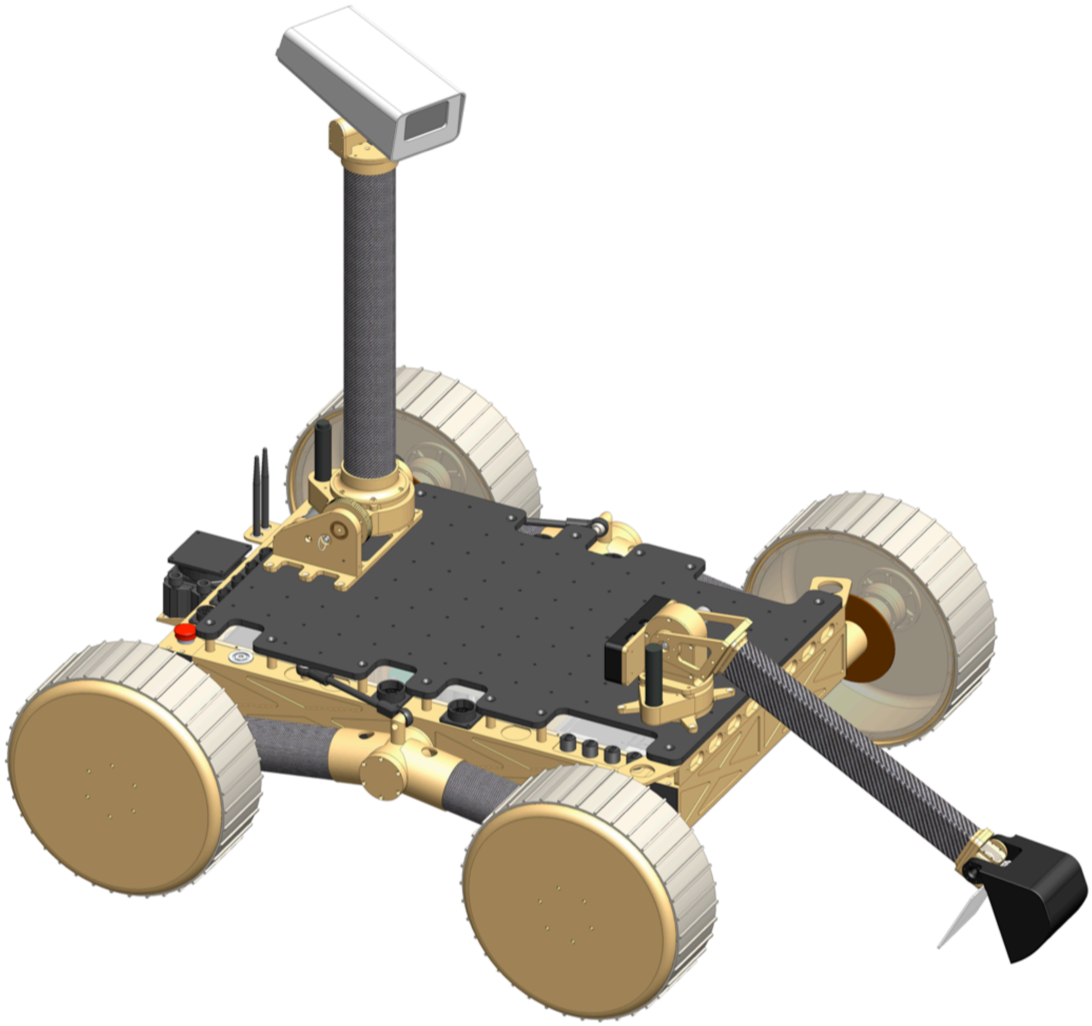
ORYX 2.0

A PLANETARY EXPLORATION MOBILITY PLATFORM

Robotics & Intelligent Vehicles Research Laboratory



WORCESTER POLYTECHNIC INSTITUTE ~ TECHNICAL REPORT
NASA AND THE NATIONAL INSTITUTE OF AEROSPACE
2012 RASC-AL EXPLORATION ROBO-OPS COMPETITION

PROJECT TEAM

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1 Introduction

The design of ORYX 2.0 was inspired by its predecessor ORYX 1.0, our rover from the 2011 RASC-AL Exploration Robo-Ops competition. While ORYX 1.0 was successful in the competition, several limitations were observed in mobility, sample detection, sample acquisition, and controls; all of which were addressed in ORYX 2.0 through new design features, increased ruggedness, and more advanced software.

To improve mobility a 4-wheel skid steering passive averaging suspension was selected. The added ground compliance greatly increases stability, traction, and the ability to traverse obstacles larger than a wheel diameter. The minimalistic suspension design also reduces mass and complexity by requiring a fewer number of actuators and mechanical components, compared to other suspension architectures such as the rocker-bogie.

Many issues related to sample collection were also addressed with ORYX 2.0. To aid in locating rock samples a deployable pan-tilt high definition camera is used to survey the landscape. Additionally, color blob detection algorithms find and circle colored rocks and alert the operator of their location. The successful arm and end-effector design of ORYX 1.0 was largely reused on ORYX 2.0. The low degrees of freedom and large scooping gripper create a lightweight, yet reliable system. The new arm on ORYX 2.0 features higher torque actuators and better controls to assist in sample acquisition.

Furthermore, a new graphical user interface (GUI) makes ORYX 2.0 easy to drive. Multiple HD video streams can be viewed at once or toggled between. Telemetry such as component and system temperatures, battery status, motor statuses, chassis orientation, and suspension angles, are all relayed back to the user through the GUI. Finally, the GUI allows for multiple parameters controlling various aspects of ORYX 2.0 to be changed real time, making for a highly adaptable and modular system.

This report will review these core design features in more detail, discussing what decisions were made and how they were ultimately implemented through the manufacturing, assembly, and validation processes. Specific attention was also given to making ORYX 2.0 reconfigurable and adaptable, something that is beneficial for the competition and also allows ORYX 2.0 to be configured for other purposed or mission scenarios. Design features related to this adaptability and easy-to-use payload interface are discussed.

Public outreach was also a key goal of our team, aiming to incite interest in science, technology, robots, and space exploration through a technical blog and specific outreach events. This report will discuss these public outreach efforts in more detail.

2 Mobility Platform

As previously mentioned a passive averaging suspension was selected, as it has many of the benefits associated with ground compliance while also reducing complexity and the number of components. The core components of the rover mobility system consist of the chassis, rocker linkages, differencing arm, and rocker arm, all of which are shown in Figure 1.

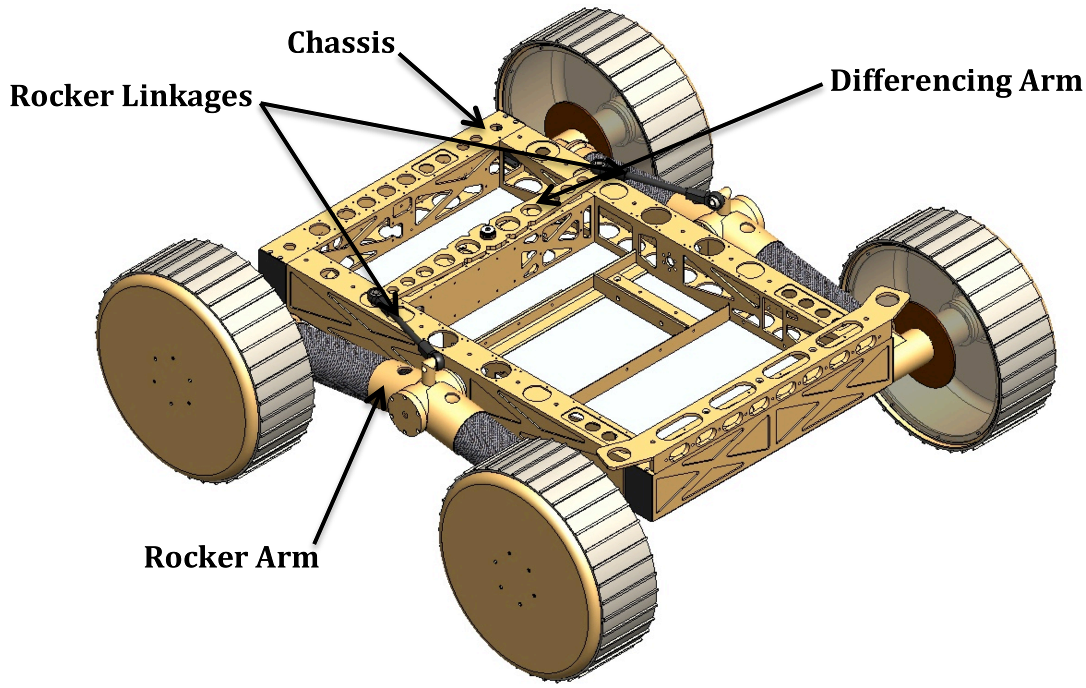


Figure 1: Chassis and Rocker Suspension Design

The chassis is made from rectangular aluminum tube, and consists of five rails welded together to form the core structure. The rocker linkages and differencing arm make up the mechanical linkage that connects each rocker arm through the chassis. To achieve the averaging effect the linkage constrains the rocker arms so that they rotate equally in opposite directions, as shown in Figure 2. This passive degree of freedom ensures that all four wheels remain in contact with the ground which greatly improves stability and traction. The two rocker arms on either side of the chassis support two wheels each.

The rocker arms are attached to the chassis through an aluminum shaft, which is supported by two tapered roller bearings housed in the central welded assembly. Carbon fiber tubes are structurally bonded with Loctite 9430 to each side and are used to connect the wheel modules to the central pivoting assembly, forming the main structure of the rocker arms.

In considering slope traversal we looked at the location of the center of mass relative to the polygon on stability in order to estimate the tipping angles. Figure 3 shows the rover's polygon of stability to be a rectangle that is 86 cm wide and 66 cm long. The complete CAD design shows that the center of gravity is ~ 16.9 cm from the ground and almost perfectly central to the polygon of stability; the resulting theoretical tipping angles are 69.0 degrees when tipping over the width and 63.2 degrees over the length. Both of these figures are well above the 33% grade requirement, however, actual limitations on slope traversal will likely be traction limited and dependent on the specific terrain.

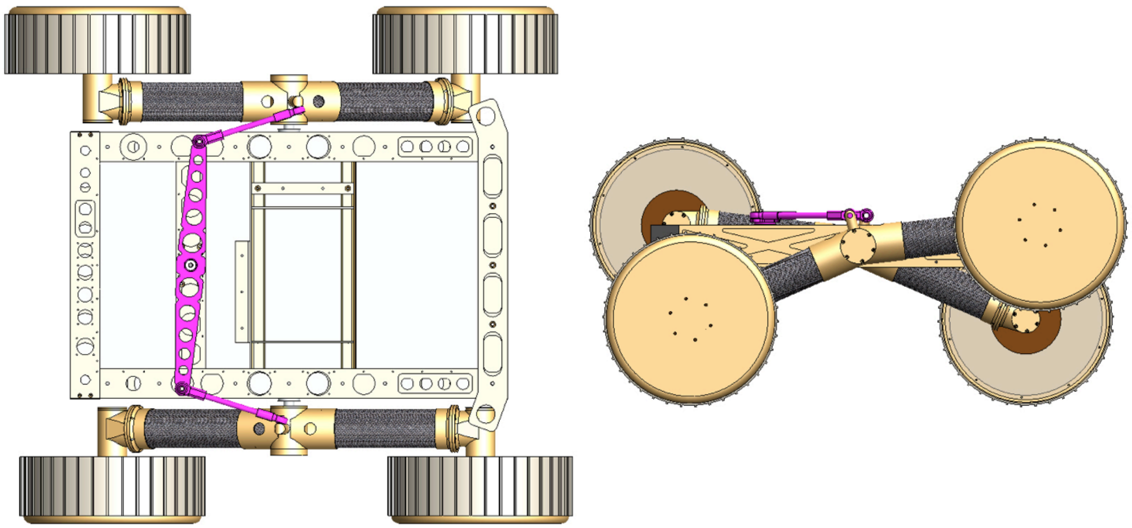


Figure 2: Passive Averaging Linkage System at Maximum Angle (shown in pink)

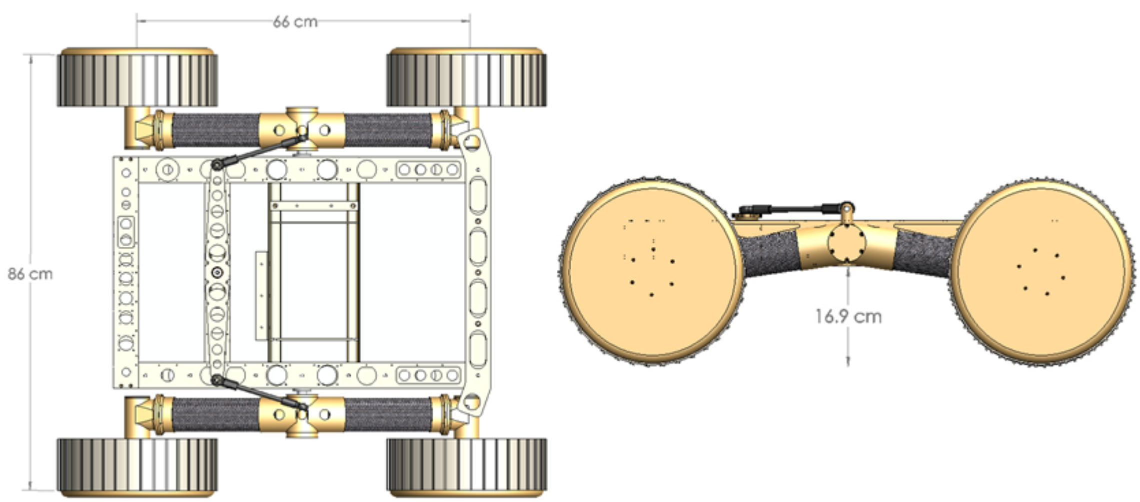


Figure 3: Rover Dimensions and Ground Clearance

Located at each end of the rocker arm is a circular flange with a bolt pattern. The idea behind this design is to create a simple mechanical interface that the wheel modules can bolt onto. This creates a modular design that allows self-contained drive modules to easily be installed or removed; which can be important if replacing broken components or new drive motors are desired to change performance.

The self-contained sealed drive module design is shown in Figure 4; with the entire CAD shown on the left and a section view on the right side to reveal internal components. Like most other mechanical components the drive modules are completely sealed for protection against water and dust ingress. A waterproof 19-pin connector is used to connect wires for the motor, encoder, and temperature sensor to the EPOS2 motor controls and Arduino.

The main structure of the drive module is a thin walled aluminum tube, which forms the basis of the weldment. An end cap is attached to the back of the assembly for environmental protection, and the front consists of a series of stacked parts that house the support bearing and lip-seal, as seen in Figure 4. A wheel hub is secured through this assembly with a retaining ring clip. The wheel hub also has a bolt circle of tapped holes for connecting a wheel, making it easy to install or replace wheels.
Shown in gray in Figure 4, the drive motors selected were Maxon's 300W 24V 4-pole brushless DC motors. Selected for high reliability and long service life these motors directly drive each wheel through a 156:1 planetary gearhead reduction; providing enough pull force to lift one quarter of the rover's weight and enough speed to travel up to 1.2 m/sec.

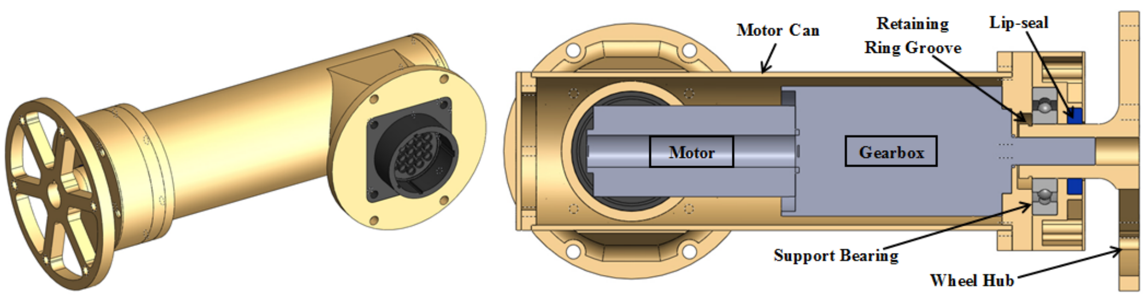


Figure 4: Design of Drive Motor Module: Whole View (left) Section View (right)

In the design of the wheels, billet and composite approaches were considered, however due to constraints in time and manufacturing resources we selected a more off-the-shelf solution. The main structure of the wheel is a 1/16" thick spun aluminum cap, 12" in diameter. This is a standard part that can be bought, and required a minimal amount of post machining to complete the wheel. With the spun aluminum cap forming the entire structure it was only necessary to drill the bolt hole pattern into the face of the wheel for connection to the drive module. For added support a ring with an "L" profile was machined and bonded into open side of the wheel, also providing a means of mounting on the plastic debris shield.

The last step in the wheel design was selecting tread. Based on tread from the MER rovers and other research regarded rover tread, we selected tread with 1/8" grousers spaced ~ 1" apart; since this was offered by a standard 4" wide nitrile conveyer belt. This was attached to the aluminum wheel using 3M VHB. The resulting wheel design is shown in Figure 5.

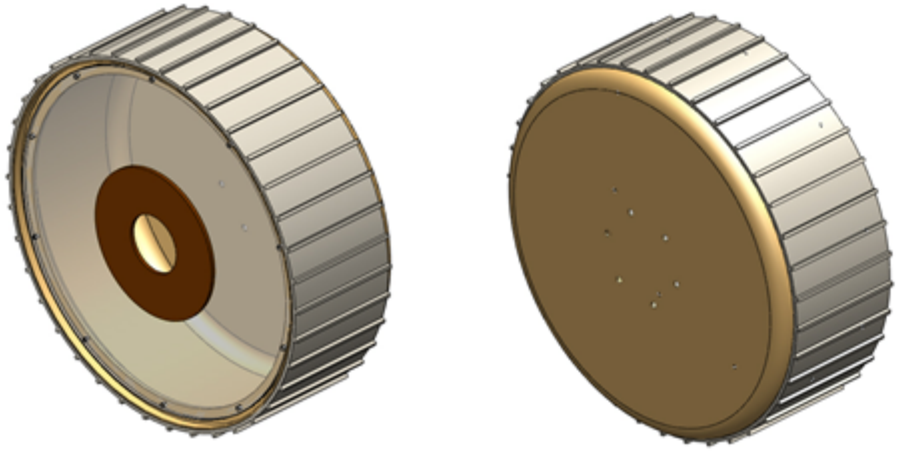


Figure 5: Wheel Assembly Front and Back Views

Following the ruggedized design, all electronics are fitted inside the chassis, which is sealed on the bottom with an aluminum sheet, and sealed on the top with two pieces of thin Mylar sheet (not shown in Figure 6). Since all other ports in and out of the chassis use water-resistant connectors, the chassis provides good environmental protection for all internal electronics. Because the chassis is sealed, there is no air flow available to cool high-power electronics. To cool the quad Core i5 processor a liquid cooling system was utilized, and the convector is placed outside the chassis in the rear.

Figure 6 shows the layout of electronics within the chassis. In general, the four EPOS2 motor controllers are in the back, power electronics are in the middle, and the main computer and related electronics are in the front. Maxon's EPOS2 motor controllers were selected for their easy interface to Maxon's motors and convenient reliable motion control.

Power electronics consist of a lithium-ion battery, battery management system (BMS), contactor, and 5V/12V power regulators. The battery was made from individual cells, creating a custom pack with a nominal voltage of 22.5V and 35Amp-hrs; providing approximately three hours of operating time. The battery management system is used during charging to balance the six cell packs in series. The main contactor is controlled by the rover power switch, and opens and closes the connection to the battery. Lastly, 5V and 12V regulators distribute those voltages to certain components and also make them available to the user for payloads.

The main computer is a mini ITX motherboard with a quad Core i5 processor. This high-power processor was selected so that intensive video processing and compression such as Theora could easily be achieved. Related accessories include a SSD, USB hub, ITX power supply, and Wi-Fi radio. Wi-Fi hardware is included for testing in locations where version 4G is not available.

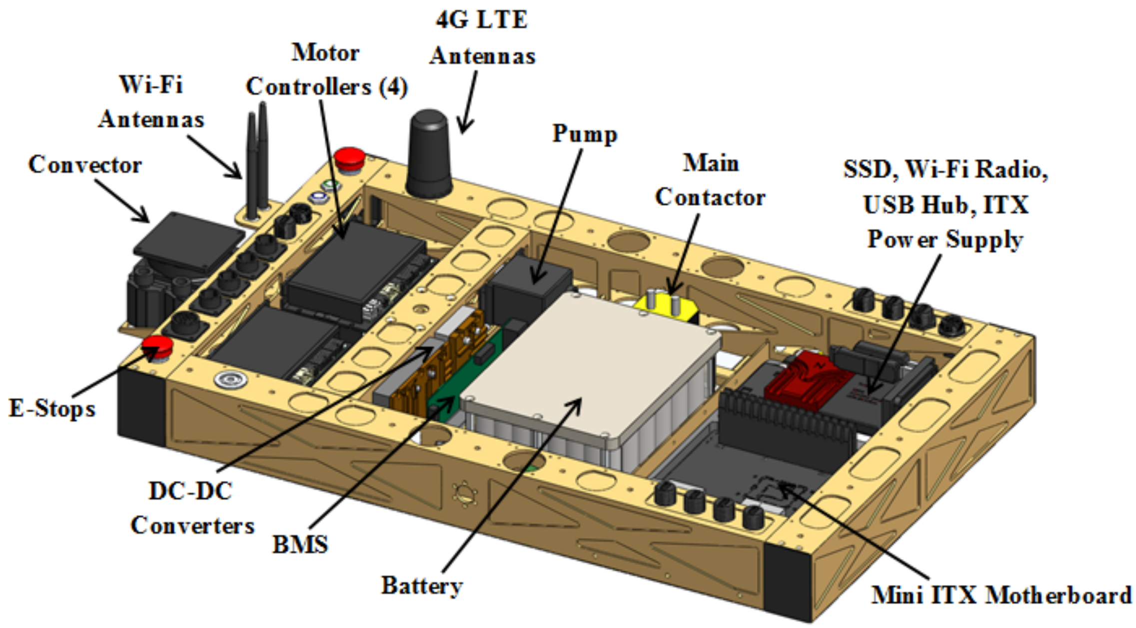


Figure 6: Electronics Layout

3 Payload Integration

A key design goal of ORYX 2.0 was incorporating features that made payload integration quick and easy. Many rovers and their payloads are developed in a parallel process, where the rover design effects the payload and the payload design effects the rover, so that both designs require accommodations and simultaneous design. While this approach is good for optimization in mission specific scenarios, it results in rover designs that are not adaptable to different tasks.

While the tasks for the Robo-Ops challenge were clear and non-changing we decided to design ORYX 2.0 with features that made it reconfigurable by easily accepting payloads. This made design easier because various payloads could be developed separately from the rover. Additionally, it allows payloads to be completely replaceable and independent of the rover design, making it possible to easily change out payloads for a better or new design. Furthermore, it makes ORYX 2.0 more adaptable, since different payloads can be developed for different missions.

For payload integration features we took a holistic approach, considering all aspects such as computing resources, data/power connections, and the mechanical interface. To make payloads easy to attach mechanically a flat top plate with a standard grid of tapped holes provided a large flat surface to mount to, as seen in Figure 7. Around the perimeter of this top plate are USB, Ethernet, and power ports that carry 5V, 12V, and battery voltage.

Figure 7 is top view of the rover, which shows the layout of USB, Ethernet, and power ports. On the front of the rover there are seven USB connections and 1 Ethernet, and on the back there is one USB, one Ethernet, and four power connections. Each of the four power plugs carries 5V, 12V and 24V. Also, all connectors are water resistant and have sealing caps for when they are not in use. The result is easy access to power and a convenient way to connect to the computer through USB or Ethernet, which should accommodate a wide variety of payloads.

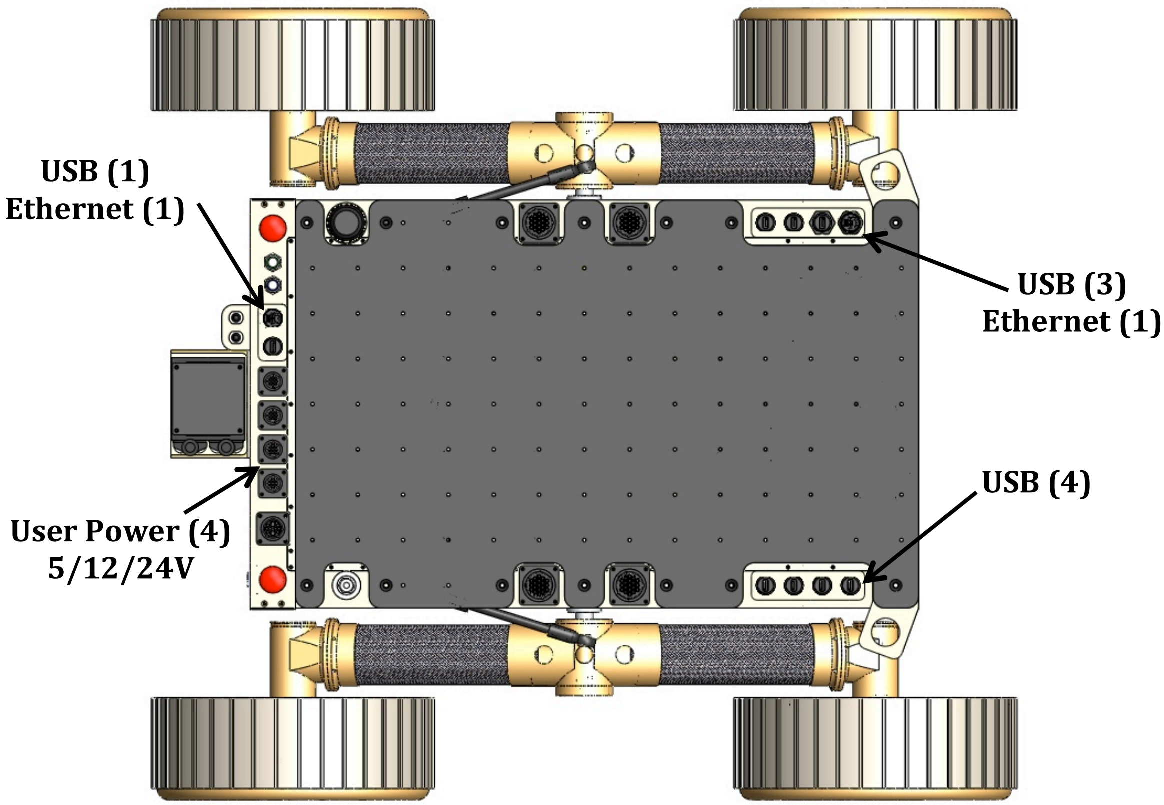


Figure 7: Top View of Top Plate and Available Connections

In terms of a software framework and computing power, ORYX 2.0's quad Core i5 has a large amount of computing power that can be utilized by payloads. We also selected the Robot Operating System (ROS), as the software framework, since its communication structure and distributive nature allows for modular software design.

The end result was a highly adaptable rover that could accommodate a wide range of payloads. For the Robo-Ops competition an arm and pan-tilt camera payloads were made and integrated with ORYX 2.0, and are discussed in more detail in Section 4, and the Payload Development Guide document is in Appendix B.

4 Sample Pinpoint and Acquisition Payloads

Equally important as acquiescing samples is having the ability to locate them. A feature that ORYX 1.0 lacked was assistive software for finding colored rocks. Additionally, the low resolution images at one frame per second made visually finding rocks very challenging.

Improving upon these limitations, ORYX 2.0 has two 720p video streams that can be transferred at ~10 frames per second over Verizon 4G by using Theora compression. One camera is located on the arm and the other is placed on top of a deployable mast that also has pan and tilt functionality. The design of this camera payload is shown in Figure 8. The bottom right picture in Figure 8 shows the motorized deploying stage and the panning degree of freedom. A carbon fiber tube connects the camera and tilting actuation assembly to the base. All actuator is done with Maxon brushless motors controlled with EPOS2 controllers. The deploying stage allows ORYX 2.0 to remain within the 1m x 1m x 0.5m size limit, and then expand to provide a higher perspective more ideal for surveying the landscape and locating colored rocks.

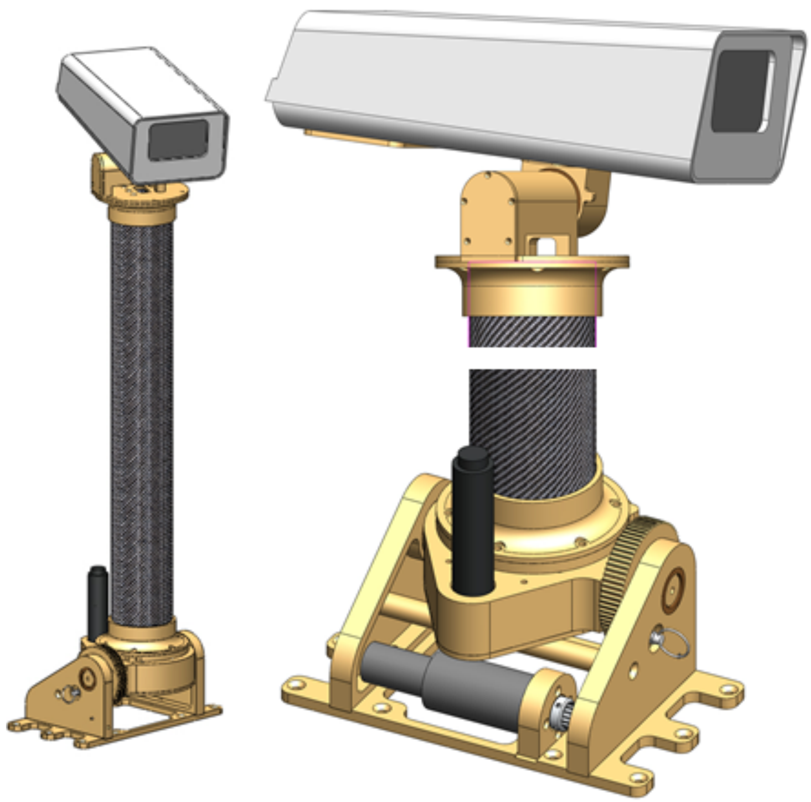


Figure 8: Deployable Pan-Tilt HD Camera Payload

While this camera greatly helps in locating rocks, ORYX 2.0 also uses assistive software, developed specifically for locating the colored rocks for the competition. The software looks for specific colors at adjustable thresholds, and then undergoes blob detection, overlaying circles on the graphical user interface (GUI) to alert the operator to the rocks location. Figure 9 shows a screen shot of the GUI during sample acquisition testing in gravel substrate. As seen, it successfully overlays circles on the yellow rock and is beginning to circle the orange rock. This software has been tested in many scenarios and has been found to be incredibly useful for locating rocks.

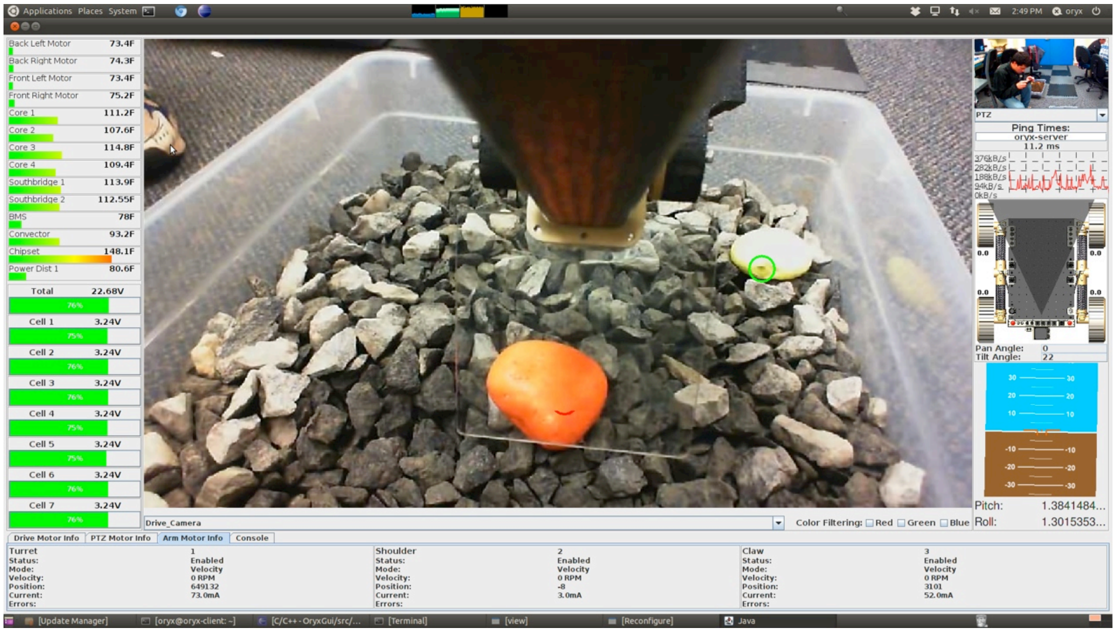


Figure 9: Screen Shot of Graphical User Interface during Sample Collection

In addition to this GUI feature, there is much other telemetry conveyed to the user to help provide situational awareness and information on the system health. In the upper left corner of Figure 9 all critical temperatures are displayed so that the user can confirm all components are within same limits. Similarly, below this panel is information on each of the battery cell voltages, providing an estimation of remaining operating time. On the right side of the GUI is a small window of the other video stream which is easily toggled between the main viewing window. Under this is a bandwidth monitoring graph followed by information on the wheel locations and the pitch and roll of the chassis to aid in providing situational awareness. Lastly, the bottom strip of the GUI provides information on the velocity, current draw, position, and state of all motors. Overall the GUI provides relevant information to the operators in a way that makes ORYX 2.0 easy to drive and monitor.

To physically collect the rock samples and arm payload is used with a similar design to ORYX 1.0. This low degree of freedom arm has one panning joint and shoulder joint at the base, with a scoop-like gripper at the end. The result is a low mass arm that is easy to control and successful at picking up rocks on most terrain. The large scoop design reduces the accuracy that is required when picking up rocks and also allows the operator to dig into the dirt (taking a divot) or pinch the rock on the surface. These different grasping options make this design effective at securing rocks on different terrain with different properties. In an effort to simulate conditions at JSC Rock Yard we tested our arm on sand, gravel, and packed dirt, and were able to pick up rocks from all three. Figure 10 is a picture in which the arm is collecting an orange rock on a gravel substrate.

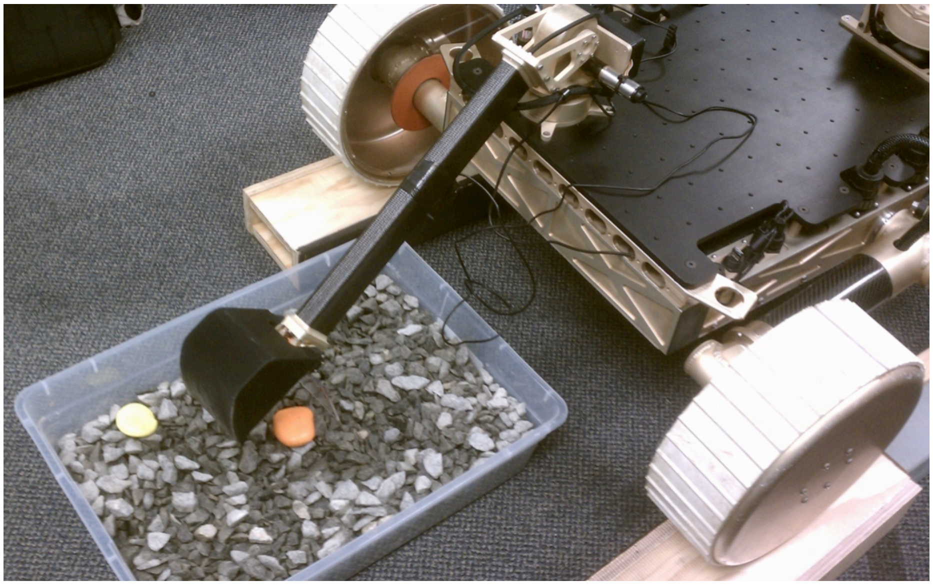


Figure 10: Testing the Arm Payload on Gravel

5 Manufacturing, Integration, and Qualification

With the design of ORYX 2.0 complete, specific attention was paid to ensure high standards of quality in all stages of manufacturing, assembly, and integration. Extensive testing was also done on subsystems and completed systems to ensure correct operation of all components.

For manufacturing, nearly all parts where CNC machined from 6061 aluminum. In total seven weldments were created from multiple aluminum parts, and precision fixtures were used to ensure accurate welds and to minimize the effectors of heat deformation caused by welding. After all parts were machined and welded as necessary they underwent a yellow chromate conversion process, which provided a non-porous coating that helps to reduce corrosion and increase ability for bonding to composites. The next step was the structurally bond all parts and weldments to carbon fiber tubes, which formed the rocker arms and camera mast; this was also done with precision fixtures. Finally, electronics were carefully installed, with all wires cut two exact lengths to reduce mass and improve cable management.

Carefully observing the quality of all solider joint and crimped connections also help to ensure the system would function reliable. A summary of the key steps in these processes in shown in Figure 11, which highlights specific aspects of each process.

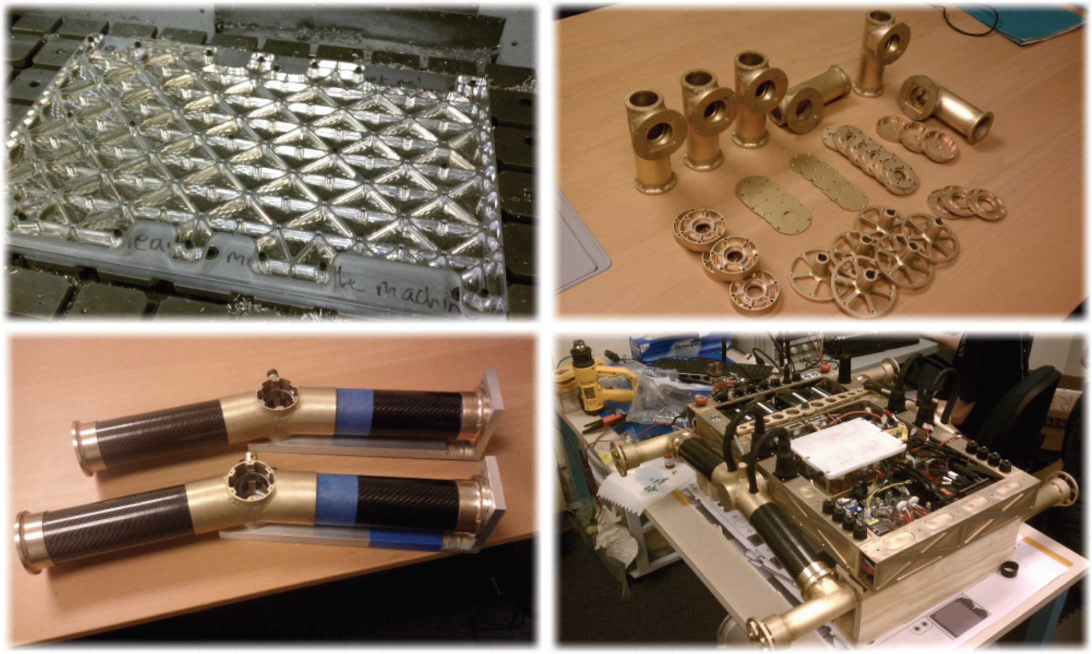


Figure 11: Manufacturing, Assembly, and Integration: Machining Top Plate (upper left), Chromate Conversion Coated Drive Module Parts (upper right), Bonding Carbon Fiber Fixture for Rocker Arms (bottom left), Electronics Assembly (bottom right)

During the development process and before complete field testing, several subsystems were tested independently to validate correct functional and operation. Most notable were extensive tests done on the drive modules, which underwent prolonged operation with various loads to observe reliability and ensure that the motors could remain within safe temperatures. Similar stress testing was done with the CPU to confirm that the liquid cooling system operated as planned. Various other tests were done which ultimately found that all systems operated correctly and within limits.

After all subsystems were confirmed to be working correctly, fielding testing was done on different terrains mainly to evaluate mobility and ruggedness. To test mobility we roved around rough terrain in the Worcester area. During these tests we made qualitative notes on general stability and traction, and also quantitatively evaluated slopes and obstacles that were traversed. In general, stability and traction were very good in all terrains tested; grassy fields, rocky terrain, small gravel, dirt and sand. The tread selected performed very well, easily gripping rocks and traversing vertical obstacles (ex. cinder block) with little to no slipping. The passive averaging suspension performed as planned, with the ground compliance guaranteeing that all four wheels remained in contact with the ground. In some rare occurrences the rocker suspension reached its mechanical limit, in which case one wheel is lifted off the ground; however, this only occurred with obstacles > 50 cm in height.

ORYX 2.0 successfully reached the design goal of being able to traverse positive and negative obstacles up to 15 cm high or deep. In all testing ORYX 2.0 never encountered a scenario where it could not traverse obstacles of this size. Overall, it could easily traverse obstacles up to 20 cm high and in some cases navigate over rocks ~ 50 cm tall. This exceeded mobility expectations in many ways. In some scenarios obstacles larger than 20 cm resulted in high centering, when a front wheel traverses the obstacle but then has the obstacle stuck under the chassis or rocker arm. In all of these occurrences the rover was able to traverse off of the obstacle.
Additionally, the rover's ability to traverse steep slopes was examined. Testing showed that it could traverse grassy slopes of ~ 37 degrees. Traction on rocky terrain or gravel should be similar although slopes with these materials were not available for testing. The maximum speed of 1.2 m/sec was also achieved on this slope. Overall, original design specifications for obstacle traversal sizes, slopes, and speeds were successfully met and verified through field testing.

Figure 12 shows some of the types of terrain used throughout the field-testing process. It is important to note that no mechanical or electrical issues were encountered in any of the testing; a testament to the ruggedness of the mechanical design. Overall field-testing demonstrated that the rover has the ability to successfully operate at the Rock Yard at JSC.

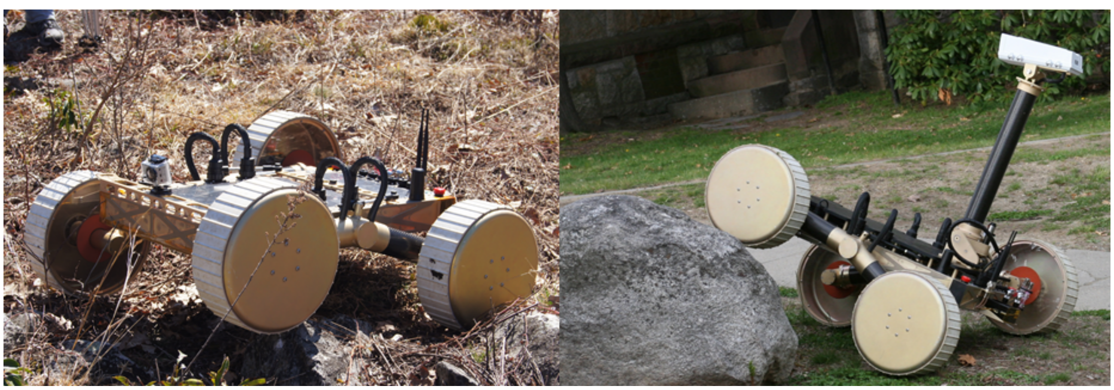


Figure 12: Field Testing: Roving on Rocky Terrain (left), Roving over ~ 40 cm Rock (right)

6 Education and Public Outreach

Throughout the course of this project our team aimed to engage the public in space exploration and rover technology by sharing our journey through a technical-style blog in addition to specific outreach events. Our blogging website was the single biggest and most continuous form of public outreach. Over the course of the year we posted a total of 80 unique blogs which ranged from detailed design updates, to progress of manufacturing and assembly, to results from various tests and experiments. In all, this method proved effective with ~6700 all-time views. In addition to the blog, our website also served as an access point to many other documents including technical reports, PowerPoint presentation, and other pictures and videos. It also included our live stream, team biographies, sponsors, and a link to our team Facebook page which currently has 250 followers.

Also available through our website are nine YouTube videos that were made during the course of the project, see Appendix C for list of videos. These videos include the ones required by the Robo-Ops competition but also include others that summarize the project, our experience at Desert RATS, the manufacturing and assembly process, and field testing of ORYX 2.0. In total these videos have a combined 2770 views and have also been used by WPI faculty at accepted student events, including the one at the FIRST Championship in St. Louis.

Furthermore specific public events were attending by our team which served as an opportunity to talk to people about or rover. The two main public outreach events included attending the Camp Reach Carnival and the Boston Museum of Science Block Parts, pictures shown in Figure 13.

Camp Reach was a science and engineering fair with educational games, interactive science, and engineering experiments to celebrate the program's success and for receiving the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring for 2011. Camp Reach is a math and science focused summer camp for seventh-grade girls, designed to engage young women in the excitement of engineering and science. We had a lot of fun showing people how to drive our rover and teaching them what rovers are all about.

During National Robotics Week we attended the Robot Block Party at the Boston Museum of Science. Every year the Boston Museum of Science celebrates National Robotics Week by inviting New England universities and robotics companies to show off their robots at this event. ORYX 2.0 was WPI's main attraction at the museum this year. Not only did we get to talk to a lot of kids and their parents about how we built our rover, we also had an unplanned demo in the museum. After noticing the strength of the 4G signal we decided to put the rover on the ground and do some teleoperated driving practice from Worcester. This event was particularly successful because we were able to reach hundreds of visitors, mostly families and children that came to learn more about robots.

In addition to public outreach events such as these we also had many technical outreach efforts. Our team and ORYX 2.0 attended the IEEE TePRA conference, where we presented our poster and submitted a conference paper. We also submitted a conference paper to IEEE-IECON and a technical report to the ASME Student Mechanism & Robot Design Competition.

We were also invited to attend the MicroRover workshop hosted by Brown University, which provided an opportunity for faculty, university students, NASA personnel, and others to discuss the future of space exploration and the role that rovers will play. We presented a poster at this workshop describing our design of ORYX 2.0 as a ruggedized mobility platform designed for analog testing of space exploration technologies.

Of particular interest to others in the technical community was our ability to successfully use Maxon's EPOS2 motion controllers in the Linux environment. One of the main software challenges in this project, we were ultimately able to reliable use the controllers by fixing Maxon's source code and understanding interactions between the versions of Linux, FTDI drivers, and firmware. Specifically we were directly contacted by researchers at Harvard University, the University of Technology of Belfort-Montbéliard, Arizona State University, and contractors of the Canadian Space Agency regarding assistance with using EPOS controllers in Linux.

Separate from these public outreach activities we also had a great deal of outreach within the WPI community. On project presentation day we had several poster presentations to industry professionals, faculty, and the public. As a result of our successful presentations we won the Provost's Award for both the Mechanical Engineering and Robotics Engineering departments, which are the highest award given for WPI projects.

We have also been helping WPI in their public outreach efforts for the upcoming NASA Sample Return Challenge that WPI is hosting this summer. This included a professional photo shoot with the rover, personal interviews with members of the team, and professional video of the rover driving. We are also planning a public outreach event and demonstration at the WPI hosted FIRST robotics competition (May 18 and 19).

Figure 13: Public Outreach: Rover's View during the Robot Block Party at the Boston Museum of Science (left), Letting People Drive our Rover at Camp Reach (right)

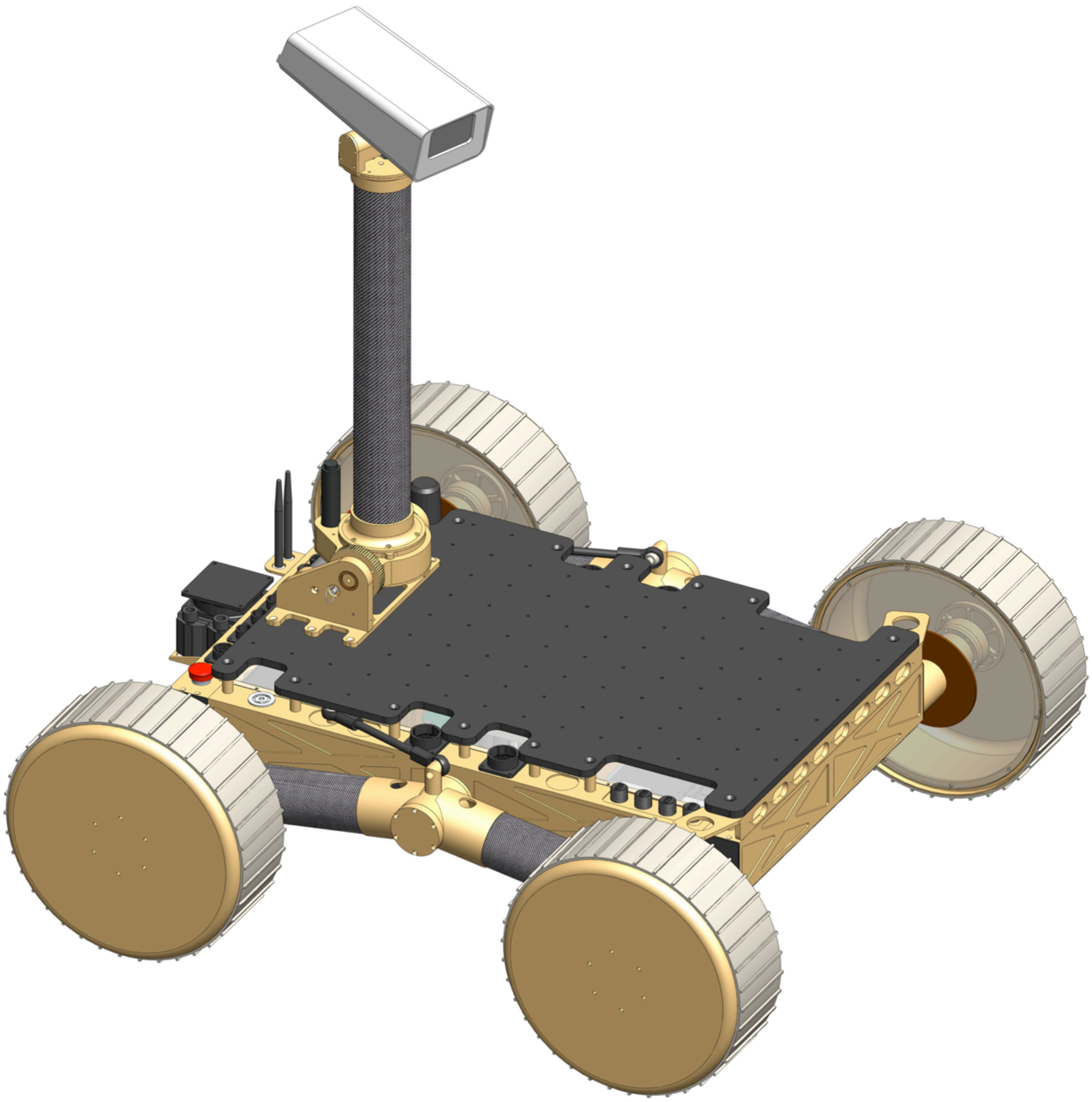
Acknowledgements

We would like to acknowledge our lead advisor, Professor Taskin Padir, as well as our co-advisors Ken Stafford, director of the Robotics Resource Center at WPI, and Brad Miller, associate director of the Robotics Resource Center at WPI. We would also like to thank our graduate student advisor Velin Dimitrov. Finally we extend a big thanks to our sponsors, whose financial support and donation of good make this project possible. Sponsors include: NASA; National Institute of Aerospace; Worcester Polytechnic Institute; Maxon Precision Motors, Inc.; Linemaster Switch Corporation; InterSense, Inc.; The Mathworks Inc.; Axis Communications; Barnstorm Cycles; Tesla Motors; and igus inc. Without the generous support of these corporate sponsors this project would not be possible.

APPENDIX A: Design Specification Sheet

ORYX 2.0

A PLANETARY EXPLORATION MOBILITY PLATFORM

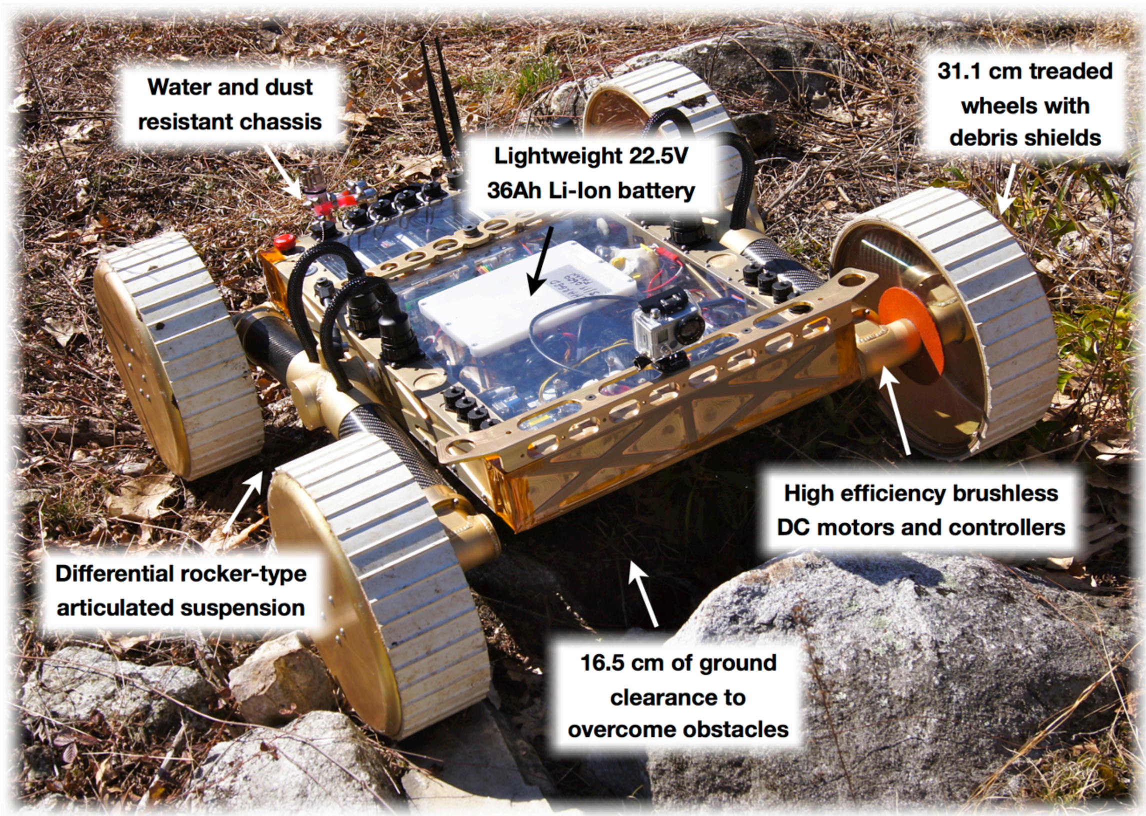


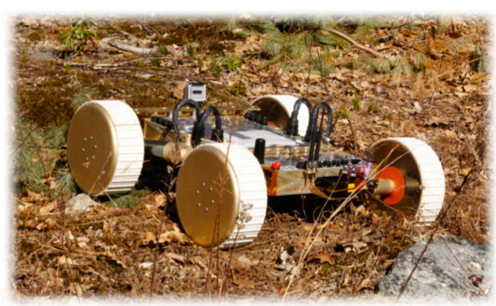
PROJECT OVERVIEW

ORYX 2.0 by Worcester Polytechnic Institute is a research mobility platform for evaluating planetary surface exploration technologies in extreme earth environments.

PROJECT FEATURES

Planetary exploration rovers are high cost partially due to their long development timelines and highly mission specific design. While specialized applications will always be necessary for space exploration, most planetary rovers are very similar from a mobility standpoint. The ORYX 2.0 is a research mobility platform aimed at tackling the mobility and situational awareness problems, allowing the user to focus on the development of mission specific technologies.

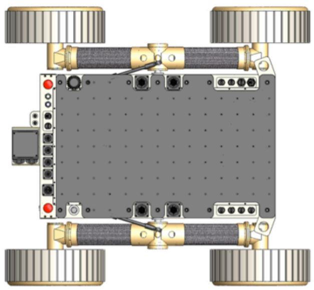




FOR MORE INFORMATION ON ORYX 2.0, VISIT **WWW.WPIROVER.COM**

TECHNICAL SPECIFICATIONS

TOP



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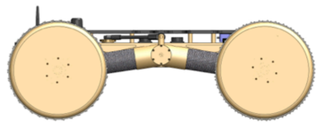
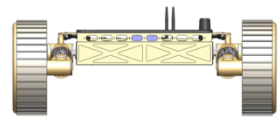


FRONT



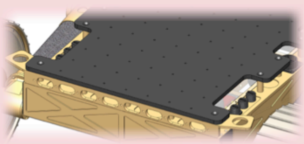
SPECIFICATION	
Dimensions (LxWxH)	96 x 89 x 31 cm 39.9 x 34.9 x 12.2 in
Mass	35 kg 77 lbs
Rated Payload	15 kg 33 lbs
Maximum Speed	1.2 m/s 3.9 ft/s
Maximum Obstacle Size	15 cm 5.9 in
Operating Time	3 hrs typ
Drive Power (Mechanical)	Up to 400 W continuous
Battery	22.5V 36Ah Lithium Ion w/BMS
On-Board Computer	Water-cooled Intel Quad-core i5 processor on Mini-ITX motherboard
Module Power Interface	Four accessible ports (5V / 12V / 24V)
Module Communications Interface	USB 2.0 (8) / Gigabit Ethernet (2) / Wi-Fi / 4G LTE
System Feedback and Sensing	Battery Voltages, System Temperatures, Rover Orientation, Odometry, Rocker Orientation, System Fault Handling
Software	ROS

FOR MORE INFORMATION ON ORYX 2.0, VISIT WWW.WPIROVER.COM

MODULE INTERFACE SPECIFICATION

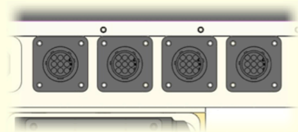
ORYX 2.0 was designed specifically to accept modules that are created by both WPI and 3rd party sources.

Definition: A MODULE is an assembly of mechanical, electrical, and/or software components which are not integral to the operation of the rover. All modules will adhere to a standard module specification (mechanical, electrical, communication) defined by the manufacturer.



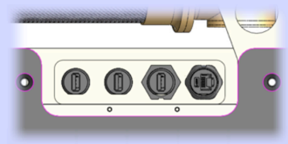
#10-32 tapped grid
top plate and front rail

MECHANICAL



4 accessible ports
each 5V / 12V / 24V

ELECTRICAL



USB 2.0
IEEE 802.3 Gigabit
IEEE 802.11n (5dB)

COMMUNICATION

USER PAYLOAD DEVELOPER GUIDE AVAILABLE AT: WWW.WPIROVER.COM

EXAMPLE APPLICATIONS

SAMPLE RECOVERY AND SITE PREP
ORYX 2.0 is designed to accept user custom solutions for planetary sample recovery and excavation.

PERCEPTION & NAVIGATION
Navigation and mapping of planetary environments is a popular topic of research right now as many new technologies are emerging.

TELE-OPERATION
ORYX 2.0 is a complete mobility system that enables users to develop advanced control systems for tele-operation.

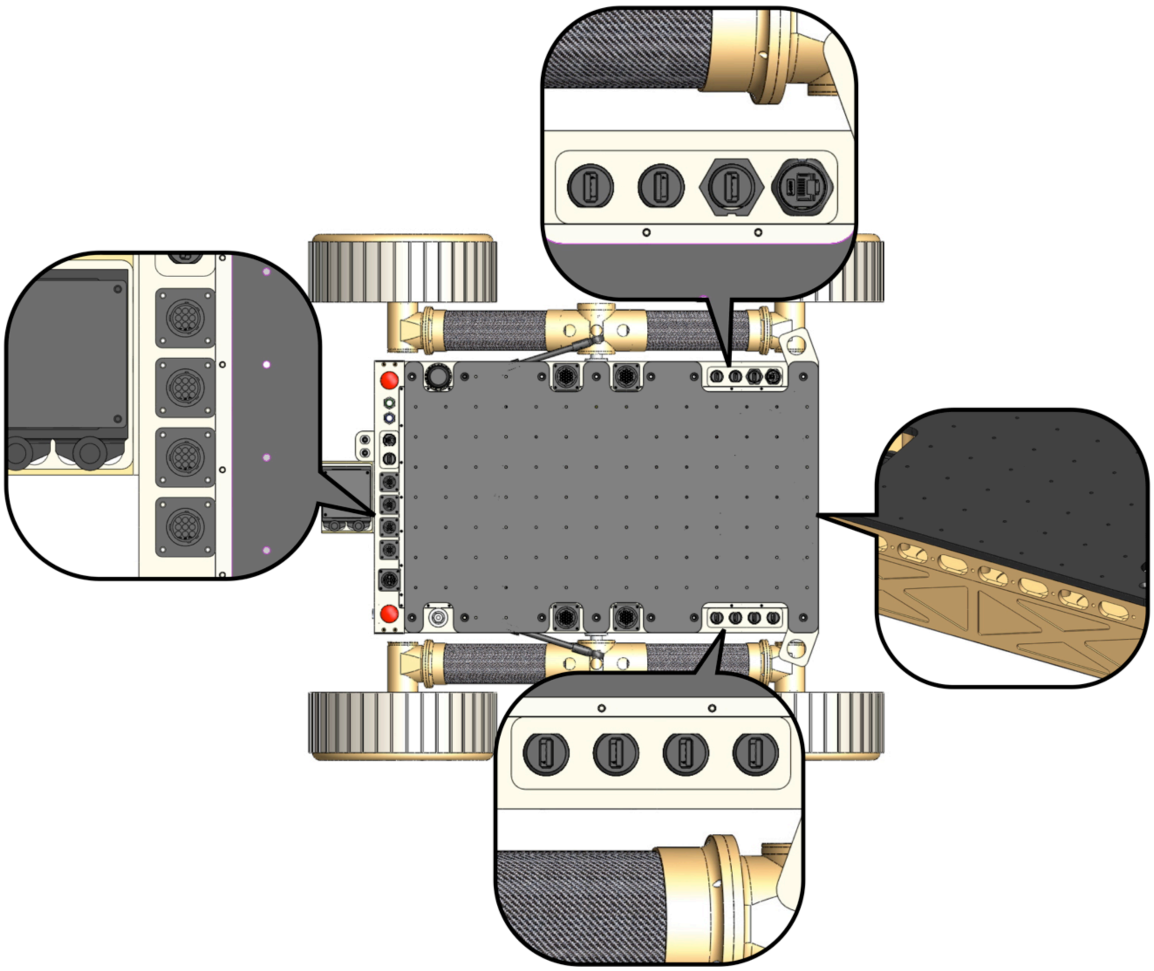
FOR MORE INFORMATION ON ORYX 2.0, VISIT WWW.WPIROVER.COM

APPENDIX B: User Payload Development Guide

ORYX 2.0

A PLANETARY EXPLORATION MOBILITY PLATFORM

WORCESTER POLYTECHNIC INSTITUTE 1865 WPI



USER PAYLOAD DEVELOPMENT GUIDE

This document provides all the relevant information for those looking to develop custom payloads for ORYX 2.0. The mechanical, electrical, and software interfaces to the rover are discussed in detail.

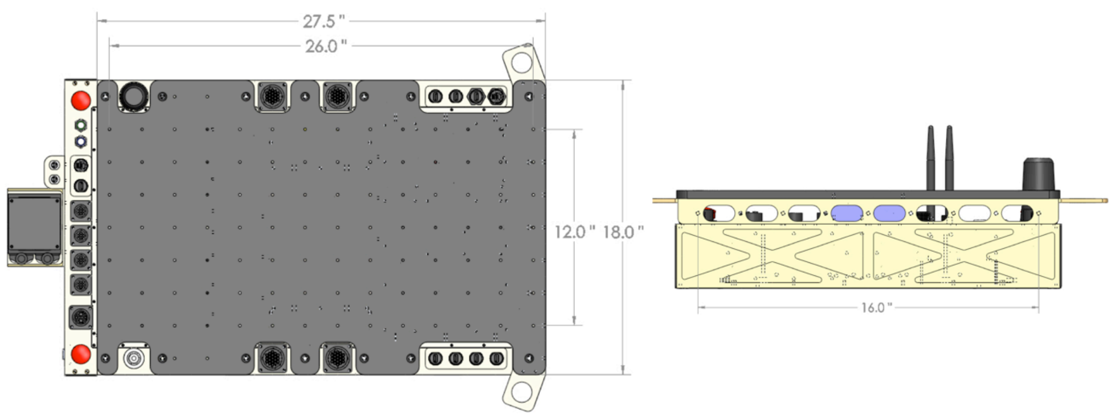
PAYLOAD ARCHITECTURE

The primary purpose of space exploration rovers is to safely transport scientific instruments between sites of interest. Payload integration is often done in parallel with rover development resulting in highly specialized systems for a given mission.

ORYX 2.0 is a planetary exploration mobility platform that is low cost and accessible to smaller organizations. It was specifically designed for mission scenario testing in analog Martian and lunar environments. ORYX 2.0 includes mechanical, electrical, and software features that foster the development and integration of custom payloads.

MECHANICAL INTERFACE

To physically attach custom payloads to ORYX 2.0 there is a series of #10-32 tapped holes on the front and top of the rover much like an optics table.



LOCATION	DESCRIPTION	PAYLOAD CAPACITY
Top Plate	27.5” x 18” x 3/8” Aluminum, 2” x 2” grid of #10-32 holes	15 kg
Front	16”, 2” spaced #10-32 holes	3 kg

FOR MORE INFORMATION ON ORYX 2.0, VISIT **WWW.WPIROVER.COM**

ELECTRICAL INTERFACE

In order to provide power to user payloads ORYX 2.0 was designed with 4 identical TE Connectivity Circular Plastic Connectors (TE PN: 206705-3) that each provide access to 5V / 12V / 24V busses. The user payload power pinout, current limit, and mating component list is tabulated below.

TE PIN #	PURPOSE	
1	24V+	
2	24V GND	
3	-	
4	12V+	
5	12V GND	
6	OneWire Temp +	
7	5V+	
8	5V GND	
9	OneWire Temp GND	

VOLTAGE	CURRENT PER PORT*
24V	10 AMPS
12V	3 AMPS
5V	2.5 AMPS

TE PART #	DESCRIPTION
206708-1	9-Pin Circular Plug
66592-1	Socket 22-18 AWG
1-66109-7	Socket 26-22 AWG
54123-1	9-Pin Heat Shrink Boot
58495-1	AMP PRO-CRIMPER III

* 24V bus connections fused at 10 amps, 12V 150W and 5V 50W current-limiting DC-DC converters

ORYX 2.0 has (8) accessible USB 2.0 ports and (2) accessible Ethernet ports that use L-Com IP67 waterproof connectors. These connectors will accept both standard cables (USB Type A, CAT-5E RJ45) as well as IP67 cable assemblies from L-Com.

L-COM PART #	DESCRIPTION
WPUSBAB-2M	IP67 USB Type A to USB Type B Cable Assembly, 2.0m
TRD5WP-1	IP67 RJ45 to RJ45 Cable Assembly, 1.0m

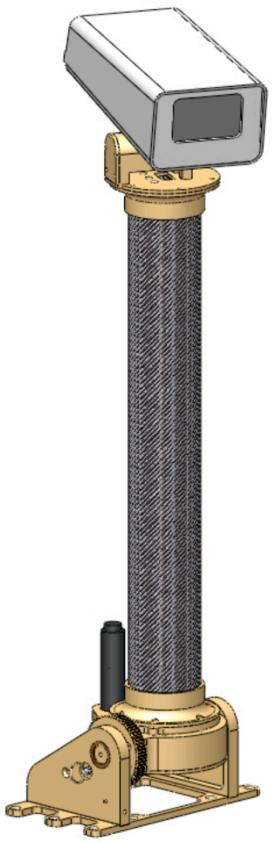
SOFTWARE INTERFACE

ORYX 2.0 has an on-board computer with a Intel Quad-core i5 processor that runs Linux Ubuntu 11.04. All of the software for the rover was developed using Robot Operation System (ROS) Electric Emys. All payload software should be developed on a similar system.

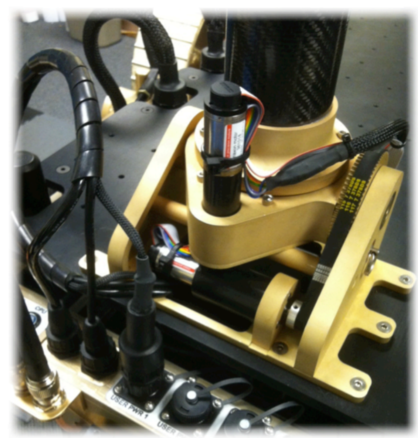
FOR MORE INFORMATION ON ORYX 2.0, VISIT WWW.WPIROVER.COM

EXAMPLE: DEPLOYABLE PAN TILT CAMERA

As an example payload a deployable pan tilt camera module was developed. This module can be attached or detached from the rover in the field with a single tool in approximately 5 minutes.



CATEGORY	INTERFACE
Mechanical	Attached to the top plate with (10) #10-32 x 1/2” fasteners
Electrical Power	24V power via user power connector to both the motor controllers and the camera
Electrical Communication	Camera interfaced to computer using Ethernet, Motor controllers interfaced using USB 2.0
Software	Custom ROS packages developed for controlling pan and tilt; accessing the IP camera video; colored rock detection



Clearpath Husky A100 upgrade to provide payload cross compatibility is available

FOR MORE INFORMATION ON ORYX 2.0, VISIT **WWW.WPIROVER.COM**

Appendix C: List of YouTube Videos for Public Outreach

Description	Link
Robo-Ops final video: Discussed the broader impacts of rovers and space exploration, and also reviewed the design, manufacturing, assembly, simulation, and testing process.	http://www.youtube.com/watch?v=1B84J-0A-nM
An abbreviated version of our final video, this also includes a complete summary of our project.	http://www.youtube.com/watch?v=fYZwzTGBkQs
Robo-Ops midterm review: Demonstrated testing and rover capabilities.	http://www.youtube.com/watch?v=T-qWfCtz2Rk
First driving test with ORYX 2.0	http://www.youtube.com/watch?v=M_ANtnEaqhQ
Time lapse video of machining the top plate, one of the more interest machined parts that had over 140 pockets to reduce mass.	http://www.youtube.com/watch?v=PX3bUJ385Lg
Time lapse video of machining the convector bracket, using high-speed tooling and machining techniques	http://www.youtube.com/watch?v=xt21k4aatFI
Time lapse video of system wide thermal testing, monitored with a thermal imaging camera.	http://www.youtube.com/watch?v=NodQGngKWCw
A video summary of our experiences at Desert RATS	http://www.youtube.com/watch?v=mg5yz6JqBZo