Lunar ROADSTER

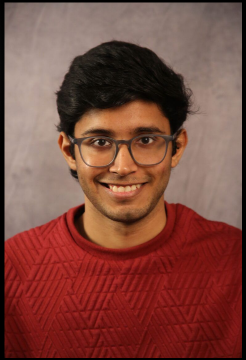
(Robotic Operator for Autonomous Development of Surface Trails and Exploration Routes)

"Starting with a foothold on the Moon, we pave the way to the cosmos"

CARNEGIE MELLON UNIVERSITY PITTSBURGH PENNSYLVANIA 1900

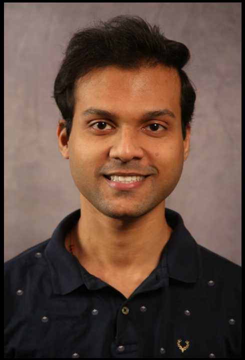
The Team

Ankit Aggarwal



Deepam Ameria

Bhaswanth Ayapilla

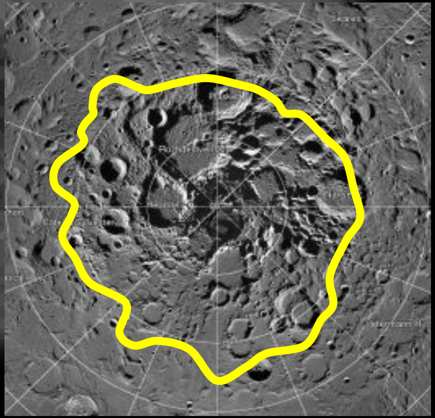


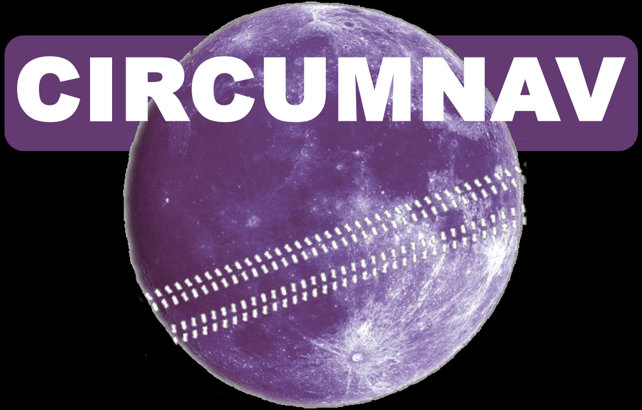
Simson D'Souza

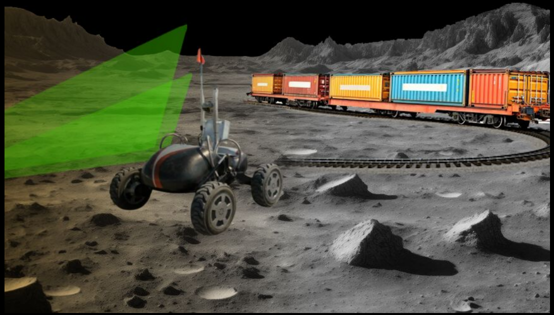
Boxiang (William) Fu

Dr. William "Red" Whittaker

Motivation: The Lunar Polar Highway







Is it possible for a solar-powered rover to repeatedly drive around the Moon and never encounter a sunset?

Motivation: The Lunar Polar Highway

Sun-synchronous circumnavigation around Moon at 28 days x 24 hr = 672 hour sun rotation

At equator	11,000 km	16 kph
At 50 deg	7,040 km	10 kph
At 60 deg	5,500 km	8 kph
At 70 deg	3,700 km	6 kph
At 75 deg	2,800 km	4 kph
At 80 deg	1,870 km	3 kph
At 81 deg	1,529 km	2.5 kph

Jogging speed if the route was flat, circular and traversable

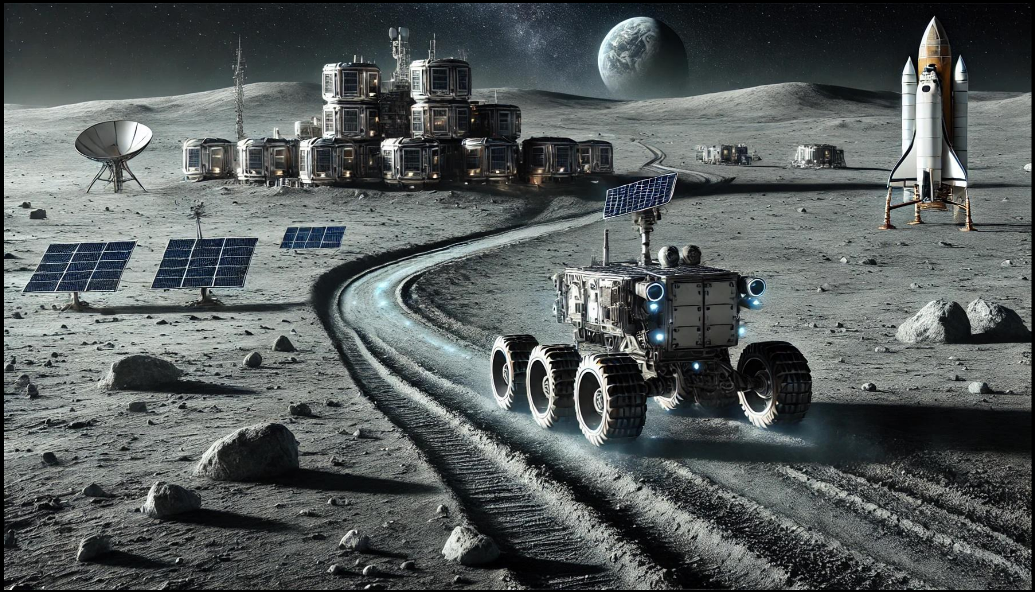
The Project: Lunar ROADSTER

An autonomous moon-working rover capable of finding ideal exploration routes and creating traversable surface trails.

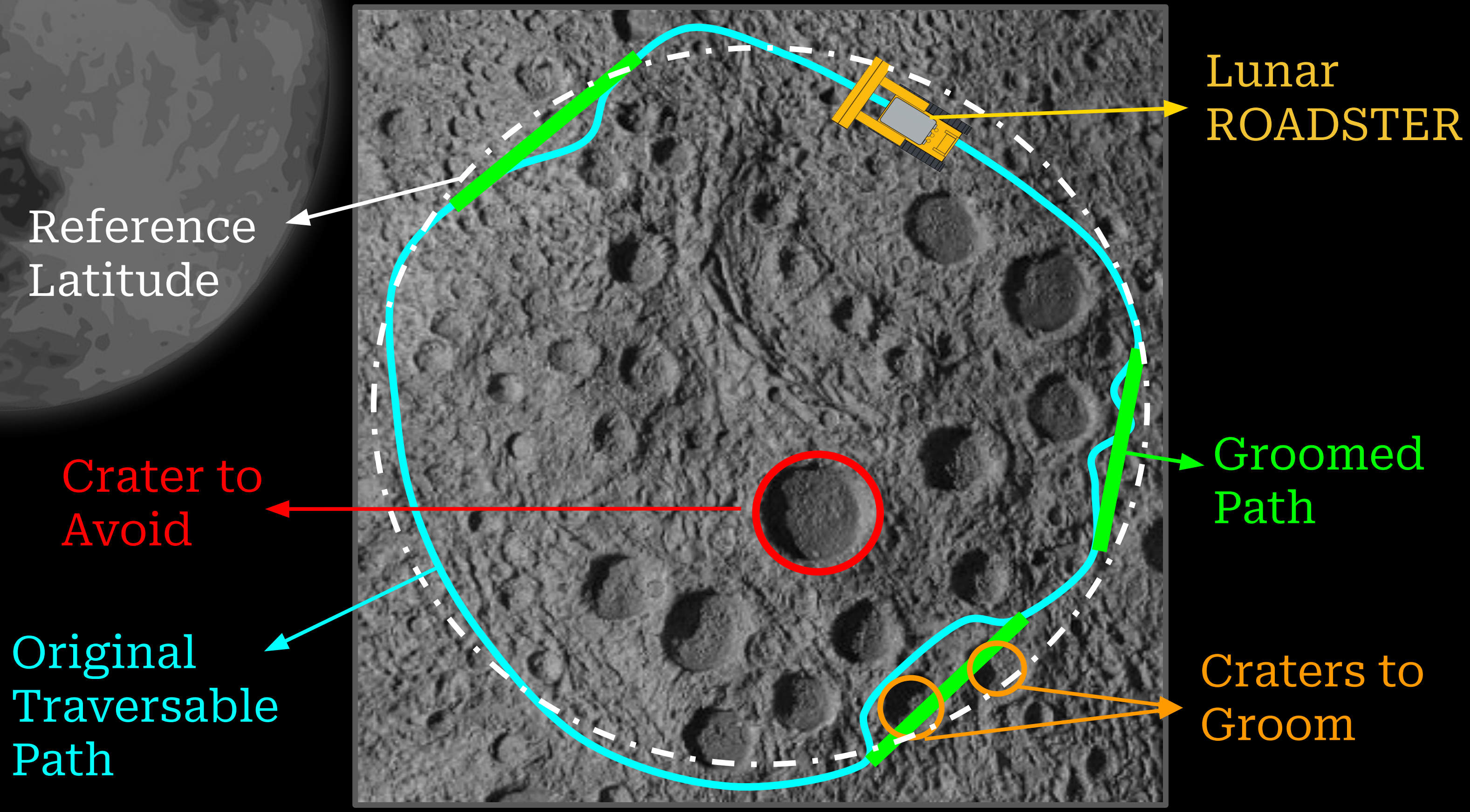
By grooming trail paths, rovers with less traversing capabilities will be able to travel at higher speeds and higher power efficiencies.

A traversable and circuitous trail path will allow rovers to maintain sun-synchronicity, thereby allowing machines to run for much longer.

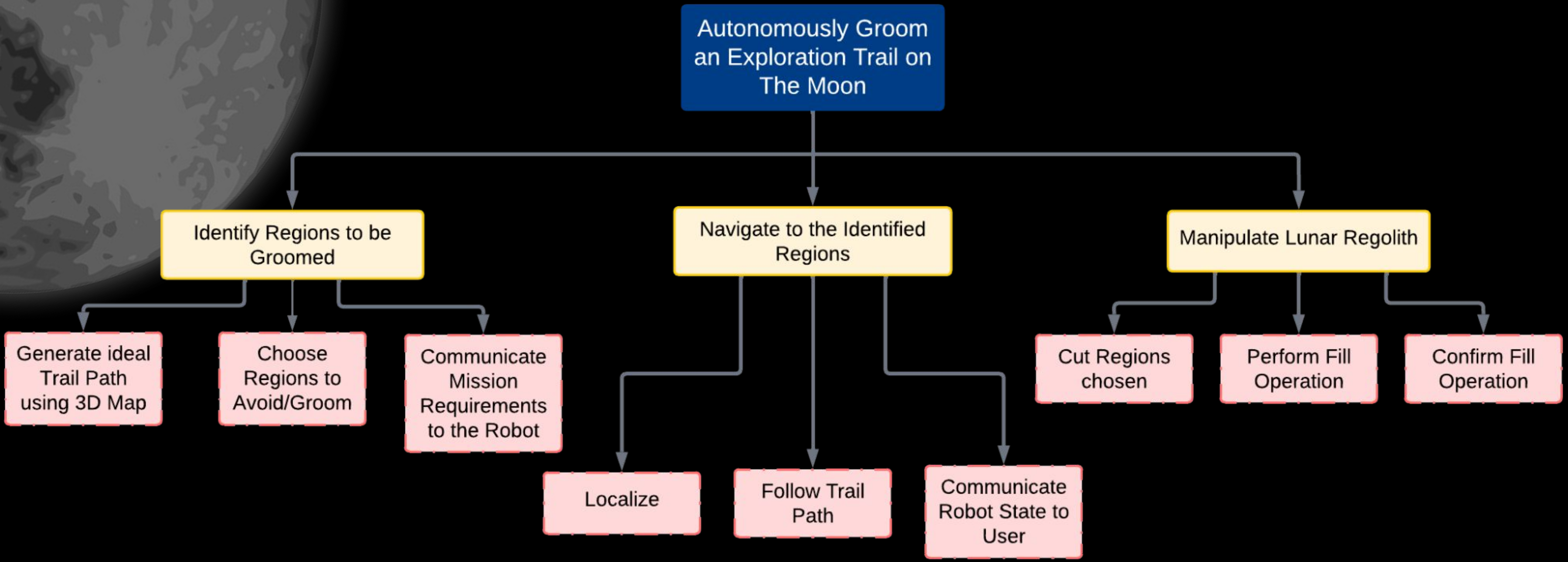
The groomed trails will become the backbone for colonization of the Moon by enabling transportation, logistics and enterprise development.



Use Case: Circular Path Grooming



Objectives Tree



Functional Requirements (Mandatory)

Sr. No.	Mandatory Functional Requirement
M.F.1	Shall perform trail path planning
M.F.2	Shall operate autonomously
M.F.3	Shall localize itself in a GPS denied environment
M.F.4	Shall navigate the planned path
M.F.5	Shall traverse uneven terrain
M.F.6	Shall choose craters to groom and avoid
M.F.7	Shall grade craters and level dunes
M.F.8	Shall validate grading and trail path
M.F.9	Shall communicate with the user

Non-Functional Requirements (Mandatory)

Sr. No.	Parameter	Description
M.N.1	Weight	The rover must weigh under 50kg
M.N.2	Cost	The cost for the project must be under $5000
M.N.3	Computing Capacity	The onboard computer should be able to run all required tasks
M.N.4	Size/Form Factor	The rover should measure less than 1m in all dimensions

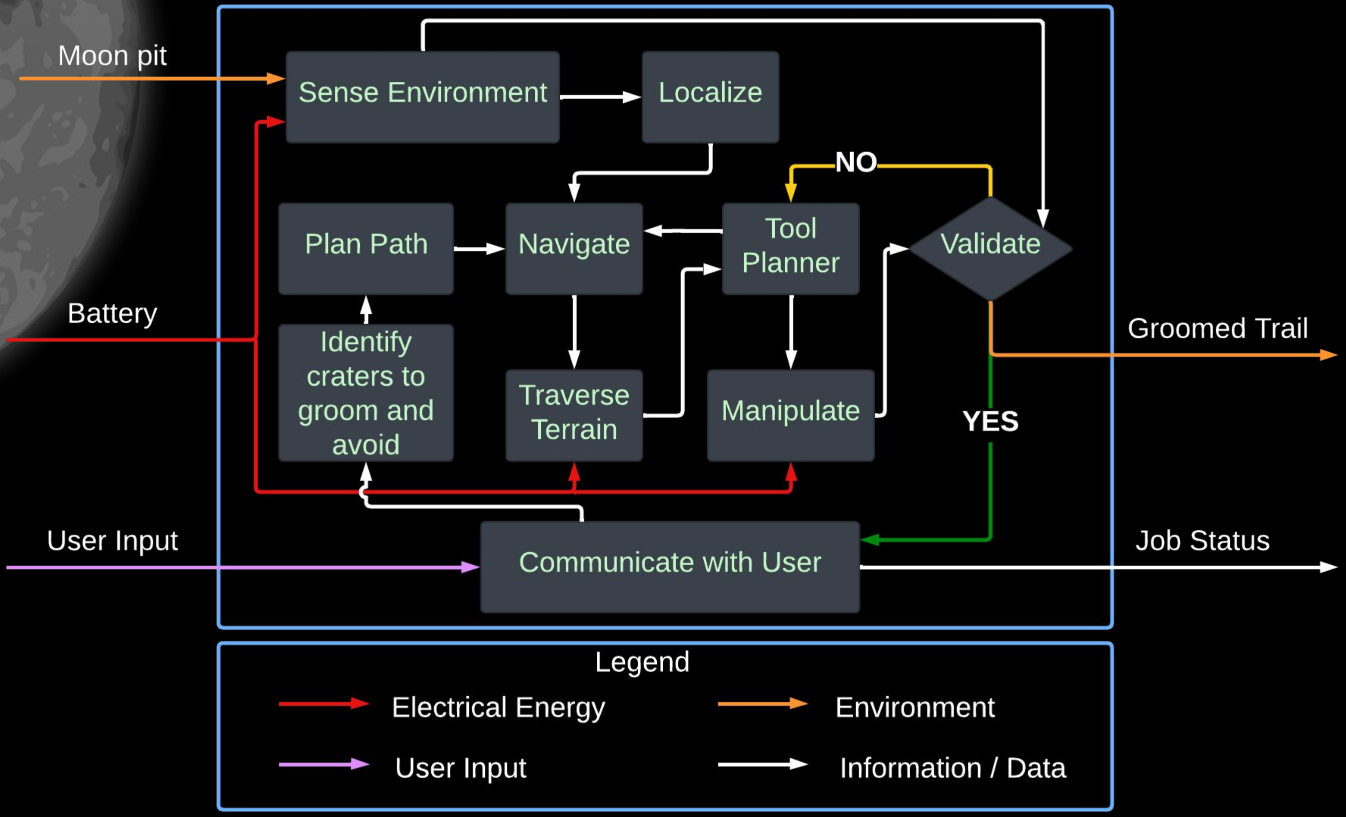
Non-Functional Requirements (Desirable)

Sr. No.	Parameter	Description
D.N.1	Technological Extensibility	The system will be well documented and designed so that future teams can easily access and build on the work
D.N.2	Aesthetics	Requirement from sponsor, the rover must look presentable and lunar-ready
D.N.3	Modularity	To enable tool interchangeability, the tool assemblies must be modular and easy to assemble/disassemble
D.N.4	Repeatability	The system will complete multiple missions without the need of maintenance

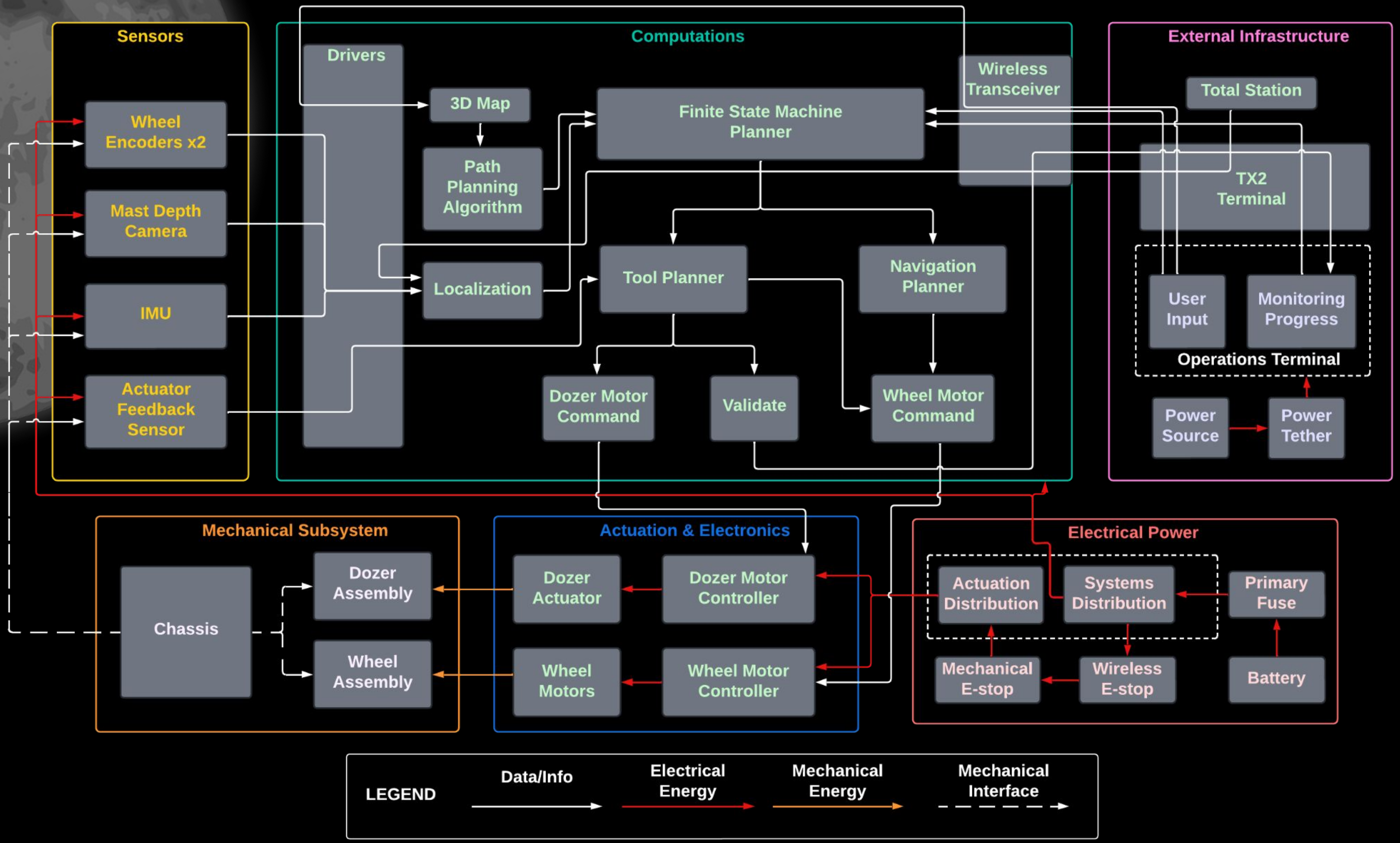
Performance Requirements (Mandatory)

Sr. No.	Performance Metrics
M.P.1	Will plan a path with cumulative deviation of <= 25% from chosen latitude's length
M.P.2	Will follow planned path to a maximum deviation of 10%
M.P.3	Will climb gradients up to 15° and have a contact pressure of less than 1.5 kPa
M.P.4	Will avoid craters >= 0.5 metres and avoid slopes >= 15°
M.P.5	Will fill craters of up to 0.5 meters in diameter and 0.1m in depth
M.P.6	Will groom the trail to have a maximum traversal slope of 5°

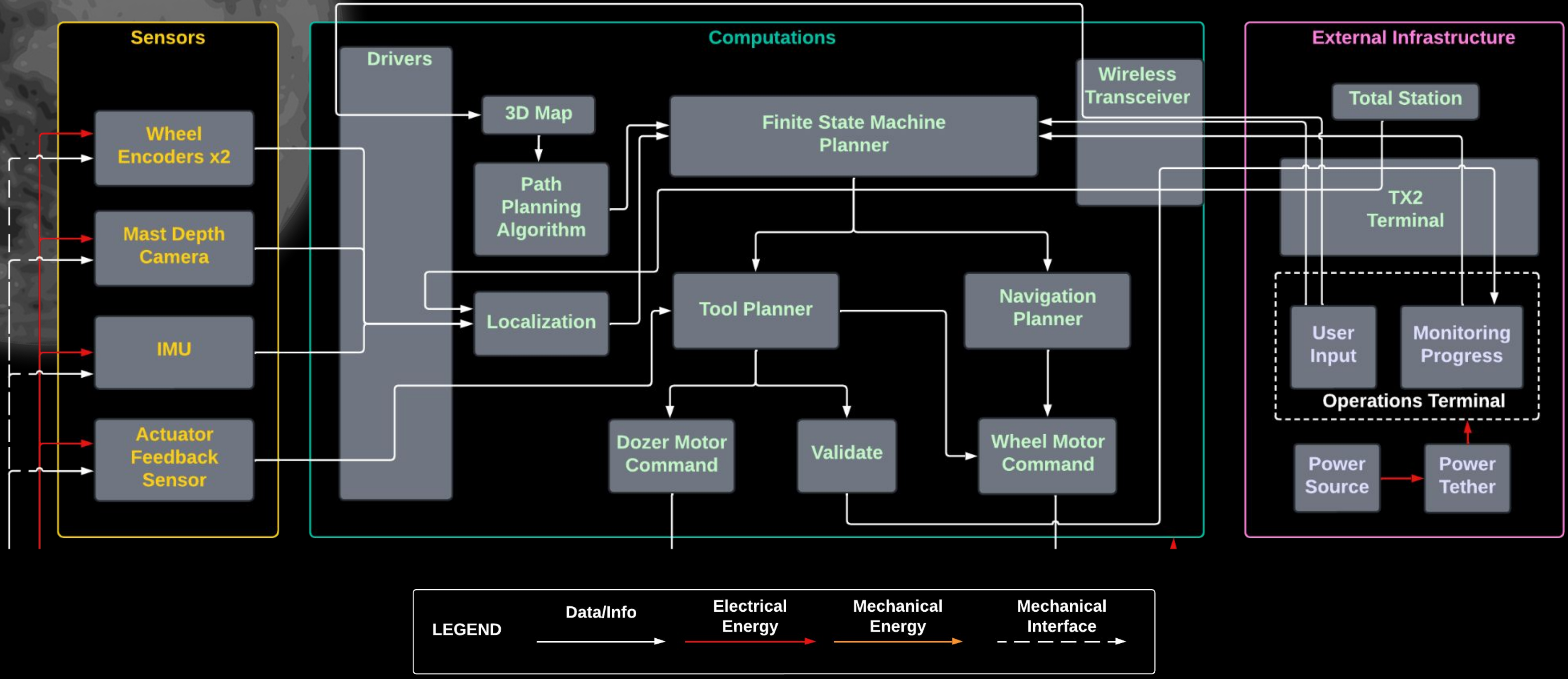
Functional Architecture



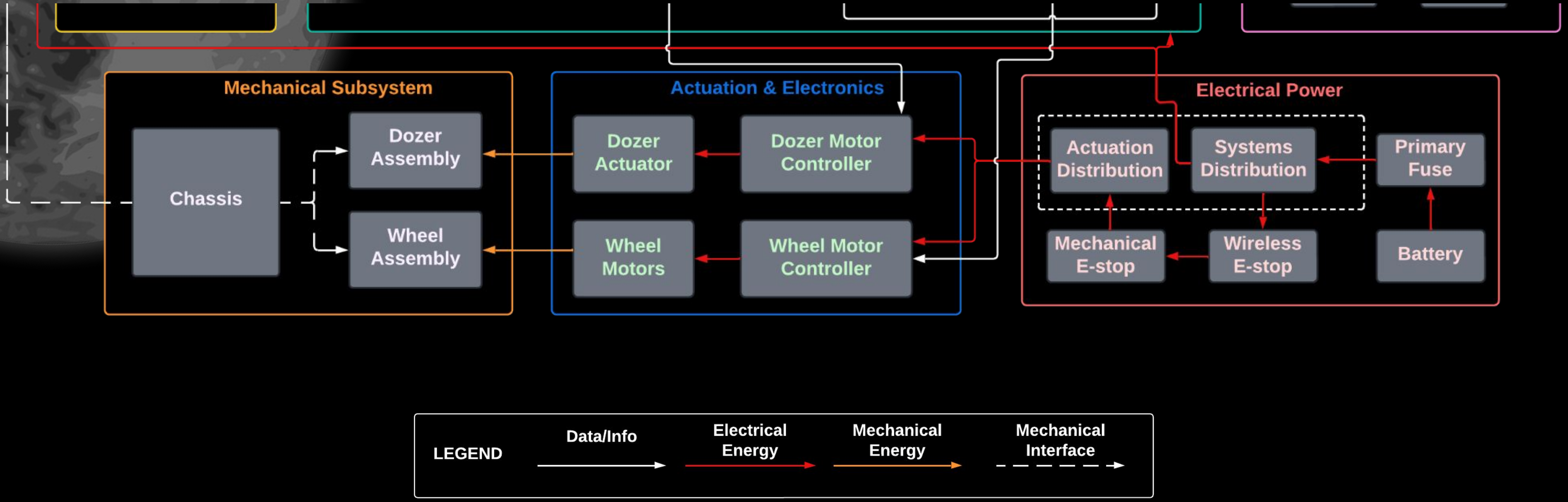
Cyber-Physical Architecture



Cyber-Physical Architecture



Cyber-Physical Architecture



Subsystem Completion Status

Subsystem	Completion %	Future Work
Sensors	50%	Interface ZED and actuator drivers with docker
Computations	50%	
1. Jetson and Docker	95%	Integrate ZED drivers
2. Localization Unit	75%	Tuning of EKF parameters
3. Tool Planner Unit	10%	Implement unit
4. Navigation Planner Unit	30%	Setup Nav Stack, Integrate Localization and Nav Unit
External Infrastructure	100%	None
Mechanical	75%	
1. Dozer Assembly	85%	Refinement of Dozer
2. Wheel Assembly	65%	Wheel Design Iterations, Final Manufacturing
Actuation	60%	Linear Actuator tuning, Wheel encoder tuning
Electrical Power	50%	Manufacturing and Integrating Electronic Box and PDB

Description: Sensors Subsystem

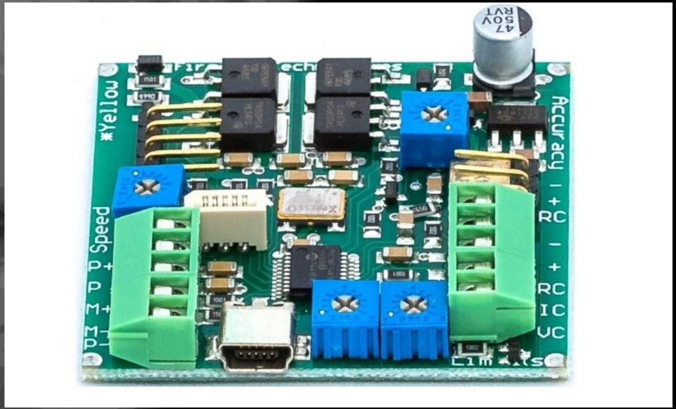
Description: All sensors used on the rover for computations.

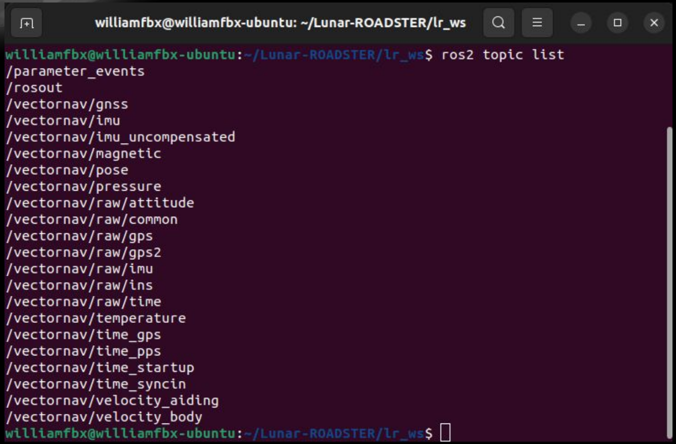
Requirements:

- Wheel Encoders (x4)
- Mast Depth Camera (ZED 2i Stereo Camera)
- IMU (VectorNav)
- Actuator Feedback Sensor

Expected Functionality: The sensor data is published to various ROS topics and can be used inside the Docker container to perform computations.

Status: Sensors Subsystem





Implementation:

- IMU implemented using VectorNav ROS package
- Wheel Encoder parsed using micro-ROS
- Purchased actuator has a feedback potentiometer

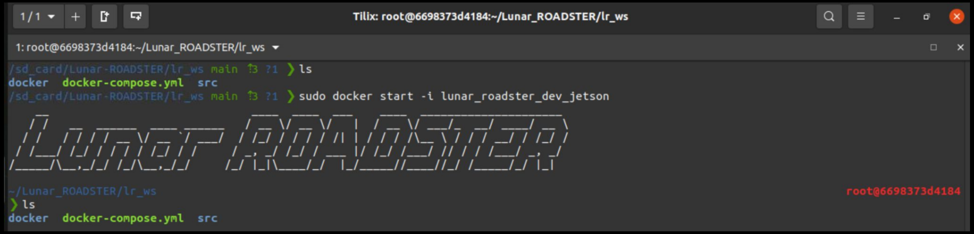
Challenges:

- Difficulty integrating ZED SDK drivers with docker container due to CUDA compatibility issues
- IMU firmware drivers were outdated

Status: 50% Complete

IMU and Wheel Encoder finalized. ZED SDK and Actuator Feedback Sensor setup in progress.

Description: Computations Subsystem Jetson and Docker Unit



Description: Set up the Jetson with Docker running necessary packages

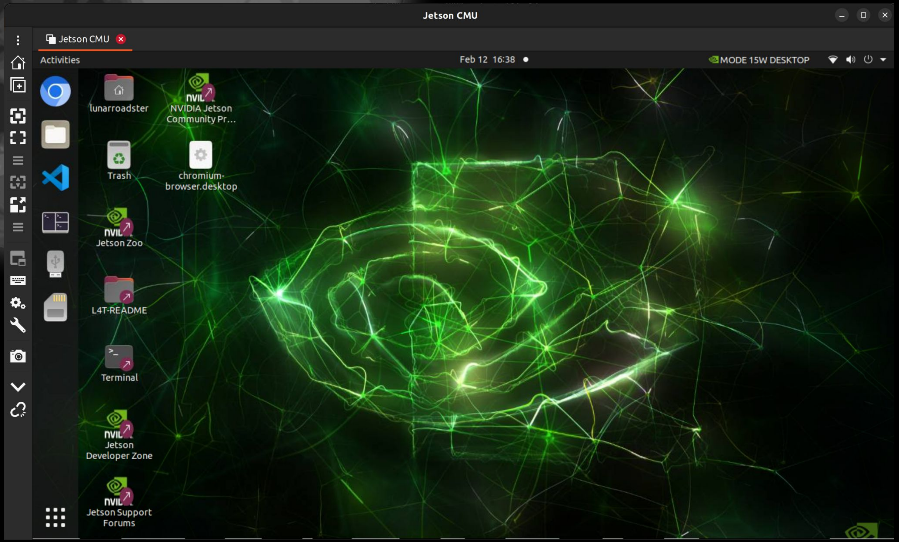
Requirements:

- NVIDIA Jetson AGX Xavier
- LAN Router
- Team laptop (operations terminal)

Expected Functionality:

- Serves as the on-board compute
- Run ROS2 Humble
- Run micro-ROS
- Run all necessary packages and drivers

Status: Computations Subsystem
Jetson and Docker Unit



Implementation:

- Connect Jetson to power source on rover
- Established static IP on LAN network so operations terminal can communicate via SSH
- Start docker container and run necessary packages

Challenges:

- Setting up VNC server for remote access

Status: 95% Complete
Need to integrate ZED SDK drivers

Description: Computations Subsystem Localization Unit

Description: Localize the rover in the Moon Yard

Requirements:

- Rover
- Leica TS16 Total Station
- NVIDIA TX2 Relay Chip
- LAN Router
- Team laptop (operations terminal)

Expected Functionality: Accurately localize rover pose inside the Moon Yard, to be used further for navigation

Status: Computations Subsystem Localization Unit

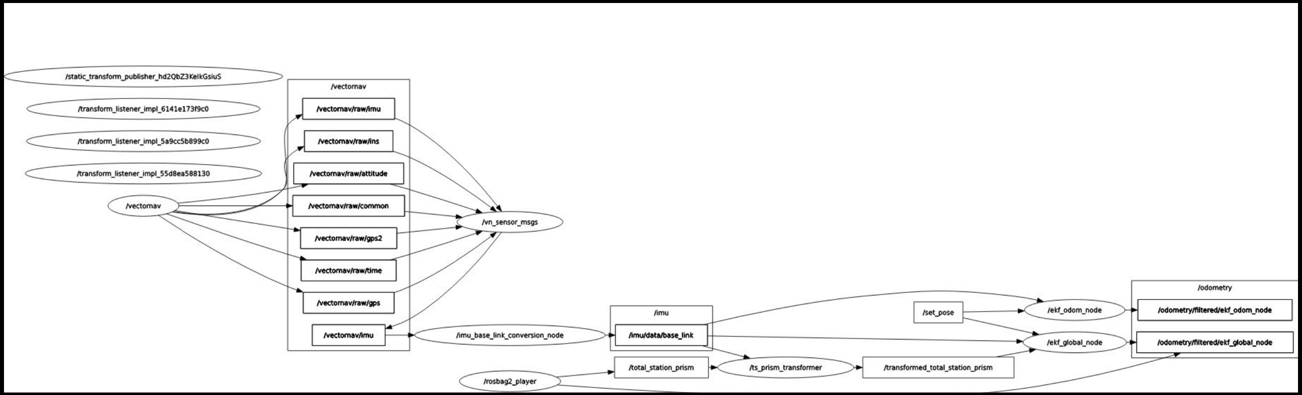
Implementation:

- On-board IMU and encoders used for local localization
- Total station data fused with IMU and encoders for global localization
- All frames are transformed to base_link
- EKF runs using robot_localization package on Jetson

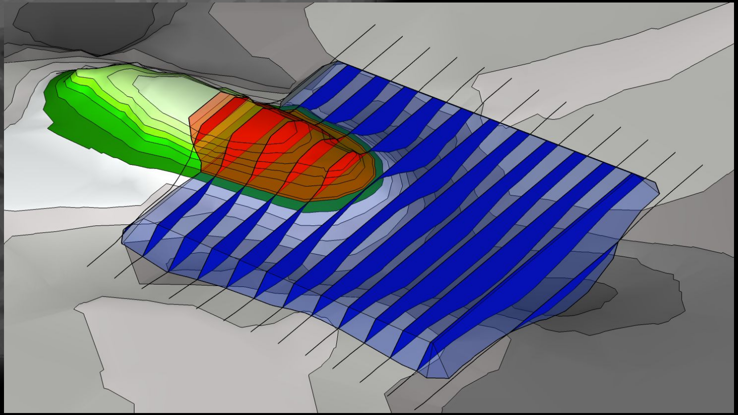
Challenges:

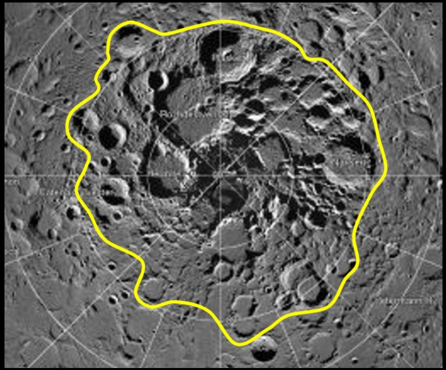
- Incorrect Jetson Docker network permissions blocked two-way communication
- Odometry keeps drifting away - EKF needs to be tuned

Status: 75% Complete



Description: Computations Subsystem Tool Planner Unit





Description: Subsystem that plans sand manipulation by using the tool and drive train.

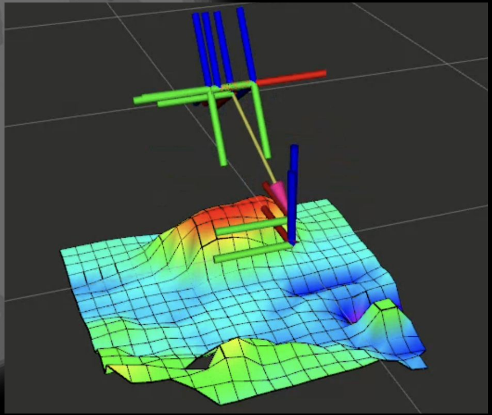
Requirements:

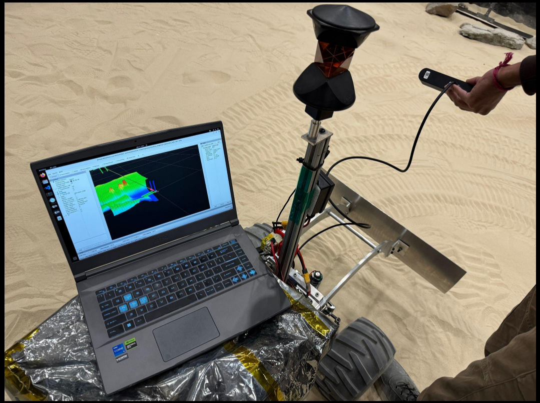
- ZED 2i Stereo Camera
- Jetson Xavier AGX
- Dozer Assembly
- Drivetrain (with Wheel Assembly)

Expected Functionality:

- Plans a control input for the tool
- Plans a trajectory for the rover for manipulation
- Reports back when job is completed

Status: Computations Subsystem Tool Planner Unit





Implementation:

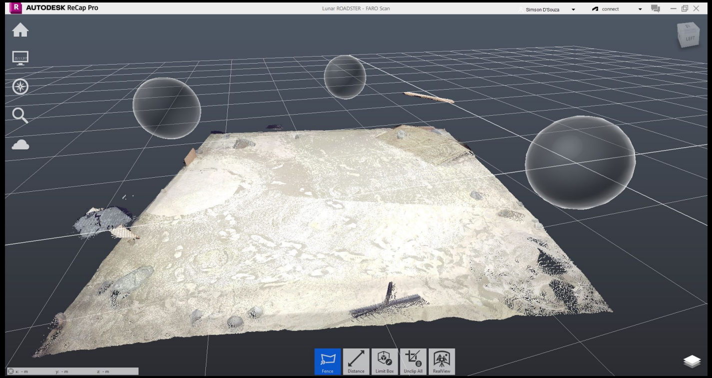
- Integrated ZED 2i Stereo Camera with Elevation Mapping ROS package to create local elevation map.
- Local map will be used to identify cut/fill regions
- Path will be planned and integrated with the navigation planner

Challenges:

- Trouble integrating ZED SDK packages with Docker container due to incompatible CUDA driver versions.

Status: 10% Complete

Description: Computations Subsystem Navigation Planner Unit



Description: Identify gradable craters, obtain coordinates, and navigate the rover to their locations

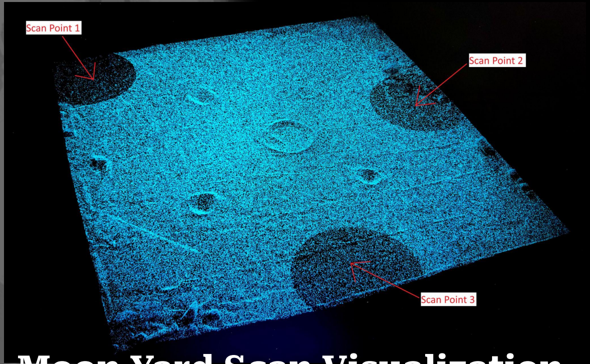
Requirements:

- FARO Laser Scanner
- Zed 2i Stereo Camera
- NVIDIA Jetson AGX Xavier
- Team laptop (operations terminal)

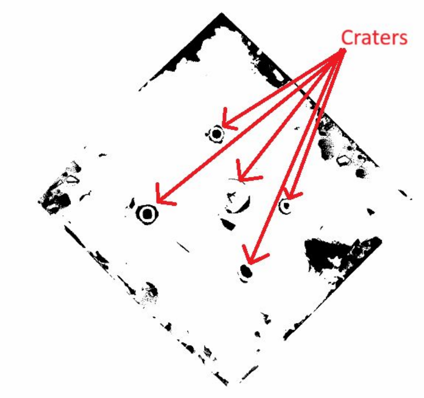
Expected Functionality:

- Accurately detect and classify gradable craters
- Ensure no gradable crater is overlooked
- Compute an optimal navigation path while avoiding obstacles (non-gradable craters and rocks)
- Navigate and reach the goal location correctly

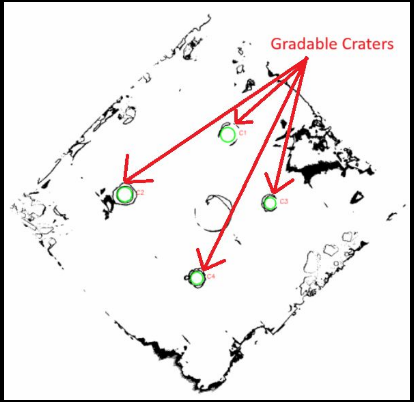
Status: Computations Subsystem Navigation Planner Unit



Moon Yard Scan Visualization



Global Costmap



Identified Gradable Craters

Implementation:

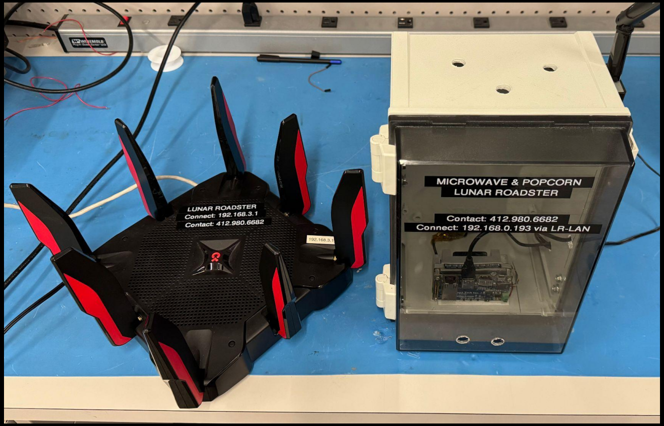
- Mapped the Moon Yard using the FARO Laser Scanner to generate a point cloud.
- Converted the point cloud file into a ROS-compatible format.
- Applied RANSAC for plane fitting and implemented thresholding to generate a 2D costmap for navigation.
- Identified craters based on diameter and depth, extracting their coordinates.

Challenges:

- FARO output file (.fls) was incompatible with the PCL library and ROS.
- Plane fitting for identifying gradable craters was challenging due to uneven terrain.
- Accurately classifying gradable craters based on diameter and depth.

Status: 30% Complete (Navigation Stack setup in progress)

Description: External Infrastructure Subsystem



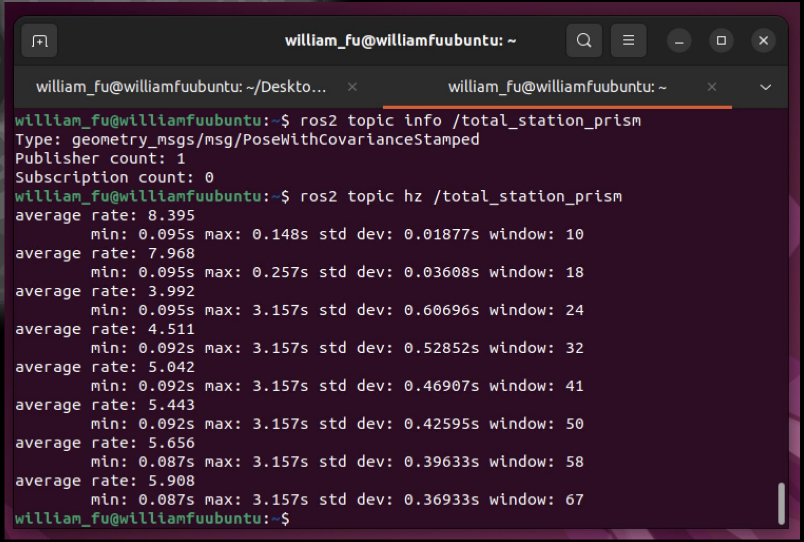
Description: Mission components that are offboard the rover.

Requirements:

- Leica TS16 Total Station
- NVIDIA TX2 Relay Chip
- LAN Router
- Team laptop (operations terminal)

Expected Functionality: Accurately localize {X, Y, Z}-coordinates of the rover inside the Moon Yard and establish two-way communication.

Status: External Infrastructure Subsystem



Implementation:

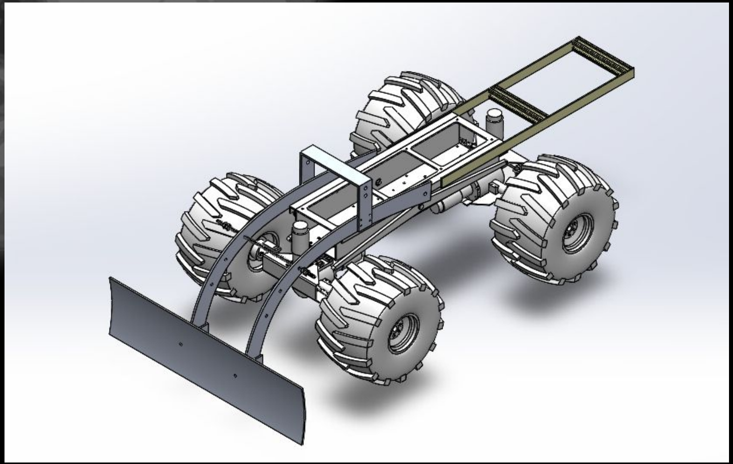
- Total Station sends rover coordinates to TX2 relay chip, sends data packet via LAN network to rover.
- Established static IP on LAN network so operations terminal can communicate via SSH.

Challenges:

- Unable to obtain access to the TX2 relay chip login details
- Incorrect Jetson Docker network permissions blocked two-way communication

Status: Completed

Description: Mechanical Subsystem Dozer Assembly



Description: Lunar terrain manipulation tool

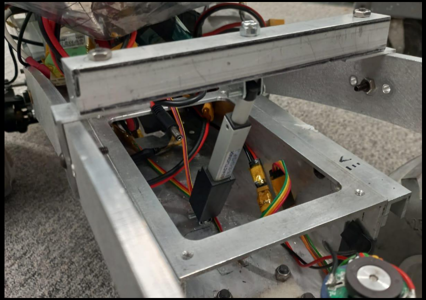
Requirements:

- Dozer blade
- Dozer arms assembly
- Linear actuator
- Arduino Due

Expected Functionality:

- Perform dozing of sand
- Perform backblading
- Actuate automatically based on commands from tool planner

Status: Mechanical Subsystem Dozer Assembly Unit

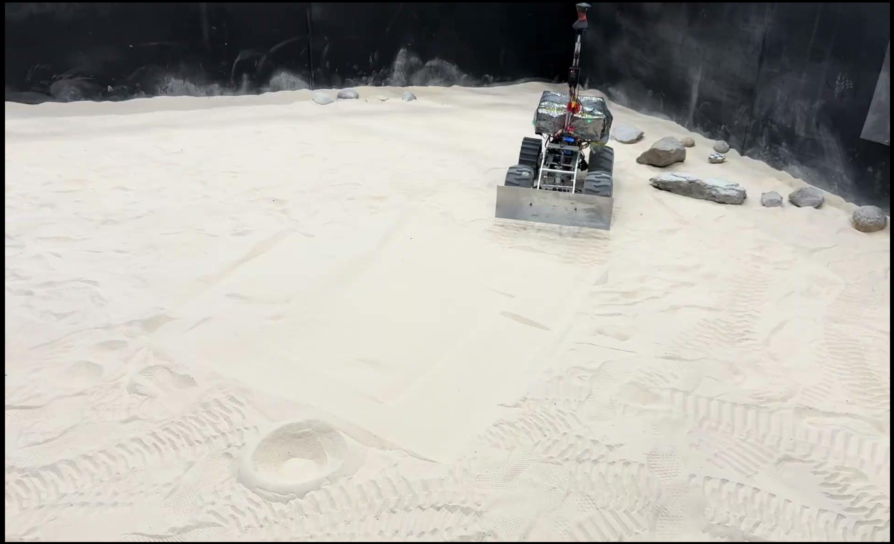


Implementation:
- Research: Dozer shapes and sizes, actuation methodologies.
- Designed the dozer assembly (blade, arms, yoke, mounts) using SolidWorks.
- Shortlisted linear actuators of different gear ratios.
- Manufactured and assembled all parts on the rover.
- Testing with different actuators

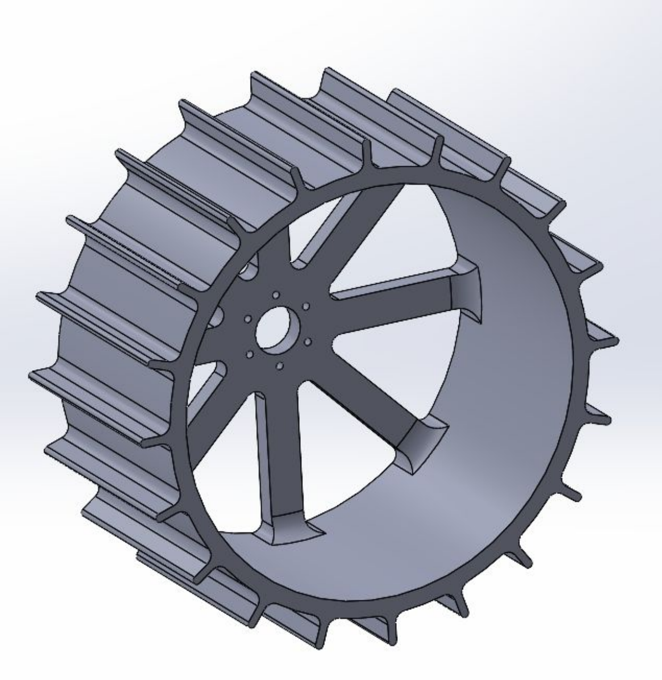
Challenges:
- Fabrication problems
- Limited access to FRC Workshop

Status: 85% Complete
- Refining assembly

Status: Mechanical Subsystem Dozer Assembly Unit



Description: Mechanical Subsystem
Wheel Assembly Unit



Description: Assembly that enables movement of the rover by acting as an interface between the drivetrain and ground.

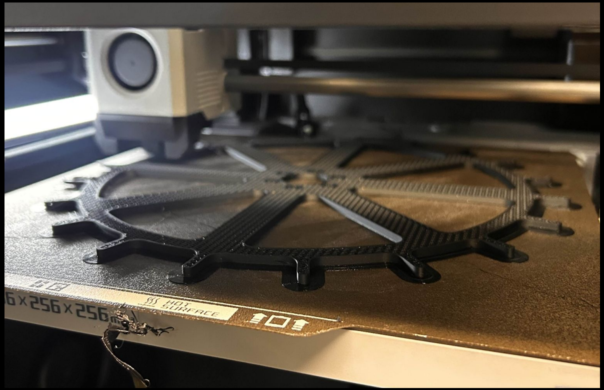
Requirements:

- Wheel (3D Printed/Metal)
- Mounting Assembly to the Suspension
- Drive Train (Differential and Steering)
- Motors

Expected Functionality:

- Provide required traction for movement and grading of sand
- Minimize wheel slip
- Allow for steering in sand
- Desirable - Use materials that can function on the Lunar Surface

Status: Mechanical Subsystem
Wheel Assembly Unit



Implementation:

- **Research:** Grouser shapes and patterns ideal for traction in sand
- Design single-part iterations in SolidWorks
- 3D-print designs and test in the MoonYard
- Observe and re-design until the design is satisfactory
- Finalize design and manufacture using aluminium.
- **Stretch Goal:** Use the wheel test bed in PRL to accurately measure performance

Challenges:

- 3D Printing the wheel is a long process with frequent failures
- Steering system of the rover is fragile and frequently disengages

Status: 50% Complete

- Iteration 2 performs better than the stock rubber wheels
- Next test will be using 4 3D-printed wheels

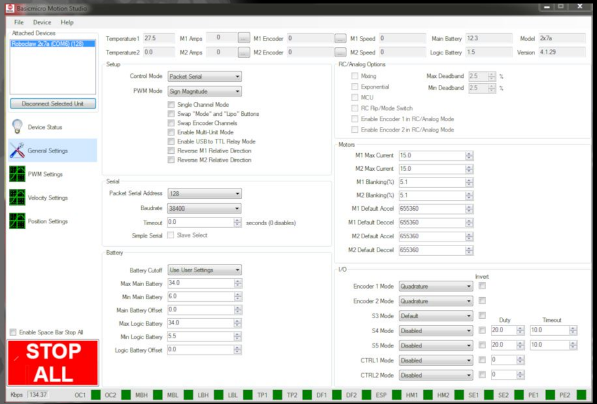
Description: Actuation Subsystem

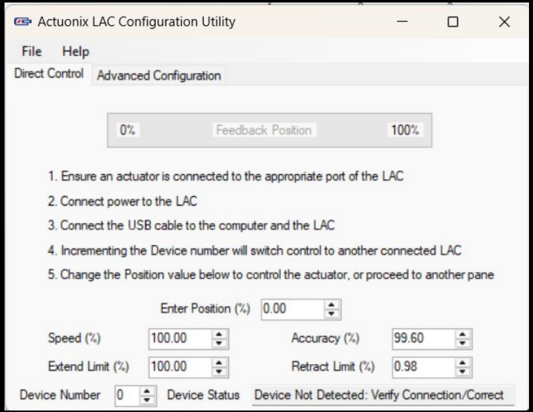
Description: Power transfer methodologies for rover mechanisms.

Requirements:
- DC Motors with Encoders (x4)
- Linear Actuator (with feedback)

Expected Functionality:
- Deliver power to wheels for mobility
- Steer the front and rear wheels
- Actuate the dozer assembly to facilitate mobility and dozing

Status: Actuation Subsystem





Implementation:

- Selected drive motors with higher torque for better traction and mobility
- Selected linear actuator for dozer assembly
- Interfaced drive motors and steering motors with Roboclaw motor controller
- Interfaced Actuator with Linear Actuator Controller Board and Arduino Due

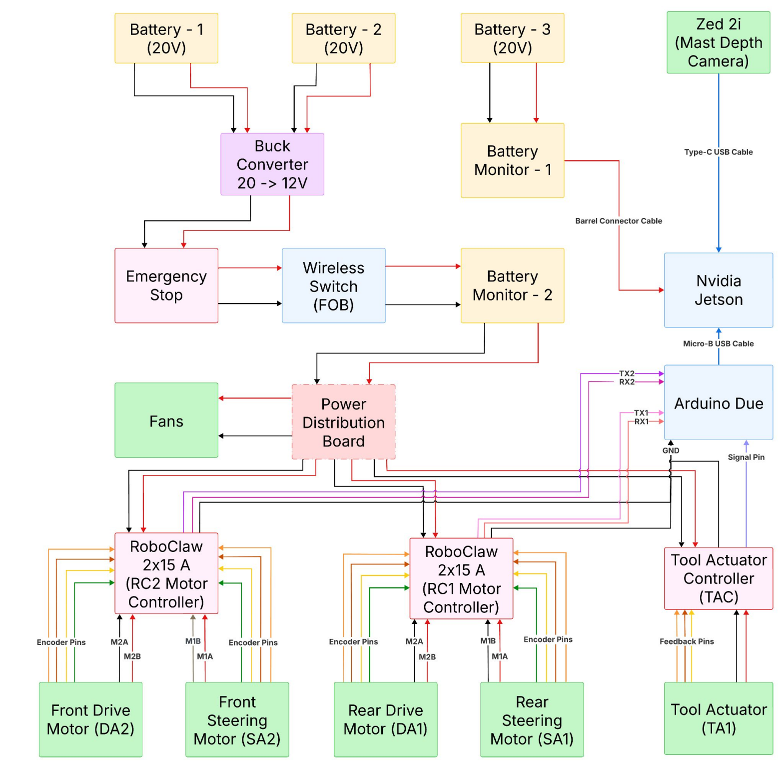
Challenges:

- Encoder QPPS to be changed using RoboClaw due to change in motors for better teleop and navigation
- Oscillations near setpoint of linear actuator under load.

Status: 85% Complete

- Tuning of actuator gains to reduce oscillations

Description: Electrical Subsystem



Electrical Circuitry

Description: Rover's power and logic circuitry.

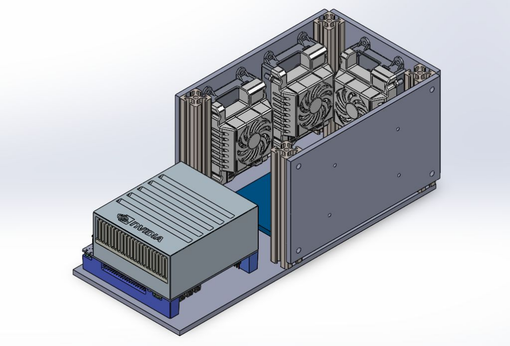
Requirements:

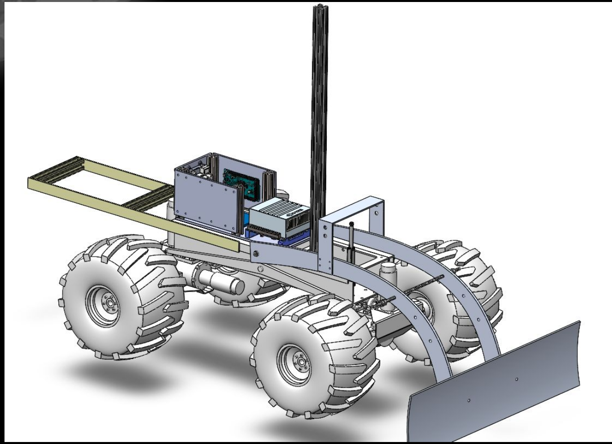
- Buck Converter (20 V -> 12 V)
- Power Distribution Board (PDB)
- RoboClaw Motor Controller - 2
- Linear Actuator Controller
- Linear Actuator
- Zed 2i Depth Camera
- E-Stop
- Wireless Switch
- IMU - VectorNav VN100
- Arduino Due
- Nvidia Jetson Xavier AGX
- Wireless Receiver for Joystick
- DC motors with Encoders

Expected Functionality:

- Distribute power efficiently to all rover components
- Ensure stable voltage levels for uninterrupted operation

Status: Electrical Subsystem





Electronics Assembly Design

Implementation:

- Analyzed the existing circuit connections of the rover designed by the Crater Grader team.
- Modified circuit connections to integrate new electrical components.
- Assessed the power requirements of the components to design a custom Power Distribution Board (PDB).
- Designed a compact and accessible electronic box to streamline the electrical subsystem setup.

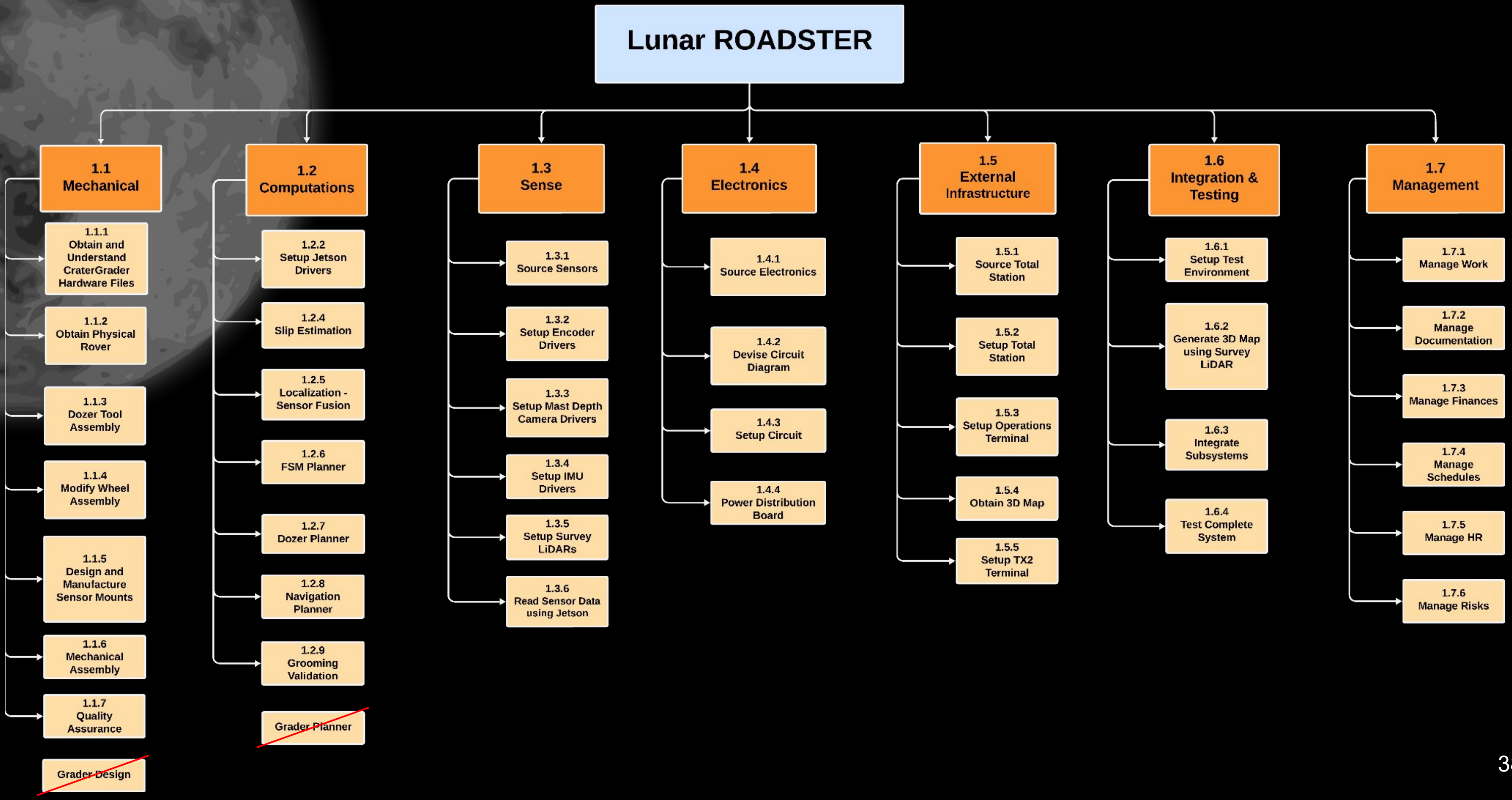
Challenges:

- Understanding and adapting to the existing circuit design and limitations.
- Ensuring the compact design of the electronic box while maintaining accessibility and proper cooling.

Status: 50%

- Manufacturing of the electronic box is in progress.
- Power Distribution Board (PDB) manufacturing and integration are planned.

Work Breakdown Structure



Schedule

ember '24
January
February
March
April
KAN-84 Milestones
KAN-1 Mechanical
KAN-22 Computations
KAN-40 Sense
KAN-49 Electronics
KAN-63 External Infrastructure
KAN-68 Management
KAN-69 Integration and Testing
PDR
Dozer Complete
External Infrastructure Complete
Localization Complete
Navigation & Tool Planner Complete
Electrical Power Complete
SVD

Spring Test Plan

Date	Event	Capability Milestones	Tests	Requirements
03/20	PR3	• Rover can localize itself accurately • Sensor placement do not block tool operations • Rover can navigate autonomously • Tool can operate autonomously	T09 T10 T11 T12	M.F.2 M.F.3 M.F.4 M.F.6 M.F.7
04/08	PR4	• Subsystems and units operate when integrated • Integrated subsystems do not hinder each other • Rover is operable as a system • Failing or degraded parts on rover is replaced	T13 T14	M.F.2 M.F.9
04/17 04/24	PR5 (SVD) PR6 (Encore)	• System can operate autonomously • System can localize itself • System can navigate autonomously • System can traverse the Moon Yard without getting stuck • System can grade suitably sized craters and dunes • System updates the operations terminal regarding progress	T15	M.F.2 M.F.3 M.F.4 M.F.5 M.F.7 M.F.9

Fall Test Plan

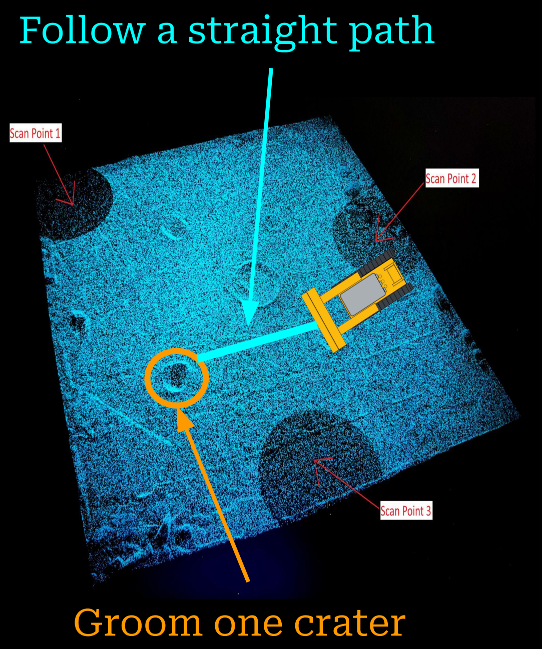
Month	Capability Milestones	Tests	Validation
August	Rover quality assurance after summer break and enhancement of the rover's facade	Check all subsystems and units are functioning correctly	The rover is able to complete all tasks from Spring
September	Integrate the validation stack for the dozing performance	Present craters of various groomed gradients to the validation stereo camera. The camera should output the perceived gradient and inform the operations terminal of the groomed status of the crater	The rover correctly informs operations terminal on whether the crater is dozed successfully or not
October	Implement new localization stack using no external infrastructure (will use pseudo star-sun tracker)	The rover is able to accurately localize itself in the Moon Yard without external infrastructure	Localization is accurate and comparable to current total station implementation
November	Integrated entire system for circumnavigation dozing of craters	Present several craters in a circular path in the Moon Yard. The rover should avoid ungradable craters and grade suitable craters specified in our performance requirements (M.P.4 and M.P.5)	The rover successfully navigates circular path and dozes suitable craters

SVD and FVD Split

Spring Validation Demo	Fall Validation Demo
ROADSTER uses the excavator to groom one crater in a simple, straight path in the Moon Yard.	ROADSTER uses the excavator to groom multiple craters and create a circuitous path around the Moon Yard.
This will be our Minimal Viable Product with simplified localization and path planning.	This will include more ambitious tasks such as Lunar-accurate environments and localization through Visual Odometry / Structure-for-Motion / Star-Sun Tracker

Spring Validation Demonstration

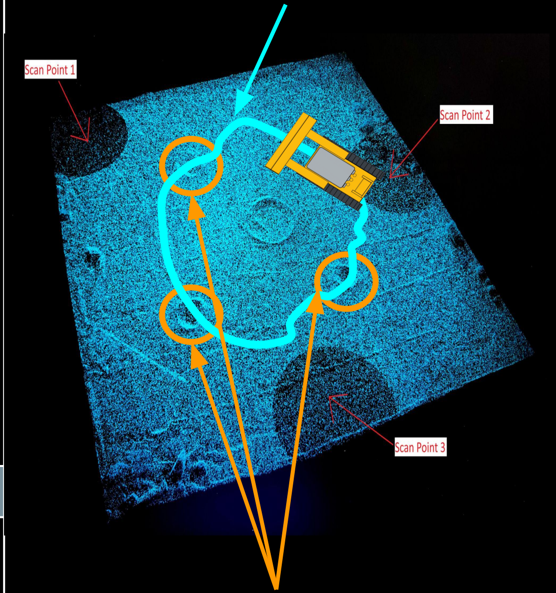
Test Location
Planetary Robotics Lab Moon Yard
Sequence of Events
Prior Setup: 1. Prepare the Moon Yard with a suitable crater and dune. 2. Scan the Moon Yard with a FARO Scanner to obtain a global map for navigation. 3. Attach and connect all the components and subsystems of the rover. 4. Set up the external infrastructure such as the total station in the corner of the Moon Yard, the LAN router, and the TX2 relay. 5. Place the rover in the Moon Yard and calibrate its localization using the total station. **During Demonstration:** 6. Turn on the rover and SSH into the Lunar ROADSTER docker on the operations terminal laptop. 7. Switch the rover to autonomous mode and run the start-up procedure. 8. Observe the rover autonomously grade one crater and level one dune. 9. If anything unexpected occurs press the emergency stop button.
Quantitative Performance Metrics
M.P.1: Will plan a path with cumulative deviation of <= 25% from chosen latitude's length **M.P.2:** Will follow planned path to a maximum deviation of 10% **M.P.4 (Part 1):** Will avoid craters >= 0.5 metres **M.P.5:** Will fill craters of up to 0.5 meters in diameter and 0.1m in depth



Fall Validation Demonstration

Test Location
Planetary Robotics Lab Moon Yard
Sequence of Events
Prior Setup: 1. Prepare the Moon Yard with several craters and dunes in a circular path. 2. Scan the Moon Yard with a FARO Scanner to obtain a global map for navigation. 3. Attach and connect all the components and subsystems of the rover. 4. Place the rover in the Moon Yard and calibrate its localization using a star-sun tracker or visual odometry. **During Demonstration:** 5. Turn on the rover and SSH into the Lunar ROADSTER docker on the operations terminal laptop. 6. Switch the rover to autonomous mode and run the start-up procedure. 7. Observe the rover autonomously grade craters and level dunes in a circular path. 8. After each dozed crater, use the ZED camera to validate whether the dozing satisfies the performance requirements. 9. If anything unexpected occurs press the emergency stop button.
Quantitative Performance Metrics
M.P.1: Will plan a path with cumulative deviation of <= 25% from chosen latitude's length **M.P.2:** Will follow planned path to a maximum deviation of 10% **M.P.3:** Will climb gradients up to 15° and have a contact pressure of less than 1.5 kPa **M.P.4:** Will avoid craters >= 0.5 metres and avoid slopes >= 15° **M.P.5:** Will fill craters of up to 0.5 meters in diameter and 0.1m in depth **M.P.6:** Will groom the trail to have a maximum traversal slope of 5°

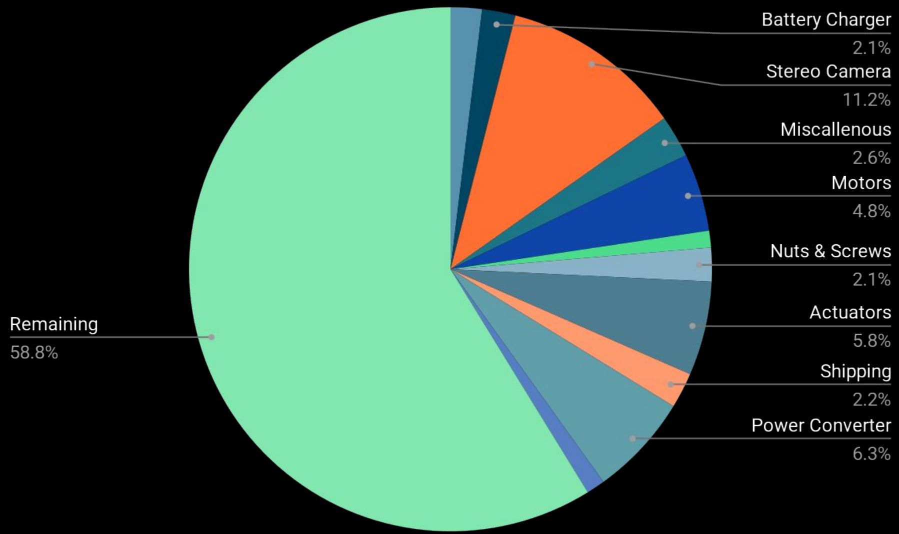
Follow a circular path



Groom several craters in a circular path

Budget

Major Items	Units	Total Price
ZED 2i Stereo Camera	1	$562.00
DC/DC Power Converter	1	$315.51
Planetary Gear Motors	4	$239.96
Linear Actuators	3	$290.00

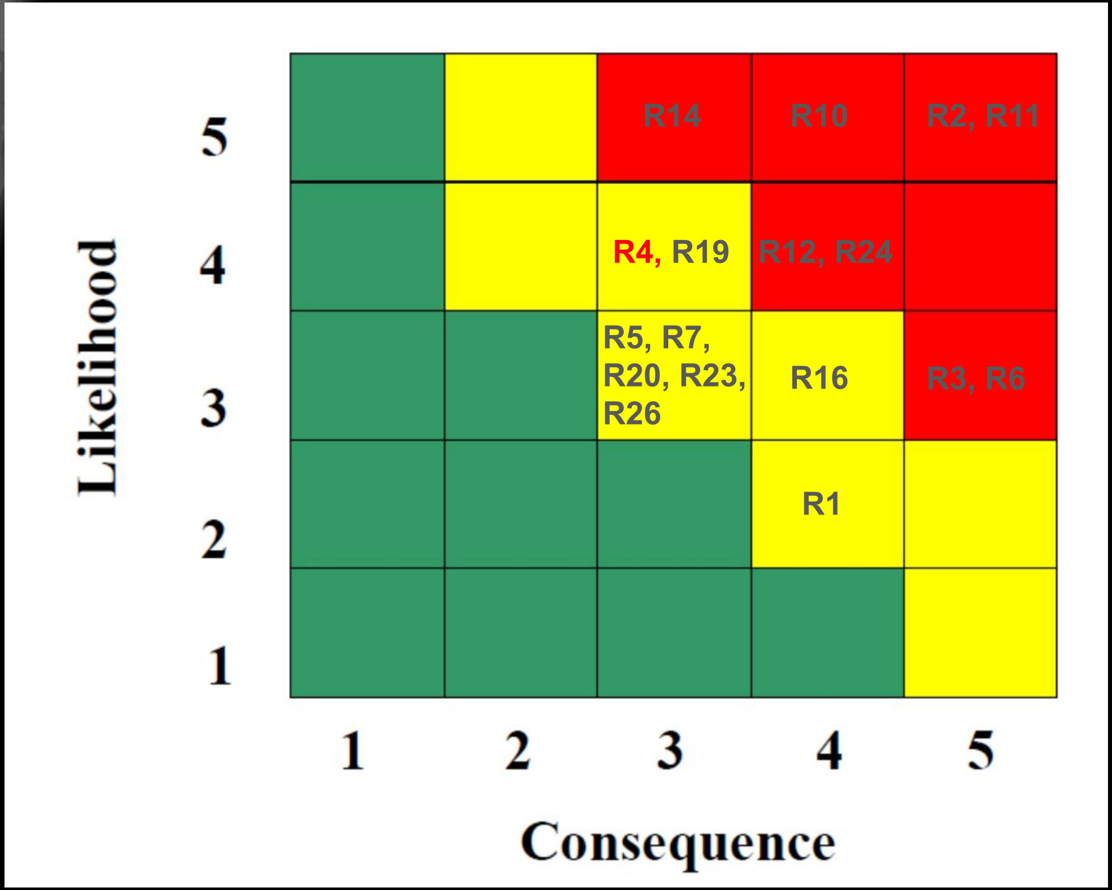


MRSD Budget	MRSD Budget Spent ($)	MRSD Budget Spent (%)	Total Budget Spent*	Remaining Balance
$5,000	$2,059.92	41.20%	$5,129.92	**$2940.08**

* Includes items inherited from Crater Grader and Supervisor

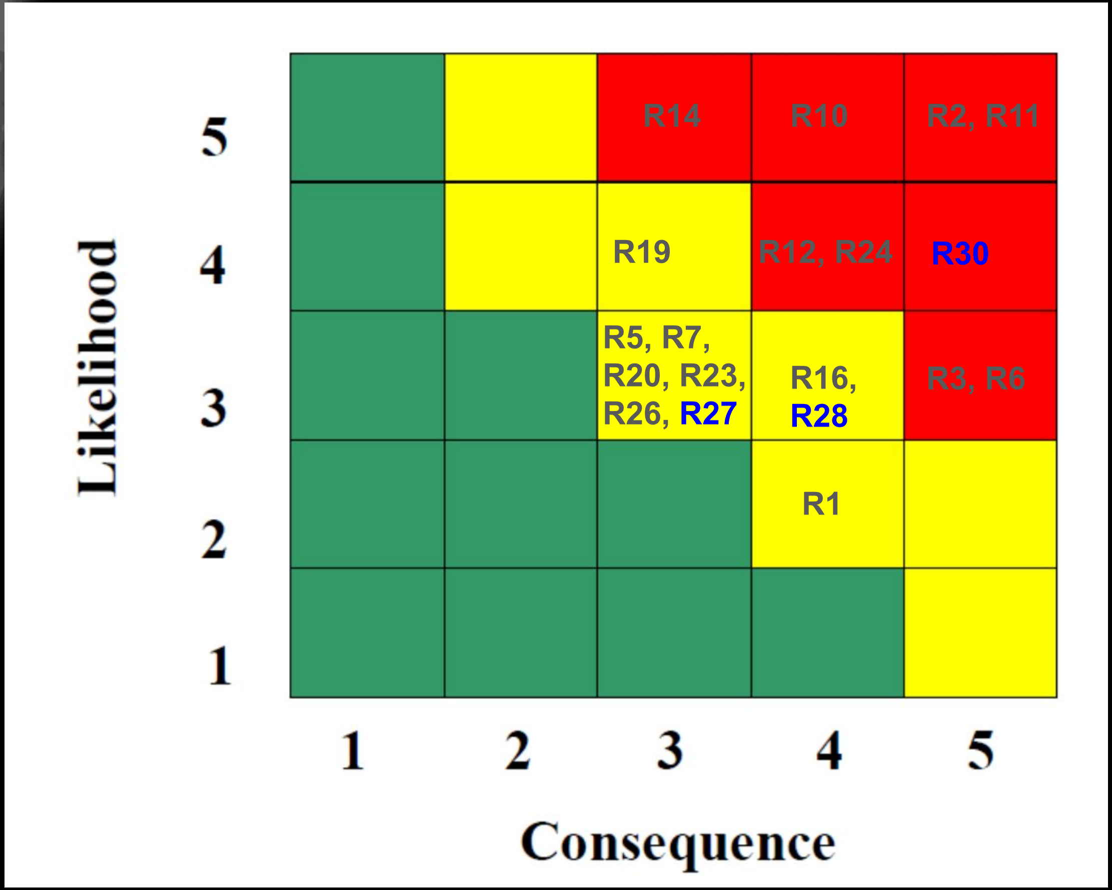
Risk Management (Previously)

Risk Summary



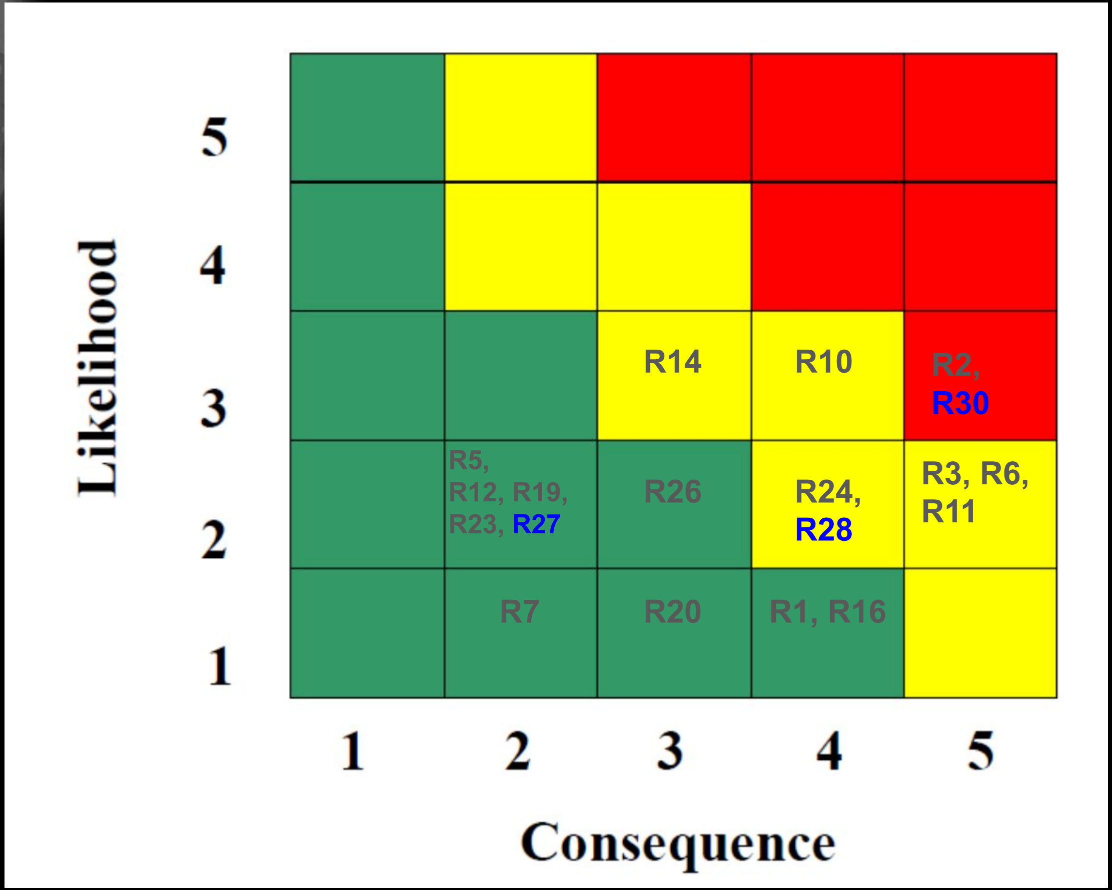
Risk Management (Updated)

Risk Summary



Risk Management (Updated)

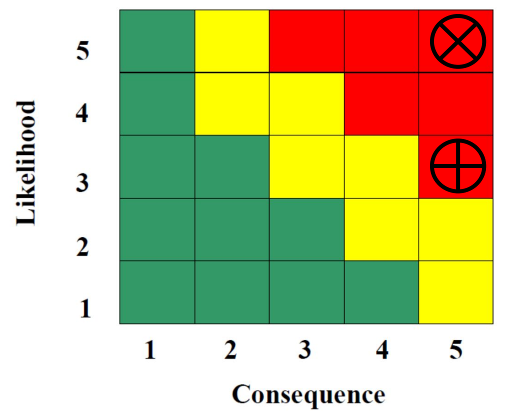
Reduced Risk Summary



Top Previous Risks

Risk ID	Risk Title	Risk Owner	Risk Type:	Technical
R2	Dozer tool planner takes longer than expected to deliver	Simson		

Description	Date Added
Implementation and integration of the Dozer tool planner takes longer than expected	11/27/2024
	Date Updated
	3/9/2024

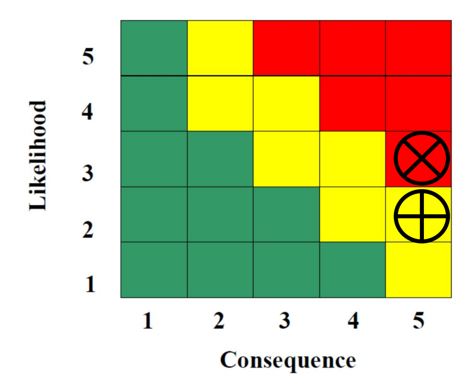


Consequence
Unable to meet SVD deadline and potential requirements change

Action/Milestone	Success Criteria	Date Planned	Implemented
Shift requirements for SVD	Updated performance requirements	11/28/2024	11/28/2024
Potentially use off-the-shelf code if available, preferably from CraterGrader	Successful integration of off-the-shelf components		

Top Previous Risks

Risk ID	Risk Title	Risk Owner	Risk Type:	Technical
R3	Integration issues between subsystems	Deepam		
Description		**Date Added**		
Subsystems work individually, but integration and communication between the subsystems are flawed		11/27/2024		
		Date Updated		
		11/27/2024		
Consequence				
Delay in integration causing scheduling overruns, requirements change and failure of the demo				



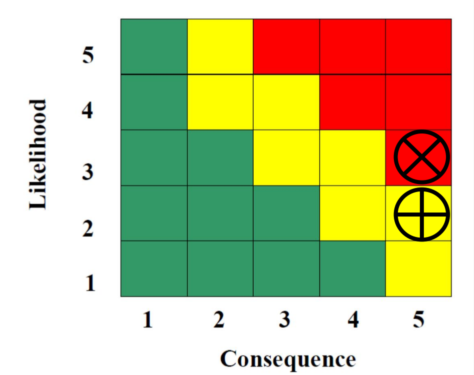
Action/Milestone	Success Criteria	Date Planned	Date Implemented
Perform unit testing and subsystem validation continuously	Successful testing of all major subsystems	11/30/2024	
Integrate one subsystem at a time	Successful integration of all major subsystems	11/30/2024	
Use a common framework (e.g. ROS2 interfaces) for communication between subsystems to reduce bugs	Adoption of common framework for communications	11/30/2024	
Keep to planned schedule and have at least 5 weeks for testing and integration	Successful integration of all major subsystems	11/30/2024	

Top Previous Risks

Risk ID	Risk Title	Risk Owner	Risk Type:	Schedule
R6	Delay in arrival and manufacturing of hardware components	William		

Description	Date Added
Shipping delays of components ordered and/or manufacturing delays on custom made components	11/27/2024
	Date Updated
	11/27/2024

Consequence
Delays in hardware integration, causing push backs in scheduling and software development

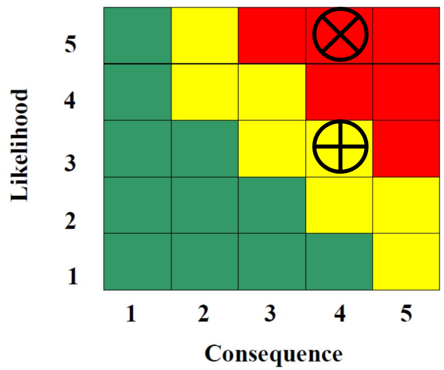


Action/Milestone	Success Criteria	Date Planned	Date Implemented
Use off-the-shelf components that are available on hand (e.g. from CMU labs or Red's workshop)	Obtain components before end of December		
Start ordering and designing components during Winter break so there is adequate leeway for delivery and manufacturing before Spring semester starts	Obtain components before end of December	11/27/2024	
Use simulations to work on software components while we wait for the components to be delivered and/or manufactured	Successful integration of all subsystems on schedule		
In case of delay in wheels, work with the existing wheels and proceed with the timeline while waiting for the new ones to arrive.	Successful integration of all subsystems on schedule		

Top Previous Risks

Risk ID	Risk Title	Risk Owner	Risk Type:	Technical
R10	Mast depth camera FOV is blocked	William		

Description	Date Added
Mast depth camera's FOV can be blocked, partially or completely, due to dust, misalignment of camera, or interference from the rover's own excavator assembly	11/27/2024
	Date Updated
	11/27/2024

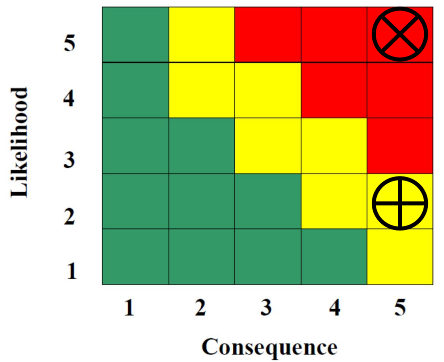


Consequence
Hinders the rover's ability to perceive its surroundings accurately, resulting in navigation errors and inefficiencies in excavation tasks

Action/Milestone	Success Criteria	Date Planned	Date Implemented
Conduct field tests to choose an optimal height to place the depth camera such that dust does not reach it and it can clearly see in front of the rover, despite the excavator assembly	Visual data such as depth perception and object detection is not compromised.		

Top Previous Risks

Risk ID	Risk Title	Risk Owner	Risk Type:	Technical
R11	Too many performance requirements	Ankit		
Description		**Date Added**		
We have a lot of performance requirements and we may not be able to meet all of them by April for SVD		11/27/2024		
		Date Updated		
		11/27/2024		
Consequence				
Delays in testing and validation, impacting project timelines and April SVD Demo results				



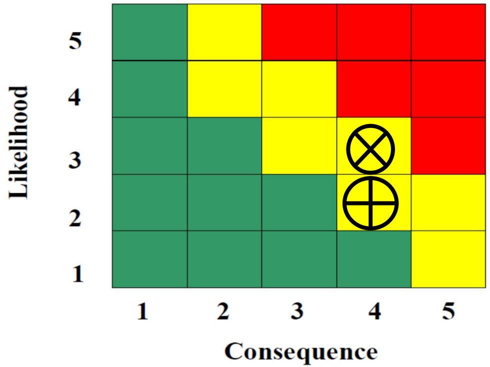
Action/Milestone	Success Criteria	Date Planned	Date Implemented
Have revised performance requirements separately for SVD and FVD (focus more on SVD)	Achievable Performance Requirements	11/28/2024	12/04/2024
Talk to CraterGrader and discuss what is feasible and what is not in the given time	Meeting conducted	11/28/2024	12/02/2024
PM should track schedule properly and team members have to push to meet the timeline	Project follows the schedule	11/28/2024	

Top Current Risks

Risk ID	Risk Title	Risk Owner	Risk Type:	Technical, Logistics
R28	Electrical Hardware Finalization	Ankit		

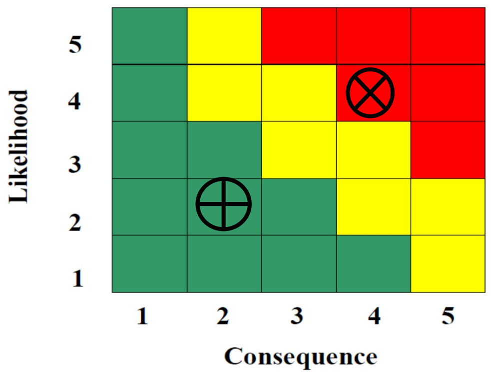
Description	Date Added
E-box Design dependence on to-be manufactured PDB.	2/14/2025
	Date Updated
	2/14/2025

Consequence
Not meeting the hardware deadline



Action/Milestone	Success Criteria	Date Planned	Date Implemented
Use previous knowledge and account for a placeholder in the design.	Successfully design and manufacture E-box compatible with the new PCB using placeholder PCB design	02/14/2025	

Top Current Risks

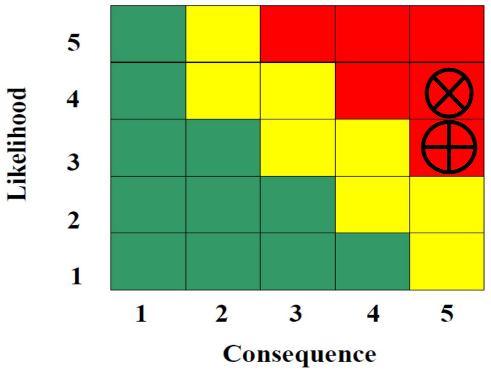
Risk ID	Risk Title	Risk Owner	Risk Type:	Logistics
R29	Access to FRC Workshop	Deepam		
Description		**Date Added**		
Without access, no hardware fabrication/repairs can be carried out in the absence of Tim		2/7/2025		
		Date Updated		
		2/7/2025		
Consequence				
Not meeting the hardware deadline				
Action/Milestone		**Success Criteria**	**Date Planned**	**Date Implemented**
Try other fab-labs on campus.		Successfully access other fab-labs and manufacture components	2/9/2025	
Request Tim, John or Red for getting temporary access, if not permanent		Successfully get temporary/permanent access to FRC Workshop	2/12/2025	

Top Current Risks

Risk ID	Risk Title	Risk Owner	Risk Type:	Logistics
R30	No spares available	Team		

Description	Date Added
Discontinued model, spare parts unavailable	3/4/2025
	Date Updated
	3/4/2025

Consequence
The whole project falling through, or redo almost all subsystems on a different rover.



Action/Milestone	Success Criteria	Date Planned	Date Implemented
Check out eBay and other similar platforms for spares	Successfully find exact spares on these platforms	3/6/2025	
Check out and stock similar parts if not same	Successfully find and stock similar parts	3/6/2025	
Find a twin rover that was used by a previous team on campus	Successfully find the twin rover and scavenge parts	3/6/2025	3/7/2025
Maintain all parts, especially mechanical parts	Successfully avoid future breakdowns and part failures	3/7/2025	

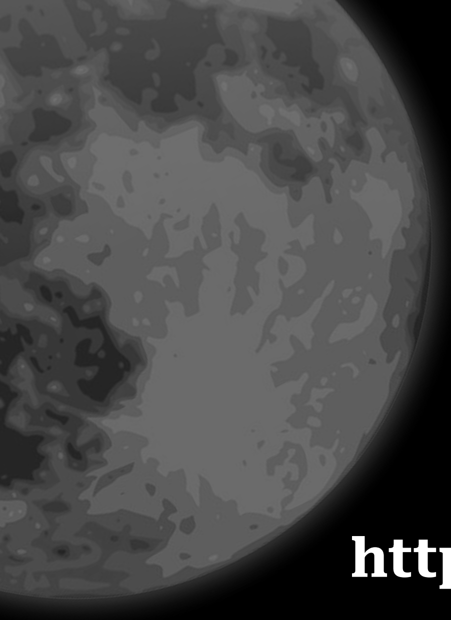
Issues

Issue ID	Date Initiated	Date Resolved	Participants	Description	Options	Resolution	Justification
I01	11/28/2024	12/04/2024	**Team**	Too many performance requirements for SVD.	Have revised performance requirements separately for SVD and FVD.	Revised performance requirements down to 6. Clearly defined SVD and FVD objective split.	Conducted meeting with Crater Grader team and discussed what is feasible and what is not in the given time.
I02	01/20/2025	01/27/2025	**Boxiang Fu**	Unable to login to TX2 chip.	Flash the chip and build docker container from scratch.	Found that chip was used by LunarX team. Got in contact and obtained login details.	No need to reinvent the wheel if not necessary.
I03	02/10/2025	02/14/2025	**Ankit Aggarwal**	Steering mechanism components failed due to wear-and-tear.	Replace broken parts.	Replaced all components of the assembly and fitted new screws and bolts.	Replaced old parts as a precaution for further failure due to wear-and-tear.
I04	02/21/2025	02/24/2025	**Boxiang Fu Bhaswanth Ayapilla**	Jetson cannot receive ROS topics published by TX2 chip due to docker driver being set as "bridge" instead of "host".	Change driver settings	Driver setting changed to "host"	This allows docker to communicate with host system

Issues

Issue ID	Date Initiated	Date Resolved	Participants	Description	Options	Resolution	Justification
I05	02/25/2025		**Ankit Aggarwal**	E-box Design dependence on to-be manufactured PDB. Can't delay the design as hardware deadline needs to be met	Estimate size based on current PDB and leave enough space		
I06	02/25/2025		**Ankit Aggarwal** **Deepam Ameria**	FRC Workshop Access	1. Request Tim 2. Ask John		
I07	03/04/2025		**Boxiang Fu** **Bhaswanth Ayapilla**	ZED SDK in docker container not working	1. Use ZED SDK outside docker 2. Use a dedicated docker container for SDK		
I08	03/04/2025	03/07/2025	**Team**	Rear transmission axle is broken	1. Ask Red for replacement 2. Look for substitutes	Found replacement chassis with axel in the PRL. Obtained permission from Red to take apart the replacement chassis for the broken part	Replaced the part so that we can continue progress on the rover

Q&A



Thank You!

https://mrsdprojects.ri.cmu.edu/2025teami/

Appendices

A.1. Derivation for P.5:

- Chang'e-4's landing site was surveyed and found that 97.5% of nearby craters were below 15.5 meters in diameter.
- Our rover is approximately 1/30th the size of a commercial grader, so it shall be able to grade $15.5/30 \approx 0.5$ meter craters at least.
- Source: DOI 10.3390/rs14153608

A.2. Derivation for P.3:

- Average depth-to-diameter (DtoD) ratio of 0.07 near the North pole
- Assuming worst-case scenario of a crater with twice DtoD ratio of 0.14, the gradient is $\theta = \arctan(0.14*2) \approx 15$ degrees
- Contact pressure requirement follows recommendation from NASA
- Source: DOI 10.1029/2022GL100886, NASA/TP—2006–214605

A.3. Derivation for P.1:

- Recommendation from Nature paper on extraterrestrial path-planning metrics
- Source: DOI 10.1038/s41598-023-49144-8

Credits for images:

- Generative AI
- Google Images
- Dr. William Red Whittaker's slides

Risk Management (Extra)

Risk ID	Risk Title	Risk Owner	Type	Description	Consequence	Risk Reduction Plan
R1	PRL Testbed Scheduling	Ankit	Scheduling	PRL Testbed unavailable due to scheduling conflicts with other high priority projects	No testbed available for testing and/or SVD	Devise and discuss a testing and demo plan with Red and other stakeholders of the PRL testbed beforehand and reserve slots
						Reach out to external testing facilities like Astrobotic or CAT for a backup testing facility
						Schedule tests at night
R2	Excavator and grader tool planner takes longer than expected to deliver	Simson	Technical	Integration of the excavator and grader software with hardware takes longer than expected	Unable to meet SVD deadline and potential requirements change	Shift requirements for SVD
						Integrate the grader during Fall semester
						Potentially use off-the-shelf code if available, preferably from CraterGrader
R3	Integration issues between subsystems	Deepam	Technical	Subsystems work individually, but integration and communication between the subsystems are flawed	Delay in integration causing scheduling overruns, requirements change and failure of the demo	Perform unit testing and subsystem validation continuously
						Integrate one subsystem at a time
						Use a common framework (e.g. ROS2 interfaces) for communication between subsystems to reduce bugs
						Keep to planned schedule and have at least 5 weeks for testing and integration
R4	Belly depth sensor is not suitable for validation	Bhaswanth	Technical	The belly depth camera is used to validate if a groomed crater is satisfiable. The sensor may not be able to adequately determine depth variations suitable for validation	Will result in major revision and changes to the validation architecture and functional requirement, causing delays in scheduling	Mount the depth camera at another location on the rover (e.g. on a mast)
						Use another sensor to determine depth variations (e.g. LIDAR, visual odometry, IR sensor)
						If all else fails, use the total station for validation

Risk Management (Extra)

Risk ID	Risk Title	Risk Owner	Type	Description	Consequence	Risk Reduction Plan
R5	Unable to get Crater Grader to perform autonomous crater filling	Bhaswanth	Technical	Our rover builds on top of the work accomplished by Crater Grader. If we cannot get Crater Grader to perform autonomous crater filling, we may need to spend more time working on the navigation stack and designing the entire pipeline	Extra time commitment to start from scratch or obtaining a suitable replacement	Thoroughly go through Crater Grader's code and the mechanical schematics provided
						Test each component and wiring to see if they are working
						If it is still not working, inherit only the software component from Crater Grader and build hardware ourselves
R6	Delay in arrival and manufacture of hardware components	William	Schedule	Shipping delays of components ordered and/or manufacturing delays on custom made components	Delays in hardware integration, causing pushbacks in scheduling and software development	Use off-the-shelf components that are available on hand (e.g. from CMU labs or Red's workshop)
						Start ordering and designing components during Winter break so there is adequate leeway for delivery and manufacturing before Spring semester starts
						Use simulations to work on software components while we wait for the components to be delivered and/or manufactured
						Implement other subsystems that are independent from the subsystem that is missing parts
						In case of delay in wheels, work with the existing wheels and proceed with the timeline while waiting for the new ones to arrive.
R7	Lack of proper simulation environment	Simson	Technical	Inability to accurately simulate the rover in a Lunar-like environment can lead to suboptimal performance	The rover's performance in the Moon Pit may be compromised, leading to inefficiencies, mission delays, or potential failure in achieving key objectives	Ask CraterGrader how they ran all their simulations and gather resources
						Explore LunarSim - https://github.com/PUTvision/LunarSim and check how useful this will be, during the winter break
						Develop Gazebo environment

Risk Management (Extra)

Risk ID	Risk Title	Risk Owner	Type	Description	Consequence	Risk Reduction Plan
R10	Mast depth camera FOV is blocked	William	Technical	Mast depth camera's FOV can be blocked, partially or completely, due to dust, misalignment of camera, or interference from the rover's own excavator assembly.	Hinders the rover's ability to perceive its surroundings accurately, resulting in navigation errors and inefficiencies in excavation tasks	Conduct field tests to choose an optimal height to place the depth camera such that dust does not reach it and it can clearly see in front of the rover, despite the excavator assembly. Ensure that visual data such as depth perception and object detection should not be compromised
R11	Too many performance requirements	Ankit	Technical, Schedule	We have a lot of performance requirements and we may not be able to meet all of them by April for SVD	Delays in testing and validation, impacting project timelines and April SVD Demo results	Have revised performance requirements separately for SVD and FVD (focus more on SVD)
						Talk to CraterGrader and discuss what is feasible and what is not in the given time
						PM should track schedule properly and team members have to push to meet the timeline
R12	Drive system wear-and-tear causes malfunction	Deepam	Technical	The transmission and steering assembly might be worn out, leading to suboptimal vehicle dynamics, and potentially mechanical failure	Rover drive system fails and may require a lot of repair and maintenance	Thoroughly check the Crater Grader's assembly and carry out maintenance of any worn-out parts
						Completely replace the assembly parts with the same/similar new parts for better performance and reliability
						Added limit switches to avoid steering gears to operate beyond their limits
R14	Dust ingress	William	Technical, Cost	Due to significant sand manipulation, the flying sand/dust can enter and accumulate over sensitive electronics (PDB, drivers, Arduino) and sensors (cameras, IMU), leading to component failure or incorrect sensing	Component failure during testing or demonstrations. Highly inhibits all future scheduled tasks	Design proper sand enclosures and mounts for sensitive components
						Review placement of components
						Review scale and speed of sand manipulation to eliminate root-cause of flying sand/dust
						Allocate contingency budget and order spares of the sensitive components in case of component failure

Risk Management (Extra)

Risk ID	Risk Title	Risk Owner	Type	Description	Consequence	Risk Reduction Plan
R16	Code version control	Simson	Technical	Code modifications or config parameter changes during testing might not be saved, affecting the final demo. Reverting to a stable version is difficult if changes do not work as expected.	Delay in code integration and implementation	Implement GitHub version control to store and retrieve the best versions of code and configuration Use Google Drive to backup important documentation explaining setup processes
R19	Items missing	Ankit	Logistics	Critical project items may go missing if not stored properly or tracked. Items may be misplaced or borrowed without proper logging	Delay in hardware implementation	Maintain an inventory tracking spreadsheet Include spare inventory
R20	Sensor ROS packages not available	William	Technical, Schedule	Finalized sensors might lack compatible ROS packages, leading to delays or significant changes in the software architecture	Delay in software implementation	Perform trade studies to pick sensors that are compatible with ROS versions before finalizing Select sensors and ROS versions that minimize potential conflicts
R23	Lunar-accurate cut/fill regions are not possible to groom	Simson	Technical	The rims of the craters may not be enough to fill the whole crater. Going to a different region to carry the sand to the crater may prove to be inefficient	The basic assumption of sand availability fails. We may need to rethink the basic concept of tool planner to fit the new parameters of the environment	Accurately create the environment and assess if the rims are enough to fill If not, modify PRs accordingly

Risk Management (Extra)

Risk ID	Risk Title	Risk Owner	Type	Description	Consequence	Risk Reduction Plan
R24	Sensor data is too noisy to fulfill performance requirements	William	Technical	Performance requirements are tough and ambitious, sensor noise may prevent us from achieving it	Failure to demonstrate performance requirements may cause us to lose marks in the demonstrations	Relax the performance requirements enough to ensure that they are achievable
						Ensure enough testing time to tune parameters
R26	Off-the-shelf wheels don't interface with the rover	Ankit	Technical	No off-the-shelf wheels fit the rover, We'll have to redesign wheel hubs and mountings as per the new wheels.	Continue with sub-optimal wheels that the rover currently has, thus, not meeting one of the non-functional requirements	Shift requirements to FVD
						Good enough market research to see find the best fit, with least amount of changes

Risk Management (Extra)

R27	TX2 Integration	William	Technic al	Unable to login to TX2 and interface with a LAN network for transmitting data over WiFi ro Jetson	Delay in finalizing localization stack	Set up a new TX2 (Re-flash the TX2). Reach out to previous teams to understand their methodology and retrieve credentials
R28	Electrical hardware finalization	Ankit	Technic al	E-box Design dependence on to-be manufactured PDB.	Not meeting the hardware deadline	Use previous knowledge and account for a placeholder in the design
R29	Access to FRC Workshop	Deepa m	Logistics	Without access, no hardware fabrication/repairs can be carried out in the absence of Tim	Not meeting the hardware deadline	Try other fab-labs on campus. Request Tim, John or Red for getting temporary access, if not permanent
R30	No spares available	Team	Logistics	Discontinued model, spare parts unavailable	The whole project falling through, or redo almost all subsystems on a different rover.	Check out eBay and other similar platforms for spares Check out and stock similar parts if not same Find a twin rover that was used by a previous team on campus Maintain all parts, especially mechanical parts