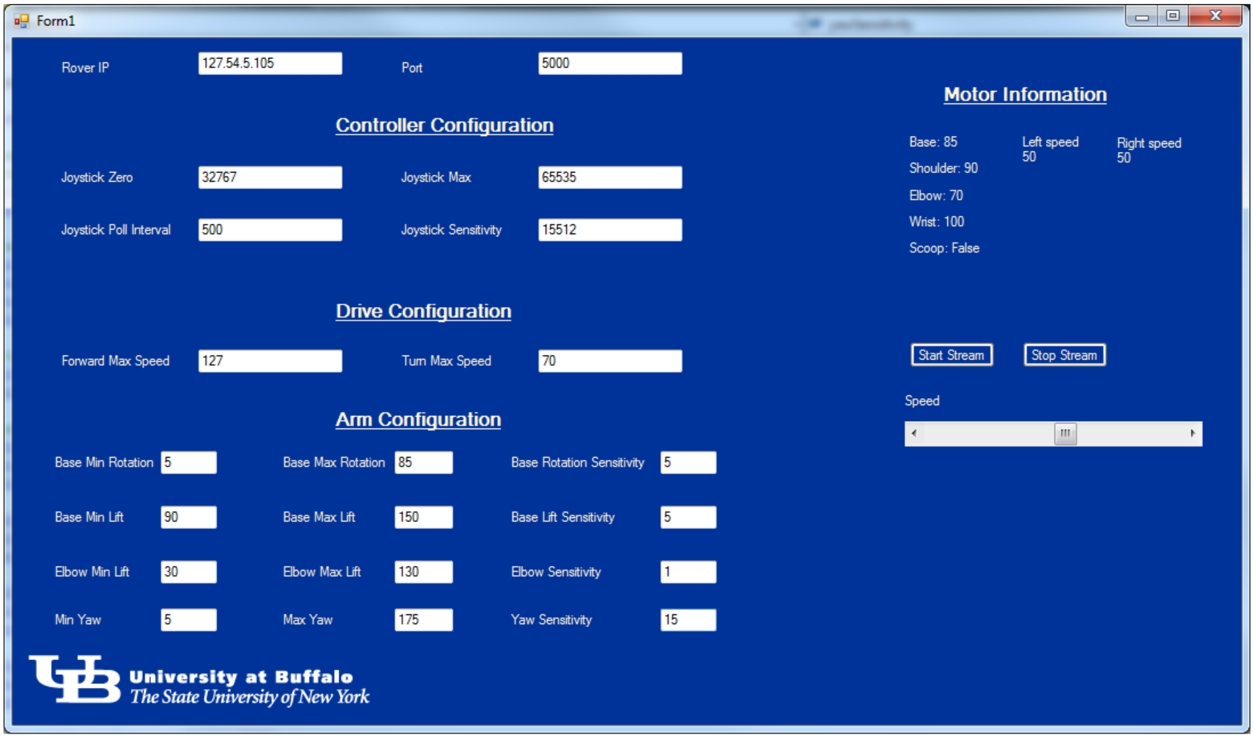
Figure 7 - Speedtest.net Results on CradlePoint IBR600 Verizon 4G LTE

Several tests were completed with the IBR600 connected to a laptop to measure connection speed to the network on the UB North Campus. Results from the series of tests shown in Figure 7 were obtained in an open area of campus at midday. Although the results are inconsistent, we have seen that these connection speeds are adequate for operation and video streaming. Video stream latency has varied throughout testing as well. In the poorly covered areas of the campus, the latency on the video stream has been as high as eight seconds. However in the more open areas of campus, the latency has been as low as three to four seconds. Further testing is ongoing in an attempt to improve the experienced latency.

3.4 MISSION CONTROL INTERFACE

The rover remote controller is an Xbox 360 USB controller. This device lends itself to the differential style steering well, as it has dual joysticks. Additionally, the triggers, pushbuttons, and directional pad are utilized for the arm and other controls. A 2.4 GHz wireless version of the same controller is utilized for local control of the rover. This local control is utilized when testing various systems independent of the tele-operation, conducting demos, and for the Olympic matches as part of the competition.

The rover operator is presented with two full-screen windows of data that is used to control and monitor the rover and its systems. The main window, shown in Figure 8, allows the operator to change various settings such as current and maximum drive speeds, servo control sensitivity, and joystick sensitivity. The second window, shown in Figure 9, shows the video stream from the rover as well as the video stream controls. The operator can choose which camera to view, its resolution and frame rate, and the pan, tilt, and zoom controls for the PTZ camera.



Rover IP 127.54.5.105
Port 5000

Controller Configuration

Joystick Zero 32767
Joystick Max 65535
Joystick Poll Interval 500
Joystick Sensitivity 15512

Drive Configuration

Forward Max Speed 127
Turn Max Speed 70

Arm Configuration

Base Min Rotation	5	Base Max Rotation	85	Base Rotation Sensitivity	5
Base Min Lift	90	Base Max Lift	150	Base Lift Sensitivity	5
Elbow Min Lift	30	Elbow Max Lift	130	Elbow Sensitivity	1
Min Yaw	5	Max Yaw	175	Yaw Sensitivity	15

Motor Information

Base: 85
Shoulder: 90
Elbow: 70
Wrist: 100
Scoop: False

Left speed 50
Right speed 50

Figure 8 - Control Interface Window 1

Figure 9 - Control Interface Window 2

4 TECHNICAL SPECIFICATIONS

A summary of mechanical and controls specifications can be found in Table 2 and Table 3 below, respectively. Several of the metrics related to the rover's capabilities may be altered prior to the competition as testing, reevaluation, and improvements are ongoing.

Table 2 - Mechanical Technical Specifications

External Dimensions	Height: 457 mm Width: 918 mm Depth: 648 mm
Weight	32 kg
Wheel Diameter	235 mm
Rated Payload	45 kg
Maximum Speed	2.20 mph (0.984 m/s)
Maximum Obstacle Size	200 mm
Maximum Suspension Travel	26 mm
Drive Power	7.0 Nm per wheel
Maximum Sample Size	92 mm
Total Rock Sample Capacity	5777 cm^3

Table 3 - Electrical and Controls Technical Specifications

Power Source	Lithium-Ion Polymer Battery Operational Voltage: 25.9V Capacity: 21Ah (544Wh) Maximum Output: 30A
Operational Time	1.8 hours
Onboard Computer	Zotac A75ITXBE mini-ITX Motherboard AMD A10-6700 APU 8GB DDR3 1866MHz RAM 120GB SSD
Software	Ubuntu Linux 12.04 Robot Operating System (ROS)
Control Hardware	Teensy 3.1 Microcontroller Roboclaw 30A 2-Ch. Motor Controller SainSmart 4-Ch. Relay Module Board
Communications Network	Verizon 4G LTE CradlePoint COR IBR600 Router

5 TESTING STRATEGY

From the beginning of the build phase, the team has been testing each individual component of each subsystem on the rover. From experience, it is best to test with as few variables as possible and integrate devices and components one at a time. The team has also built and manufactured prototype parts in order to save time and money. Several components of the center axis and suspension were 3D-printed prior to machining out of aluminum. The 3D printing does not require any man-hours and is significantly more cost effective than machining. Several of the electrical and control systems were tested utilizing development boards and bench top power supplies before installing or integrating into the main power and control system.

Figure 10 - Hill Climb Testing Outside Davis Hall

In order to test the rover's performance on a variety of terrain, the motor controllers were configured to utilize a standard RC control input. This allows the operator to evaluate the response of the rover in real time and eliminates the tele-operated variable. The rover was first driven on pavement to evaluate its top speed, handling, and turning characteristics. The rover operated as expected, however the operator could not fully utilize the differential steering capability due to the increased surface friction. The rover was then tested on flat grass in a similar manner. The differential steering performance was more favorable, as the wheels were able to slip and skid on the grass. The rover was then driven over a rock bed with dirt and rocks approximately 2cm – 4cm in diameter. The maximum speed was reduced, however performance was adequate. A potential issue for the remote operator is the lack of a steady video stream when the rover is traversing over the rough terrain. Lastly, the rover was driven in a sand pit. Similar to the rockbed, the maximum speed was reduced, however the tread pattern and wheel width allowed the rover to navigate the sandy terrain adequately. The team is not concerned that the rover will become immobilized in this type of terrain. The differential steering performance is reduced with the excessive slipping and skidding, however the operator is still able to execute a turn in a reasonably tight radius.

In order to test the articulating pin and suspension performance, the rover was driven down a 15cm high curb. The operator was able to maneuver the rover down the vertical drop one wheel at a time. The articulating axis provided a majority of the movement, with the suspension making up the differences as necessary. The rover was then driven up the same 15cm high curb with the same results.

The rover was driven up and down slopes of varying degree, all of a similar grassy terrain. The rover was able to climb and descend up to a maximum 60° grade. This is far greater than the 30° grade required for the competition. The rover's low center of gravity and battery placement enabled this ability.

6 OVERALL COMPETITION STRATEGY

The most noticeable difference in the Space Bulls rover compared to other teams is the size, particularly the height of the rover. The ground clearance is 21cm in the center of the chassis. This allows the rover to traverse over any obstacle that it may face in the rock yard, given that the largest obstacle will be 10cm in diameter. The two-section articulating chassis with a four-wheel independent suspension allows the rover to climb over any obstacle with all four wheels making contact with the terrain. This yields greater traction and enables the rover to traverse nearly any terrain without the risk of becoming immobilized. The rover operator may therefore choose any desired path, with minimal concern over obstacles that would hinder movement. This is a characteristic carried over from the previous iteration of the Space Bulls rover. The new rover, however, has a higher clearance and vertically mounted drive motors for a wider underbody clearance.

The rover is also designed to climb steeper slopes with loose terrain, based on feedback from previous team members. The team learned that many of the rovers in previous years have struggled to climb out of the crater or up the Mars hill due to the steep incline and loose terrain. The rover's large diameter wheels, tread pattern, and high torque drive motors have enabled the rover to traverse any terrain at slopes up to 60°.

The arm and manipulator has been chosen to give the rover a long reach and a large working area. This enables to rover operator to position the rover to be able to retrieve multiple samples consecutively. This will reduce the retrieval time, which will enable the operator to cover larger areas of the rock yard overall and retrieve a larger number of samples.

7 BUDGET

In addition to the $10,000 grant received from NASA, the team has been fortunate to work with several industry sponsors and supporters. A collection of donated and sponsored materials and equipment can be seen in Table 6. The team is truly grateful for the generosity and support from these organizations. Without their assistance, the Astraeus I would not be as capable as it is. A full breakdown of material and equipment expenses and competition related expenses is shown in Table 4 and Table 5, respectively.

Table 4 – Inventory of Expenses Related to Fabrication

Material and Equipment Expenses		
Vendor	**Item**	**Cost**
Engineering Machine Shop	(15h) Welding, CNC, Labor	$450.00
Metal Supermarkets / Online Metals	Aluminum and Steel Materials	$600.00
Robot Marketplace	(3) Motor Controllers	$375.00
NewEgg	Computer (CPU, Motherboard, SSD, RAM)	$575.00
ServoCity	Servo motors for arm and manipulator	$1,000.00
Amazon	(3) Webcams	$270.00
AA Portable Power Corp	(2) Lithium-Ion Polymer Battery: 25.9V 21Ah	$1,400.00
AA Portable Power Corp	(2) Smart Charger (6.0A) for 25.9V Li-ion/Polymer Battery	$158.00
Digikey, Mouser, Jameco	Electrical connectors, wire, and components	$350.00
Buffalo Bearing	Center axis pin bearings	$80.00
Lowes, Home Depot	Hardware and fasteners	$200.00
Robot Marketplace / Amazon	Joystick, Controllers	$150.00
Maker Farm	ABS Filament for 3D Printer	$148.00
Harbor Freight	Tools, Connectors, Heat Shrink	$120.00
Sparkfun	Microcontrollers, Sensors, components	$350.00
Lowes, Home Depot	Paint, Fiberglass Materials	$100.00
Total		***$6,326.00***

Table 5 – Inventory of Expenses Related to the Competition

Competition Expenses		
Vendor	**Item**	**Cost**
NIA / NASA	(4) Competition Registration Fee	$1,200.00
Enterprise	(7 days) Rental Van	$100.00
South Shore Harbor Hotel	(5 nights) Hotel Stay	$600.00
Various	Round Trip Gas and Tolls	$700.00
Al Ross	Team Shirts, Banner, Stickers	$1,000.00
Total		***$3,600.00***

Table 6 – Inventory of Donated and Sponsored Materials, Equipment, and Services

Sponsorship and Donations		
Vendor	**Item**	**Cost**
AM Equipment	(6) 218 Series Gearhead Motors, 64mm, 24V	$445.74
AA Portable Power Corp	Discount on battery and charger pairs	$400.00
Atmel	(4) AVR Xplained Mini Development Boards	$100.00
CradlePoint	COR IBR600 Router	$610.00
Digital Surveillance Solutions	Axis P5534 PTZ Network Camera	$2,600.00
Merritt Machinery	Machine Work and Material	$500.00
Mini-Box.com	(2) picoPSUs with AC power adapter	$158.90
Verizon Wireless	4G LTE Service Plan, 4G USB Dongle	$500.00
UB Facilities Plumbing Shop	26” x 8” Schedule 40 PVC	$50.00
Total		***$5,364.64***

8 PUBLIC AND STAKEHOLDER ENGAGEMENT

The Space Bulls team has utilized a website and Facebook page to post and share team information and updates throughout the semester. Updates are usually posted on a weekly basis, if not more frequently. These resources allow the team to track progress throughout the building and testing process and to keep interested parties informed.

The team has partnered with the UB IEEE Student Branch at various Open House events throughout the semester. The team was able to reach current and potential UB students and show them what is possible in engineering at UB. One particular event was the University at Buffalo Accepted Student Open House on March 29, 2014. The team was able to demo the assembled and partially functioning rover to an audience of 100 students and their family members. This was an excellent opportunity for students fresh into engineering to get an idea of the multidisciplinary nature of most engineering endeavors.

The Buffalo branch of the American Association of University Women (AAUW), a national organization that advocates for equity and education for women and girls, hosted its ninth annual Tech Savvy conference on March 15, 2014. This program is designed to inspire middle school girls to pursue careers in STEM areas through workshops. The conference brings several hundred girls along with their family members and teachers to the campus to participate in workshops, seminars, and social events. This year, the team hosted a “Rover Races” workshop, which is a NASA Classroom Activity. Several team members also assisted with a hands-on “pop bottle wind turbine” exercise workshop. Each participant built their own wind turbine using a pop bottle, propeller, and small electric motor.

Figure 11 - "Rover Races" Activity at Tech Savvy 9

The UB School of Engineering has partnered with Westminster School consisting of grades K-8, with an 80% minority population. There have been several demonstrations at the school for appropriate age groups. A few team members have also participated in several activity day events at the school focused on engineering and science. The Space Bulls have specifically adopted the three 5th grade classes at Westminster and will have interactive sessions with the classes in addition to the mission control event.

Figure 12 - Pop Bottle Wind Turbines with Westminster Students

On April 12, 2014 several team members participated in UB Community Day along with some students from the UB IEEE Student Branch. The members helped cleanup the old Uptown Theater on Bailey Avenue in downtown Buffalo in preparation for it's upcoming remodeling.

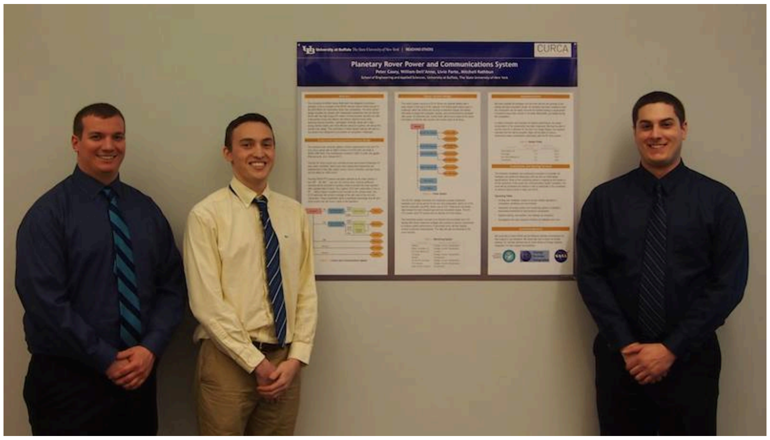


Figure 13 - Celebration of Student Academic Excellence Poster

Several team members were invited to participate in the Celebration of Student Academic Excellence poster fair in early April. Several of the team members presented a poster showcasing the team's progress, particularly on the power, control, and monitoring systems. It was an excellent opportunity to share the team's work with UB faculty and guests, and to learn about some of the research fellow students are conducting.

As part of the Rocketry Event hosted by the UB chapter of the Students for the Exploration and Development of Space (SEDS), several team members designed, built, and launched a model rocket utilizing 3D-printed fins. The rocket launch was one of only a handful of successful flights with the rocket still usable upon retrieval.

As part of the roving portion of the competition at Johnson Space Center, the team will be hosting a Mission Control Event at UB. The rover operators will be driving the rover from one of the large lecture halls so that the rover stream can be shown on the projector screen. The team will invite friends, family, faculty, and community members to take part in the competition. The team will also be facilitating the students from the Westminster School to take part in the Mission Control event as well. Additionally, we will advertise our live stream link to our supporters so everyone can experience the competition.

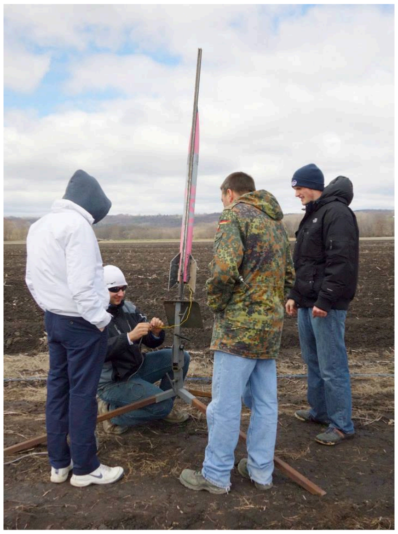


Figure 14 - SEDS Rocketry Event

9 MOVING FORWARD

As the team finishes out the last few remaining weeks before the competition, extensive testing of the integrated systems will continue. The team is searching for weak points and potential failures of the rover in order to ensure a fully functional rover for the duration of the roving portion of the competition. The team will also be working to complete certain tasks such as the underbody panels and rear section cover that enhance the overall system and demonstrate a complete prototype.

The team will be testing and training the rover operators so those individuals are prepared for the competition. Initial testing has taken place in the lab with the rover tethered to the local network. This allows the operators to test adjustments to the controls interface and movement sensitivity in real time. Additionally, the team will be transporting the rover to different locations with different terrain types. This will allow the operators to experience new terrain with an increased latency on controls input and video feedback.

10 ACKNOWLEDGMENTS

The UB Space Bulls team would like to sincerely thank all of our donors, sponsors, and supporters. Without the collective efforts and generosity of our peers, professors, advisors, and industry partners we would not be as successful as we are today.

UNIVERSITY AT BUFFALO
SPACE BULLS
2013 2014
ROBO-OPS TEAM