SONOMA STATE UNIVERSITY | ENGINEERING SCIENCE

Senior Design Project Progress Report
EE 492 Senior Design Project Planning

NASA Robotic Mining Challenge LUNABOTICS 2021

Sonoma@RMC

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Abstract

Our team will design, build, and test a mobile robot equipped with a mobility system, a mining system, and a dumping system for participating in the 2021-2022 NASA LUNABOTICS robotics competition. Under many titles, the LUNABOTICS challenge has been going on for over a decade. The LUNABOTICS challenge was previously known as the Robotic Mining Challenge, or RMC, before the pivot to the Artemis mission. Its primary goal remained regolith collecting, but it was now targeted on the Martian surface. Following the shift to Artemis, the RMC was renamed the LUNABOTICS challenge, with RMC remaining the aim for the time being, but with the intention of changing it as needs dictate.

We intend to optimize for simple designs that we could iterate on and add complexity as needed. We aim to deliver minimum viable product type hardware and software and allow for future upgrades and optimization. We are laying groundwork for future teams to work on robotic systems and to perform systems engineering tasks. To achieve our optimization we have several criteria that we evaluate potential options with such as our current familiarity with the options, the mechanical complexity of options, and if we can use as many commercial off the shelf modules as possible so that we can focus on more complex integration tasks.

Our team will utilize widely available single board computers in conjunction with a Pixhawk flight controller running the ArduRover branch of ArduPilot. Our robot control architecture will be built around this combination. The robot will be broken down into numerous major subsystems, including the mobility system, mining system, dumping system, and network stack.

We intend to evaluate our technical performance on a regular basis. Early in the development process, we want to create a minimal viable product and then iterate quickly to improve the outputs. We want to test essential task performance as soon as possible. This competition aims to tackle the technical problem of collecting regolith as well as train a future workforce for NASA and other organizations.

Table of Contents

List of Figures

List of Tables

1. Problem Statement

The National Aeronautics and Space Administration (NASA) currently plans to return to the moon by the year 2024 for the Artemis mission. Part of this mission includes a desire to have astronauts live and work on the lunar surface for longer periods of time than has ever been attempted before. It is cost prohibitive to constantly ship resources to a lunar landing site, so another method of sustaining consumable resources will be needed. One key technology that NASA and other organizations who intend to stay longer on the lunar surface will use is In-Situ Resource Utilization (ISRU), or In-Situ Resource Utilization. The lunar surface is covered in regolith, which is different from soil because it doesn't have organic components. ISRU is a method to break down the lunar regolith into its constituent elemental components. NASA would like a robot to collect the lunar regolith and enable access to the regolith for ISRU. [1]To help reduce their technological risk and to bolster the aerospace workforce, NASA runs a competition called LUNABOTICS. This competition has run for several years and has been focused so far on mining the Lunar Regolith to provide the materials needed for that ISRU.

This ISRU technology requires bulk collection of regolith on the lunar surface for further processing into other usable consumable resources. Once the regolith has been collected more processing can be performed to break it down into more usable components. Previous regolith collection efforts during the original lunar landings in the 1960's were a very manual process, requiring an astronaut to physically dig with hand tools. Requiring astronauts to dig regolith is a costly and time consuming process as working and moving in low gravity is difficult and made more difficult by the bulky pressure suits needed to survive in vacuum. A method of autonomously mining and collecting regolith will be needed to enable larger scale collection efforts.

The LUNABOTICS challenge has been ongoing for over a decade under several names. Previous to the pivot to the Artemis mission, the LUNABOTICS challenge was simply known as the Robotic Mining Challenge, or RMC. It's main focus was still on regolith collection, but instead it was focused on the Martian surface. After the pivot to Artemis, the RMC rebranded as the LUNABOTICS challenge, with RMC still being the goal for now, but intending to change the goal as needs dictate. The 2021-2022 season is still focused on mining regolith for ISRU, but next year the plan is to change the competition to be something else like berm construction, or bricklaying. [2]

Other universities have been competing in the challenge for several years, with several universities having well established teams with up to a dozen people in cases. Our challenge is to quickly learn as much as we can about the challenge and the environment in order to solve the problem of collecting Lunar regolith.

2. Introduction

In this work our goal is to design, build, and test a mobile robot that can perform a basic mining cycle of operations. We aim to build a robot for telerobotic operation with manual control for movement across the terrain of the competition arena, and programmatic control for the mining system. We define a mining cycle of operations as the robot in a parked state at a set dig site, where the robot digs or by some means excavates Lunar Regolith Simulant, and then stores that Lunar Regolith Simulant onboard the robot. Collecting and dumping of the mined material will be controlled by a separate dumping cycle where some dumping apparatus raises the collected material into a position where it can fall into the collection bin at the arena.

A map of the arena is provided below in figure 1. The arena is a rectangle 6.8m by 7.5m long, with the last 2.5m being the excavation zone. The mining zone has a depth of ~30 cm of BP-1 Lunar Regolith Simulant over a ~15cm bed of gravel which simulates the icy regolith that we are aiming to collect [2]. This means that the robot has a minimum size that it has to be to prove its viability, and making a smaller scale model is not viable to present to the competition. We have to be able to get through the entire 30cm of dusty regolith before we get to the desired icy rocks below and as such our mining tool must be large enough to do so.

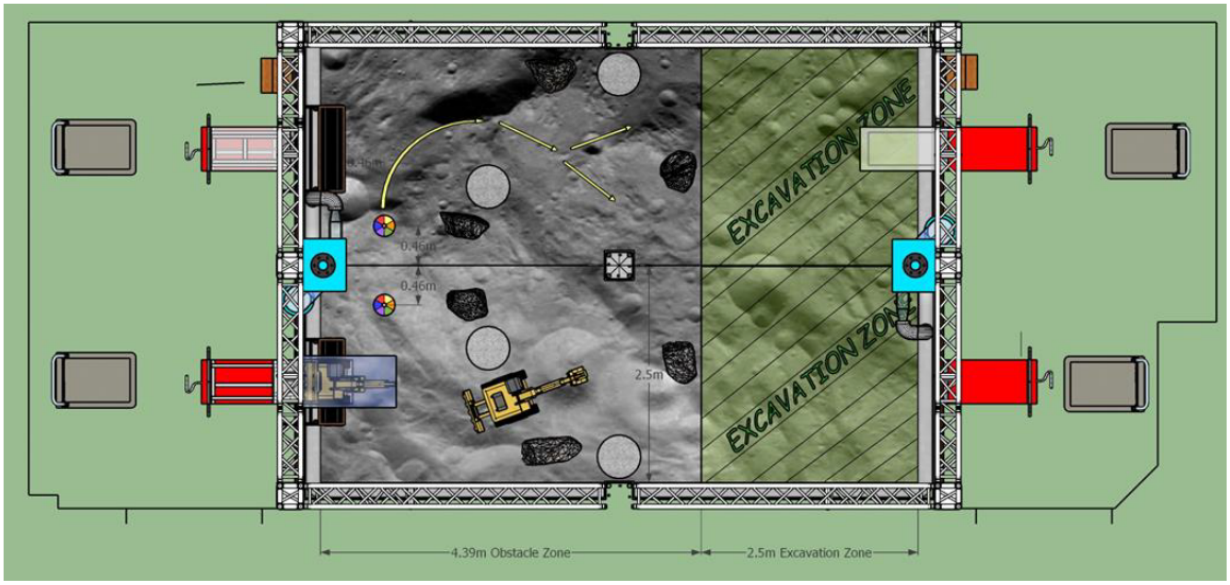


Figure 1: LUNABOTICS Arena layout.
"LUNABOTICS Guidebook Registration, Rules and Rubrics 2022, page 37"

For the entirety of the competition we are subject to the rules and regulations put in place by NASA, the organizing body of the competition. There are a variety of requirements placed on our robot and overall system that we must adhere to. First and foremost is safety, as incase of fire or other catastrophic event, the robot must be able to be made safe. There are numerous other requirements that we are expected to meet, like size, weight, and communication requirements. We intend to the best of our abilities meet these requirements.

In the next section we review some of the other attempts at solving the problem that other universities have previously worked on

3. Literature Review and Previous Works

This is a challenge that many organizations are putting work towards. Many universities have been competing in this challenge for several years and have developed teams with long track records. This is our first year at the competition, so we expect many lesions to be learned on our first attempt at the competition. The other designs come in a variety of shapes and methods of operation.

We looked at previous years competitions and saw there were a few main categories of mining tools, the first being a scooping dig arm, second being some sort of conveyor belt mining tool, third being a bucket wheel, and the last being an archimedes screw type mechanism. Since our team is heavy on EE skills we decided the tool we use should be the simplest to design and build. We felt that was the archimedes screw or the bucket wheel types as they had less joints and complexity compared to other options. From there we selected the bucket wheel because other designs using bucket wheels performed well on actually mining the lunar regolith simulant, whereas archimedes screw types relied too much on the regolith simulant not just falling out of the screw when stopped, but this happened to several teams as they extracted their tool from the dig site, the mined material simply fell out of the screw. The bucket wheel type excavator is also used in industrial design concepts for Lunar Regolith excavation with the Regolith Advanced Surface Systems Operations Robot (RASSOR) design of special note which uses an evolved bucket wheel they refer to as a bucket drum. That design uses two large bucket drum excavators to perform its duties. [3] The RASSOR design relies on large cantilevered arms to control the bucket dums, and we felt the mechanical complexity of the cantilevered arm was outside our scope so instead we opted for a more up and down type movement.

Other research has been done with bucket-wheel type excavators and they appear to be superior to other types of excavators especially in low-gravity situations due to the unique way the regolith interacts with the collection tool. According to research done by the Carnegie Mellon Field Robotics Center, as classic excavator tools move through a cutting motion, the forces on the tool increases rather than stays consistent as they do on earth. This increase in forces makes continuous cutting bucket wheel or archimedes screw type excavators superior to bulldozer or front-loader types because the continuous cutting type always has new cutting surfaces presented to the regolith. [4]

As regards to mobility many designs used wheels, with a few using tracks. We could see the usefulness of tracks because several wheel type designs got stuck either in the soil itself or in the obstacles in the terrain. The tracked designs seemed to handle the loose regolith well, but again we looked at our team's strengths and weaknesses and decided that they are too mechanically complex, and we could instead design a wheel based system and reduce the complexity by a significant amount.

One of the schools in particular that our team liked was the University of Minnesota's robot [5], which shared the same general traits we had selected. It used 4 wheels, and a large mining bucket wheel in the center of the robot that plunges downwards. Another that our team liked a lot was the University of Akron's robot[6], which also had a mining bucket wheel, but instead used tracks and an arm to hold the mining tool. We liked the use of aluminum t-slot extrusions for their frame as it is a simple framing material that is widely flexible to a lot of applications. Their robot also had LED light indicators on the side to indicate what mode the robot is, enhancing human-machine interaction.

To control our robot we investigated open source autonomous vehicle control and ended up deciding on the ArduRover branch of ArduPilot. This runs on commonly available hardware, and there are many software interfaces written to communicate with ArduPilot. As per their documentation ArduRover is an advanced open source autopilot for guiding ground vehicles and boats. [4] Common controllers that work with ArduPilot are the pixhawk series.

The pixhawk 5 is an advanced autopilot system mainly used for inexpensive autonomous aircraft. It uses a FMU 32 bit ARM processor (216MHz, 2MB memory, 512KB RAM). Professor Wu thought that using a Pixhawk in conjunction with a Raspberry pi would be better than only using the Raspberry pi by itself.

To comply with the competition guidelines we will communicate to the robot over IEEE standard 802.11n hardware and radio link. Of the allowed 802.11a/g/ or n, n had the highest performance. [5] During the competition we will be subject to restrictions in what channels we can use and we are expected to be able to switch channels in 15 minutes if the need arises.

For controlling the servos and linear actuators in our design we decided to use Pulse Width Modulation (PWM), which is a method of reducing the average power delivered by an electrical signal, by chopping it up into discrete parts by turning ON and OFF the digital voltage quickly. Doing this will produce a waveform that is rectangular. The pulse width can be modulated by adjusting the speed and delay when switching on and off the voltage. The majority of PWM drives operate in three distinct modes: Pure PWM at lower speeds, pure six-step at higher speeds, and quasi-PWM at intermediate speeds [9]. For lower speed ranges a six-step inverter and variable dc voltage supply would normally meet the requirements. However, if drive requirements have very large ranges and low speeds, this can cause three problems: communication ability from the inverter, low frequency torques that can cause irregular rotation, and low-speed stability caused by the low pass filter between the inverter and the dc voltage supply. By using PWM we can eliminate all of these problems.

4. Methodology

Our team proposes a combination of commercially available off the shelf single board computers with a pixhawk flight controller running the ArduRover branch of ArduPilot. This combination will form the core of our robot control architecture. We will subdivide the robot into several main subsystems, notably the mobility system, the mining system, the dumping system, and the network stack. Because of the rules of the competition we have a particular network stack that utilizes TCP/IP for handling message traffic to and from the robot for control and miscellaneous communication. The dumping system and mining system will both share a common central stage platform in the center of the robot. This central stage will be able to elevate up and down by using a linear actuator consisting of a pair of stepper motors with attached lead screws. The central stage is attached to linear slides and moves in a controlled travel range with position feedback of limit switches at the extreme ends of travel. The dumping system separately also has

-another stepper motor based linear actuator for moving mined material out of the robot to the dump bin. The mining system uses a brushed DC permanent magnet gear motor to spin a large excavation wheel that performs the actual task of mining the regolith. Finally the mobility system has 4 brushed DC permanent magnet gear motors for providing power to the 4 wheels individually for moving the robot across the terrain. The robot will also be equipped with a camera for situational awareness that will stream video to the telerobotic control station with the personnel controlling the robot.

5. Challenges and Risks

In this section we have selected some challenges and risks. We decided to organize each challenge and risk with its own ID number, statement, and level based on the Qualitative Risk/Challenge Analysis Model. Followed by each assessment and score, in a separate table we have a mitigation plan and a contingency plan. The risks and challenges we selected were the ones we felt were most impactful to multiple systems or multiple functions simultaneously. Many of the systems and tools we are using have risk, but we can only focus on some risk areas.

	Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Almost Certain (5)
Negligible (1)	Low 1	Low 2	Low 3	Moderate 4	Moderate 5
Minor (2)	Low 2	Moderate 4	Moderate 6	High 8	High 10
Moderate (3)	Low 3	Moderate 6	High 9	High 12	Extreme 15
Major (4)	Moderate 4	High 8	High 12	Extreme 16	Extreme 20
Catastrophic (5)	Moderate 5	High 10	Extreme 15	Extreme 20	Extreme 25

Table 1: Risk Analysis Matrix

Risk	**Risk Statement**	**Risk Level**	**Mitigation Plan**	**Contingency Plan**
Shortage of parts for project	With the supply and demand for parts being high, getting parts on time could be an issue, which could halt progress.	Likelihood: 4 Consequences: 4 Overall Risk: 16 Extreme	Keep in touch with ordering personnel and track our shipments. Try not to order too much at once, inadvertently slowing down the ordering process.	Have alternate parts that could be used as substitutes.
Lack of work space	SSU does not have a mechanical workshop for us to use.	Likelihood: 3 Consequences: 4 Overall Risk: 12 High	Try and use what resources are available. Use the Makerspace at SSU for 3D printing.Use personal tools.	Find off site workshops to make precise measurements and cuts.
Scope exceeds time and resources	If scope is not properly defined, team bandwidth may potentially not be enough to complete all scoped tasks in time	Likelihood:3 Consequences:4 Overall Risk:12 High	Careful consideration of scope before commitment.	If risk materializes, scope needs to change to reflect amount of available personnel

Table 2: Table of selected risks

Challenge	**Statement**	**Strategy Plan**
Lack of institutional knowledge	Since we are the first SSU team to attempt the robotic mining challenge, we will have to start from scratch, with potential for pitfalls.	Performed trade studies on previous teams.
System integration	The integration of all robot subsystems will be difficult.	20% extra time added to system integration.
Lack of personnel	Since we are a small team compared to other LUNABOTICS teams, we are potentially faced with more work per team member compared to other teams.	Added junior students to help the larger project.
Environmental Hazards during competition	The amount of fine dust in the arena can affect the overall performance of the robot.	Try to encase components with some kind of sealant to protect them.

Table 3: Table of selected challenges

6. Project Requirements

Our project requirements largely came from our study of the NASA LUNABOTICS 2022 guidebook. We decided one which requirements were most key to capture the critical safety features and the critical functionality features in order to get a minimum viable product. The key requirements are reflected by being highlighted in yellow.

6.1. Marketing Requirements (MR)

M.R. 1. Provide a robot with a means to collect regolith for the competition

M.R. 2. The robot shall be able to drive to the mining site in a reasonable amount of time

M.R. 3. The robot shall be able to have its power cut in case of emergency

M.R. 4. The team shall be trained for safely operating the robot

M.R. 5. The robot must be able to operate remotely using a communication link

M.R. 6. The communication link shall not exceed the competition bandwidth limits

M.R. 7. The battery shall provide enough power to operate for a competition run

M.R. 8. The robot shall be compact enough and lightweight enough to be easily transported

6.2. Engineering Requirements (ER)

E.R.1. The robot will have a digging system capable of mining 1 kilogram in 15 minutes (M.R.1)

E.R.2. The robot shall be able to drive 7 meters in 90 seconds. (M.R.2)

E.R.3. The robot will have an emergency stop capable of cutting the robot power in 5 seconds (M.R.3)

E.R.4. The robot operators must pass a RMC robot operation safety exam with a score of 75% or higher (M.R.4)

E.R.5. The robot must use wireless communication standard IEEE 802.11b, 802.11g, or 802.11n for main communication. (M.R.5)

E.R.6. The robot shall not exceed an average bandwidth speed no more than 5Mb/s. (M.R. 6)

E.R.7. Battery must be able to provide power for a minimum of 15 minutes to the robot during expected load. (M.R.7)

E.R.8. The robot shall fit inside a volume envelope no larger than 1.1m length by 0.6m wide and 0.6m tall, and weigh no more than 80kg (M.R.8)

7. Implementation

7.1. System Architecture

To implement our system we needed to design a complete control system for the various tasks the robot has to perform. We intend to use an off the shelf flight control system as the core for our mobility system, and disable the more advanced features of the control system more intended towards flight applications. There is a separate software branch for the underlying ArduPilot software called ArduRover, which is more tailored to ground vehicle applications, and we intend to run that branch. We will use a companion computer to communicate with the flight control system (FCS) and use that companion computer to be the communication bridge between the FCS and our telerobotic control.

We also have separate mining and dumping systems as part of our robot and we intend to control that with a separate companion computer to ensure both operations have real time control at all times. To drive those systems we will use a combination of brushed DC motors with gearboxes to increase torque and stepper motors for fine control and position holding where needed. Shown below in Figure 1 is the general system architecture for our robot. We will have our telerobotic control station separated from the robot, the ring side communication link, and the robot itself.

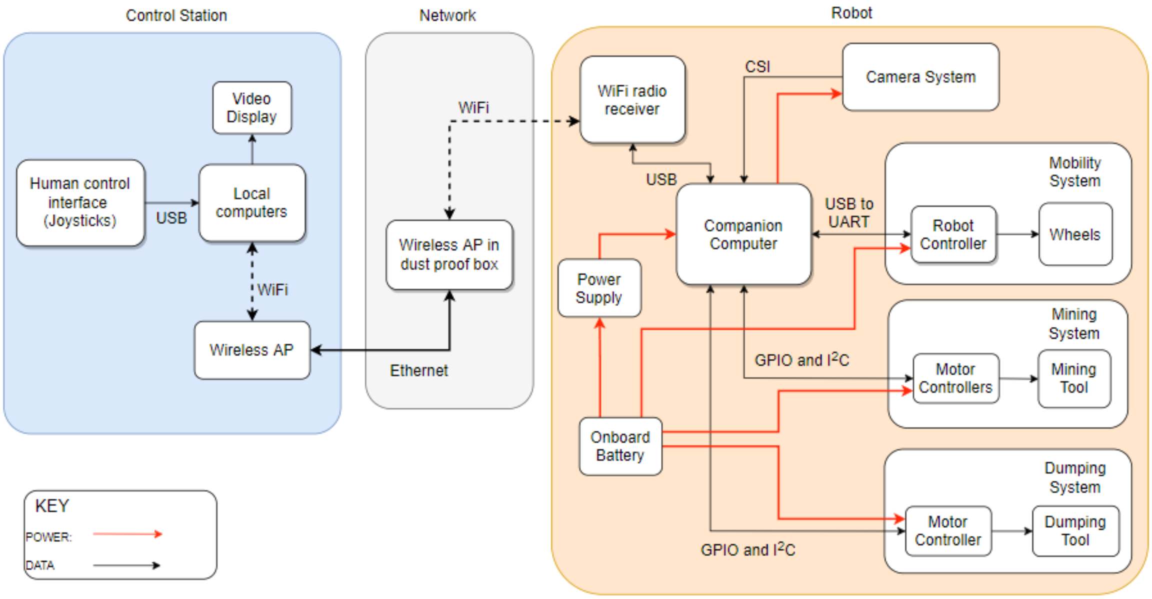


Figure 2: System Diagram

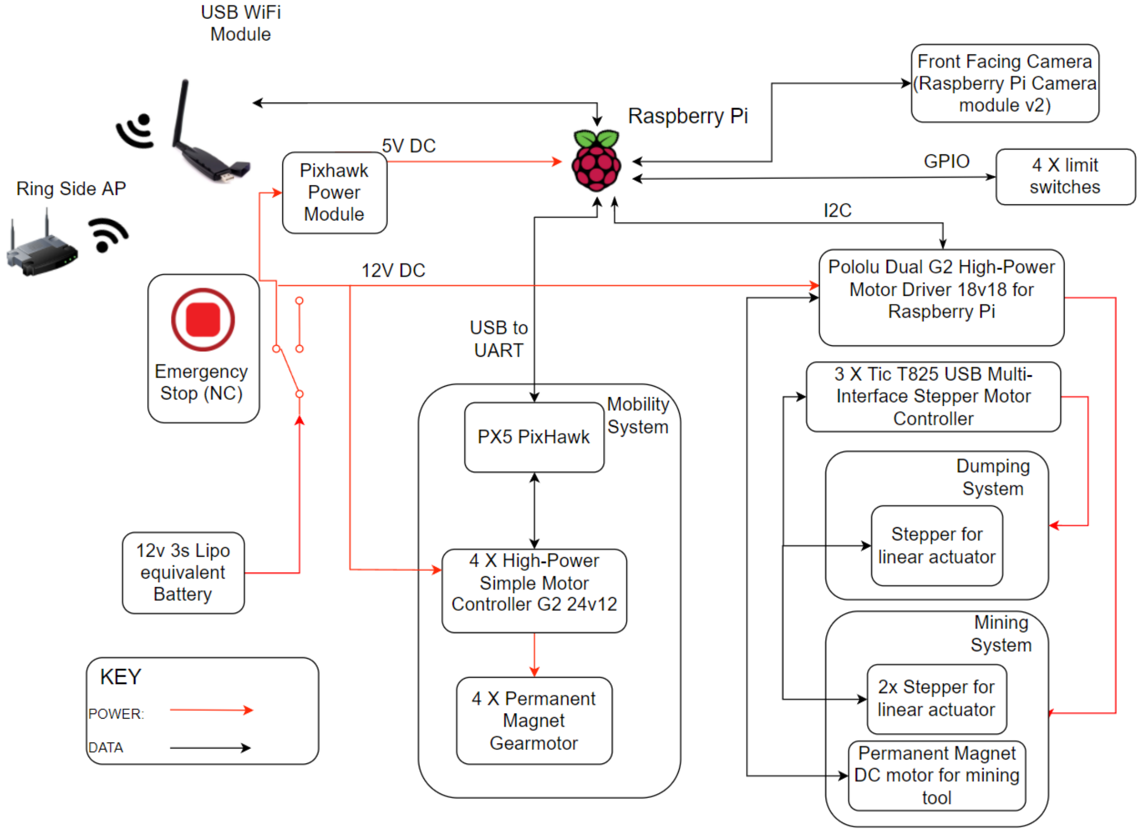


Figure 3: Hardware Diagram

7.2. Alternate Design Matrix

For our alternate design matrices we decided on a 5 point scale per category. This point scale was made less granular such to simplify our decision space and make categorically sorting the devices easier.

	Power use	IOs	Mass	Libraries	Total Score
Raspberry Pi 3B+	5	4	5	5	19/20
NVIDIA Jetson Nano	2	4	4	2	12/20
Beagle Bone Blue	5	5	5	3	18/20
Intel NUC	1	1	2	3	7/20

Table 4: Alternate Design Matrix, Embedded System

For embedded systems, the Raspberry Pi 3B+ and the Beagle Bone Blue embedded systems came out with the top scores. The Beagle Bone Blue seemed slightly better at conserving power over the Raspberry Pi, but the Raspberry Pi had a better library score. When it came to power use, motor control IO's, and Libraries, the Raspberry Pi and Beagle Bone Blue out scored the Intel NUC and the NVIDIA Jetson Nano. In the end the Raspberry Pi scored better overall with a 19/20, and was our choice for our embedded system from our analysis.

	PWM Connectors	Host GPIO accessibility	Commercial Availability	Link Complexity (Less complex scores higher)	Total Score
V5 Pixhawk	5	5	5	3	18/20
Navio2	5	1	2	5	13/20
Beagle Bone Blue	3	4	4	4	15/20

Table 5: Alternate Design Matrix, Robot Controller

For robot controllers, the Pixhawk controller scored the best on our alternate design matrix, with a score of 18/20. It scored 5 in all categories except for the link complexity category, where it scored a 3. The Navio2 scored highest in the link complexity category, but scored a 1 when it came to GPIO accessibility. The Beagle Bone Blue scored an overall 15/20, scoring the lowest in PWM connectors category, coming in second to the Pixhawk. We ended up choosing the Raspberry Pi, with an overall score of 18/20 on the alternative matrix design.

7.3. Budget

Since our robot has a long list of mechanical and electrical parts, we decided to include our categorical budget estimates rather than list all of our parts down to the individual fastener or circuit element. We felt an overall project budget would be a more useful assessment tool for how we decided to allocate our funding.

Costs by system	Cost Estimate
Materials and Systems	
Mobility System	$ 1,750.00
Mining System	$ 1,250.00
Communications System	$ 400.00
Companion Computers and Robot Controllers	$ 500.00
Power System	$ 500.00
Ringside communications system	$ 250.00
Control Station communications system	$ 100.00
Tools	$ 250.00
Labor	
CNC shop time for large robot parts	$ 750.00
Materials and systems subtotal	$ 5,750.00
Total Costs	$ 5,750.00

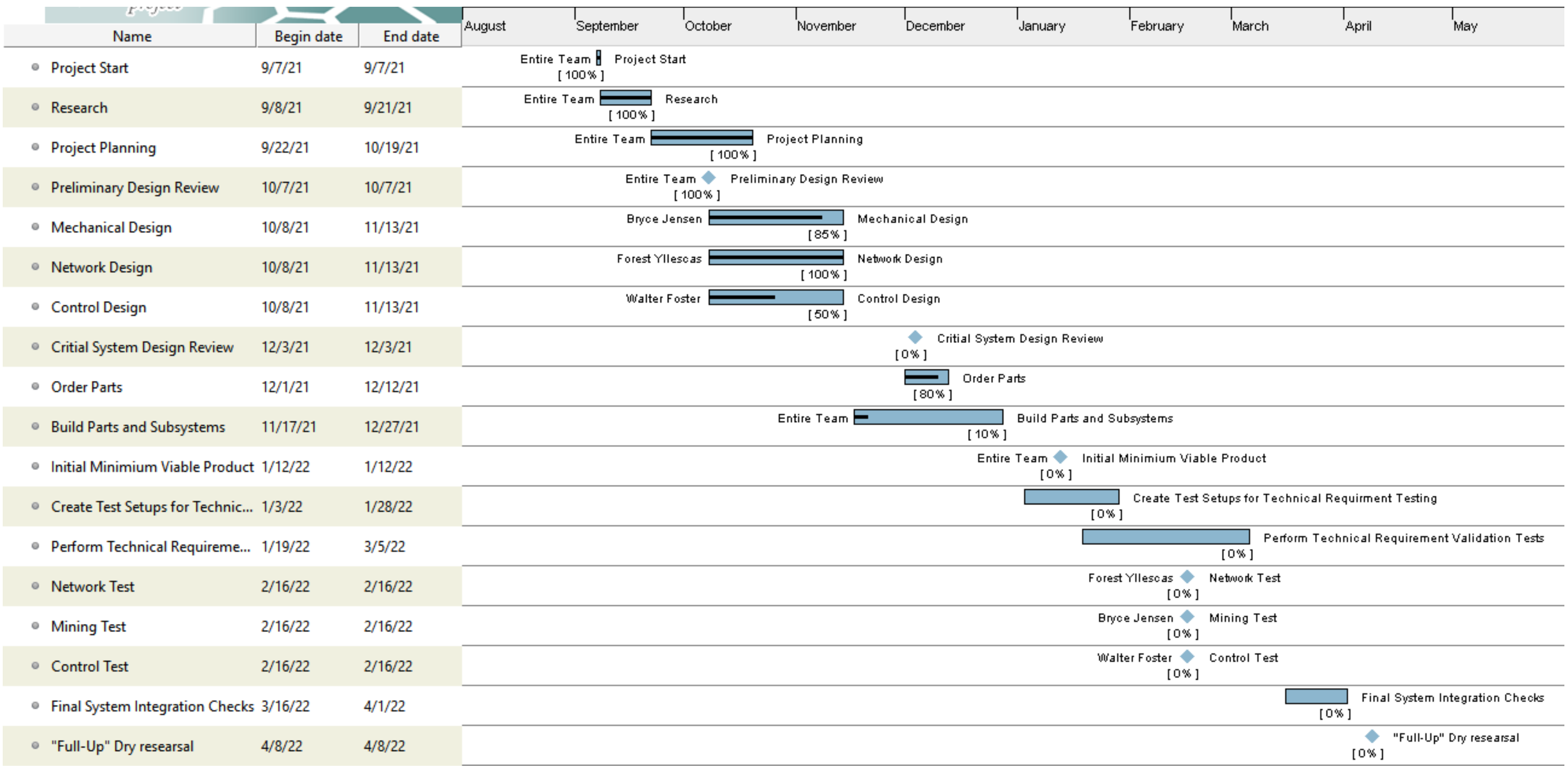
Table 6: Budget Estimate: Materials

Travel and shipping	Cost Estimate
Airfare+Lodging	$2,250.00
Crate and shipping costs	$2,000.00
Total Costs	$4,250.00

Table 7: Budget Estimate: Travel and Shipping

7.4. Project Schedule

The first phase of our project will consist of research and planning throughout the months of September and October. The Preliminary Design Review will take place with our project advisor at the beginning of October. The Mechanical, Network, and Control Design will be worked on starting the second week of October and ending November 13th. We will also start working on building subsystems starting mid November. With our project advisor, the critical design review will take place on November 30th. Ordering parts will follow after the critical system design review on the 1st of December and will go through to the 12th of December. Initial minimum value product, set up for testing for technical requirements, and the testing itself all begin in the month of January and will finish up at various dates. The Network, Mining, and Control test is scheduled to take place on February 16th, and should only take one day. The final system integration checks will be started on March 16th, and will continue till April 1st. From this point we will prepare for our Dry Rehearsal that is scheduled to take place on the 8th of April. We will continue to review the schedule and make any adjustments based on our test results and time schedule.



Name	Begin date	End date
Project Start	9/7/21	9/7/21
Research	9/8/21	9/21/21
Project Planning	9/22/21	10/19/21
Preliminary Design Review	10/7/21	10/7/21
Mechanical Design	10/8/21	11/13/21
Network Design	10/8/21	11/13/21
Control Design	10/8/21	11/13/21
Critial System Design Review	12/3/21	12/3/21
Order Parts	12/1/21	12/12/21
Build Parts and Subsystems	11/17/21	12/27/21
Initial Minimium Viable Product	1/12/22	1/12/22
Create Test Setups for Technic...	1/3/22	1/28/22
Perform Technical Requireme...	1/19/22	3/5/22
Network Test	2/16/22	2/16/22
Mining Test	2/16/22	2/16/22
Control Test	2/16/22	2/16/22
Final System Integration Checks	3/16/22	4/1/22
"Full-Up" Dry researsal	4/8/22	4/8/22

Table 8: Gantt Chart

8. List of Tests

For our test plan, we decided to focus on core components of the control system, and to work outward from there. In a general sense our strategy is to build a backbone and then connect things to that backbone. To that end we focused our tests for fall semester around the control systems and the networks systems. We divided our tests into Functional Tests (FT) and System Verification Tests (ST). We drew heavy inspiration from our market interviews where the commonly reported problem was in the process of system integration. On advice we got from our interviews we decided to focus on that core backbone described earlier, get that functionality locked in place and then not have to worry about it again. We want to focus on the risky problems that have risk across multiple systems first. Once the cross-system risk is lowered, we intend to do more focus system by system tests for our marketing and engineering requirements.

For our fall semester we have four Functional Tests: Average Bandwidth Test, Wireless Standard Compliance Test, Arena Bandwidth Test, and a Power Draw Test. We felt that the Average Bandwidth Test and the Wireless Standard Compliance Test were important to meet the NASA requirements as per the guidebook and not risk disqualification for not meeting relatively simple standards. The tests are important because we want to be able to show we can use the proper amount of bandwidth, and be on the proper channel, and on the proper wireless standard. The intent of the Arena Bandwidth Test is to determine if we need to add an additional wireless antenna to our Raspberry Pi, as the onboard antenna may not have as good reception as an external antenna. We intend to test this hypothesis by simulating the actual size of the arena and making sure that we can provide at least 5mbps to the robot with either the onboard antenna, or the external USB antenna. The Power Draw Test is to demonstrate that we will have enough power to power all subsystems and motors for operation. We have one System Verification Test, which is The Network Control Test. The purpose of this test is to demonstrate our backbone style system approach, as it represents the main chunk of that backbone with the wireless network infrastructure connected to the companion computer, and the robot controller.

8.1. Summary of Tests

Below, we present a summary of tests that are planned for the fall semester.

Test	Test Name	ER	Status	Notes
FT-1	Average Bandwidth Test	ER.5	50%	IN PROGRESS
FT-2	Wireless Standard Compliance Test	ER.4	Completed	PASS
FT-3	Arena Bandwidth Test	ER.1	Completed	PASS
FT-4	Power Draw Test	ER.6	Pending Receiving of Parts	PENDING
ST-1	Network Control Test	ER. 2	Pending Receiving of Parts	IN PROGRESS

Table 9: List of Fall Semester Tests

8.2. Description of Tests

FT-1 Average Bandwidth Test

Objective:

Measure system bandwidth while using camera and control system. E.R.5

Setup:

- Have Pi connected to PixHawk
- Have Pi on full network stack
- Connect Camera to Pi
- Wireshark installed on Raspberry Pi capturing network traffic

Procedure:

- Turn on Camera and stream video
- Issue random commands over Mavlink to pixhawk for 15 minutes
- Measure Average Bandwidth over 15 minutes using wireshark

Pass/fail criteria:

Pass if less than 5Mbps. Fail if exceed 5Mbps.

FT-2 Wireless Standard Compliance test

Objective:

Measure Network setup to verify the network is only on 802.11b,g,or n standards. E.R.4

Setup:

- Pi connected to full network stack
- Netspot installed on laptop to measure WiFi channels

Procedure:

- Measure wireless network using netspot to verify correct SSID and channel as per competition guidelines
- Change SSID and channel to alternate channel as per competition guidelines
- Measure time it takes to change channels

Pass/fail criteria:

Pass if the network is on the correct channel and with the correct SSID and is able to change to the correct alternate channel and alternate SSID within 15 minutes. Fail if the network is on other bands or takes longer than 15 minutes to update.

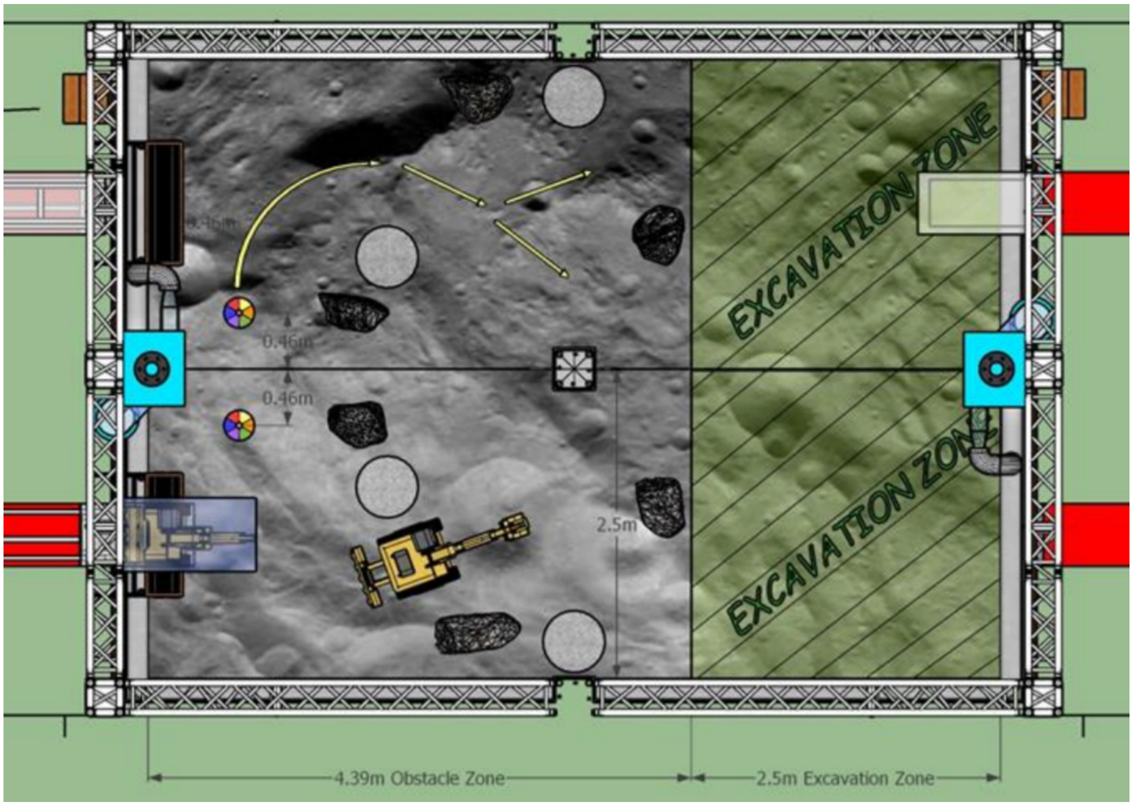
FT-3 - Arena Bandwidth Test

Objective:

To measure wireless data rate in an area like the expected arena to verify we can make a connection at any point in the arena (E.R.1).

Setup:

- Mark area of open space to the size of the competition arena
- Place AP where it would be at competition, inside dust proof box to simulate competition arena conditions
- Measure data rate at 4 corners of arena to verify line of sight data rates



$$\bar{r}_A \equiv \frac{\sum_{t=1}^{T} r_t}{T}$$

Figure 4: Arena Dimensions

Procedure:

- Run iperf on both the server and client computers
- Observe results

Pass/fail criteria:

Network can sustain at least 5Mb/s at all 4 corners of the arena

FT-4 - Power Draw Test

Objective:

Measure the power draw of motors during load to accurately determine how much battery storage to put on robot

Setup:

- Have all four drive motors connected
- Have all three steppers connected

Procedure:

- Energize steppers and spin brushed DC motors
- Measure current flow via Hall effect current sensor

Pass/fail criteria:

This is a measurement test intended to provide a consumption baseline

ST-1 - Network Control Test

Objective:

Show that the drive motors will spin when issued network commands

Setup:

1) Have motors in tact with frame of robot
2) Make sure our control station is running properly
3) Have the LAN working properly on the robot itself
4) Controllers connected to the LAN as well

Procedure:

1) User inputs forwards, backwards, left or right command
2) Observe results

Pass/fail criteria:

All four motors spin in correct directions when control commands are input. All forward for forward, all backward for reverse, and half forward and half backwards for left and right.

Tests Conducted (Results)

FT.1:

Pending

Rpi Camera Raw Bitrate	
Number of Pixels (Height * Width)	8 Megapixels
Color Depth	8 bits
Color Channels	3
Frames per second	30
Uncompressed bitrate	**5.67 Gb/s!!!**

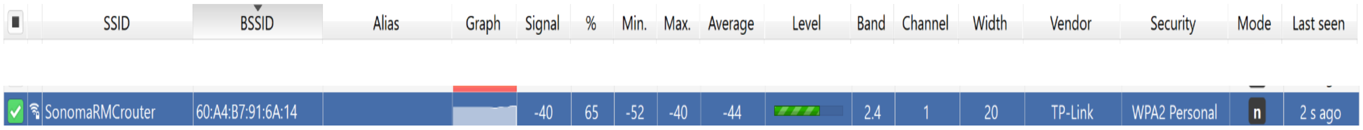
- Video raw bitrate = Width of video * Height of video * Color depth * Number of color channels * Video frames per second

Conclusion: Video compression or downsampling will likely be needed. Waiting on parts for actual test with real bit rate

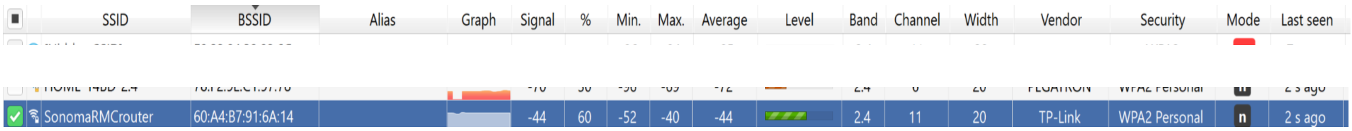
FT.2:

- Verified Network could switch channels between 1 and 11 within 15 minutes.
- Verified AP was on 802.11b,g,n standard.
- Verified Max spectral bandwidth as 20MHz for all 2.4 GHz transmission equipment.

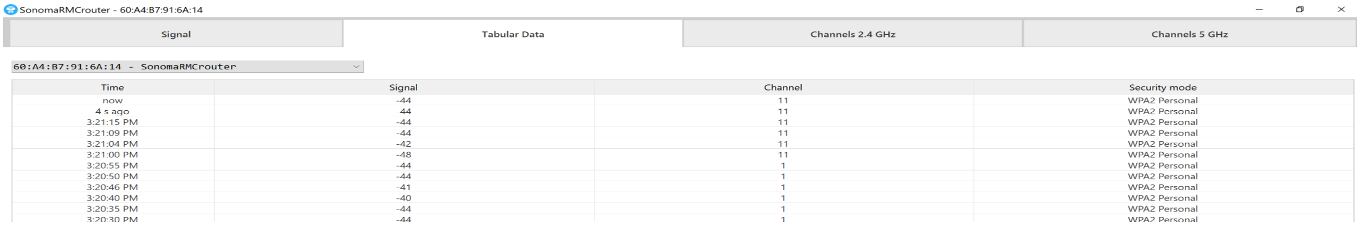
Conclusion: The AP is able to provide network requirements.



■	SSID	BSSID	Alias	Graph	Signal	%	Min.	Max.	Average	Level	Band	Channel	Width	Vendor	Security	Mode	Last seen
☑	SonomaRMCrouter	60:A4:B7:91:6A:14			-40	65	-52	-40	-44		2.4	1	20	TP-Link	WPA2 Personal	n	2 s ago



■	SSID	BSSID	Alias	Graph	Signal	%	Min.	Max.	Average	Level	Band	Channel	Width	Vendor	Security	Mode	Last seen
☑	SonomaRMCrouter	60:A4:B7:91:6A:14			-44	60	-52	-40	-44		2.4	11	20	TP-Link	WPA2 Personal	n	2 s ago



Time	Signal	Channel	Security mode
now	-44	11	WPA2 Personal
4 s ago	-44	11	WPA2 Personal
3:21:15 PM	-44	11	WPA2 Personal
3:21:09 PM	-44	11	WPA2 Personal
3:21:04 PM	-42	11	WPA2 Personal
3:21:00 PM	-48	11	WPA2 Personal
3:20:55 PM	-44	1	WPA2 Personal
3:20:50 PM	-44	1	WPA2 Personal
3:20:46 PM	-41	1	WPA2 Personal
3:20:40 PM	-40	1	WPA2 Personal
3:20:35 PM	-44	1	WPA2 Personal
3:20:30 PM	-44	1	WPA2 Personal

FT.3:

- Verified size of arena in backyard
- Verified sufficient bandwidth 5x for best-case location and worst-case location
- **Close-**

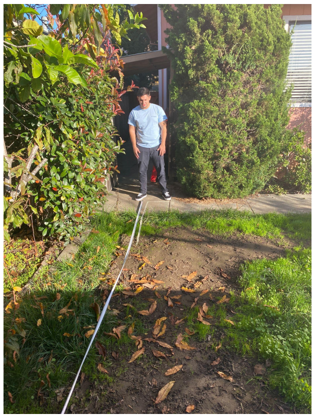
  Avg Down: 39.8 Mb/s

  Avg Up: 39.9 Mb/s

- **Worst-**

  Avg Down: 26.3 Mb/s

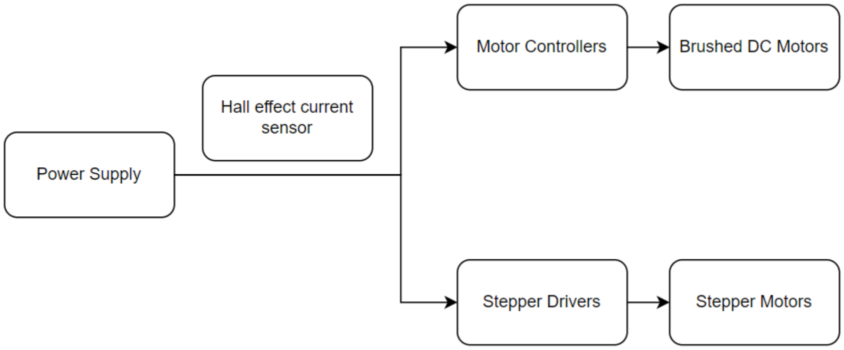
  Avg Up: 41.3 Mb/s



Conclusion: The AP is able to provide network requirements.

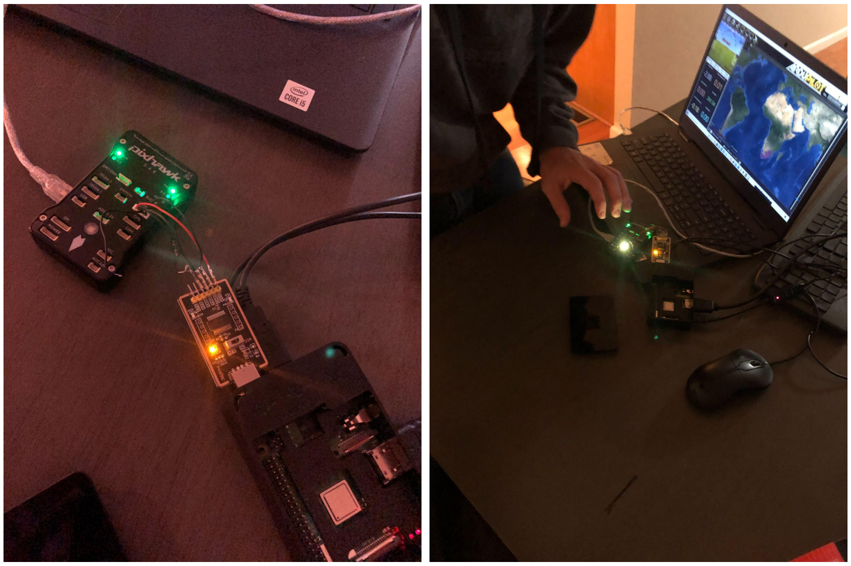
FT.4:

Pending



ST.1:

Pending



9. Ethics of the Engineering Profession and Our Project

The ethical design in our robot was to help with the problem of finding a way to safely and effectively mine and deposit regolith in a lunar environment. The safest way to accomplish this task would be by building a robot that could do it.

The robot is powered electrically by a battery, which can be recharged for continuous uses. The parts of the robot can be reused for other projects in the future if it’s decided that the project will no longer be worked on. The frame is made of aluminum and can be easily taken apart and recycled. Since the robot has several subsystems, like the raspberry pi and pixhawk, they can be used for other projects in the future as well. It will be easy for anyone to disassemble the robot since we used a modular design approach. The tracks for the robot's wheels are 3-D printed and are biodegradable.The robot has little to no negative impact on the environment or society.

We designed our robot with the intent of taking it to the RMC competition. Since we have some knowledge in electrical engineering, we feel that we can accomplish this task in an ethical way. We plan on ending the project in May 2022, after the competition is over with. After that we plan to leave the robot with the engineering department, with the hopes that it will be maintained and possibly upgraded for the following year's competition. The robot is not intended to be used by anyone other than engineering students and faculty at SSU.

Our RMC robot is being built to mine simulant regolith. Trying to mine regolith by hand would be time consuming and dangerous. By building these robots for competition we are actually helping society by strengthening the workforce that is needed to continue future Artemis missions by NASA. These future missions are important for humanity because their purpose will be to learn more about the Moon and Mars, and how to live on them.

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