BENJAMIN M. STATLER COLLEGE OF
ENGINEERING AND MINERAL RESOURCES

2014 NASA/NIA RASC-AL Exploration Robo-Ops Student Challenge Final Report

West Virginia University
Statler College of Engineering and Mineral Resources

The Mountaineers

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1 Introduction

The 2014 Revolutionary Aerospace Systems Concepts Academic Linkage (RASC-AL) Exploration Robo-ops Competition serves to challenge university teams to build and demonstrate a planetary rover at the Johnson Space Center (JSC) Rock Yard. The competition supports the NASA mission "to engage the public in its missions and research" by requiring teams to include the public through the project development by posting updates to social media sites, hosting an informative project website, streaming video from the competition, and performing outreach activities [1].

West Virginia University (WVU) provided undergraduate and graduate students with two special topic courses focusing on the RASC-AL competition and robot fabrication. The team included students from both courses as well as cadets from Air Force ROTC Detachment 915. The team consists of students from varying disciplines including: aerospace, civil, computer, electrical, mechanical, and systems engineering as well as computer science.

The rover is composed primarily of additive manufactured 3D printed parts. Traditionally, additive manufacturing has proven useful in rapid prototyping and conceptual modeling [2]. The WVU rover pushes the envelope of additive fabrication by employing ABS in areas that would normally be machined using aluminum or other composites. Aluminum and carbon fiber were reserved for structure-critical areas. The mars rover features a six-wheel independent drive, four-wheel steering, and rocker-bogie suspension. Three wide angle Pan-Tilt-Zoom (PTZ) IP cameras were placed 120 degrees about the center of the rover. Each camera incorporates color detection and zoom capabilities. The rover also features an Intel i7-based Razer tablet PC [3], Arduipilot APM [4] for autonomous control and telemetry, and an AT&T CradlePoint wireless modem [5] for reporting to the server and receiving instruction.

A "base station" was also integrated into the final deployment package. The base station consists of a Verizon Cradle Point modem and PTZ camera. Once deployed the base station will prevent network dead zones and allow operators to search for additional samples. Additionally, the base station modem will provide the rover with communication redundancy via Wi-Fi in the event the AT&T modem experiences signal degradation.

This report defines the systems engineering process followed by the team, the development of the rover from requirements development to fabrication, and the overall system design broken down into three major subsystems: Drive, Sample Acquisition, and Control and Communications (C^2). It also details the team's Education and Public Outreach activities.

2 Systems Engineering

The Mountaineers Rover Team began the systems engineering process upon initiation of the project proposal effort, late in the fall 2013 semester. Initial requirements analysis lead to a preliminary design presented in our project proposal. The project kicked off upon reward of a competition spot in December and the development of the proposed design commenced in January 2014. This necessitated implementation of an aggressive nineteen week schedule and a solid systems engineering process. The systems engineering approach taken is based on the Capability

Maturity Model Integration (CMMI) process-improvement model for product development [6]. The CMMI model is made up of twenty-two process areas covering the entire life-cycle of a project as well as organizational process improvement [6]. The entire CMMI model was not implemented, but select components were employed to ensure timely and successful completion of the project. A breakdown of system requirements is provided in Appendix A.

The project required the contributions of students spread across different engineering departments, and with different academic concentrations. Coordination of the team necessitated development of a comprehensive project plan. Project planning increases overall quality and productivity through the estimation of work, determination of resources needed, production of a schedule, and identification and analysis of project risks [6]. Refer to Appendix B for the complete risk assessment matrix. The team's project plan details the project goals, deliverables, schedule, budget, risk mitigation, and team organization. The plan was developed per the *Project Planning* (PP) and *Project Management and Control* (PMC) process areas outlined by CMMI. The PP process area contains guidelines for establishing the basic components of a project plan including: project scope, schedule, budget, risk assessment, life cycle and team organization. The PMC process area provides guidelines for creating a project management plan through the definition of work products, or deliverables, that team management can use to track the project's progress.

2.1 Budget

The project budget was projected to be $26,000 based on projected travel and fabrication expenses. Funding for the budget was received through generous sponsorships from the NASA WV Space Grant Consortium, the WVU Benjamin M. Statler College of Engineering and Mineral Resources and the Lane Department of Computer Science and Electrical Engineering, as well as the stipend received from NASA/NIA. The budget covers all costs associated with fabrication and travel activities. The approximate overview division of funds is shown in Table 1. All fabrication expenditures were tracked by the faculty advisors and the team's Chief Financial Officer (CFO).

WVU Mars Rover Budget Overview		
		Estimated Expense ($)
Mechanical Parts and Drive Train		8000
Computer and Electronics		11500
Travel & Registration		5500
Total Expenditure		25000

2.2 Concept of Operations

The concept of operations describes the operator and system's progression during the mission to meet objectives [7]. The mission objective of the rover is to traverse the simulated planetary surface at the JSC Rock Yard, find and collect rock specimens or targets, and return with them to the Mars Hill starting area [8]. A basic set of rules have been defined to assure these goals are met. The diagram in Figure 1 illustrates these rules. First, the base station is deployed.

The co-operator will utilize the base station camera to search remote areas for stray targets. When a target is located it is added to the “target stack” and is assigned a quality factor. Target quality is based on the remaining trial time, current rover position, acquisition difficulty, and target color. Low quality targets are pushed to the queue for a later pick-up. When a target is spotted the timer is reset and the time is recorded. Targets in the queue are reevaluated for pick-up when the timer reaches set intervals.

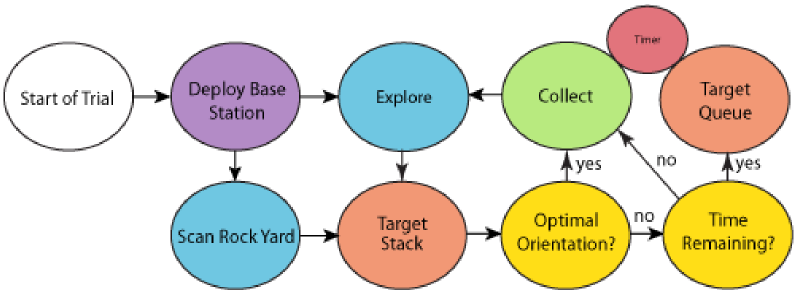


Figure 1: Concept of Operations Flow Chart

3 System Description

The rover is composed of three primary systems: drive, sample acquisition, and control and communications (C^2). Dividing the systems in this way allowed three specialized teams to work in parallel, allowing an accelerated schedule. The drive system comprises the basic mechanical and electromechanical components necessary for rover traversal. The rover's power subsystem includes lithium-ion rechargeable batteries, power supply, and various circuit protection components.

3.1 Drive System

The drive system comprises the basic mechanical and electromechanical components necessary for rover traversal. These include the chassis, sensory subsystem, and power subsystem components. The chassis includes the frame and drive elements such as motors, gearboxes, and wheels.

3.1.1 Chassis

The rover is built upon the rocker-bogie suspension system with a gearbox differential. This system does not use springs or pressurized elements, such as hydraulics or pneumatics, making the chassis more viable in most environments encountered during space exploration. Rather, it employs kinematics to maximize traction. The system is designed to evenly distribute the rover’s mass across all six wheels minimizing sinking in soft and uneven ground [9]. The rocker-bogie arms are constructed from carbon fiber tubes, providing a strong, lightweight foundation. The rocker-bogie connection members demonstrate the clever use of additive manufactured 3D printed ABS. Finite Element Analysis (FEA) in conjunction with static and dynamic stress testing was performed early in the rover design stage. The black “cap” shown in Figure 2 depicts a structural ABS junction.

Figure 2: Wheel Assembly using ABS

Propulsion is provided by six in-wheel brushed DC motors. These motors have an added planetary gearbox to provide adequate torque while still allowing the rover to move at a brisk pace. The rubber wheel diameter is 25 centimeters providing ample ground clearance and reliable traction. This ground clearance allows the rover to negotiate 12 centimeter tall obstacles per system requirements. Powerful servomechanisms, incorporating position-based control, steer the rover. The servomechanisms control the four corner-mounted wheels. The wheel assembly is shown in Figure 3.

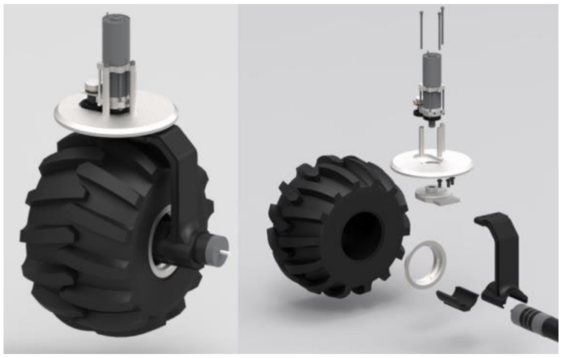


Figure 3: Computer model of wheel assembly

Brushed motors, small motor controllers, and potentiometers were used to create the servomechanisms that steer the rover. The servomechanisms control the four corner-mounted wheels. A four-wheel steering design allows a near-zero turning radius, enabling the rover to effectively maneuver around any obstacle.

3.1.2 Sensory System

3.1.2.1 Environmental Camera Array (ECA)

The ECA consists of a series of PTZ cameras used to visualize the area around the robot. One camera is directed towards the front of the robot and two cameras are mounted on the back of the rover one looking over each of the bogies. The resolution and frame rate of all cameras is individually selectable via the rover interface. The capability to switch between multiple stationary cameras allows the user to switch viewing sides instantaneously. Figure 4 shows the proposed ECA layout on the robot.

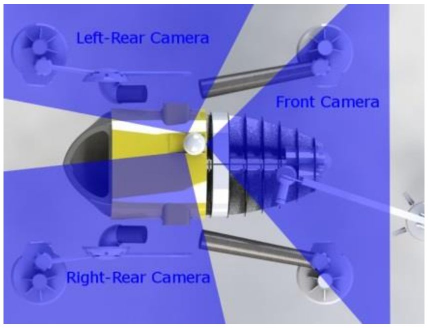


Figure 4: Operator Blind Spot Diagram

3.1.2.2 Object Identification System (OIS)

To improve the ability to visualize targets using the on-board cameras, a color-based OIS was implemented. The vision algorithm is performed on-board the rover using the high resolution images collected by the cameras. The processed images will then be subsampled to reduce the amount of data transmitted. This allows the visualization of objects of interest at a further distance while simultaneously reducing the strain on communications. The sensitivity of the object detection algorithm will be remotely selectable via the robot interface.

3.1.2.3 Navigation Assistance System (APM)

The primary navigation method for the rover is teleoperation, based on imagery transmitted from the onboard cameras. However, due to communication latency, controlling the rover in real-time is impossible. The rover employs an Ardupilot APM 2.6 autopilot system [4] which provides a precise state vector including global position, three-axis velocity, and three-axis altitude. This data allows the operator to know where the rover is in the operating environment as well as the goal position to be navigated to autonomously. The APM also provides the operators with power consumption information, way-point navigation and mission planning. The APM module is shown in Figure 5.

Figure 5: APM Module

3.1.3 Power System

The power system is designed to provide ample power for a full 60 minute competition run and isolate the power used for the motors from the C^2 components. It includes over-current protection for the control electronics and includes an external battery cutoff switch to allow for quick disconnect of power if necessary.

The power system is comprised of two batteries, motor controllers, a DC-DC voltage converter, circuit protection, and an emergency battery disconnect circuit. Two off the shelf Lithium-ion cordless drill batteries were used to power the rover and its components. The drive motors/controllers are directly powered by a 40V 4AH battery. An 18V battery in conjunction with the DC-DC converters are used to power the cameras, steering servo controllers/motors, sample acquisition system and support electronics. The Razer tablet is powered by an independent internal rechargeable battery.

3.2 Sample Acquisition System

The sample acquisition system includes a five DOF robotic arm with a bucket-scoop end-effector. The test results for the initial three DOF configuration demonstrated that the arm required additional articulation in order to properly position the end-effector for sample collection over an acceptable range of potential collection points. It was determined that without this additional freedom of movement, the system would rely too heavily on repositioning the rover while attempting to collect a sample, which would put additional strain on the battery supply and require increased coordination between operators.

Figure 6: Arm Assembly

The bucket-scoop design shown in Figure 6 proved to be successful during the initial testing phases, but the scoop's excessive weight and bulkiness was a major concern. This issue has been resolved by narrowing the oversized opening of the scoop and reducing construction material by placing slots across the majority of the scoop's surface area without compromising structural integrity. This serves to both reduce the weight of the scoop and allow for sediment to freely pass though these slots while collecting a sample. The collection bin has been placed adjacent to the arm on the front of the rover to minimize the time required to deposit a sample and stow/deploy the arm.

Dynamixel servo motors are used to actuate the five individual joints of the arm. These motors were chosen based on their ability to produce a large amount of torque in a small, lightweight package. The motors are connected in a daisy chain configuration, allowing commands to be sent and feedback to be received over a single USB connection. Each motor provides relevant feedback to the control system, including motor position, voltage, current, internal temperature, load direction, and moving status. Based on this feedback, the motors are configured to automatically disable torque application when a situation is encountered that could potentially damage the motors, such as a collision with an external object. The motors can then be safely re-enabled remotely by the operator after the situation has been resolved. Torque is also disabled while the arm is in a stowed position to reduce power consumption while the arm is idle.

The arm linkages are constructed from lightweight aluminum, which helps bring the overall weight of the arm, including the end effector, down to 1.37 kg. Fully extended, the arm has a total reach of 84 cm, and can effectively retrieve samples at a distance of 66 cm from the front of the rover. At this distance, the arm is capable of collecting samples weighing up to 1 kg. With this lifting capacity, the arm can reliably control samples of maximum size with speed and precision.

3.3 Control and Communication Systems

The rover has two unique independent drive modes. The initial drive mode is controlled by two computers: the Operator Control Unit (OCU) and the Robot Control Unit (RCU). The OCU is housed on a server at WVU. Its software is composed of two sub-packages: Control and the Camera Control Unit (CCU). The CCU is responsible for displaying imagery sent from the rover and base station. Each camera is designated its own IP address and operates independent of Control. IP cameras allow the visual feed to be accessed directly. Control is responsible for the status of the rover, drive commands, arm commands and telemetry from the rover. The OCU and CCU are also responsible for broadcasting and recording live USTREAM video streams. The OCU is designed to be a TCP/IP Server. The OCU software listens for connections from the rover, accepts connections, and transmits commands.

The RCU computer resides on the rover and provides robust control interfaces for the servo and motor controllers, monitors the state-of-health, adjusts robot performance relative to environmental conditions, and implements autonomous self-sustained protocols during loss of communication. The OCU and RCU are linked by a communications system incorporating a wireless broadband modem. Figure 7 shows the communications relationship between the OCU and RCU. The RCU is designed as a TCP/IP client

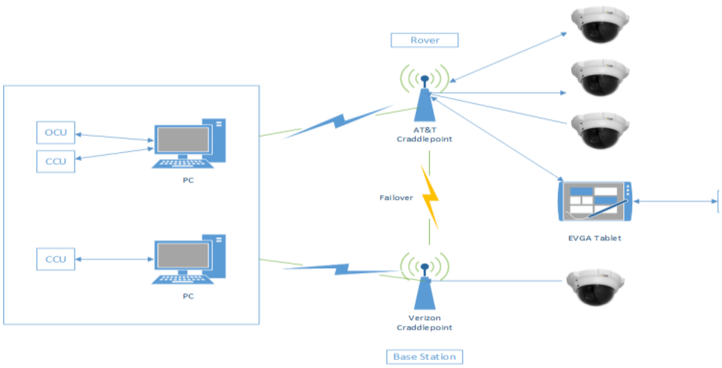


Figure 7: Communication connection diagram

that will continuously attempt to connect to the OCU if a loss-communication-disconnect were to occur.

The second method of operation is controlled autonomously via the on board Autopilot APM module. When in autonomous mode the robot is controlled by its current location and set way-points. Way-points are set by the operator via Google Maps and built-in OCU functions. The operator decides which driving mode the rover is executing via the OCU.

3.3.1 RCU Hardware

The 'brain' of the RCU is the on board computer. It receives and dispatches operator commands, interfaces to the robot's subsystems, and performs autonomous macros to aid the operators in driving the robot, navigating the Rock Yard, and operating the sample acquisition arm. The Razer Edge Pro gaming tablet [3] serves as the rover's main computer. It offers a 3.0GHz Intel Core i7 Dual core processor with Hyper Threading and 8GB of DDR3 RAM. The tablet provides the user with a 10.1" LCD touch screen for interacting with the RCU and other tools. Using a tablet eliminates the need for multiple components and excessive wiring. An external USB hub is used to dispatch instructions to the various components.

3.3.2 Motor Controllers

Roboteq SDC2160 controllers [10] were selected for the drive motors. The selection was based on performance history, dual output channels, and their ability to accept PWM signals as a form of input. Other forms of input are also available. The Roboteq controller can provide a maximum of 20A to each channel with a peak voltage of 60V.

3.3.3 OCU Hardware

The hardware for the OCU is comprised of three components: a server on the WVU network and two USB-connected Xbox 360 controllers [11]. The server has a graphics card capable of running three monitors to give the Control, the CCU, and arm operators their own displays.

3.3.4 Control and Communications Software

In order to meet the networking demands of the competition a number of design decisions were made. One guiding principle was to maximize the robustness of the networking equipment and reliability of the connection to the rover. Towards this end two CradlePoint COR IBR600 mobile broadband routers [5] were selected for use in the project. Each CradlePoint (CP) is connected to a different mobile provider's service, one using Verizon's network and the other AT&T's. This protects us from losing connection altogether in the event of losing connection to one of the networks. In order to take advantage of this two CPs are networked together so that should the primary CP lose connection, the secondary CPs network will be used.

To execute this setup, the primary CP has been installed onto the rover and makes use of a static IP address. This CP is connected to the rover and the three attached cameras and is connected to the secondary CP via a Wi-Fi bridge in case of network loss. The second CP is located at the base station and is used as a backup for the primary CPs network as well as connecting to the base station's camera.

As has been stated, emphasizing reliability and fault tolerance guided all networking choices that were made. The approach taken ensures the rover is operational even in the event of a connection failure of one of the networks. The CPs were chosen as they were affordable, allowed for Wi-Fi bridging between routers, and met our needs in regards to mobile broadband connection and bandwidth.

The wireless modem based network gives two options for socket-based communication: TCP or UDP. TCP is a connection-oriented protocol, in which two devices communicate between each other using a handshaking procedure. The handshaking procedure enables synchronization between the devices and methodology to request re-transmission of lost packet data to prevent data loss. UDP is a connectionless protocol without any handshaking procedure. The lack of handshaking is faster, but doesn't provide any data loss prevention.

Any data being transmitted from the rover (RCU) to the OCU is sent using UDP for these reasons:

1. It is not critical that every pack of telemetry data (GPS coordinates, compass heading, etc) reach the OCU. If a packet of telemetry gets lost, the packet will simply be replaced with more up-to-date data.
2. Video camera MJPEG frames are transmitted most efficiently using UDP. For the same reason mentioned in number one, if a single frame is lost it will simply be replaced with a newer frame.
3. Any unsolicited communications, such as transmitting of GPS telemetry and imagery, must be sent via UDP from the rover due to the limitations of the cellular wireless.

Rover commands from OCU to RCU, such as camera control and rover movement, are sent via a TCP link. The RCU server is a TCP/IP client that constantly connects to the OCU TCP/IP server. Once the connection has been established commands can be transmitted directly to the RCU from the OCU. This TCP/IP connection effectively opens a “tunnel” between the OCU and RCU that allows commands to be sent directly through the wireless firewalls and NAT.

Control of the bandwidth usage is provided by user-adjustable parameters for video and telemetry. The rate, at which the RCU sends telemetry and video updates, as well as the video quality, is adjustable on the fly. This dynamic capability provides maximum control over the distribution of bandwidth to allow for optimal balance depending on the network performance and the task at hand.

3.3.5 RCU Software

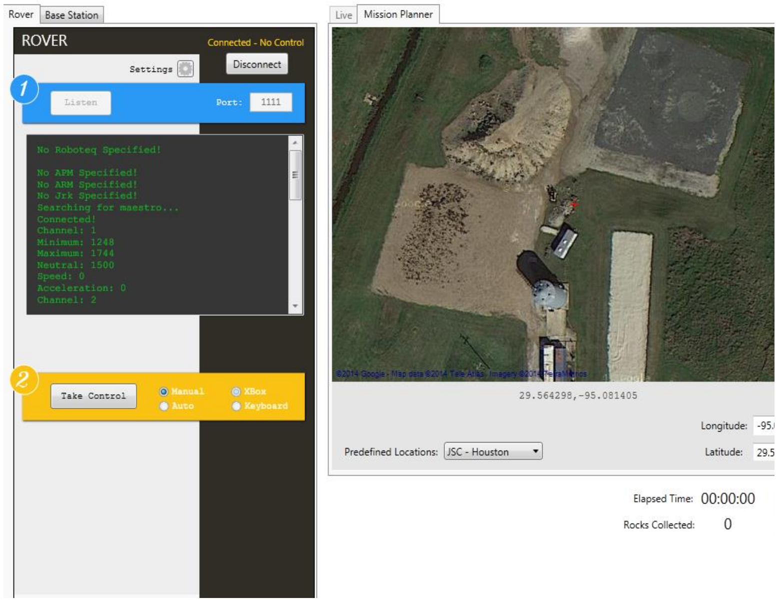
When the rover is operating in manual drive mode the RCU software is responsible for motor control, broadcasting telemetry to the OCU, and accepting commands from the OCU. The software is a heavily multi-threaded environment to provide optimal performance and interaction between each software component. The use of separate threads to handle operation of each individual component allows all of the components, which may operate at different update frequencies, to function harmoniously. The division of work amongst these classes and threads separates each component from the others, ensuring that the failure of a single one does not adversely affect the rest of the system. This way, a non-essential component could fail, but the rest of the rover can continue operation. The RCU packages all telemetry into a single packet which is serialized and transmitted via UDP to the OCU.

Safety mechanisms are implemented with watchdog timers in the device controller layer. This provides each controller its own timeout policy and enforcement procedures, and isolates the task from the communications system. The OCU and RCU maintain a heartbeat signal between them so the RCU does not continue operating under loss of the OCU. A timeout between the OCU and RCU will cause rover motion to cease by triggering the independent timeout policies for each motor controller.

3.3.6 OCU Software

3.3.6.1 Control

The primary function of the control software involves sending drive commands to the rover's RCU. The control software receives real-time updates relative to the rovers system status, telemetry, and global position. A satellite image of the course with the ability to place markers and way points is also included in the final software package (shown in Figure 8). The marker and way-point feature ties into the concept of operations defined in section two. New features are currently being added to the OCU control software that will allow the operator complete control over the robot on/off state as well as a rover icon showing real-time rover position relative to the way-points. Individual system status LED's, battery power meters, and electronic case temperature are also being incorporated into the final design.



Connected - No Control

Port: 1111

```
No Roboteq Specified!

No APM Specified!
No ARM Specified!
No Jrk Specified!
Searching for maestro...
Connected!
Channel: 1
Minimum: 1248
Maximum: 1744
Neutral: 1500
Speed: 0
Acceleration: 0
Channel: 2
```

29.564298,-95.081405

Longitude: -95.

Predefined Locations: JSC - Houston

Latitude: 29.5

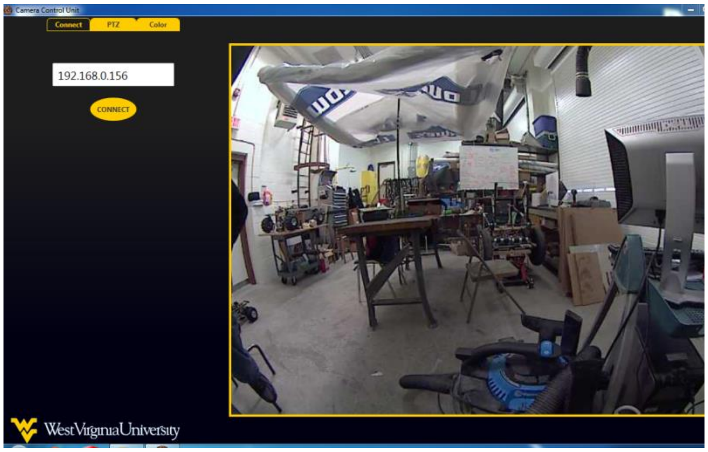
Elapsed Time: 00:00:00

Rocks Collected: 0

Figure 8: OCU Control Software Main Screen

3.3.6.2 Camera Control Unit (CCU)

The CCU is an interface that allows the control of the IP PTZ cameras. Since multiple cameras of the same type are used, each camera will have a separate instance of the CCU. Additionally, there also exists two different editions of the CCU due to the use of two different types of cameras (Axis and Panasonic). Currently the CCU contains three panels of control. The first panel



192.168.0.156

Figure 9: OCU CCU Main Screen

holds on the connection dialog that allows the user to enter the IP address of the camera. The second panel contains the PTZ control. This consist of four directional buttons, zoom control, and a home button. The third panel controls the rock detection algorithm which enhances the ability for a user to identify rocks. The algorithm functions by converting the RGB image to its HSV representation. Thresholding is then performed for each color using a defined range. The range for each color can by dynamically changed in real time from the CCU color panel. Dilation and erosion is applied to each thresholded image. A box is placed around each detected region and then the image is displayed to the user. Figure 9 shows the CCU in single camera mode.

4 Verification and Validation

In order to ensure that the rover would be competitive, all requirements defined in the requirements definition needed to be met. Verification, the process ensuring that "selected work products meet their specified requirements" [2] and validation, the process of "demonstrating that a product component fulfills its intended use when placed in its intended environment" [2] were planned and implemented throughout the system development. The verification process began with the Preliminary Design Review, ensuring that the system design met the defined requirements. Early verification processes included CAD modeling of key components, subsequent assembly of a fully functioning CAD model of the robot, and extensive calculations to verify that components selected for the rover would meet or exceed system requirements. Once the CAD models and component selections were vetted, mechanical prototypes were fabricated for testing of the drive system under load. Because additive manufacturing is relatively new it was critical that the plastic parts undergo extensive testing analysis and inspection. Figure 10 depicts a 3D printed rover wheel bracket being tested under a static load.

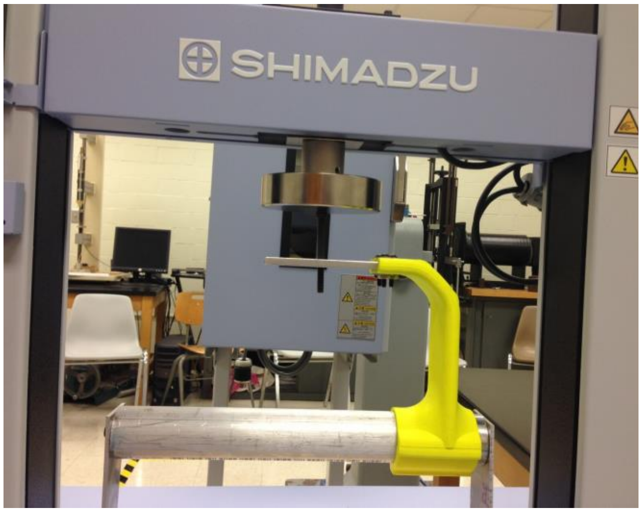


Figure 3: Wheel Bracket Load Testing

As system components were assembled, physical requirements were checked by observation to ensure that the rover being built would meet size and mass requirements. As systems became operational, unit tests were performed to check accordance with power and C^2 requirements.

The communications framework software has been thoroughly validated to ensure that communications between the operators and the rover will be robust and reliable. Testing has focused on the latency, throughput, and behavior of the wireless modem in various scenarios of rover system design. The primary data transmitted on the communications channel will be TCP command packets and Camera imagery. Latency for imagery was consistent at approximately one second; this was observed during a good 3G signal (3+ bars). An OOKLA speed test [12] from Morgantown to a Houston server resulted in an 8.27Mbps download and 14.57Mbps upload rate using the AT&T modem. The Verizon modem is still being tested for speed and functionality.

Degraded communications testing has been performed to evaluate the robustness of the software. Testing conditions included very poor 3G service and 1xRTT (approximately 0.15 Mbps) service. Because the RCU software is a TCP Client, it is responsible for always maintaining a communications link to the OCU server. This testing has demonstrated that if the communications fail, the RCU will repeatedly attempt to connect to the OCU automatically.

The rover, with full payload, was tested in the environments listed in the project requirements: rocks, sand, and a 33% grade. The rover was able to make multiple consecutive traversals across a 12 ft. sandbox, overcome a 4 inch rock, and ascend and descend a rocky 30% grade in addition to a 54% obstacle strewn grade. Tests were carried out with the operators quarantined in the server room, operating using rover video.

5 Education and Public Outreach

Educational outreach, an important component of the NASA Robotic Mining Competition, is a key goal in the 2014 team strategy. The Mountaineer Robotics Team (MRT) is determined to represent the project to the fullest through various service based opportunities in the community. This year the MRT supported many university events, local school visitations, and collaborated with various organizations to achieve the outreach goal. The largest of these outreach activities are further described in the following sections. The full breakdown of outreach activities, including man-hours, and students reached can be seen in Appendix C.

5.1 STEM in Schools

Technology Education for Kids (TEKids) is an after school enrichment program that educates kids in the areas of technology, engineering, computers, and physics using real-world applications. TEKids aims to provide elementary and middle-school aged students with the tools and support necessary to learn to successfully analyze and create innovative solutions to real-world challenges. In order to excite and inspire students from local elementary schools to learn STEM concepts, the MRT partnered with TEKids, providing mentors for after school programs four days a week. (See letter of recognition in Appendix C) As a product of this partnership, TEKids and the MRT were able to reach Mountainview Elementary School, Cheat Lake Elementary School, and North Elementary School. This program ran from February 4th, 2014, to March 24th, 2014, with each session lasting an hour or more and reaching 40 to 60 students.The students shown in Figure 11 covered different STEM concepts each week, with the overarching goal of building a Grow-bot, a

Figure 4: Lunabotics demonstration for TEKids

robot designed to monitor and care for a small garden or plant. Topics introduced included circuitry basics based on Ohms Law, Arduino programming, input and output circuitry, and an introduction to plant and soil sciences. Classes were hands on, with students forming small groups and working to complete each daily goal. Mentors provided encouragement and advice to students as needed, ensuring that work was done correctly and concepts were properly understood. On the final week of the program, students put all of the concepts they had learned into practice to construct and program a Grow-bot that used an Arduino and breadboard circuit to read environmental data and determine when the connected plan was in need of light or water.

Students proved to be both technologically savvy and eager to participate in the program. Likewise, they were excited to see and learn about the MRTs previous entries into the NASA mining competition. The Mountaineers plan to continue to teach and inspire as many local children as possible through partnerships with great organizations like TEKids.

5.2 First Lego League (FFL)

The MRT is able to directly apply robotics experience and knowledge throughout the year with various First Lego League (FLL) teams, scrimmages, and competitions. FLL is a robotic organization that engages students, ages 9 to 14, through the spirit competition with science and technology activities. Through robotic demonstrations, as well as lab and university tours, the MRT was able to show FLL teams what their future could hold. The MRT reached out to the NASA IV&Vs Educator Recourse Center (ERC), located in nearby Fairmont, WV, for help connecting with FLL. Through the ERC, the team was able to construct the competition playing fields, assemble the state championship Lego trophies, seen in Figure 12, and judge regional competitions and the state championship.

Figure 5: First Lego League Sponsors, Judges, and Trophies

5.3 Girl Scout Day

Each spring semester, the Society of Women Engineers at West Virginia University hosts a day dedicated to providing educational experiences to Girl Scout troops throughout the state. The goal of the event is to expose girls to the numerous STEM opportunities available to them at WVU. The MRT was invited to participate in hosting this event, creating robotic themed activities and demonstrating several robots. Girl Scout Day is always a fun-filled day for both the team and the scouts. Each year the MRT sets up a station to reach out to scouts that are curious about robotics and may be interested in pursuing STEM fields. For this event, Figure 13, the Mountaineers demonstrated the 2013 Mountaineer Lunabot, Mecanum, and the scouts' favorite, the Puppy Bot.

The Puppy Bot is a robot programmed to follow the color green, which is the color of the girls' sashes. This little bot was vigilant in its mission of tracking down all the green sashes in close proximity. The main purpose of this event is to show the Girl Scouts that they can create fun and exciting things with simple code and a little bit of hardware. For these scouts to have the opportunity to see and interact with the robots is one of the best ways to spark, or rekindle, an interest in STEM concepts.

Figure 6: Girl Scout Day demonstration

5.4 8th Grade Career Day of Monongalia County

The WVSGC asked the MRT to join them in attending the Monongalia County 8th Grade Career Day. Monongalia County's Career Day introduces many different careers split into corridors based upon their specialty, such as medical, safety, and technology. Over 500 eighth graders from across the county were in attendance to get a brief look into the different career paths that they could pursue. The Mountaineers brought their popular Puppy Bot and the 2013 competition Lunabot, seen in Figure 14. The WVSGC also brought other fun and educational hands-on activities and materials. Students had the opportunity to ask questions about the robots, college, and the job opportunities within the field. A few lucky 8th graders were able to drive the award winning Lunabot around the technology corridor.

Figure 7: 8th Grade Career Day Lunabot Demonstration

5.5 Out of Class Experience (OCE)

The West Virginia University Benjamin M. Statler College of Engineering and Mineral Resources requires all freshmen engineering student to attend a minimum of five Out of Class Experience (OCE) events each semester. The OCE events are designed to expose the new students to a broad spectrum of engineering fields and career paths to help them choose a field of study. The MRT represents Aerospace, Civil, Computer, Electrical, and Mechanical Engineering by showing the individual subsystems that each field covers. The events include a technical presentation to show a more in depth view of what the team does, as well as a live demonstration of the robot's capabilities.

5.6 Local School Visitation Days

Each year, whether through former contacts or by new requests, the team makes time to visit with local schools. The MRT is made up of passionate members that want to help introduce robotics to their hometowns and individual regions. The students are able to take the robots and experiences back to their schools, showing classmates what an individual from their area is able to accomplish. At these events students talk about their experiences and introduce the team and robots, Figure 15. Focus is given to engaging students in discussion and encouraging critical thought and questions. Additionally, several robots are taken for operational demonstrations.

Figure 8: Local School Group Photo

5.7 Summary of Team Mountaineers EPO

Through hard work and dedication, the MRT was able to maintain and build upon a highly effective outreach program. Starting only two weeks after returning from the 2013 competition, the MRT reached out to and mentored more than 4081 students over 648 man hours throughout the year. This great accomplishment was made possible due to the experiences, relationships, and contacts made during the previous competitions.

6 Bibliography

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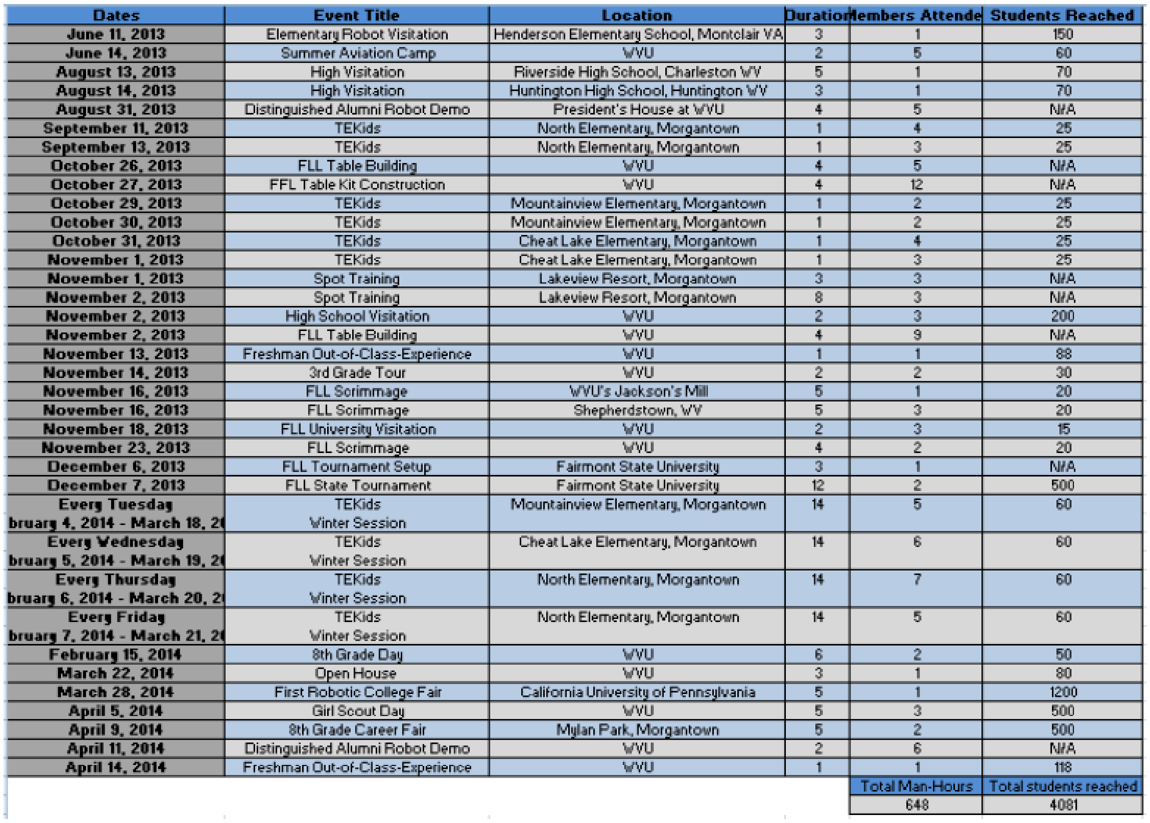
Appendix A: System Requirements Document

ID	Category	Requirement	Required/ Objective
1	Physical	Robot shall fit within a 1 x 1 x 0.5 meter container	R
2	Physical	Rover should take less than 30 minutes to deploy	O
3	Physical	Mass shall be less than or equal to 45 kilograms	R
4	Physical	Rover shall be weatherized to withstand light rain	R
5	Operational	Rover shall traverse obstacles 10 cm in height	R
6	Operational	Rover shall ascend and descend slopes up to 33% grade (18.26 degrees)	R
7	Operational	Rover shall pick up rocks 2 - 8 cm in diameter and mass ranging from 20-150 grams	R
8	Operational	Rover shall transport at least 5 rocks of 150g mass, 8 cm diameter	R
9	Operational	Rover should transport at least 30 rocks of 150g mass, 8 cm diameter	O
10	Operational	Rover shall identify the colors red, purple, blue, green, yellow, orange	R
11	Operational	Rover shall traverse sand for distances exceeding 20 feet	R
12	Operational	Rover shall operate for 1 hour on battery power	R
13	Operational	Rover shall supply all necessary data for operation including, but not limited to, video, sensor feedback, GPS	R
14	C^2	Rover shall communicate via Verizon Broadband Card	R
15	C^2	Rover shall be controlled from the WVU campus while operating at Johnson Space Center	R
16	C^2	Rover shall be controllable with a data rate of 0.6 MB download, 0.4 MB upload and data transmission latency of 300 ms	R

Appendix B: Risk Assessment Matrix

Risk	Category	Effect	Mitigation
LiPo/LiFe battery discharged below safe voltage	High	Power system fails, causing loss of drive, communications and/or excavation hardware.	Utilize control hardware to prevent over-discharge.
Control or communications power failure	High	If power fails to this system, control of the rover will be lost, rendering it useless and unsafe if motors are in on state.	Utilize separate battery, ensure total draw does not exceed 9A (10A fuse). Use high quality DCDC converter. Ensure motors stop if control is lost using watchdog timer.
Camera Fails	Moderate	If any of the camera fail it can hinder the operability of the rover	Use multiple cameras to provide redundancy, If one fails, continue with the others in degraded state
Arm Servo Fails	Moderate	If an arm servo fails the arm may be rendered inoperable and not be able to acquire samples	Use multiple servos at high-torque joints so that arm may be able to continue to pick up lighter samples. Monitor load on each servo and drop samples that may exceed capability
Wheel drive motor failure	Low	If a motor fails, the attached wheel cannot propel the system. This can reduce the lifetime of the remaining motors and gearboxes since they have to work harder.	Utilize independent drive on each wheel so that if 1 fails the other 5 can still propel the system in a degraded state.
NAS fails	Low	If the NAS fails rover tracking and assisted movements will not be available	Operate on vision only in degraded mode, use visual keys to identify where rover has been and hand-log

Appendix C: Supplemental Outreach Material



Dates	Event Title	Location	Duration	lembers Attende	Students Reached
June 11, 2013	Elementary Robot Visitation	Henderson Elementary School, Montclair VA	3	1	150
June 14, 2013	Summer Aviation Camp	WVU	2	5	60
August 13, 2013	High Visitation	Riverside High School, Charleston WV	5	1	70
August 14, 2013	High Visitation	Huntington High School, Huntington WV	3	1	70
August 31, 2013	Distinguished Alumni Robot Demo	President's House at WVU	4	5	N/A
September 11, 2013	TEKids	North Elementary, Morgantown	1	4	25
September 13, 2013	TEKids	North Elementary, Morgantown	1	3	25
October 26, 2013	FLL Table Building	WVU	4	5	N/A
October 27, 2013	FFL Table Kit Construction	WVU	4	12	N/A
October 29, 2013	TEKids	Mountainview Elementary, Morgantown	1	2	25
October 30, 2013	TEKids	Mountainview Elementary, Morgantown	1	2	25
October 31, 2013	TEKids	Cheat Lake Elementary, Morgantown	1	4	25
November 1, 2013	TEKids	Cheat Lake Elementary, Morgantown	1	3	25
November 1, 2013	Spot Training	Lakeview Resort, Morgantown	3	3	N/A
November 2, 2013	Spot Training	Lakeview Resort, Morgantown	8	3	N/A
November 2, 2013	High School Visitation	WVU	2	3	200
November 2, 2013	FLL Table Building	WVU	4	9	N/A
November 13, 2013	Freshman Out-of-Class-Experience	WVU	1	1	88
November 14, 2013	3rd Grade Tour	WVU	2	2	30
November 16, 2013	FLL Scrimmage	WVU's Jackson's Mill	5	1	20
November 16, 2013	FLL Scrimmage	Shepherdstown, WV	5	3	20
November 18, 2013	FLL University Visitation	WVU	2	3	15
November 23, 2013	FLL Scrimmage	WVU	4	2	20
December 6, 2013	FLL Tournament Setup	Fairmont State University	3	1	N/A
December 7, 2013	FLL State Tournament	Fairmont State University	12	2	500
Every Tuesday bruary 4, 2014 - March 18, 2	TEKids Winter Session	Mountainview Elementary, Morgantown	14	5	60
Every Wednesday bruary 5, 2014 - March 19, 2	TEKids Winter Session	Cheat Lake Elementary, Morgantown	14	6	60
Every Thursday bruary 6, 2014 - March 20, 2	TEKids Winter Session	North Elementary, Morgantown	14	7	60
Every Friday bruary 7, 2014 - March 21, 2	TEKids Winter Session	North Elementary, Morgantown	14	5	60
February 15, 2014	8th Grade Day	WVU	6	2	50
March 22, 2014	Open House	WVU	3	1	80
March 28, 2014	First Robotic College Fair	California University of Pennsylvania	5	1	1200
April 5, 2014	Girl Scout Day	WVU	5	3	500
April 9, 2014	8th Grade Career Fair	Mylan Park, Morgantown	5	2	500
April 11, 2014	Distinguished Alumni Robot Demo	WVU	2	6	N/A
April 14, 2014	Freshman Out-of-Class-Experience	WVU	1	1	118
				Total Man-Hours	Total students reached
				648	4081

TEKids
TECHNOLOGY EDUCATION FOR KIDS

TEKids
3041 University Avenue
Morgantown, WV 26505
(724) 835-4370

April 14th, 2014
RE: Community Partnership and Outreach

Mining Robot/RASC-AL MARS Rover
West Virginia University
PO Box 6109
Morgantown, WV 26506-6109

To Whom It May Concern,

TEKids is an afterschool enrichment program which serves the community by providing Science, Technology, Engineering, and Mathematics (STEM) courses to elementary and middle school children, connecting students to West Virginia's high technology industry. TEKids is comprised of certified teachers, committed volunteers, and field experts actively collaborating with the community to instill skills and *ignite imagination in the next generation.* Through partner community schools, businesses, and organizations, TEKids programs enable hands-on problem-solving, community immersion, and STEM exploration opportunities for our youth.

Throughout the TEKids session, students accelerate learning and move beyond concepts to create visible, tangible results. At the end of the session, the students present their projects at a large community culmination event. Students gain a higher level of confidence, demonstrate broadened skill sets, and internalize career aspirations in STEM fields.

The Mining Robot/RASC-AL MARS Rover Team has partnered with TEKids to deliver programs which directly support STEM education in our community. Their partnership with the TEKids program comprises curriculum development and implementation through field experts and student demonstrations, considerable effort and involvement in the coordination/management of volunteers for each session, and community panel participation at culmination events. Each student volunteer spends over 20 hours per semester directly teaching elementary-aged students in the TEKids after school community program. This year twenty-six members from the Mining Robot/RASC-AL MARS Rover Team became student volunteers in the classroom. Countless hours are also dedicated to the coordination of volunteer resources and STEM curriculum development. In the 2013-2014 academic school year, *over 400 students* were enrolled in the after school program and were *direct beneficiaries* of the Mining Robot Team's dedication.

The WVU Mining Robot student volunteers' extraordinary commitment and enthusiasm in the classroom are unparalleled. They are truly leaders who inspire and serve as role models to the children. Their direct service has made a tremendous impact on the youth of our community by instilling confidence and providing an education to compete and lead in the modern world.

Sincerely,

Natalie Aggarwal
Program Director