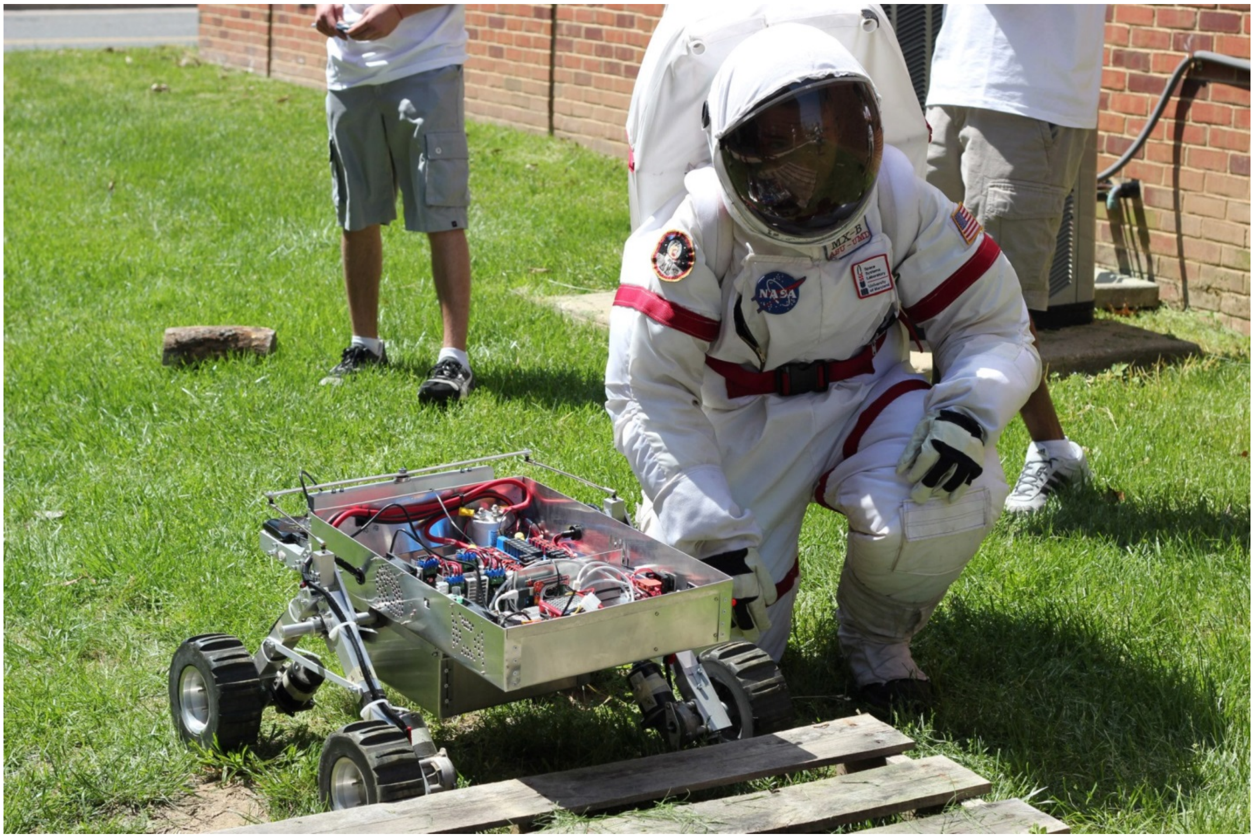
Team Demeter



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Introduction

System Description

For the mechanical portion of Demeter, the requirements we were given was to design a rover that would fit inside a 1m x 1m x 0.5m box while weighing in at less than 45 kg. Other design parameters we had on Demeter were that it would need to be able to traverse over objects up to 10 cm in height and be able to negotiate upslopes and downslopes of 33% grades. Both of these constraints are respectively the maximum object height and maximum slope grade seen on the different terrains at the NASA JSC Rock Yard. With these design parameters, we then designed the body of the rover to be able to withstand the worst case scenario of loads and stresses of the rover going up a 10 cm object while on a 33° slope. On top of prepping for the worst case scenario, we also added a large factor of safety (FOS > 5) in all of our parts so that we can test Demeter more harshly without noticeably damaging any of its parts.

In Figure 1, we can see how Demeter looks like with the frame, legs, four wheel rocker, and the electrical and battery boxes assembled together. The only components that are not seen in Figure 1 that are on the final version of Demeter are the camera mast and the sample acquisition system. While the arm is not attached yet in Figure 1, the arm is designed to be mounted onto the part of the frame that is not being used in front of the electrical box. Next to the arm, we also have a small mesh bag hanging from the frame that is used to store the rocks and objects collected on the rock yard.

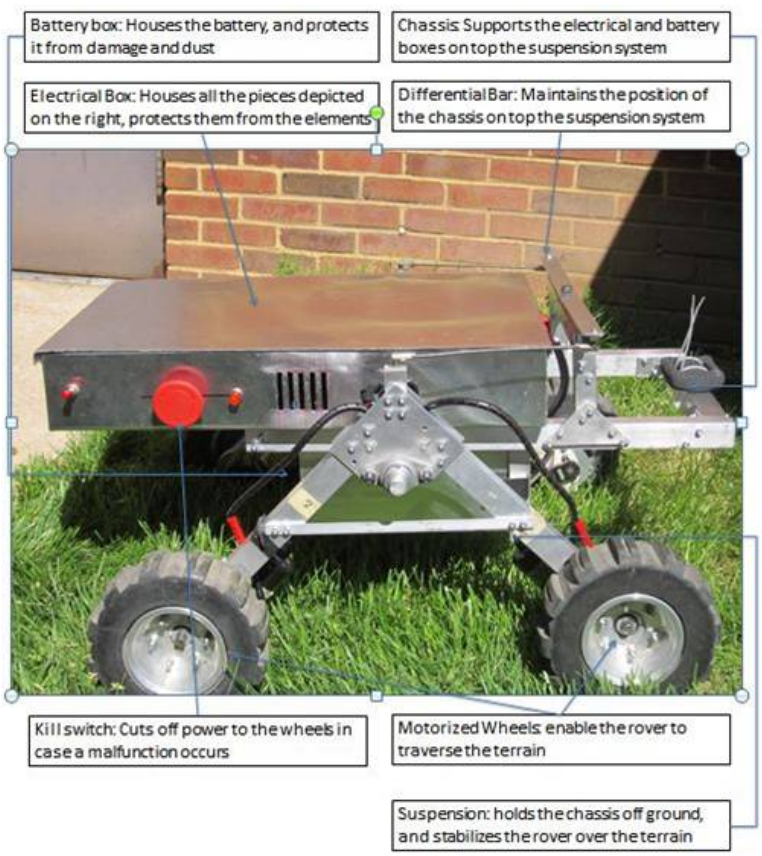


Figure 1: Demeter without Arm and Camera Mast

Chassis Design and Drive System

Wheels and Suspension

For the suspension system we initially considered several different suspensions for Demeter such as a six-wheel rocker-bogie, a four-wheel rocker, and a hard four-wheel suspension. The four-wheel rocker was selected because it is light and dynamically stable, while still allowing for maneuverability over obstacles. The suspension was designed to be able to go over a 10 cm obstacle while going up/down (or sideways along) a 33° incline, as previously stated. The four-wheel rocker has a body averaging differential bar, which runs across the top of the rover. Figure 2 shows CAD models of the rocker system from both the side and the top views.

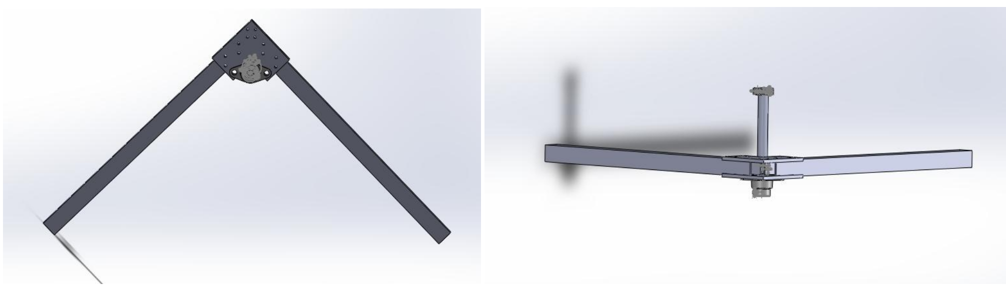


Figure 2: Side and Top View of Rocker

To connect the frame, legs, and the suspension system together we had to design custom brackets using a manual mill to hold the bearings and attach the legs and differential bar. We have also designed custom fittings to attach the differential bar into the aforementioned bracket containing the legs and bearings. There is also a hardened steel rod that runs from the bracket to the frame of Demeter and attaches with a flanged mounted collar. Once we finally had the suspension system built and perfected, we were able to test it out by driving Demeter over sidewalks and small logs as shown in Figure 3. These test runs worked out very well as the four-wheel rocker was able to keep all 4 wheels on the ground when going over objects that were around the height of the wheels (~20 cm), which is almost twice the maximum height we expect to see in the rock yard. The only problem we saw with the suspension system was that the differential bar experienced a lot stress after being driven over the course of an entire day and as a result there was a lot of deflection on the bar.

Figure 3: Suspension System being tested

It is crucial for us to have the differential bar properly working because it serves to stabilize the chassis and keep it from freely rotating about the pivots. When Demeter goes over a rock on one wheel, the rocker is displaced causing the differential bar to rotate about a central shoulder bolt. This stabilizes the center of mass, allowing Demeter to drive over larger rocks. Therefore, we decided to fix the problem of deflection in the differential bar by making the bar much thicker, and so we chose a 1/4" thick aluminum 6061-T6511 bar as the new piece, whereas we previously had a 1/8" thick aluminum 6061-T6511 bar. This differential bar is connected at both ends to horizontal threaded rods by a ball-and-socket swivel joint. This allows the bar to swing about the central shoulder bolt while remaining attached to the rocker. The other end of these rods are connected by another pivot joint to the differential bar fitting, which is attached to the leg struts and pivot by the rocker bracket.

Chassis

The chassis of Demeter was constructed out of 6061-T6 aluminum square tubes. We have two beams running along the length of the rover for 23.62 inches. These beams are then connected together by two beams placed on the inside at each end which have a length of 11.02 inches. All the beams were connected together with bolts that are run through angle brackets on the inside of the frame setup. This frame setup is considered to be the main frame of our rover with the electrical box, containing all the electrical components, is bolted on top of the frame and the battery box, while the battery is hanging below. Both the electrical and battery boxes are made from 6061-O aluminum sheet metal. Connected to the outside of the frame are the legs of the rover, which are centered on the battery box since that is where most of the weight is placed. Like the chassis, the legs of the rover are made from 6061-T6 aluminum square tubes. These leg beams were not only designed to constantly support the weight of Demeter on all 4 legs, but they are even designed to support all this weight on only one leg, just so that we have a higher margin of safety at the legs. In Figure 4, we can see how the final frame assembly looks like with the legs attached on the side of the frame by means of a hardened steel rod.

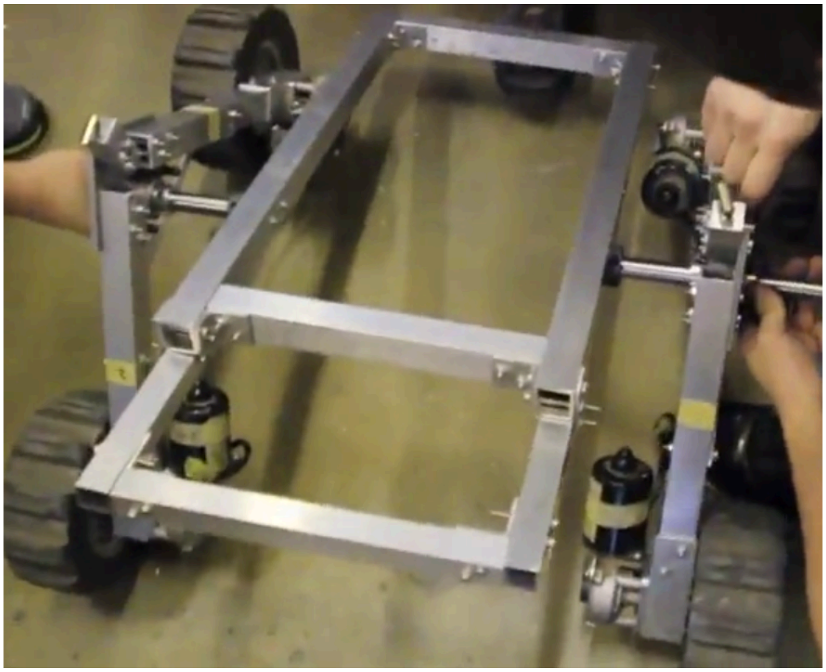


Figure 4: Frame

Camera Specifics

With the exception of our pan-tilt-zoom camera, Demeter uses several small auto-focus/auto-iris webcams to enable remote driving and arm manipulation. These cameras interface with ROS through a well-defined node called usb_cam, which automatically connects to each camera and publishes a ROS topic containing the image stream. A second ROS node called mjpeg_server then subscribes to each image stream and broadcasts it over the internet, where our control software can access it via html.

Pan-Tilt-Zoom Camera

For its main camera used for navigation and rock identification, Demeter is using a Panasonic pan-tilt-zoom camera atop its mast. This camera has the capability to rotate 270 degrees, pan up and down, and zoom in to a point with extreme focus. The camera motion will be controlled by our mapping team at the command station using a webpage interface, and the video feed will be used to survey the area around the rover to target rocks. The camera will be connected to its own modem, separate from the modem used for the computer, so the large bandwidth needed for the camera's data will not inhibit the control of Demeter.

Manipulator System

For the RASC-AL Robo Ops competition we needed to create a sample acquisition system in order to pick up rocks during the field competition.

The sample acquisition system (SAS) will operate under a four degree of freedom (DOF) system. The sample acquisition system has been designed with three joints; the shoulder, the elbow, and the wrist. Each joint has its own DOF.

The shoulder established the first two degrees of freedom. The shoulder will be able to roll and pitch allowing for coarse adjustment of the position of the end effector. The motion will be controlled using servo motors that are attached to the base of the sample acquisition system. Attached to the shoulder joint is a square metal tube that is 1"x1". This square tube is connected to another square tube and this junction will form the elbow.

The elbow establishes the third degrees of freedom. The elbow will be able to pitch allowing for fine adjustment to the end effector location. There is a rod connecting the elbow joint to the servos at the base. This will allow the elbow to pitch and established the third degrees of freedom. The rod is approximately 10" A picture of this rod connecting the elbow to the base can be seen below in Figure 5.

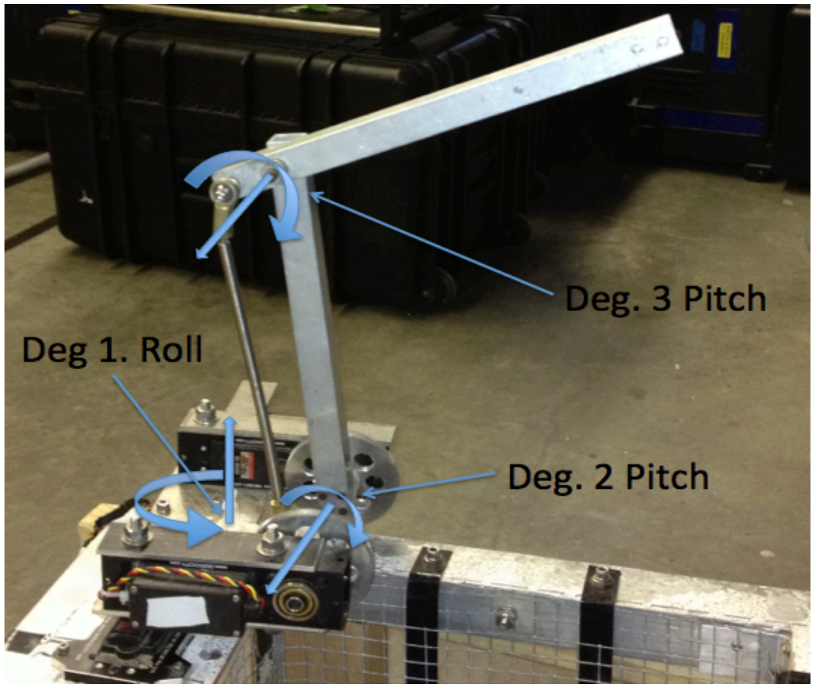


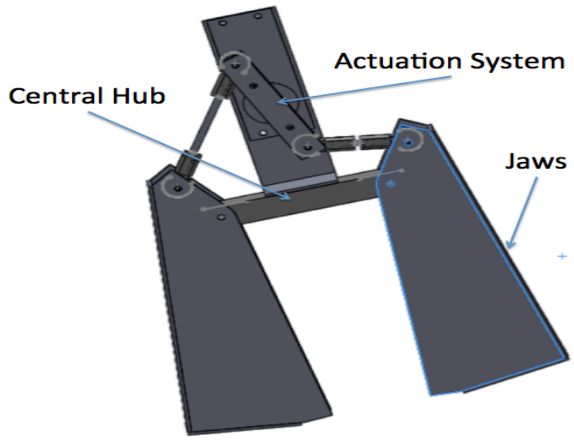
Figure 5: Elbow connection to servo at base

The length of each of the square tubes is approximately 10”. They are designed as such so the end effector has ample ability to reach the ground from its position on the rover.

The final piece is the end effector itself. The end effector attaches to the end of the second tube to create the wrist joint. This joint established the fourth degrees of freedom as the wrist will be able to pitch. This degree of freedom will allow us to make the final adjustments to the end effector positions in order to pick up rocks.

The most important design aspect of the sample acquisition system is the way in which we control the jaws of the end effector. The jaws are responsible for holding the rocks while we put the rock into the basket; they act as a hand.

The wrist utilizes a servo attached to two rigid plates. The plates are then attached to two push rods. As the motor spins the plates rotate pushing the rods causing the jaws of the end effector to close. The jaws and servo are attached to a plastic piece that we are calling the central hub. The central hub is approximately 5” long to provide appropriate spacing for the jaws and push rod system. For a better idea of what this central hub looks like a picture of the isolated wrist and CAD models are provided below in Figures 6 & 7.



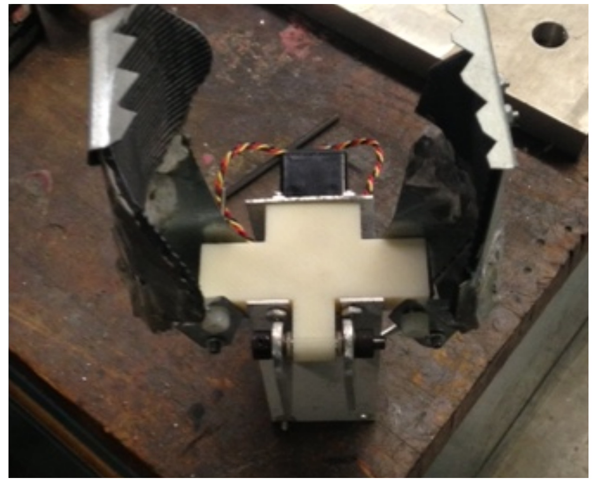


Figure 6: CAD, End Effector with Central Hub   Figure 7: Actual jaws and central hub

While attempting to pick up a rock the worst case scenario is considered to be when the rock is pinched and not enclosed by the jaws. Thus the jaws had to be built such that they apply a high enough normal force to be able to carry a rock by pinching it. The servo was rated to apply a max torque of 343 oz-in. Most of the rocks will be in the hundreds of grams meaning that the jaws will be able to provide a sufficient pinching force.

Furthermore, we wanted a quick acting sample acquisition system. The system is designed so that the motor only has to rotate the rigid plates in order to close the jaws.

A picture of the full system can be seen below in Figure 8.

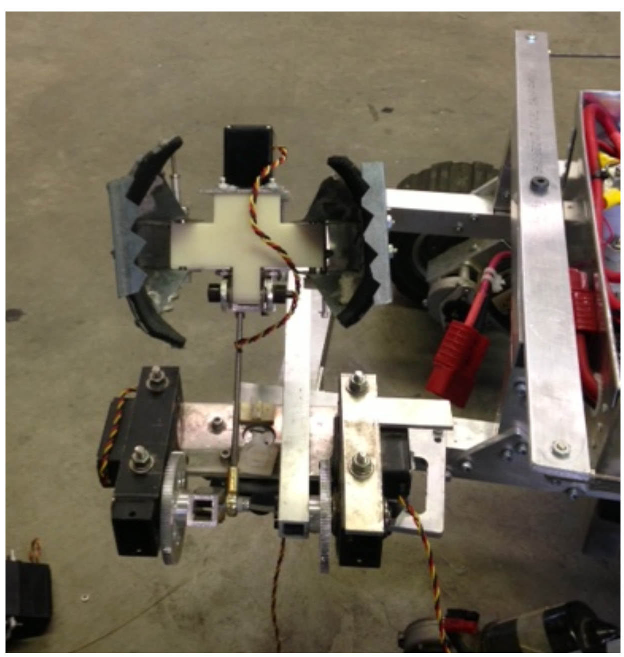


Figure 8: SAS Full System

A problem that occurred during the design process was mounting the sample acquisition system to the rover chassis. We needed to find a way to mount the arm to the chassis without interfering with the differential bar. Also we needed to maintain as much volume as we could in the basket meant for storing the rocks we pick up.

In order to remedy this problem we designed a bracket to be attached to the rover so we could hang the sample acquisition system off of the side of the rover. As you can see in the Figure 8, the sample acquisition system is attached the chassis as we have machined the mounting bracket. However, for a more detailed picture the mounting bracket (in CAD form) can be seen below in Figure 9.

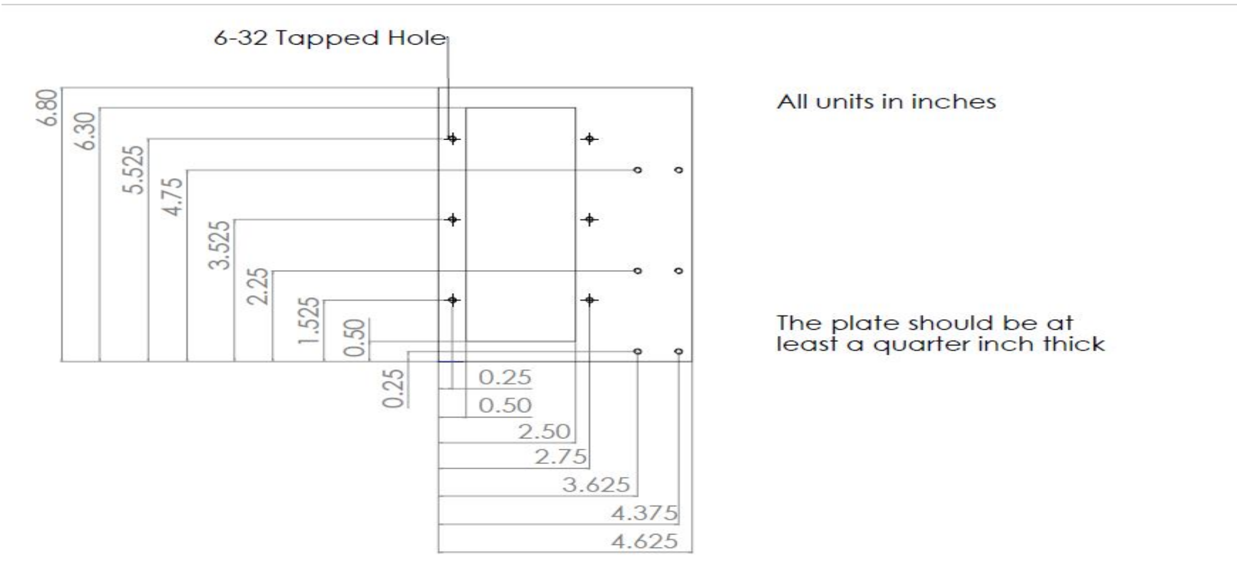


Figure 9: SAS mounting bracket

The large hole in the bracket is meant for the servo at the base of the arm. The servo fits through the hole and then the arm is mounted to the bracket. The holes to the right are placed accordingly to mount the bracket to the chassis and so the bracket mounting does not interfere with the differential bar. Figure 10 below shows a view of the bracket mounted to the rover.

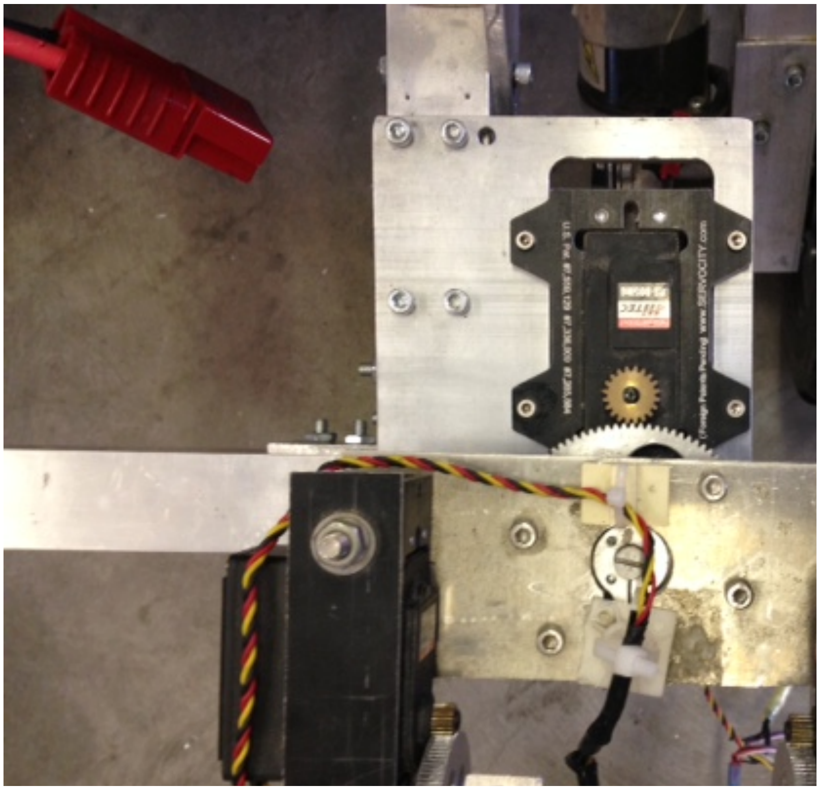


Figure 10: Bracket and SAS mounted to rover

Control and Communication System

All of Demeter's command and control software is based around Stanford University's ROS (Robot Operating System) message-passing system running under Ubuntu Linux on a 64-bit processor. With the exception of our pan-tilt-zoom mast camera, which operates using proprietary software and a separate, dedicated web connection, every interface between a piece of hardware and Demeter's central computer is accomplished via a ROS node.

Arduinos

All of Demeter's motors and servos link to the central computer using Arduinos, which are operated by an open-source ROS node called rosserial. The software running on the Arduinos themselves differs by purpose.

One Arduino Mega, dedicated entirely to running our four wheel motors, receives speed commands and translates these to motor outputs based on a closed-loop PID control law. The controller calculates a personalized motor output for each wheel based on input from an attached wheel encoder, allowing us to compensate for slippage and local differences in traction.

A second Arduino, which will drive our five arm-control servos, runs much simpler software which simply writes inputted servo angles to the five attached servos. These servo angles can be either commanded directly from our ground control interface, or calculated by a customized kinematics solver which takes Cartesian based inputs from a joystick and solves for each servo angle. The kinematics solver runs as a standalone ROS node which an operator can choose to bypass if individual angle servo control is desired.

Demeter's ground station connects to the rover using a ROS node called Rosbridge, which works by opening a specified port and listening for messages formatted as JSON strings. These strings are put together and sent to the rover using javascript, which runs behind an html-based GUI that can be run in a web browser. Due to its native support of joystick input and simple API, we have chosen to use Google Chrome.

Our primary interface is an interactive web page which can control either Demeter's four wheels or her arm, depending on options specified when the page loads. If arm-control is selected, the operator has the further option to use a joystick with our Cartesian kinematics solver to derive servo joint angles automatically. Alternatively, the operator can elect to send each joint angle individually if the situation requires it.

The camera feeds which are broadcast by mjpeg_server are accessed through another html/javascript webpage which acts as a wrapper for the image stream. Mjpeg_server provides functionality out of the box to enable one to point a web browser at a specific address and receive the stream, and formatting options are configured by concatenating additional arguments onto the address. Our html/javascript wrapper simply encapsulates the generation of this address, allowing us to quickly access a stream given Demeter's current public IP address, the name of the ROS topic containing the image, and the image quality we desire.

Technical Specifications

The brain of Demeter is a Zotac motherboard with dual-core Intel processor and 4 GB RAM running Linux. All of the rover movements, sensors, and communication with mission control are coordinated through this computer. A 36GB Solid-State Hard Drive provides the storage space for the CPU.

Demeter’s power stems from a LiFePO4 12.8V rechargeable battery pack located on the undercarriage of the rover, which is distributed to all of the other electrical components through the power distribution board. Power to the computer first goes through an M4-ATX Power Supply. Two DC-DC converts are needed to power our arm servomotors

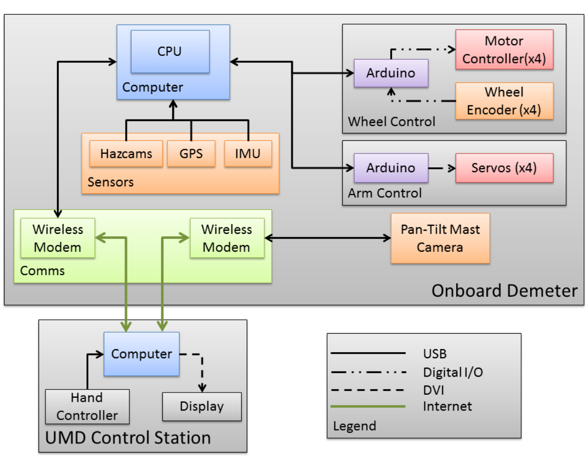


Figure 11: Communication Flow

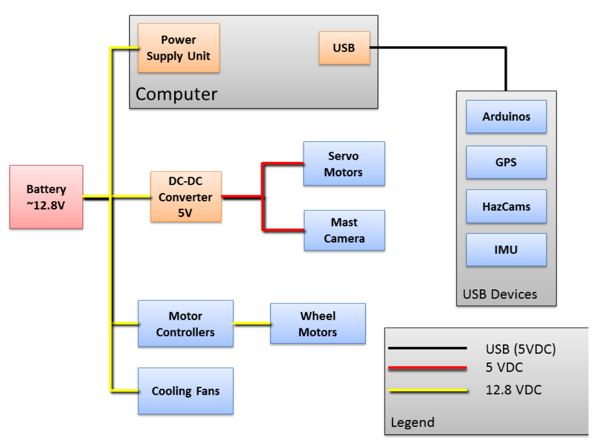


Figure 12: Power Flow

Budget

The fabrication of Demeter cost approximately $2800 over the course of the project. The cost breakdown is shown in the following tables. The fabrication cost breakdown is split between Electrical and Mechanical system costs and broken down by item in Table 1. The team's estimated travel budget is also listed in Table 1. Finally, a summary of all the projected costs is totaled at the end of Table 1.

Electrical Costs

Category	**Cost (USD 2013)**
Computer	320
Networking	200
Wire	175
Connectors	255
Motor Controllers	150
Microprocessors	80
Joysticks	80
Servo Motors	80
Cameras	225
Encoders	50
GPS	50
Misc	85
Subtotal	**1750**

Mechanical Costs

Category	**Cost (USD 2013)**
Material Stock	310
Fasteners	145
Linkages/Joints	165
Tools	120
Bearings	120
Misc	110
Subtotal	**970**

Travel Cost Estimate

Category	**Cost (USD 2013)**
Vehicle Rental	650
Gas	960
Lodging	1050
Subtotal	**2660**

Budget Summary

Category	**Cost (USD 2013)**
Mechanical Systems	970
Electronics	1750
Competition Travel	2660
Total	**5380**

Table 1: Budget Summary

Public Outreach

The Demeter team had two major education and public outreach activities throughout our design process. The first activity consisted of a day of teaching a group of second graders in a nearby elementary school (Montgomery Knolls, in Silver Spring, MD), and the second was reaching out to the public at the University of Maryland's annual family day. The trip to Montgomery Knolls took place on April 9th, and Maryland's family day took place on April 27.

Montgomery Knolls Elementary Trip

On April 9th, a portion of the Demeter team made a trip to Montgomery Knolls Elementary school in Silver Spring, MD, where they taught seven 2nd grade classrooms about the phases of the moon. The lesson plan for the day included a powerpoint presentation, and two mini experiments to reinforce the kids' understanding of what they had learned.

The first hands-on mini experiment let the kids simulate the moon orbiting around the Earth using a tennis ball and flashlight. One child was given a tennis ball, while another child shined a flashlight at the ball. The first student would move the ball around their head, and depending on the balls position relative to their face and the flashlight, different amounts of the ball would be lit up just like how the moon appears to us as it orbits around the Earth!

The second hands-on experiment was both delicious and informative! Each student was given two Oreos each, along with two different phases of the moon. Their task was to open the Oreos, leaving the frosting on one side of the cookie, and then to scrape away frosting until their Oreos looked like the two phases of the moon they were given. Once they finished drawing their phases of the moon, they were allowed to eat the Oreos, who knew that science could be delicious?

Overall, the entire trip was incredibly rewarding. Everyone that went from UMD had a blast teaching the kids, and we've been told that the kids are all asking when the astronauts from college are coming back!

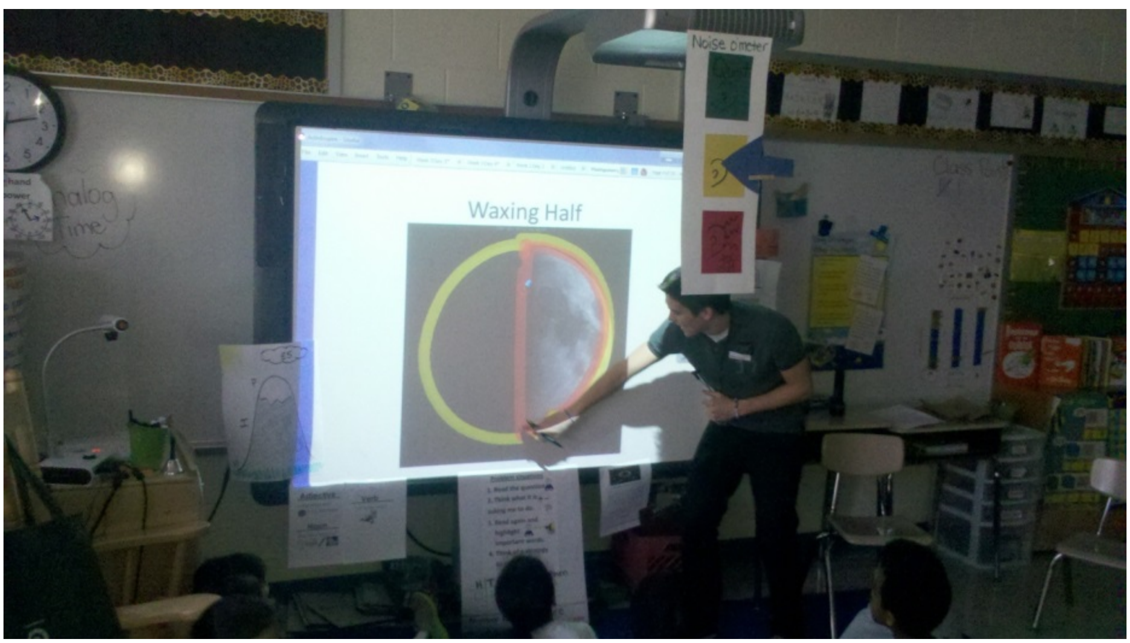


Figure 13: A member of team Demeter shows students a waxing half moon

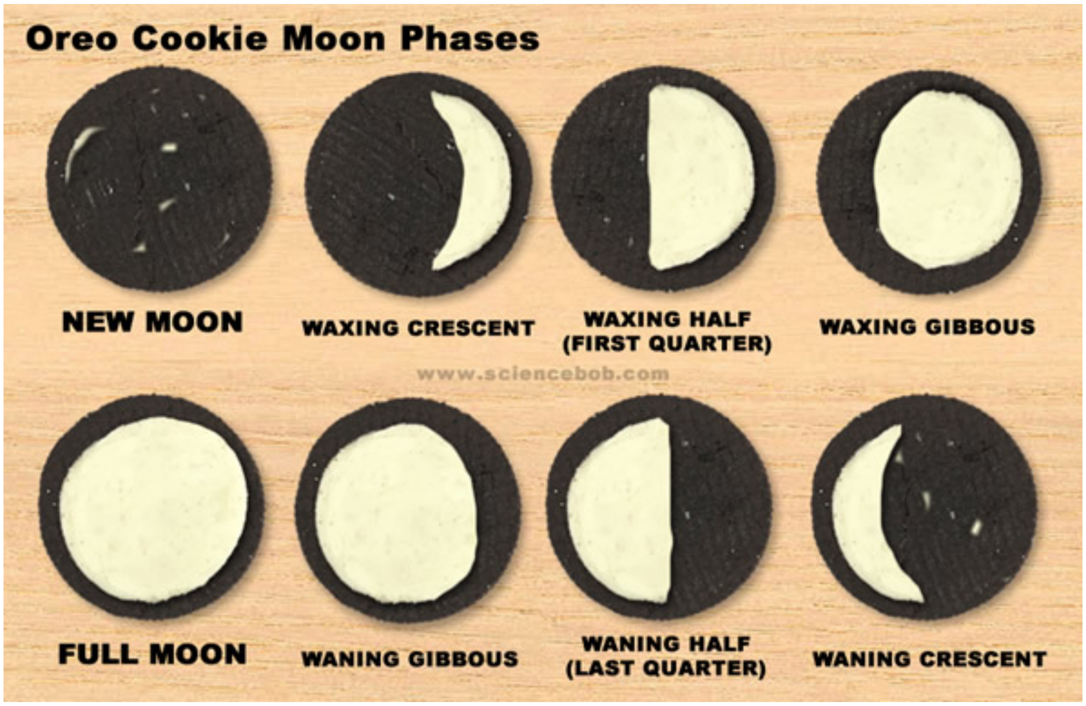


Figure 14: Example completed set of Oreo Cookies

Maryland Day

On the University of Maryland's family day, Maryland Day (April 27th), Demeter was put through its paces, and she performed beautifully all day! Throughout the six hour event, Demeter was driven by hundreds of kids, and they all had a great time doing it. Kids were given full control of the robot, although we did have a few key components like the sample collection system off the robot for their protection. The kids' goal was to navigate through a course of obstacles and make sure Demeter made it home back to the start safe and sound. Altogether, the event was a huge success and lots of fun for everyone involved, even our resident astronaut got to give Demeter a try!