University of Arkansas – CSCE Department
Capstone II – Final Report – Spring 2022

NASA Lunabotics Competition with The Arkansas Razorbotz

Nicholas Beck, Cade Courtney, Levi Davis, Michael Ebbs, AnElizabeth Henry, Tristen Teague

Abstract

The National Aeronautics and Space Administration (NASA for short) has established themselves as a worldwide force in space exploration since it was established in 1958. As a part of their research in space exploration, NASA has planned many goals for the future of space exploration. One of the goals includes investing in the future generations' technologies and inspiring current students to pursue career paths in STEM related fields through interactions with space program [1]. Another one of the goals that NASA has planned is a mission to put a woman and a person of color on the moon for the first time ever and use more innovative and advanced technologies to explore the lunar surface in hopes to begin to establish a permeant presence of life on the moon [2]. This mission is known as the Artemis mission. At the intersection of these two plans that NASA has for the future we can find a creative competition known as NASA's Lunabotics Competition.

NASA's Lunabotics Competition (called NASA's Robotics Mining Competition in previous years) is a university level competition established in 2010 where teams that are comprised of at least two undergraduate students and a working robot will compete to demonstrate full operation and capability of the robot and its's ability to maneuver through a simulated environment and mine rock/gravel material [3]. The purpose of the robot for each team in the competition is to be capable of navigating, mining, and extracting resources from an area that is simulated as the surface of the moon. In such a simulated environment, the robot will have to navigate around obstacles, mine materials, collect the materials, and then return to a specific navigation site to dump the materials off for collection. The competition is designed to allow teams from universities across the country to "use the NASA Systems Engineering Process to design, build, and operate a lunar robot" and to "also perform public outreach, submit systems engineering papers and present and demonstrate their work to a NASA review panel." [3] To compete in the competition, the University of Arkansas has entered the competition with their very own team: The Razorbotz. The Razorbotz team is comprised of many sub-teams that each work on different aspects of the robot to produce the overall final design. Some examples of the sub-teams are: Electrical, Excavation, Chassis, and Computer Science. During this semester, Capstone group 5 will be joining the Computer Science sub-team to help implement the computer systems of the robot. As a result of joining the team, our capstone group will be afforded the knowledge of working through the systems engineering process and the challenges

associated with it to design a complex machine. As a result of our hard work, we can put forward the knowledge that we gained through the process so that NASA may see our work and possibly use our technologies for the future of space exploration.

1.0 Problem

As NASA continues to develop technological advancements in space exploration, they are looking for steps they can take to secure their future as a worldwide leader in the industry. Two areas that they focus on are the immediate missions that they can plan for space exploration and long-term missions that they can plan to invest in the future of NASA, but each of these areas' present problems in and of themselves. Space exploration missions require fully developed pieces of technology before being sent into space. Investing in the future of NASA and their goals requires positive interactions between the company and aspiring STEM students. So, to understand the problem further, we can analyze current examples of the goals mentioned above.

An example of an immediate mission that they have planned for space exploration is the Artemis Mission. The Artemis Mission was planned by NASA to achieve feats of space exploration that have not yet been achieved. Those feats include the following: landing the first woman on the moon, landing the first person of color on the moon, establishing more suitable conditions for lunar surface exploration, establishing more suitable conditions for humanity’s long-term presence on the moon, and preparing for further exploration to Mars [4]. The lunar landing of this mission was originally scheduled to take place by 2024 but was recently delayed to 2025 because missions such as these will require fully developed pieces of technology before being sent into space.

An example of a long-term mission that they have planned to invest in the future of NASA is the Lunabotics Competition. The Lunabotics competition was created by NASA in 2010 to allow university level students to design and build robots that are capable of mining materials in a simulated lunar environment. The goal of the competition is to create a robot that has a wide scope of operational functionality while adhering to design limitations set forth by NASA in the competition.

Both goals are important for NASA, because they understand that they need to continue to develop more advanced technology for safer and cost-efficient space exploration, while simultaneously investing in their future by encouraging current students to pursue degrees in STEM related career fields. Missions such as the Artemis Mission require fully developed machines such as lunar rovers that are capable of navigating and mining material in the harsh environment of the moon. If space exploration by NASA were to cease, though, humanity would be confined to the limitations of resources that we can find on earth and the cost, both monetary and environmental, associated with mining those resources. If interactions between NASA and students pursuing further education in STEM related fields were to cease, then we might see a decrease of interest in NASA and their program, and ultimately space exploration would cease to be an asset that humanity pursues.

2.0 Objective

The objective of this project is to design a robot for NASA’s Lunabotics Competition. Our capstone team will be focusing on the computer systems of the robot, as we are on the computer science sub-team of Razorbotz. In the competition, our robot will receive two attempts at maneuvering through the terrain to collect the maximum amount of rock/gravel material within the 15-minute time limit of the competition while operating remotely or through autonomous operations using ROS2 (Robot Operating System). The robot must adhere to the size and weight limitations put forth by NASA in the 2022 Lunabotics Challenge Guidebook [4]. The limitations of our design are included below in the "Design" subsection entitled "Requirements and Design goals." Here are a few examples of weight and size limitations for the robot as well as minimum expectations that the robot must meet in the competition:

- The design of the lunar rover must satisfy the smaller undeployed volume of 1.1 m length x 0.6 m width x 0.6 m height.
- The lunar rover must weigh less than the maximum mass of 80 kg.
- The rover must have a "KILL SWITCH," which is a red emergency stop button that will shut down the lunar rover's electrical systems.
- A minimum amount of 1.0 kg of gravel must be mined and deposited during either of the two competition attempts.
- Subsystems used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.
- Robots may deploy or expand beyond the envelope after the start of each competition attempt but may not exceed 1.5 m in height.
- Multiple robot systems are allowed, but the total mass and starting dimensions of the entire system must comply with the volumetric dimensions given in this rule.
- The robot must provide its own onboard power. No facility power will be provided to the robot during the competition runs. There are no power limitations except that the robot must be self-powered and included in the maximum mass limit.
- The robot cannot employ any fundamental physical processes, gases, fluids, or consumables that would not work in an off-world environment.
- Components (i.e., electronic and mechanical) are not required to be space qualified for Lunar or atmospheric, electromagnetic, and thermal environments.

All design limitations are listed in the NASA in the 2022 Lunabotics Challenge Guidebook [4].

The main components that our capstone team will work on as a part of the computer science sub-team of Razorbotz is the operation of the robot. During the competition, as stated above, the robot may operate in one of two ways: remotely or autonomously. Additional points may be earned by the team for implementing autonomous operation within the robot. Examples of all autonomous features that could earn additional points in the competition are listed below:

- Excavation Automation
- Dump Automation
- Travel Automation
- Full Autonomy (One Cycle) - Successful completion of one cycle of Excavation, Dump, and Travel
- Full Autonomy - Robot is in hands free control for the entire 15-minute period of the competition and has completed two or more cycles of Excavating, Dumping, and Traveling

All autonomous features that we will try to achieve are listed in the NASA in the 2022 Lunabotics Challenge Guidebook [4].

By the end of the project, each member of our capstone group will have also completed working through the systems engineering process and the challenges associated with it, which is one of NASA's main objectives for each of these robotics teams.

3.0 Background

3.1 Key Concepts

There are several key technologies that we are using to accomplish unique goals and solve individual problems that are required for an autonomous excavating robot.

The Rev Spark Max Motor Controller is the new motor controller that the design team decided to use for wheel functionality. It "features 60A continuous current with passive cooling and bi-directional limit switch inputs" [5]. It is compatible with the Spark Neo brushless Motor that we are using. "Brushless motors replace the mechanical commutation function with electronic control." [6] Our motor controller is compatible with both brushed and brushless motors, but we only need the brushless functionality from it.

The Rev NEO brushless motor is the motor that will be used to control the drive train of the excavating robot. It will be controlled by the Rev Spark Max Motor Controller and implemented using ROS 2. The Rev NEO has a nominal voltage of 12 V and 2.6 Nm of torque [7]. While that is not a lot of torque, it is enough to move the robot without breaking the delicate 3d printed wheels.

The Zed 2i camera is a stereo camera that features 2 lenses side by side and calculates the depth of objects up to 20m [8]. The camera also contains sensors for temperature, magnetometer, barometer and IMU [8]. The IMU (Inertial Measurement Unit) measures the x, y, z, pitch, yaw, and roll of the camera [9] which will help us map out where the robot is in a 3d environment. Temperature and barometer measurements are not needed for this competition because they should remain constant the entire time. The magnetometer is used to measure the "strength and direction of magnetic fields" [10] and it is explicitly disallowed for the competition [4] because the magnetic field on the moon is drastically different than on earth where the competition will be held.

The operating system we are using is Robot Operating System 2 (ROS 2) which is a "set of software libraries and tools for building robot applications [11]." ROS 2 uses a subscriber and publisher system where nodes send packets of information out and they subscribe to information being sent from another node if they need it. Ros 2 is open source and there is a wealth of public information on how to implement different peripherals such as the ZED camera.

3.2 Related Work

In "Trajectory Planning and Collision Avoidance Algorithm for Mobile Robotics System" [12] Marwah M. Almasri, et al, studied real time path planning and obstacle avoidance in an unknown environment. They used 8 infrared sensors positioned all around the robot instead of a camera to detect obstacles in the robot's predetermined path. While Marwah M. Almasri's, et al, robot is able to detect obstacles all around the robot, it cannot detect images, markers, or holes in the ground because the experiment assumed a flat predetermined path. Using a camera will not only let the robot know all these things, but it will also be able to transmit images back to the computer controlling it.

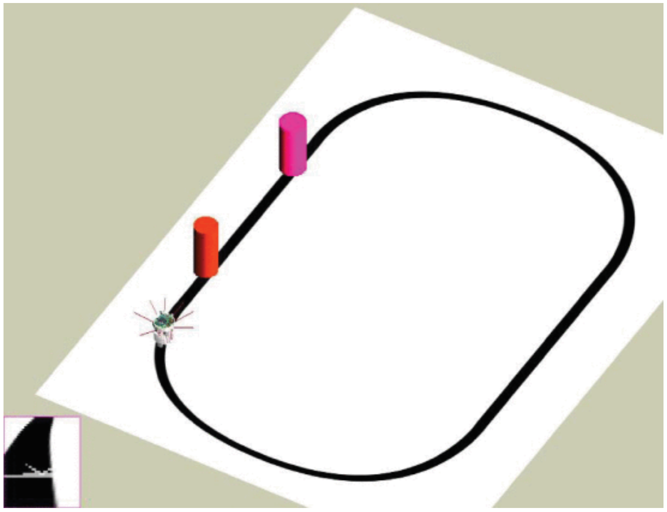

Fig. 1 –” Robot platform of the simulation where there are two obstacles placed on the robot path” [12]

Luckily, there is a wealth of related work available specifically for rovers. The most recent NASA rover deployment is NASA’s Mars 2020 Perseverance rover which landed an autonomous rover on mars. One of the rover's main goals is to find signs of ancient life on the planet [13], although there are several other tests being conducted in parallel with the search for life. The Perseverance rover will use radar imaging to map out the geological structure of the planet, as well as conduct the “Mars Oxygen In-Situ Resource Utilization Experiment” [13] which will attempt to convert carbon Dioxide from the atmosphere of mars into Oxygen that can be used by astronauts.

Our autonomous excavating rover is far less sophisticated than the Perseverance rover, but our robot does outperform Perseverance in one aspect – Excavation. During a question-and-answer session conducted by NASA, Dr. Heather Graham said the Perseverance rover can only collect samples of about 20 grams [14]. The autonomous excavating rover we are working on should be able to excavate far greater amounts of rock and regolith when finished.

The moon is covered with a thick layer of regolith, a material that “consists of approximately 42% oxygen by mass” [15] as well as other things like water, hydrogen, helium, and carbon monoxide. This regolith material can hopefully be transformed into oxygen in a similar way to what Perseverance is attempting to do with the “Mars Oxygen In-Situ Resource Utilization Experiment” [13]. If the Perseverance experiment is successful, then the next goal is to figure out an efficient way to excavate regolith. In 2013, Robert P. Mueller, et al, designed the Regolith Advanced Surface Systems Operations Robot (RASSOR) [15] which contains the excavating drum (shown in Figure 2 below). The drum is driven by a motor on an excavating arm that drives it into the regolith while rotating. We adapted and simplified this design by reducing the number of drums and internal components to accommodate our budget. Those changes can be seen in figures 6 and 7 much farther down. These changes also allowed us to meet the design requirements listed below.

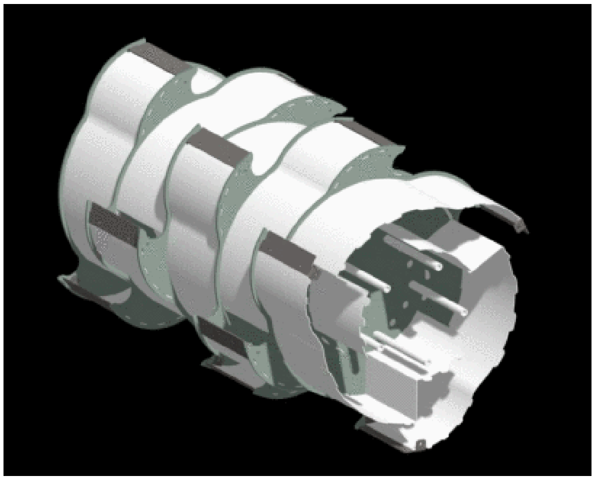

Fig. 2 - RASSOR excavating drum without end caps [15]

4.0 Design

4.1 Requirements and/or Use Cases and/or Design Goals

- The design of the lunar rover must satisfy the smaller undeployed volume of 1.1 m length x 0.6 m width x 0.6 m height.
- The lunar rover must weigh less than the maximum mass of 80 kg.
- The lunar rover cannot employ any fundamental physical processes, gases, fluids, or consumables that would not work in an off-world environment.
- Must be able to communicate with the lunar rover remotely or the rover must operate autonomously.
- The computer system’s telecommunication is required to have a total average bandwidth of no more than 5.0 megabits/second.
- Telerobotic operators are only allowed to use data and video originating from the mining robot and the NASA video monitors.
- Autonomous operation period.
  - Once autonomous operations begin, telecommunication is not allowed to alter the rover’s path.
  - The rover’s autonomous systems may not use the walls of the arena.
- Must be able to control the lunar rover’s drive train and excavation motors.
- The lunar rover is required to only excavate in the designated excavation zone.
- The rover must have a “KILL SWITCH,” which is a red emergency stop button that will shut down the lunar rover’s electrical systems.
- The lunar rover must avoid obstacles throughout the course.
  - At least three randomly placed boulder obstacles of approximately 30 cm to 50 cm.
  - At least two craters of varying depth and width, no wider or deeper than 50 cm.

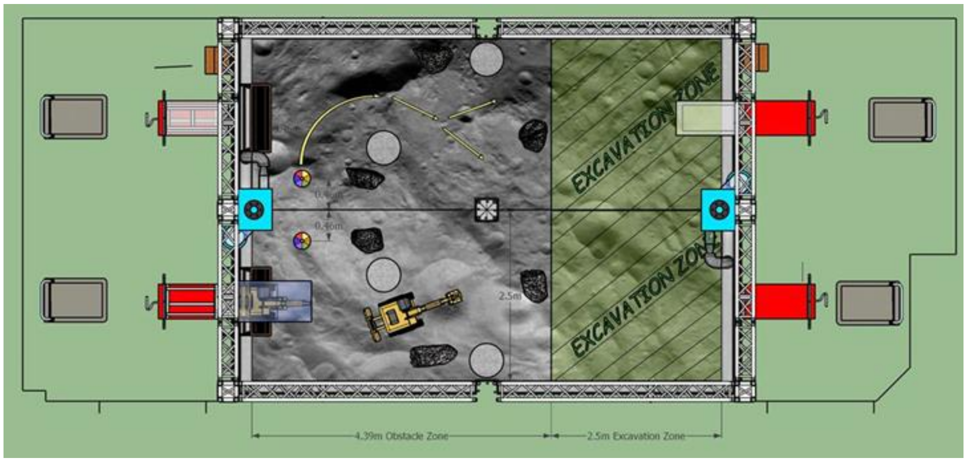

Fig. 3 Mining Arena From “NASA Lunabotics 2022, Registration, Rules and Rubrics,” NASA, 2021

Design Goals

- Replace the previous rover’s talon motor functionality with the new rover’s REV motors.
- The lunar rover will be fully autonomous.
    - Autonomous arena navigation
        - The rover must be able to localize objects to detect obstructions in the rover’s path.
        - The rover must be able to detect the excavation zone and dumping zone.
    - Autonomous excavation and unloading
        - The excavation process must start once the rover reaches the excavation zone.
        - Once the rover returns to the starting area and finds the unloading bin the rover must be able to deposit its contents.
    - These goals have shifted towards manual control due to time constraints.
- Coding and documentation standards
    - The rover will be programmed in the latest stable release of ROS2, which is the foxy distribution.
    - Object-oriented programming paradigm.
    - Publisher and subscriber programming model will be used for rover communication.
    - We will create new documentation and update old documentation using the tool Doxygen.
    - Documentation structure
        - A brief file description.
        - A detailed file description that includes any topics the node publishes or subscribes to.
        - Function descriptions that include parameters and return values and links to the relevant files.

Use Cases

- The purpose of this competition is to simulate off world communication.
- We will also simulate NASA operations.

  - Such as meeting specific physical and digital requirements and having a mission control team who operates the rover.

4.2 Detailed Architecture

The goal of our team's project is primarily to autonomize the existing capabilities of the Razorbotz mining robot. These capabilities include not only course traversal, but also the excavation and dumping capabilities of the system. As the NASA Robotic competition scoring places quite a heavy weighting upon the autonomy capabilities of the robot, implementing a system that is fully or partially autonomous is very important overall.

Secondarily, the refactoring of old code from previous years is another objective. Improving the modularity and readability of the code of any systems is extremely valuable to not only the current implementations of the system, but also for the evolution of the system over a given period of time. As this project has spanned many years —and hopefully many more— making sure that personnel newly joining the team have concise and easily readable code is a must. However, as the system is very much a hardware/software interdependent project, not only will the design and implementation of the software systems be discussed, but also the hardware components and general mechanical robot construction as well.

The most important part is the autonomization of the system with object detection and recognition. In order to traverse the environment, the robot must be able to detect and recognize any obstacles in its path so that it can take appropriate action—whether avoidance, interaction, or some other process. Similarly, the system must be able to detect and recognize the appropriate locations to excavate or dump the excavated materials.

The ZED stereo camera allows for determining three dimensional locations of objects from digital images via two forward facing cameras. The two forward facing cameras attempt to mimic the way humans perceive depth via stereo disparity—the difference in image location of an object seen in one eye, compared to its location as seen by the other. Using this approach, the stereo camera can triangulate a pixel's location in a digital image by comparing the location of the same pixel in one camera with its location in the other camera, and compute that pixel's—or collection of pixels— location in a 3D space (fig. 4). However, detecting an object and recognizing an object are two different endeavors.

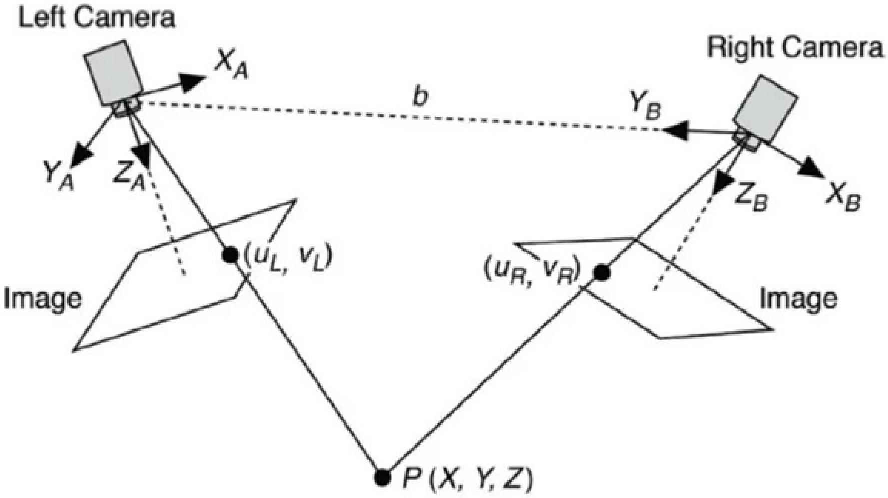

Fig. 4 Stereo Vision Model. From Nair, D. (2012, October 1). *A Guide to Stereovision and 3D Imaging*. Tech Briefs.

The ZED2i camera will ultimately be used to recognize rocks on the simulated lunar surface and relay the object position back to the controller to take appropriate action. It will also be used to detect the appropriate excavation site. While the ZED2i object detection API comes with a limited number of prebuilt classes, these do not include rocks. However, the system does offer integrations with both PyTorch and TensorFlow; systems that enable the training of neural networks in endeavors such as object recognition. At the time of this writing, the team has yet to decide which method of object detection training we are going to utilize.

Robot Operating System 2 (ROS2) is a middleware that acts as a system of interconnected paths that allow communication between different modular components in the codebase. It can be used with both C++ and Python and is a very powerful tool to both compartmentalize and modularize processes. ROS2 uses a publisher and subscriber system that uses the node, topic, service, and action elements to facilitate the intercommunication of each software-controlled component and processes of the robot.

The node element can be thought of as a piece of code that is used for a singular purpose. As an example, in this project each talon motor that controls a specific wheel on the robot is assigned a “Talon” node. This node contains all the code functionality that enables the wheel to move. Alone, this node does not contain the functionality to independently determine whether the wheel should move, and if so, how much and at what rate. This is where the topic element of ROS2 comes into focus.

Topics in ROS2 act very much like a shared bus between nodes. Each node can either subscribe or publish to any given topic, so that the topic may pass on the data to another node—or nodes. Topics pass data continuously in real-time to each publisher/subscriber, and as such are useful for implementing things like interpreting sensor data. In the previous example, the Talon motor node subscribes to a topic that receives the desired speed and direction of the wheel from the controlling logic node (whether autonomous or user driven). Whenever this topic has been passed relevant information (motor speed or direction) from the controlling nodes, being subscribed to this topic, the Talon motor node takes in the values and propagates them through the nodes code so that the wheel moves in the desired manner. A flowchart of the publisher/subscriber method can be seen in fig 5.

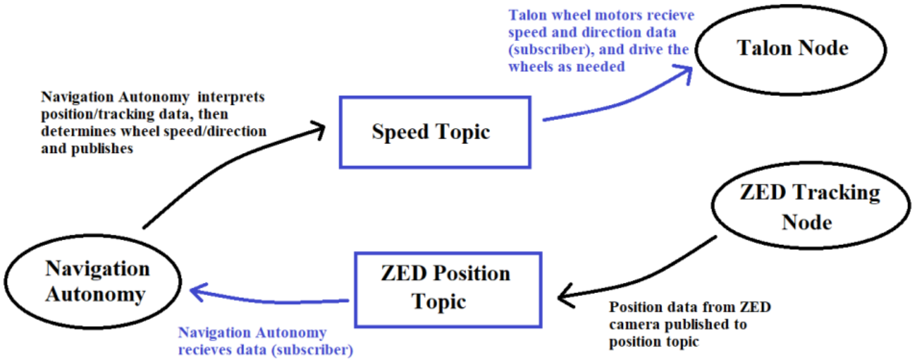

Fig. 5 Node/Topic relationship graph.

ROS services are basically a synchronous implementation of topics. Whereas topics are continuously polled by their publishers and subscribers for relevant data, services only pass data when called explicitly. Services are not preemptable, and as such, should be used only for calls that will return quickly so that there are no preemption issues during the call. This project does not currently include any services as it utilizes topics for the communication between nodes, but potential service implementation is being discussed.

Current nodes in our ROS implementation include the communication, excavation, logic, power distribution, Talon, and the Zed camera nodes. The current Zed node consists of detecting an ArUco marker — a marker commonly used in computer vision pose estimation. This involves using the Zed SDK to enable the camera to detect the marker and then publishing information such as the orientational vectors. The Talon node consists of utilizing the Talon SDK to initialize the motors, set the speed of each motor, and sets whether the motors are allowed to move or not. This node will be replaced by the NEO motors, but the functionality should be similar. The next node is the power distribution panel node. This node only publishes its information of the devices power into topics. The excavation node utilizes the ODrive motor SDK in Python. There will be two motors on the excavation node: one for the arm and one for the drum. One ODrive motor will raise and lower the arm and the other ODrive will spin the drum for extracting material.

The communication node consists of retrieving information from most of the nodes and moving the information between the client and the rover. The logic node will take all the information published from the communication node and will turn them into topics where other nodes can read those values. This node is where the automation of the excavation, navigation, dumping, and failure management will be implemented. Current functionality consists of utilizing the Zed camera to spin the rover until the ArUco marker is detected. Once the marker is detected, the robot will drive towards it until it is a specified distance away. Once the distance is met and the marker is still in sight, the robot will cease traversal. The layout of the nodes can be seen in figure 6.

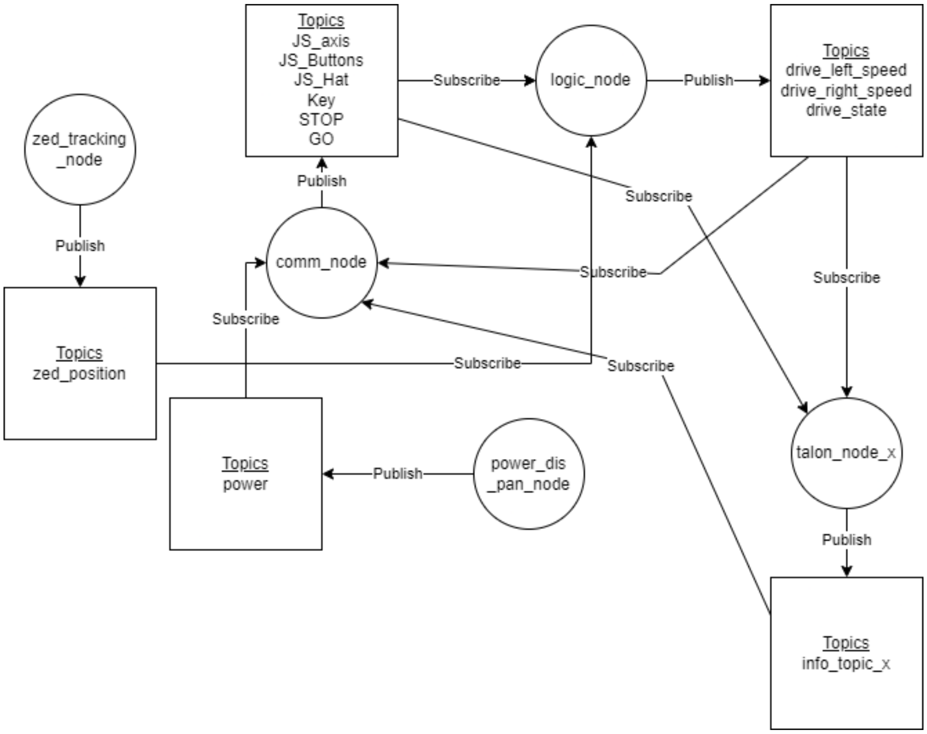

Fig 6. Node Diagram

The central control unit used in this design is the Jetson NANO, a microcontroller developed specifically for embedded AI applications. It uses Linux OS onboard, and with the NVIDIA Jetpack SDK, the system offers support for many of the peripherals used in the robots' design—including the ZED2i cameras object and depth detection capabilities. All of the components of the robot are driven by the NANO via general purpose input/output (GPIO) pins. The NANO also enables manual joystick control of the robot through Wi-Fi using socket protocol.

The mechanical construction of the robot is based on a 39.4” x 12” frame built with aluminum t-slotted extrusion. Below the right and left rear of the frame, two REV NEO brushless motors are mounted to the frame to directly drive the custom 3D printed wheel assembly. This drive is extended from the back to the front set of wheels through a belt drive that runs through an extrusion between them. This design allows for less weight and cost by using only two motors to drive all four wheels, as opposed to having each wheel directly driven. A prototype CAD model of the robot can be seen in fig. 7.

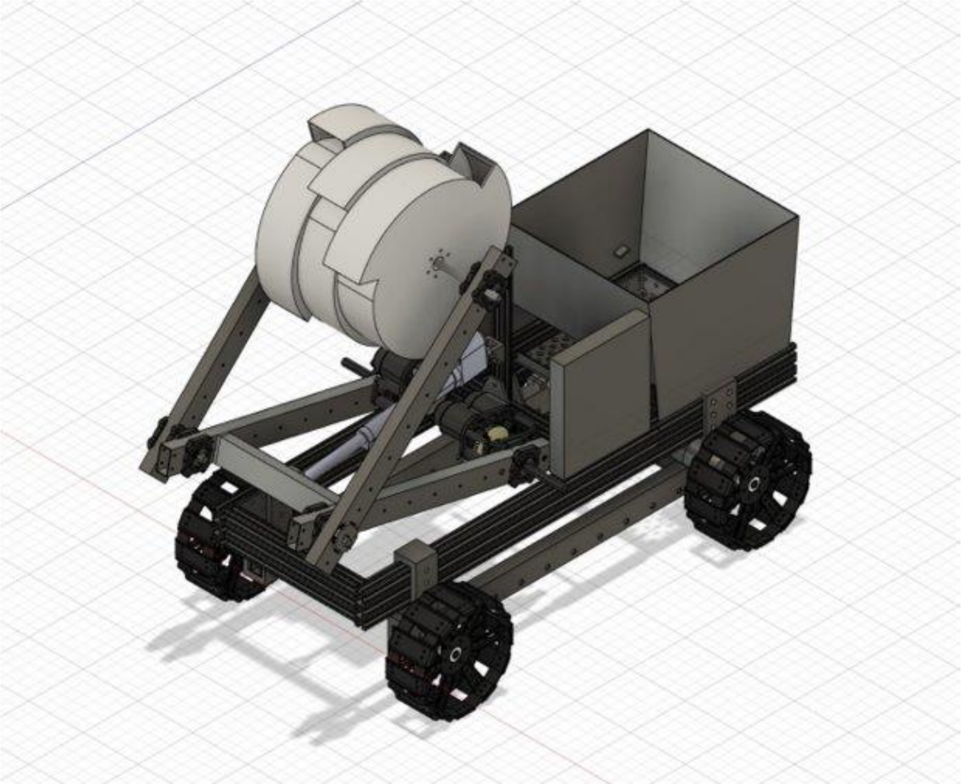

Fig 7. Prototype CAD Model

The excavation system is mounted atop the aluminum frame. It is constructed of four 23.6” aluminum extrusions that connect at a 2.6” offset from each end to form an articulated joint. The excavation drum is then mounted to one end, and two ODrive electric motors are mounted the opposite ends. These motors are then able to drive the excavation drum using a linked belt drive system that is located inside the frame arms. This allows the weight of the motors to be located more central to the robot, and results in lighter/less materials to be used on the extremities of the frame arms themselves.

In order to articulate the excavation drum up and down to facilitate excavation, a linear actuator is installed between the vertical center extrusion and the cross member of the arm assembly. By increasing and decreasing the extension of the linear actuator, the excavation assembly extends, and contracts as needed for excavation. An extended model of the excavation arm and drum drive assembly can be seen in fig. 8. Note that the frame crossbar for the attachment of the actuator is omitted in this figure, but a full assembly can be seen in fig. 7.

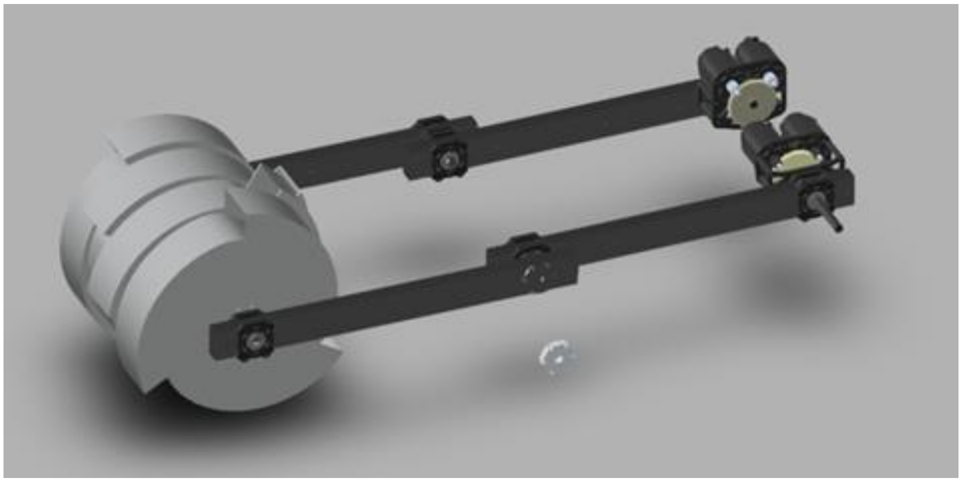

Fig 8. Prototype Excavation Arm/Drum Assembly

4.3 Risks

Risk	Risk Reduction
Autonomy system failure	Added the "KILL SWITCH" to stop all electrical components. Train the robot's computer vision object detection thoroughly to move through a variety of settings.
Communication between differing fields	Compartmentalized different sections of the robot. Each group has a team leader who handles communication and coordination.
Groups at different stages in the design process	This year two rovers are available to the Razorbotz team. This will increase productivity. While the rover is being built, the computer systems team will update and standardize coding documentation.
ROS2 documentation not as thorough as ROS1	Documentation will be a major part of the computer systems team. The team will be creating foundational documentation for future Razorbotz competitions.

4.4 Tasks

(~: In-progress, °: Completed, ×: Uncompleted)

- Upgrading ROS Distribution °
  - Older system utilized and older version of ROS
  - Integrate ROS2-Foxy distribution
  - Ensure all existing nodes work as expected
- Document existing codebase °
  - Documentation of every single node
    - Autonomy
    - Logic

        - Excavation (ODrive motors)
        - Zed camera
        - Power Distribution Panel
        - Communication
    - List what the node publishes and subscribes to °
    - Document functions within each node °
- Integrate new changes into codebase
    - Utilizing the new Zed 2i camera °
    - Replacing Talon motors with NEO Rev motors °
    - Update existing GUI to fit new devices °
    - Update power distribution panel to work with new devices °
    - Update excavation node to work with the new excavation tool ~
- Implementing Manual Control
    - With a new chassis and excavation tool, we will need to reimplement manual movement
        - Control of arm to raise and lower tool ~
        - Control of drum to excavate materials ~
    - Control movement of drivetrain through joystick ~
    - Ensure each device is getting the power needed ~
    - Ensure communication between devices is working as expected ~
    - Manually mine with press of button from joystick ~
    - Manually dumping mining load ~
- Implementing Autonomy
    - Navigational Autonomy
        - Utilizing Zed 2i camera to traverse the environment ~
            - Using a point of reference to know its surroundings
            - Object recognition through Zed SDK
        - Locating the dump site and mining site ×
        - Navigating around obstacles such as craters and large rocks ×
    - Excavational Autonomy ×
        - Mine rocks on the mining site without human interaction
        - Deposit the mined rocks into a bin for storage
    - Dump Autonomy ×
        - Must align correctly with the dumpsite
        - Dump mining contents into a hopper
    - Failure Management Autonomy ×
        - Detecting failures with autonomy
            - Getting stuck on an obstacle
            - Excavation tool getting stuck
            - Possible device failure
- Compete in the NASA Lunabotics competition ×

4.5 Schedule

Tasks	Start Dates	End Dates
1. Download VirtualBox to be able to download ROS2 and complete the tutorials for ROS2	11/04/2021	01/22/2022
2. Create/Update Documentation to ensure it is structured with well detailed comments and information as needed. Document Autonomy Node	1/22/2022	1/29/2022
3. Work on the ZED camera functionality	2/14/2022	4/20/2022
4. Implement the navigation autonomy	2/14/2022	4/25/2022
5. Implement travel autonomy to recognize rocks and hazards	Future Work	
6. Implement the excavation autonomy	Future Work	
7. Implement the dump autonomy to recognize the dump site.	Future Work	
8. Test the camera functions.	04/02/2022	04/12/2022
9. Test the travel, excavation, and dump autonomy.	Future Work	
10. Implement failure management.	Future Work	
11. Perform final tests on the robot.	04/20/2022	05/02/2022
12. Competition in the NASA Lunabotics Competition	05/25/2022	

4.6 Deliverables

- Systems Engineering Report: The Razorbotz team will submit a separate report explaining the architecture of the computer systems of the rover. We also will make sure to involve descriptive sections that will explain our design process and charts/diagrams to help the readers understand. This will be helpful for next year's coders who are working to improve the robot with our code.
- Doxygen Code Documentation: For this project, our team will use Doxygen, a documentation generator, to create better documentation for the code that has already been completed by past teams. We will also be making sure to update the code so that we can implement good coding habits we have learned over the years. When making these changes we will also be adding detailed information for future coders.

- Capstone Project Website: We will have a project website that will stay up to date with the tasks which we are waiting to complete or have completed. It will hold all the information of the project once the team has completed it. The website will have a link to the repository and the final report.
- Razorbotz Code: ROS2 will be used for remote and autonomous operations of our robot. We will use this for excavation, navigation, dumping, failure management, and any other movement or action that the robot will need to perform at the Lunabotics competition.
- Final Report: Once the team has completed the project, we will write a final report that will explain the team's design thoughts throughout the coding process.

5.0 Obstacles and Challenges

During the completion of the capstone project, our team ran into multiple challenges which lead to limited resources and time to complete the original goals of the project. Ahead of the project start date, we prepared for the following challenges:

- Challenge 1: Working with different sub-teams on the Razorbotz team presented communication-related challenges, because of the number of diverse students we include on our team.
    - Solution: Immerse our team into the Slack application to enable inter-sub team and intra-sub team communication.
- Challenge 2: Post COVID-19 related obstacles were still present during the development of our project as the virus continues to develop into multiple variants.
    - Solution: Create virtual spaces for meetings and project development to allow those that the virus affected to work on the project remotely.

As expected, however, there were also challenges that we encountered that we were not able to prepare for in advance of the project start date. These challenges were created through the limited schedule of the project as well as ending design goals for the robot. Listed below are challenges that our team encountered on the project which we did not prepare for in advance:

- Challenge 3: Difference in design expectations between sub-teams caused some sub-teams to have to re-design the robot during the spring semester.
    - Solution: Work to establish a more consistent manner of communication by defining communication expectations during Friday team meetings.
- Challenge 4: There was a large amount of background information needed by every individual on the Razorbotz team to understand and contribute work to the project.
    - Solution: Ask as many questions as necessary and conduct personal research outside of team meeting times to allow for better project understanding and coding structure of the robot's computer systems.
- Challenge 5: The completion date of the first prototype robot was delayed multiple times throughout the semester.
    - Solution: Search for and complete tasks that are available for development while tasks that are listed for current development are unavailable for progress.

In the end, our team dealt with these challenges in an efficient and effective manner – completing as many tasks as possible given the time and resources available to us

6.0 Future Work

Because of the obstacles our team encountered during the project completion, there were tasks of the project that we had originally planned to finish that we were unable to complete. Among those uncompleted tasks, we felt that the most necessary and urgent tasks that could be completed as future work would be the following:

- More thorough documentation of the code that is used for manual and autonomous operation to allow for a better understanding of the program's functionality.
- Further implementation of Navigational Autonomy can be completed so that the robot can navigate through the arena more efficiently.
- Accurate robot prototype completion dates can be established so that the computer science sub team can complete system testing in a more efficient manner.

Because of the additional work that our capstone team has provided to the Razorbotz Computer Science sub team, future Razorbotz teams will be better equipped to develop an understanding of the robot's system architecture, which will allow for easier completion of the tasks listed above.

7.0 Key Personnel

Nicholas Beck – Beck is a Senior Computer Science major in the Computer Science and Computer Engineering Department at the University of Arkansas. This is the first year he will be on the Arkansas Razorbotz team, but he has experience in researching machine learning with Professor Justin Zhan. Beck will be responsible for developing the autonomy of the robot's computer system.

Michael Ebbs – Ebbs is a Senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. This will be his first year on the Razorbotz team. He has completed courses in Embedded Systems/System Synthesis programmed in C/C++/Java/Python and others. He will be responsible for refactoring preexisting systems and developing new autonomous systems.

Cade Courtney- Courtney is a senior Computer Science major in the Computer Science and Computer Engineering Department at the University of Arkansas. Throughout his academic career, he has programmed in multiple languages, C++/Java/Python. For the last three Summers, he interned at Globitech incorporated, where he learned how to work in a team environment and produced code at the production level. He will be working on the rover's autonomy.

AnElizabeth Henry – Henry is a senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. This will be her first year being a part of the Arkansas Razorbotz team. She has worked for ClickClaims in New Orleans Louisiana for a summer as a software developer intern. She will be responsible for the development of the robot's autonomy.

Levi Davis – L. Davis is a senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. He has worn many different hats in his lifetime, with responsibilities ranging from CAD engineer for government aircraft parts to installing antennas on broadcast towers. After deciding that he should challenge himself more, he decided to pursue a computer engineering degree. In collaboration with the CSCE

Razorbotz team, he is responsible for the development of the autonomous functionality of the mining robot.

Tristen Teague –Teague is a senior Computer Engineering major in the Computer Science and Computer Engineering Department at the University of Arkansas. This will be his first year on the Razorbotz team. He is a part of the AESIR Labatory where he performs research on Post-Quantum Cryptography on embedded systems. He has experience of working with embedded systems and firmware engineering. Teague will be responsible for working with excavation autonomy.

Dr. Uche Wejinya – Dr. Wejinya is currently an Associate Professor for the Department of Mechanical Engineering here at the University of Arkansas. He received his Bachelor of Science degree, Master of Science degree, and Doctor of Philosophy degree in Electrical Engineering from Michigan State University, East Lansing. Dr. Wejinya has many research interests, some of which are: mechatronics with emphasis on nanotechnology, control systems design and application, robotics, biomechanics, batteries & energy storage devices, micro-tools for handling and manufacturing of micro and nano devices, and modeling and simulation of micro and nano structures. Dr. Wejinya has been the faculty advisor for past University of Arkansas Razorbotz teams and continues to serve as such while growing interest of the team within the engineering community.

8.0 Facilities and Equipment

8.1 Facilities

- Robotics Laboratory – Lab within the MEEG department where meetings are held and where the robot is both held and assembled
- Mining Test Site – Area where the robot will be tested in navigation, excavation, and dumping. The surroundings will attempt to mimic the environment of the moon.

8.2 Equipment

- NVIDIA Jetson Nano: Embedded device that will act as the computer for the system
- Zed 2i Camera: Camera used for navigational autonomy and object recognition
- NEO Brushless Motors: Motors that run the drivetrain of the robot
- Rev Spark Max Motor Controller: Controls the NEO brushless motors
- ODrive Motors: Motors used for utilizing the excavation tool
- Power Distribution Panel: Device that gives power to all devices on the system
- Logitech Joystick: Allows manual movement of the drivetrain for the robot

9.0 References

[1] "National Aeronautics and Space Administration (NASA)." *Performance.gov*, url: https://obamaadministration.archives.performance.gov/agency/national-aeronautics-and-space-administration.html.

[2] "Artemis." *NASA*, NASA, url:

https://www.nasa.gov/specials/artemis/.

[3] Hall, Loura. "Lunabotics." *NASA*, NASA, 30 Sept. 2021,

https://www.nasa.gov/solve/LUNABOTICS/.

[4] “NASA Lunabotics 2022, Registration, Rules and Rubrics,” NASA, 2021, url: https://www.nasa.gov/sites/default/files/atoms/files/lunabotics_guidebook_2022_-_ver_1_1.pdf

[5] “Spark Motor Controller.” *REV Robotics*, url: https://www.revrobotics.com/rev-11-1200/.

[6] Millett, Pete. “Brushless vs Brushed DC Motors: When and Why to Choose One over the Other: Article: Mps.” *Article | MPS*, url: https://www.monolithicpower.com/en/brushless-vs-brushed-dc-motors#:~:text=As%20their%20names%20imply%2C%20DC,DC%20motor%20can%20be%20used.

[7] “Neo Brushless Motor.” *REV Robotics*, url: https://www.revrobotics.com/rev-21-1650/.

[8] “Zed 2I - Industrial AI Stereo Camera.” *STEREOLABS*, url: https://www.stereolabs.com/zed-2i/.

[9] “The Importance of IMU Motion Sensors.” *CEVA's Experts Blog*, 13 Sept. 2019, url: https://www.ceva-dsp.com/ourblog/what-is-an-imu-sensor/.

[10] “Magnetometer.” *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., url: https://www.britannica.com/technology/magnetometer.

[11] “Ros 2 Documentation.” *ROS 2 Documentation - ROS 2 Documentation: Rolling Documentation*, url: https://docs.ros.org/en/rolling/index.html.

[12] M. M. Almasri, A. M. Alajlan and K. M. Elleithy, "Trajectory Planning and Collision Avoidance Algorithm for Mobile Robotics System," in IEEE Sensors Journal, vol. 16, no. 12, pp. 5021-5028, June15, 2016, doi: 10.1109/JSEN.2016.2553126.

[13] “Mars 2020/Perseverance Fact sheet” NASA Facts, March 2020.

[14] NASA. (Feb 17. 2021). Q: How far can the rover dig, and how will NASA collect those samples? #CountdownToMars - @Tongu3Tied A: Dr. Heather Graham, @NASAGoddard Astrobiologist [Tweet]

[15] R. P. Mueller, R. E. Cox, T. Ebert, J. D. Smith, J. M. Schuler and A. J. Nick, "Regolith Advanced Surface Systems Operations Robot (RASSOR)," 2013 IEEE Aerospace Conference, 2013, pp. 1-12, doi: 10.1109/AERO.2013.6497341.