Lunar ROADSTER

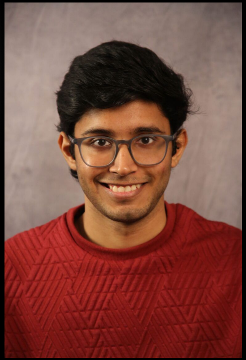
(Robotic Operator for Autonomous Development of Surface Trails and Exploration Routes)

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

CARNEGIE MELLON UNIVERSITY
PITTSBURGH PENNSYLVANIA 1900

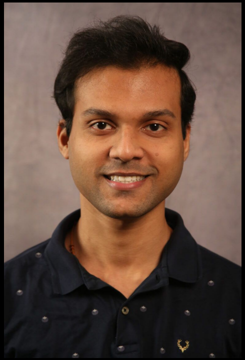
The Team

Ankit Aggarwal



Deepam Ameria

Bhaswanth Ayapilla

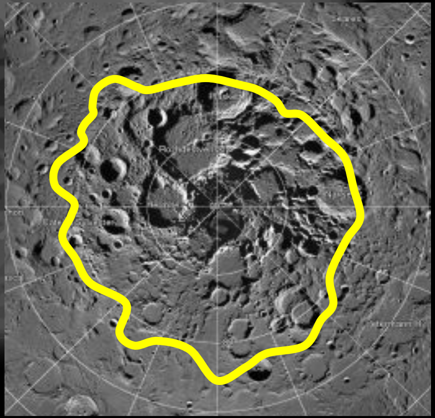


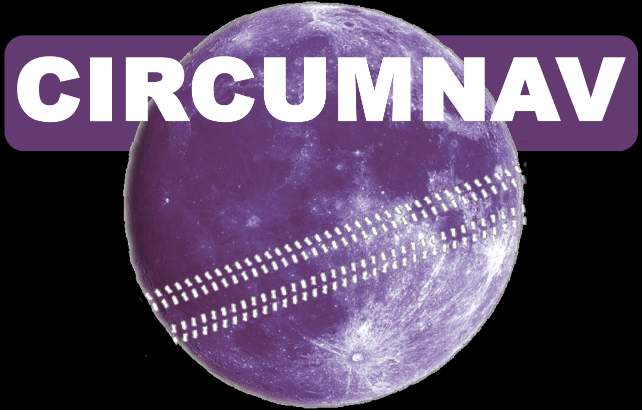
Simson D'Souza

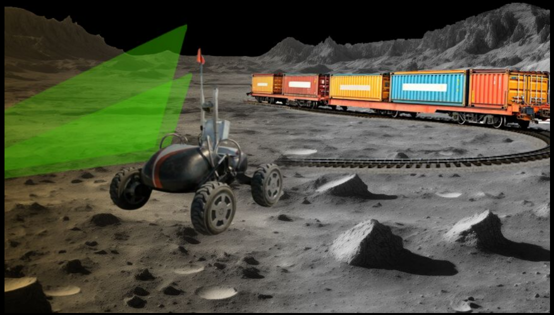
Boxiang (William) Fu

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

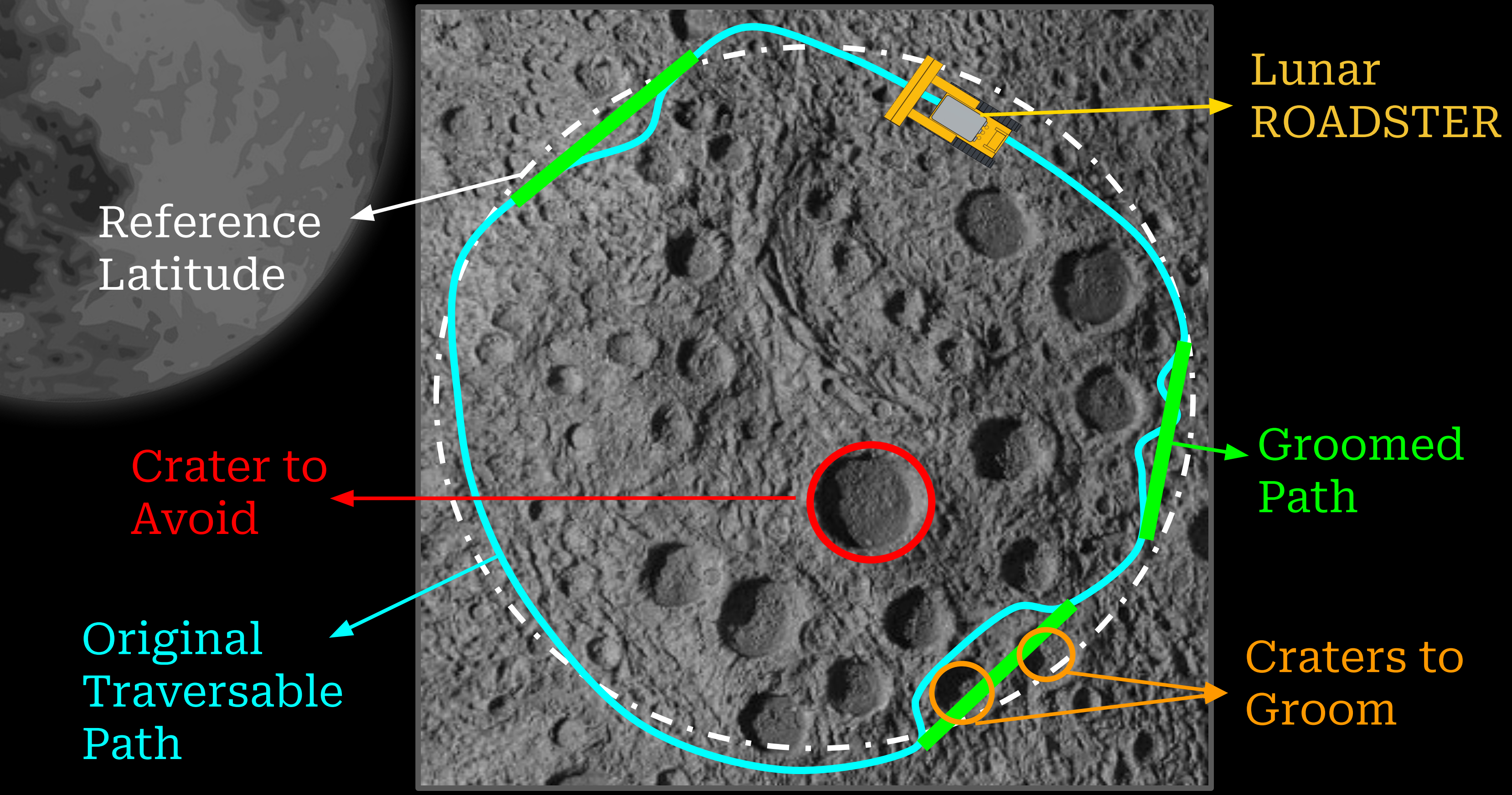
At equator	11,000 km	16 kph
At 50 deg	7,040 km	10 kph
At 60 deg	5,500 km	8 kph
At 70 deg	3,700 km	6 kph
At 75 deg	2,800 km	4 kph
At 80 deg	1,870 km	3 kph
At 81 deg	1,529 km	2.5 kph

Jogging speed if the route was flat, circular and traversable

The Project: Lunar ROADSTER

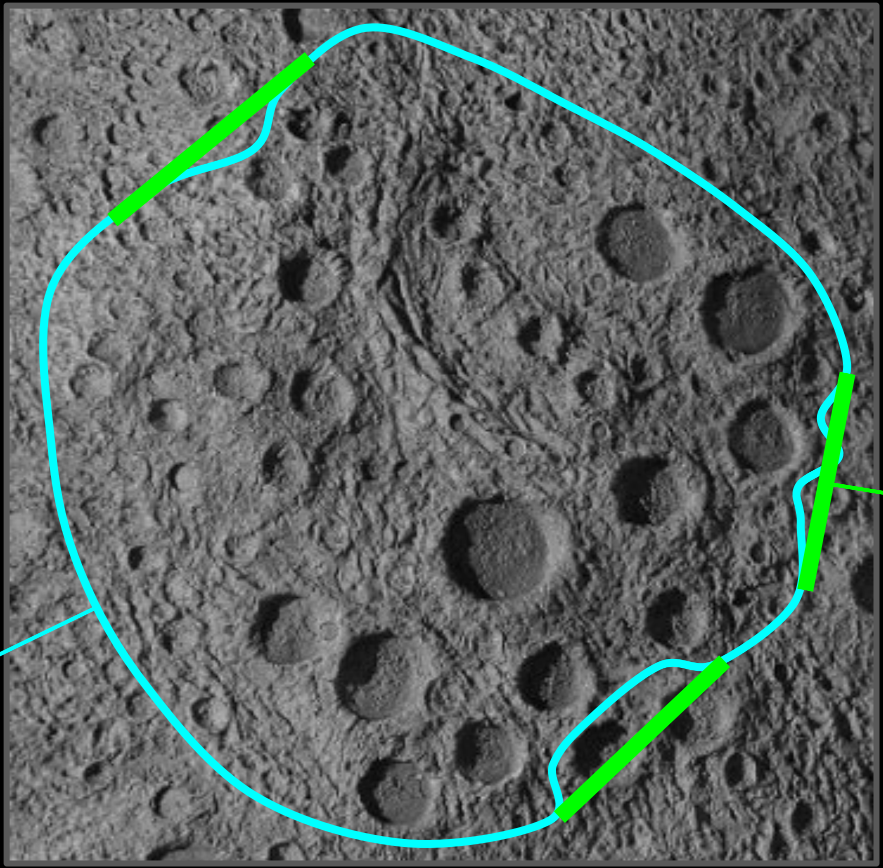
An autonomous moon-working rover capable of finding ideal exploration routes and creating traversable surface trails

Use Case



Lunar ROADSTER
Reference Latitude
Groomed Path
Crater to Avoid
Original Traversable Path
Craters to Groom

Use Case



Original Traversable Path

Groomed Path

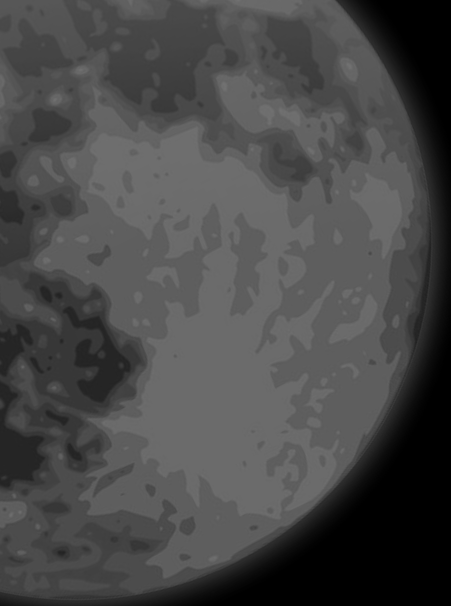
Today's Demonstration

Pre-Demo Setup

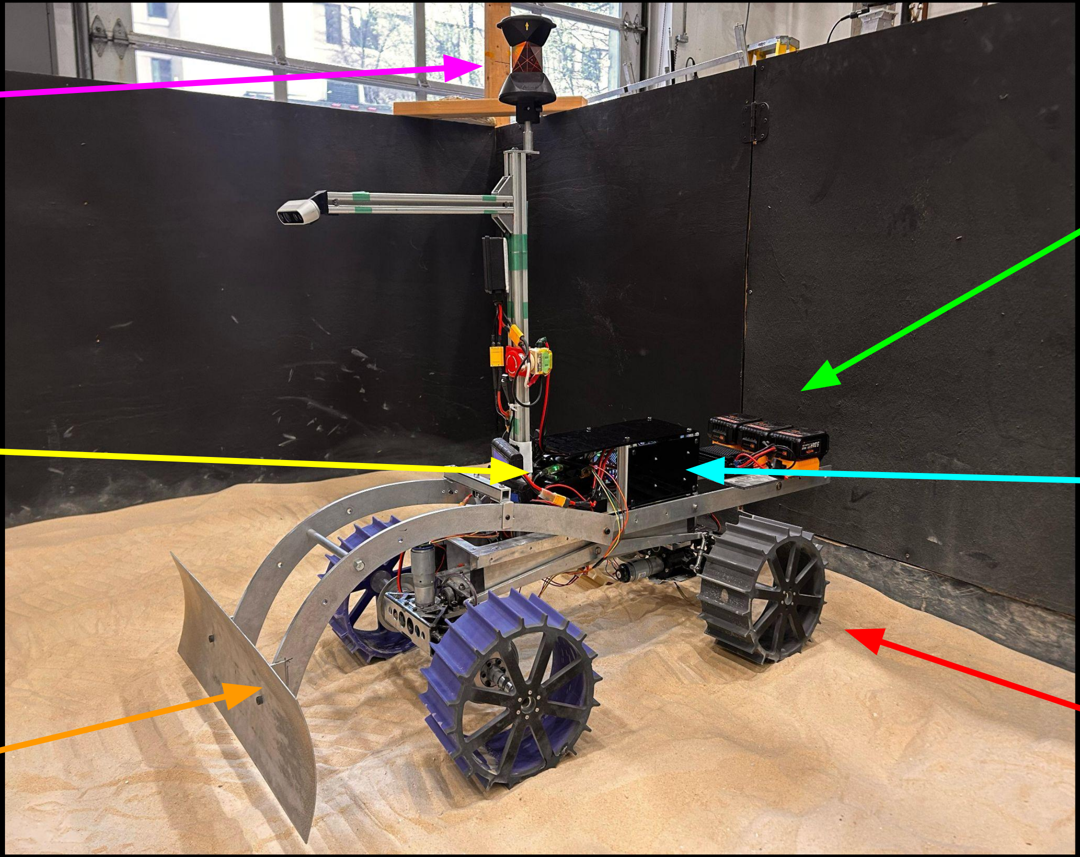
- ROADSTER Ready
- Prepare test environment (MoonYard)
- Obtain global map (PointCloud)
- Set up external infrastructure
- Calibrate localization (yaw and position)
- Plan optimal sand manipulation path

During Demo

- Switch to Autonomous Mode
- Use goal poses and offsets to plan path
- Navigate and traverse autonomously
- Autonomously groom the crater
- Failsafe: Use key fob to manually turn off the rover during emergency

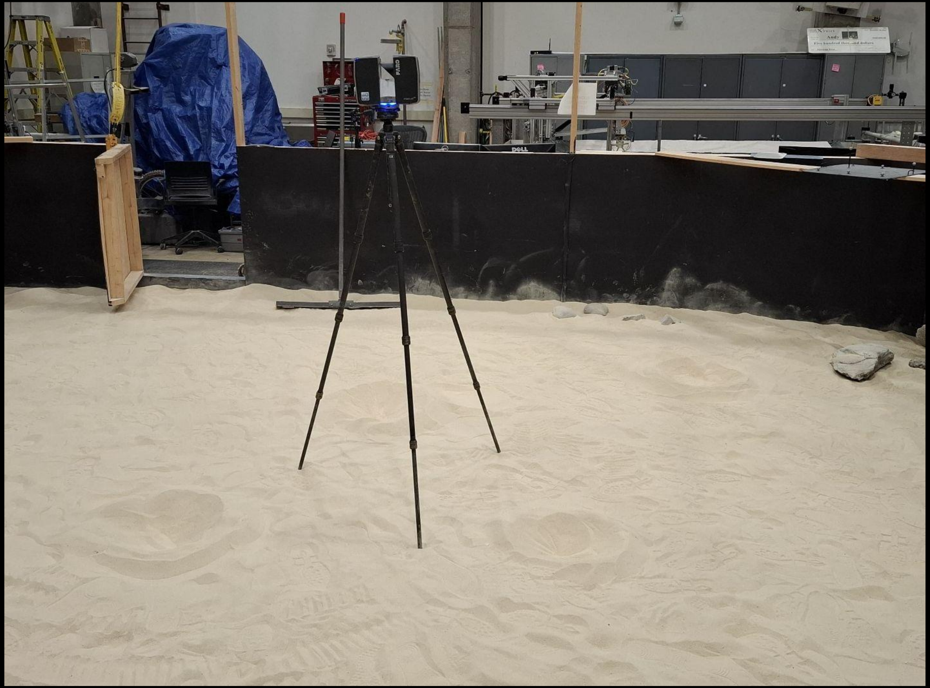


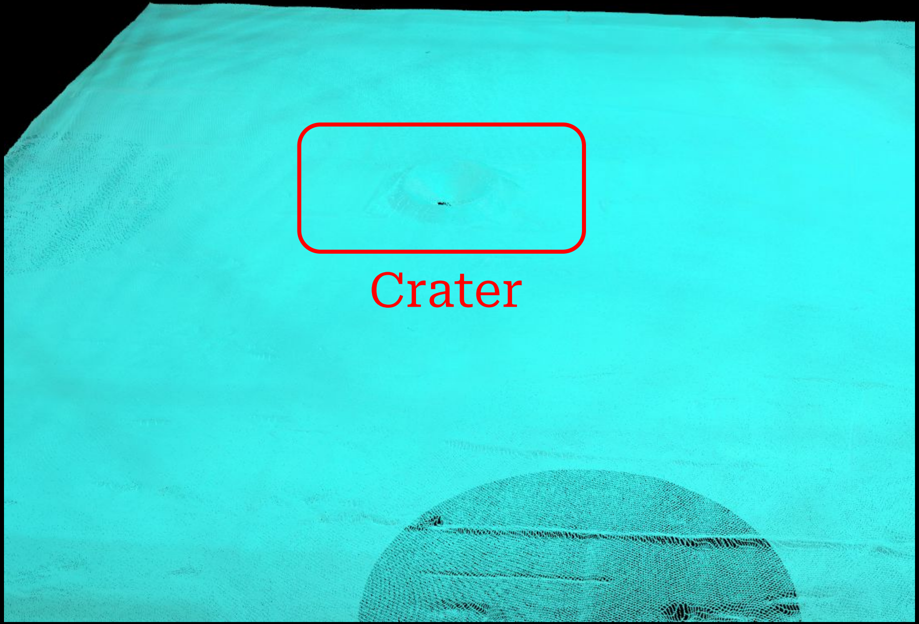
Pre-Demo Setup


Leica Prism
Jetson Xavier AGX
Custom Dozer Blade
3 20V Batteries
Electronics Box
Custom Wheel Design

ROADSTER

Prepare test environment (Moonyard)



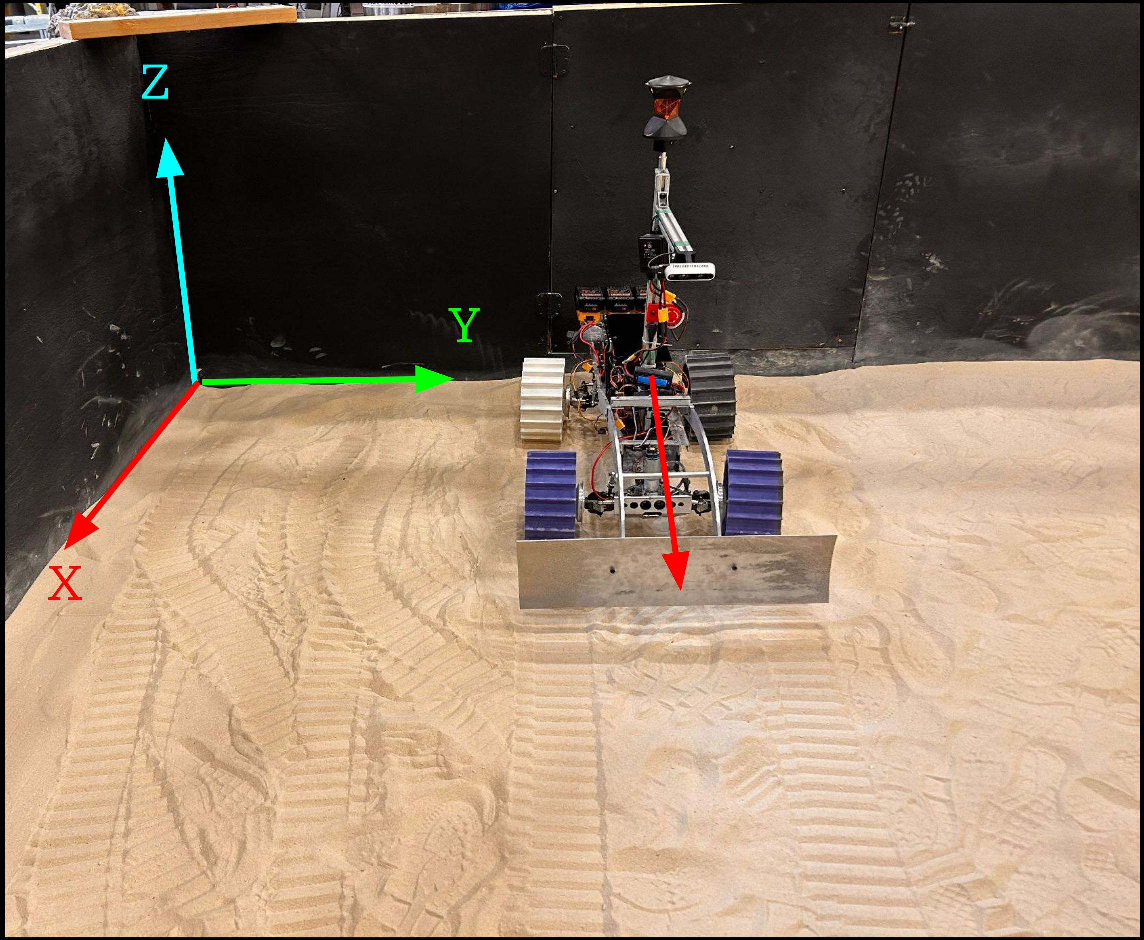


Obtain global map using FARO Scanner

Leica TS16 Total Station

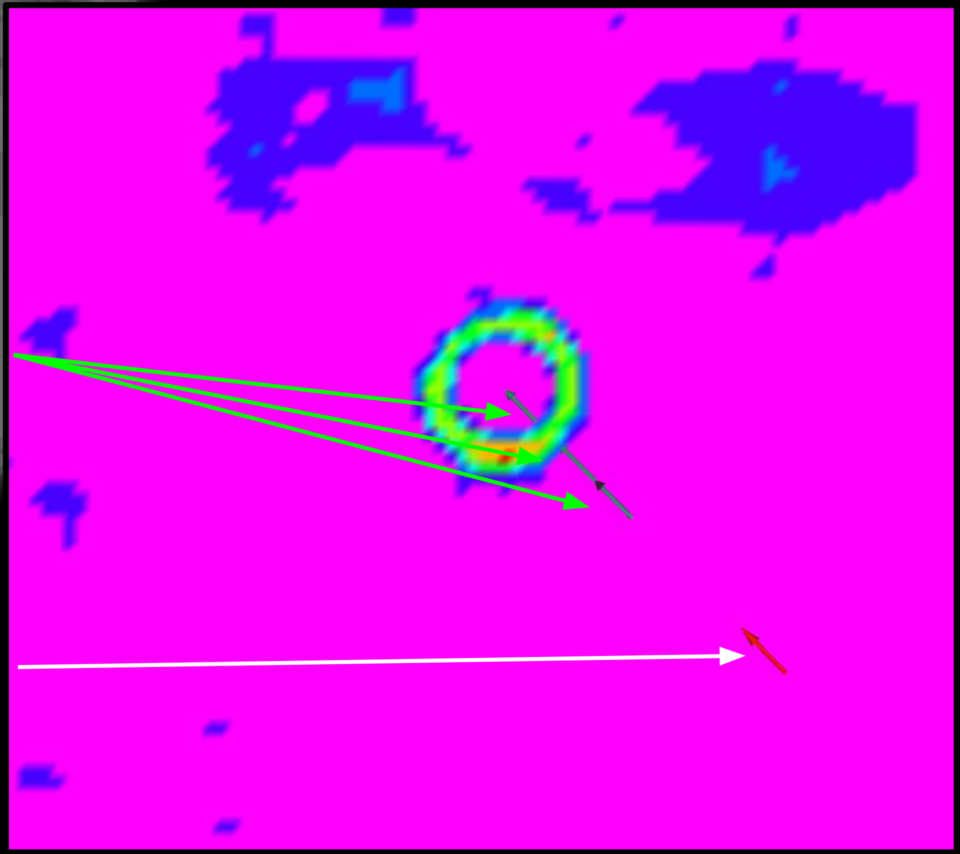
LAN Router & TX2 Relay

Set up external infrastructure



Calibrating relative heading angle (yaw)

Planned Goals



Current Goal

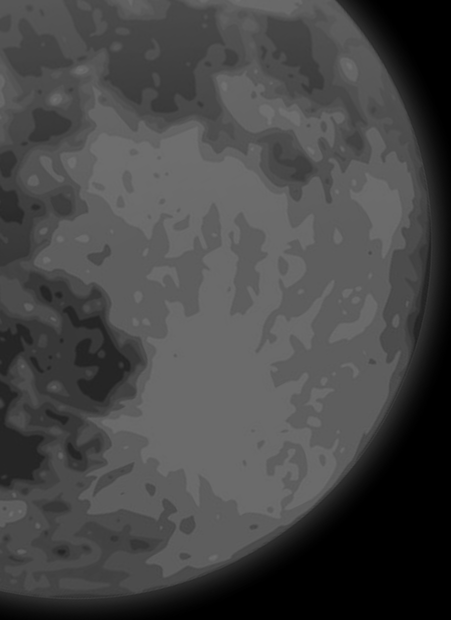
Objective: Grade crater optimally

Cost Function minimizes

- Transport volume
- Transport Distance

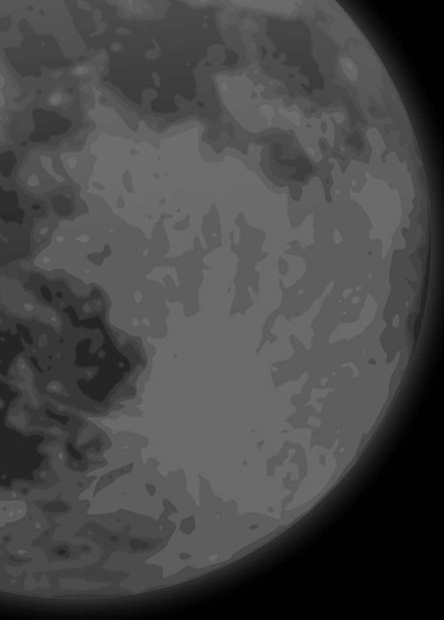
Waypoints generated based on the outputted transport assignments

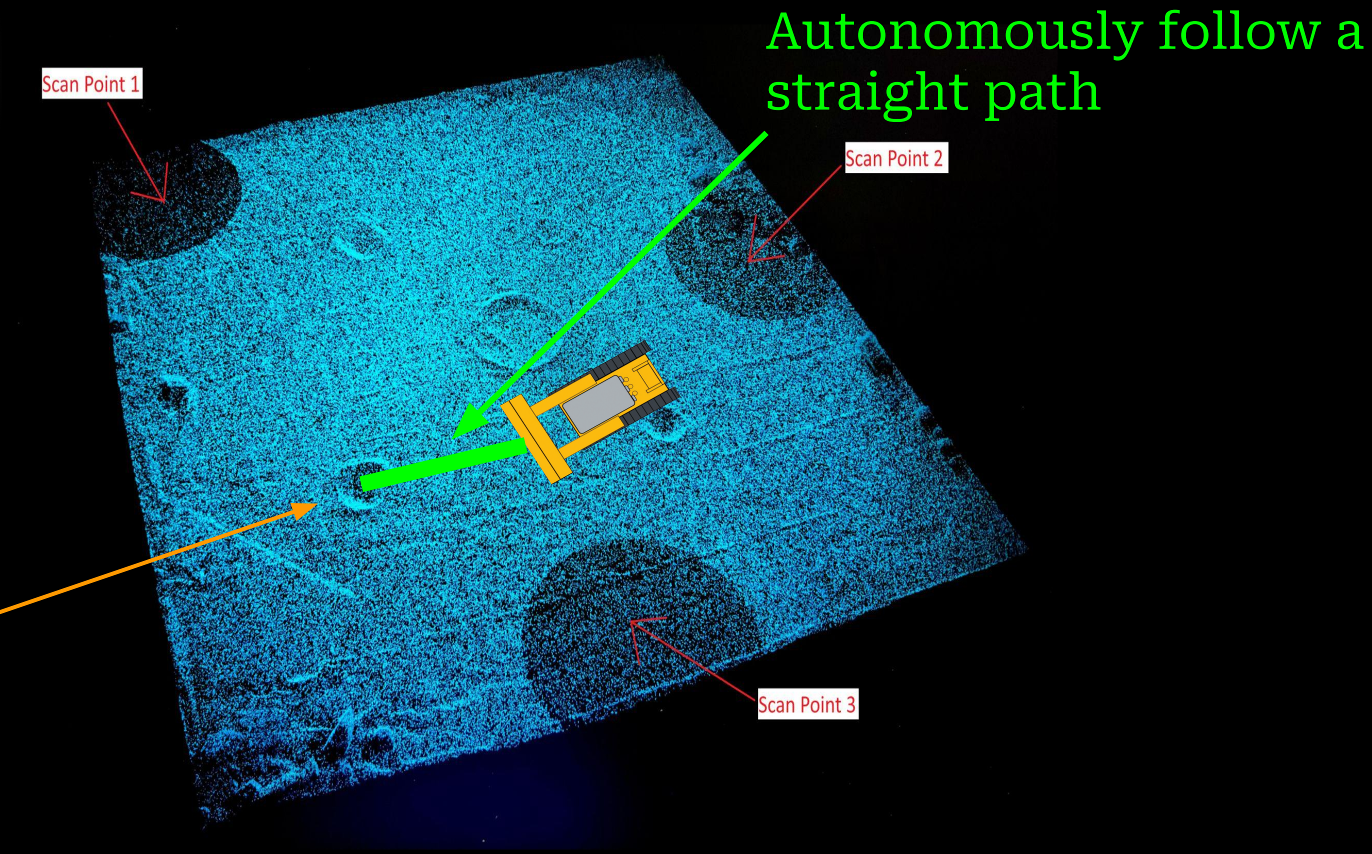
Plan optimal manipulation goal poses



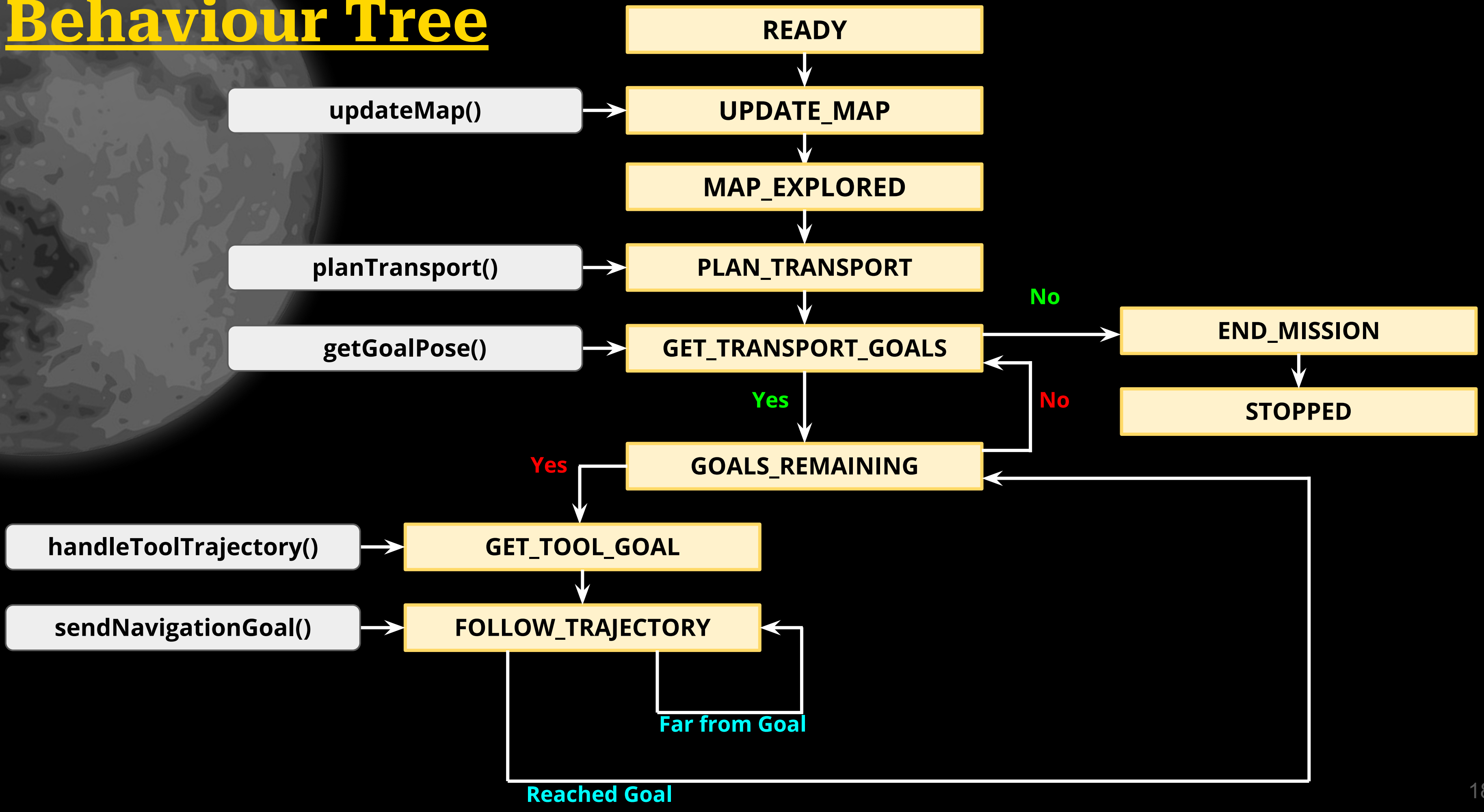
Demonstration

Demonstration





Behaviour Tree



Localization Method

Leica TS16 Total Station

VectorNav VN-100 IMU

Wheel Encoders

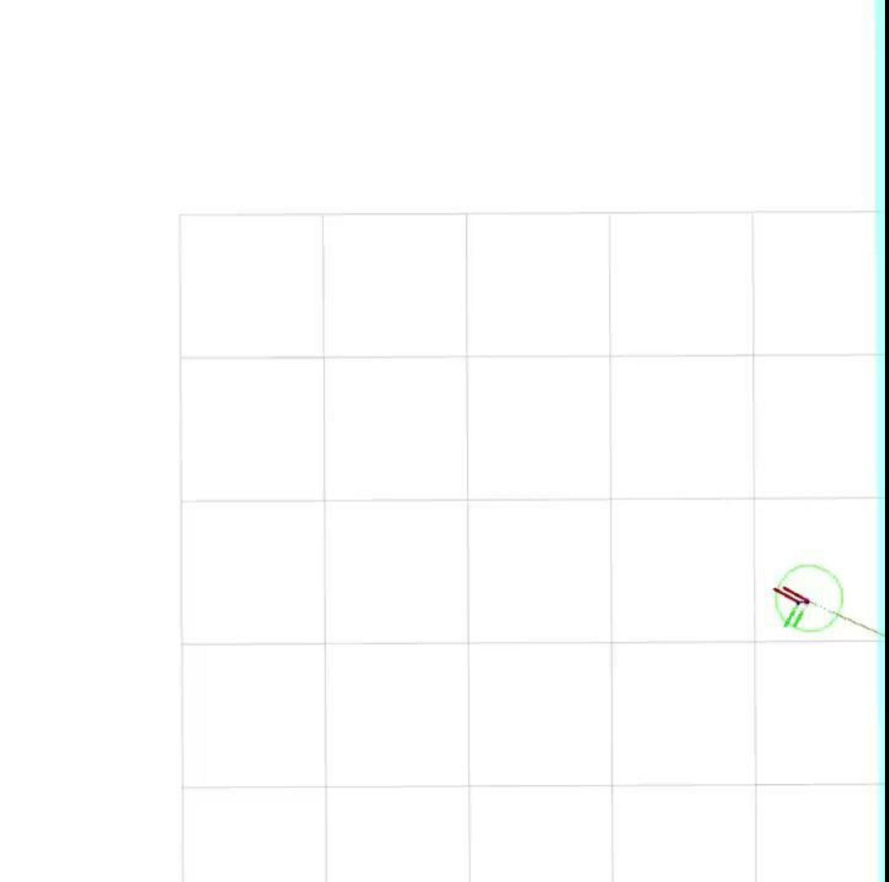
Global Localization

Local Localization

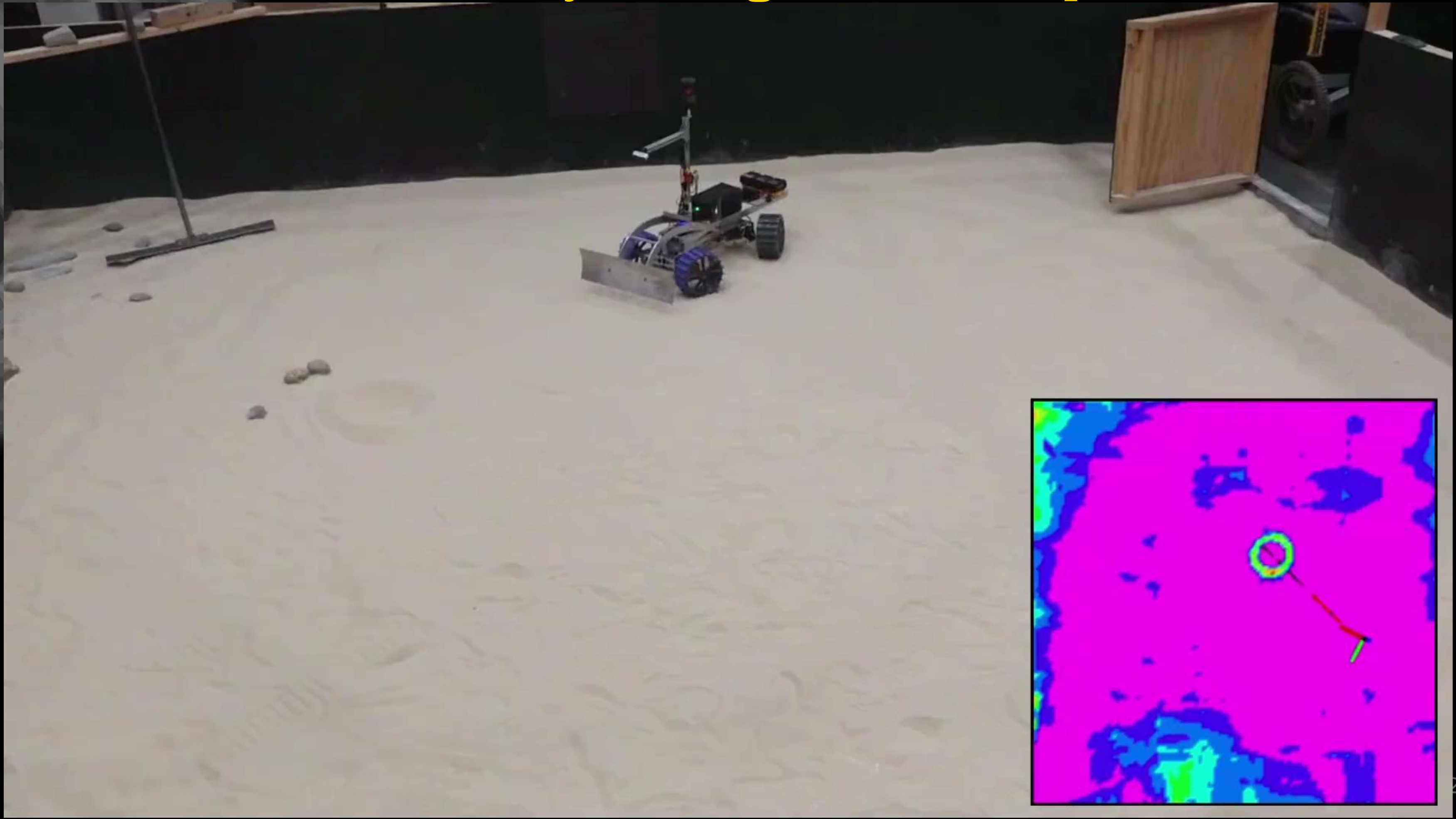
Extended Kalman Filter

Rover Pose

Navigation Method



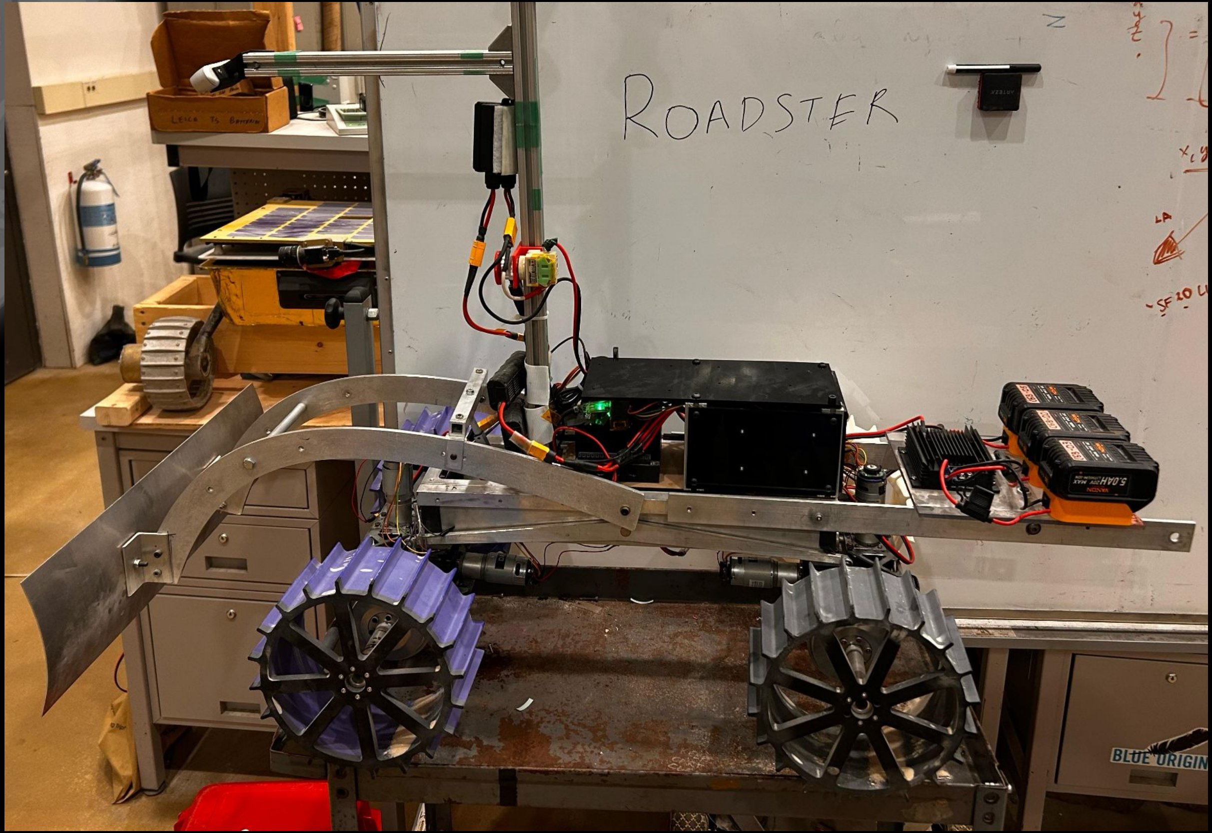
Autonomously Grading a Crater (2x speed)



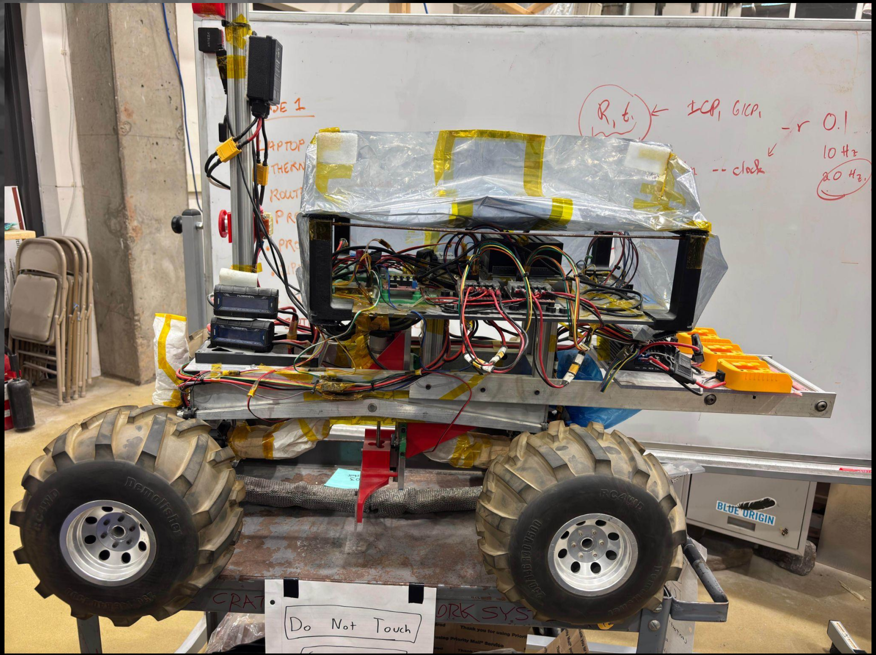
Rover Capabilities Demo

Out with the old...

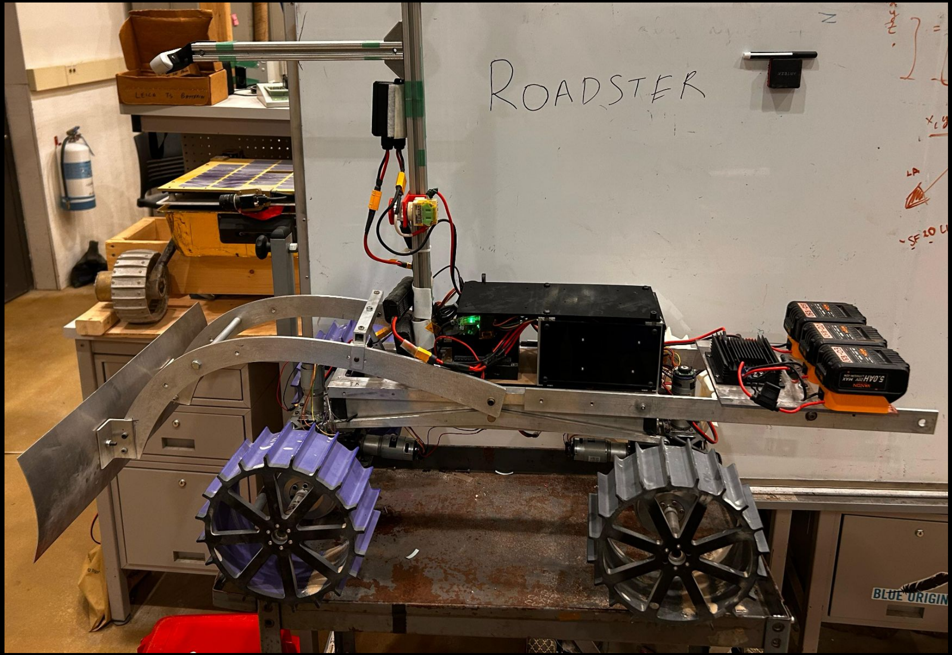
In with the new!



CraterGrader - - - - → Lunar ROADSTER



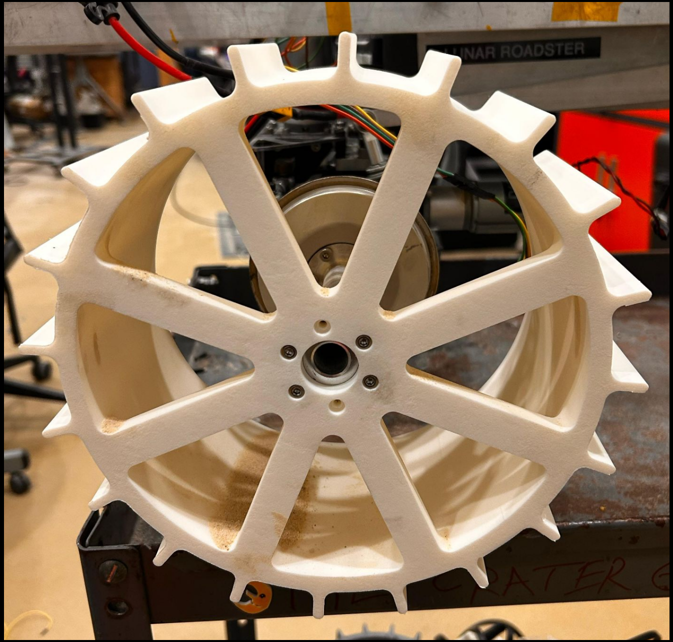
Before



After

Stock Wheels - - - - → Lunar Wheels

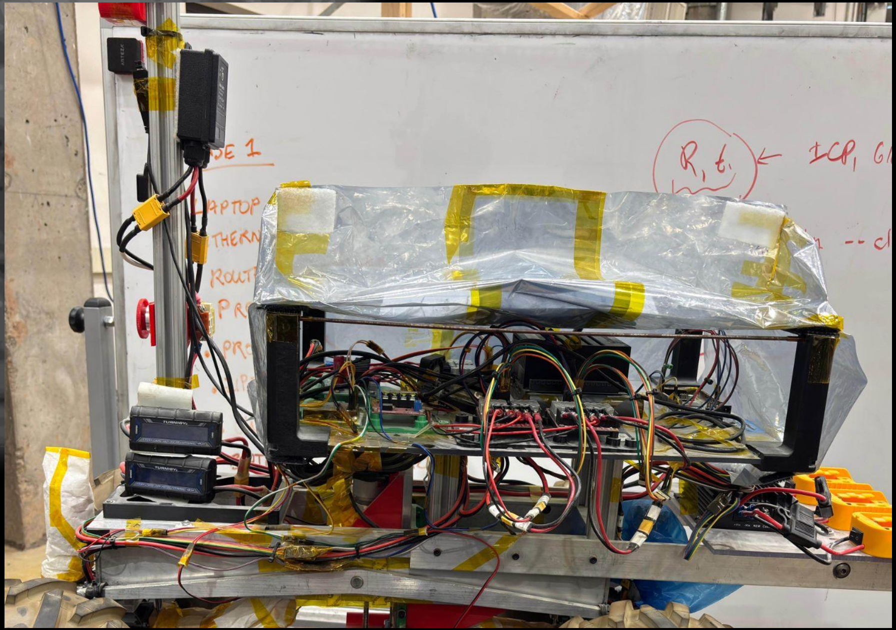
Before



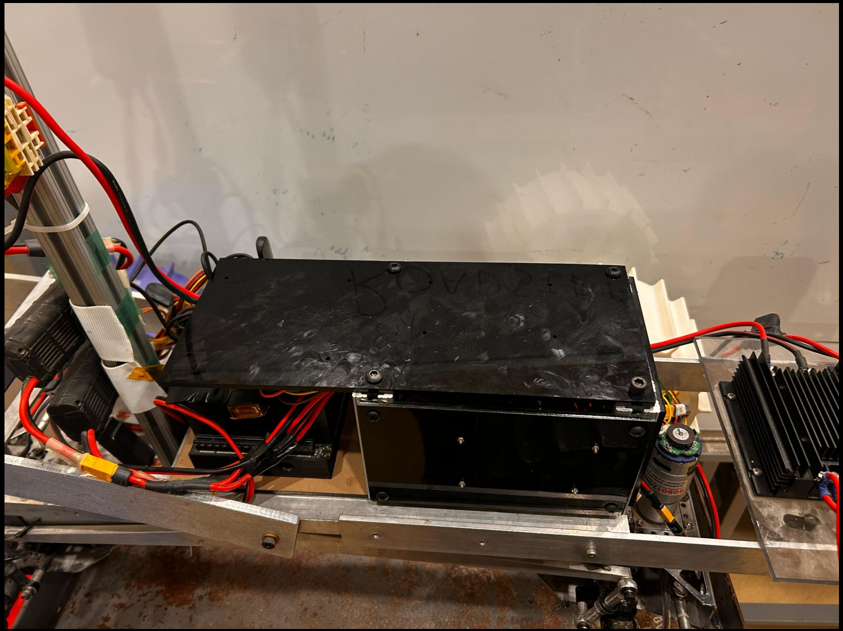
After

Wheel with more rimpull, coupled with higher torque motors results in higher traction generation

Cluttered Wiring - - - - → Compact E-Box



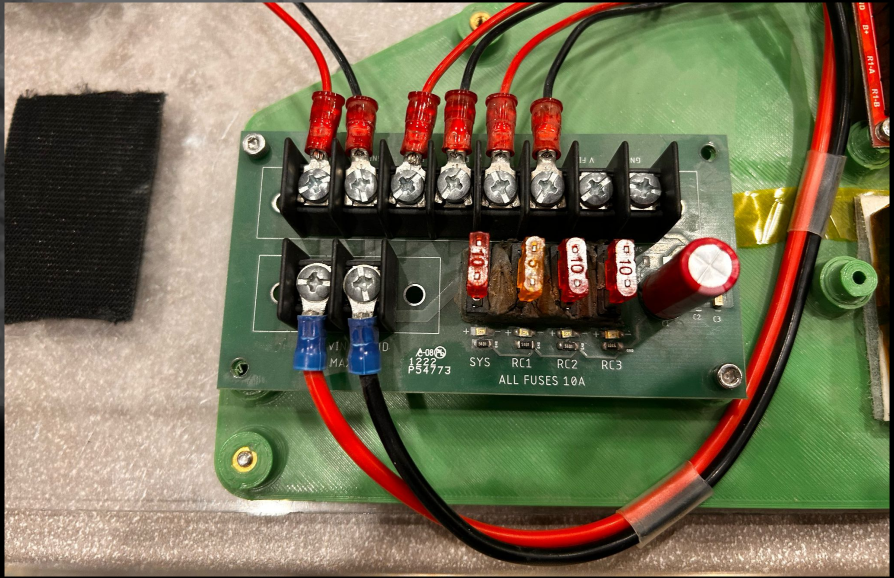
Before



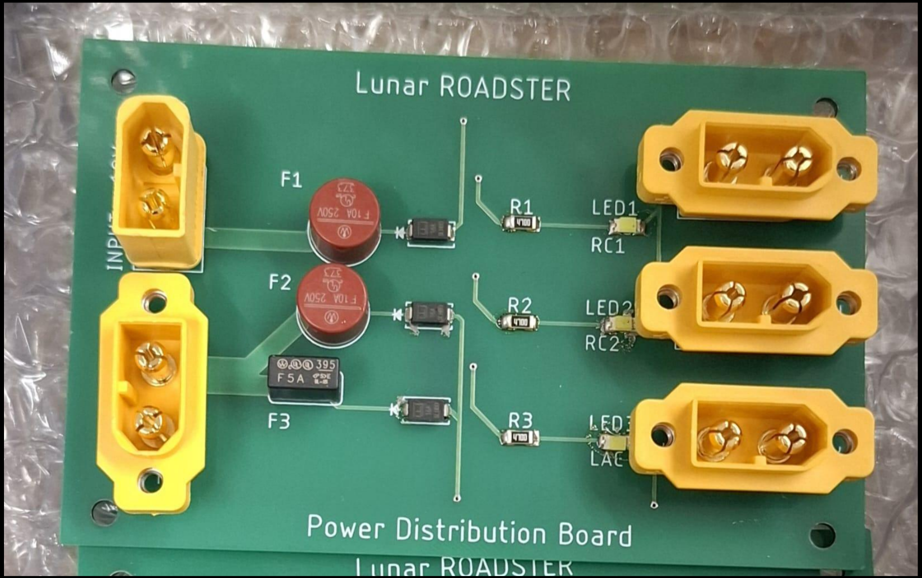
After

Custom PCB with an enclosed compact design creates more finished and reliable onboard circuitry

Improved Power Distribution Board



Before

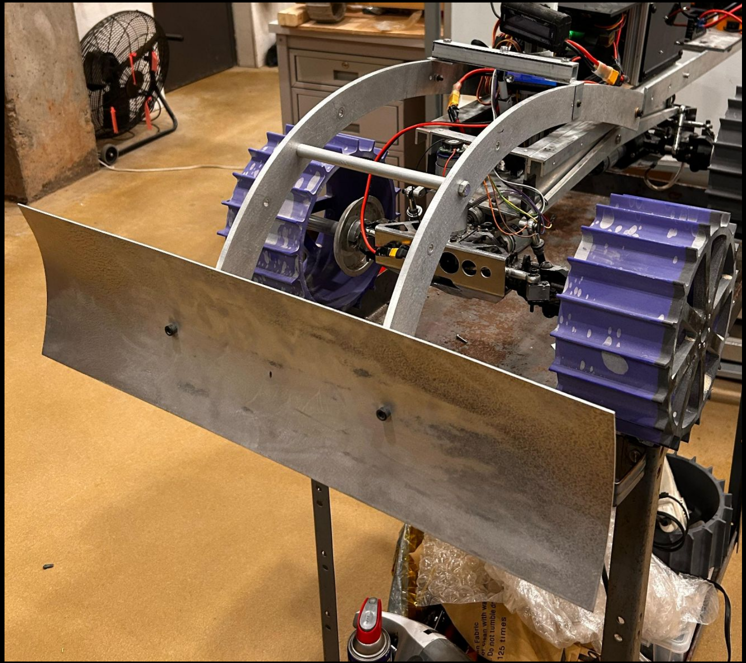


After

New design featuring OVP/RVP along with XT60 terminals for ease of assembly and reliability, has been fully integrated into the system.

Central Grader - - → Frontal Dozer

Before

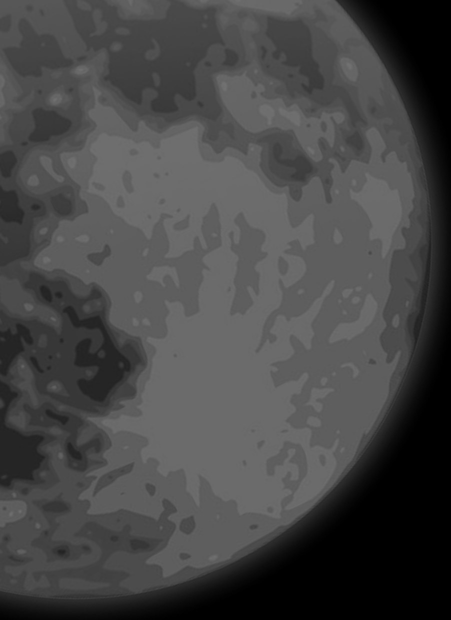


After

Frontal tool enables increased dozing area while maintaining stable wheel-ground contact

ROADSTER Capabilities

- Teleoperation
- Traversal in uneven, sandy terrain
- Ackermann Steering
- Dozer Actuation Strength
- Dozer Pushing Strength
- Crater Grooming



Results

Results

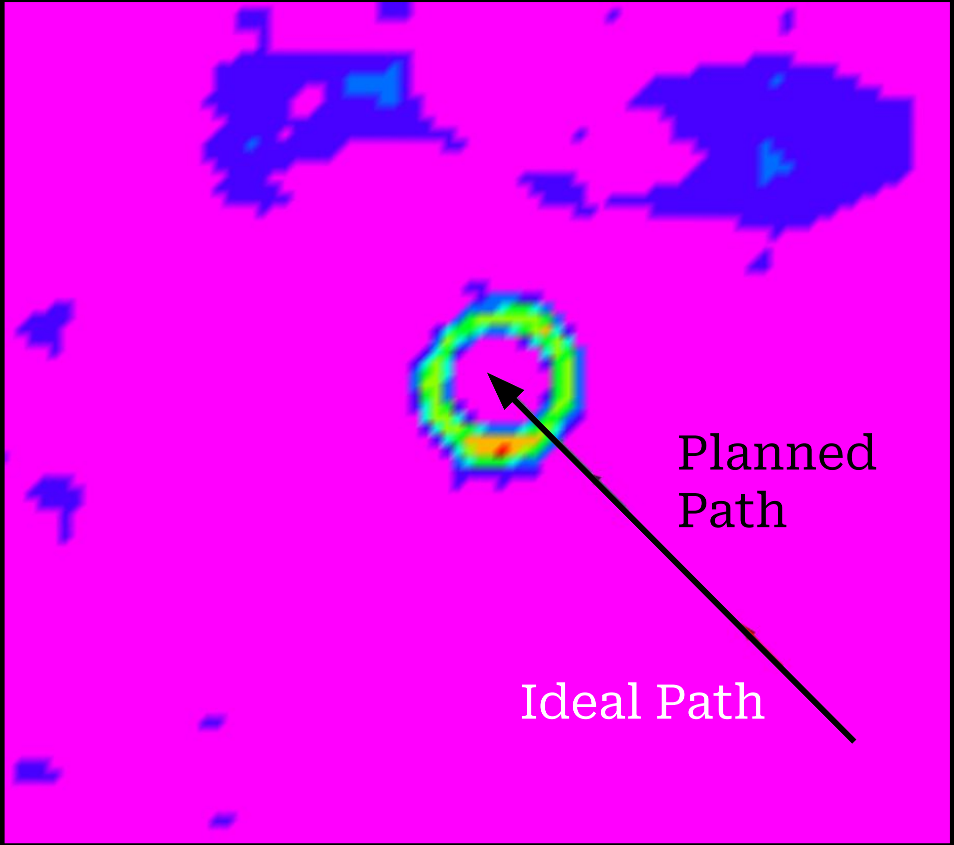
- Mechanical Design
- Electrical & Electronics Design
- Machine capable of grooming craters
- Localization and Autonomous Navigation
- Identification of craters to groom/avoid
- Crater Grooming

ROADSTER

An autonomous mechatronic bulldozer for the Moon

- 60cm dozer width (3 times the predecessor)
- Increased tool actuation strength
- Custom wheels with improved rimpull and grip
- 135 kgf-cm drive actuators (2 times the predecessor)
- Far greater pushing power
- Organised and reliable circuitry
- Efficient power distribution
- **An optimal, specialized machine for crater grooming**

M.P.1: Will plan a path with cumulative deviation of <= 25% from chosen latitude's length (due to untraversable terrain)



M.P.2: Will follow planned path to a maximum deviation of 10% (due to localization/navigation error)

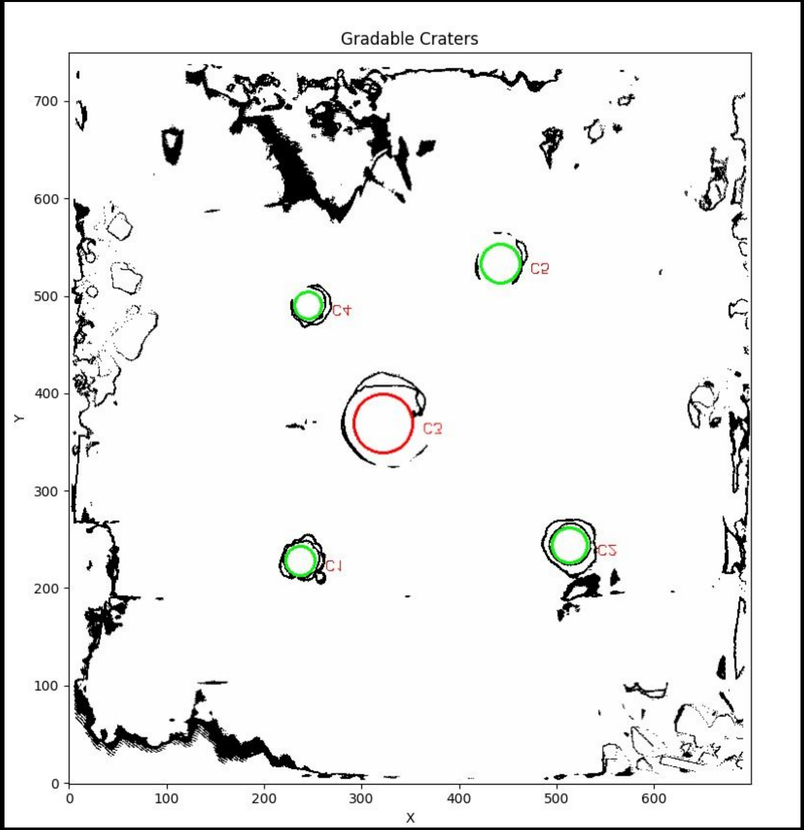
M.P.2: Will follow planned path to a maximum **deviation of 10%** (due to localization/navigation error)

Global Path Distance (m)	Local Path Distance (m)	Deviation (%)
4.34	4.88	12.5
4.05	4.45	9.8
4.23	4.49	6.2
4.16	4.40	5.9
4.03	4.29	6.4

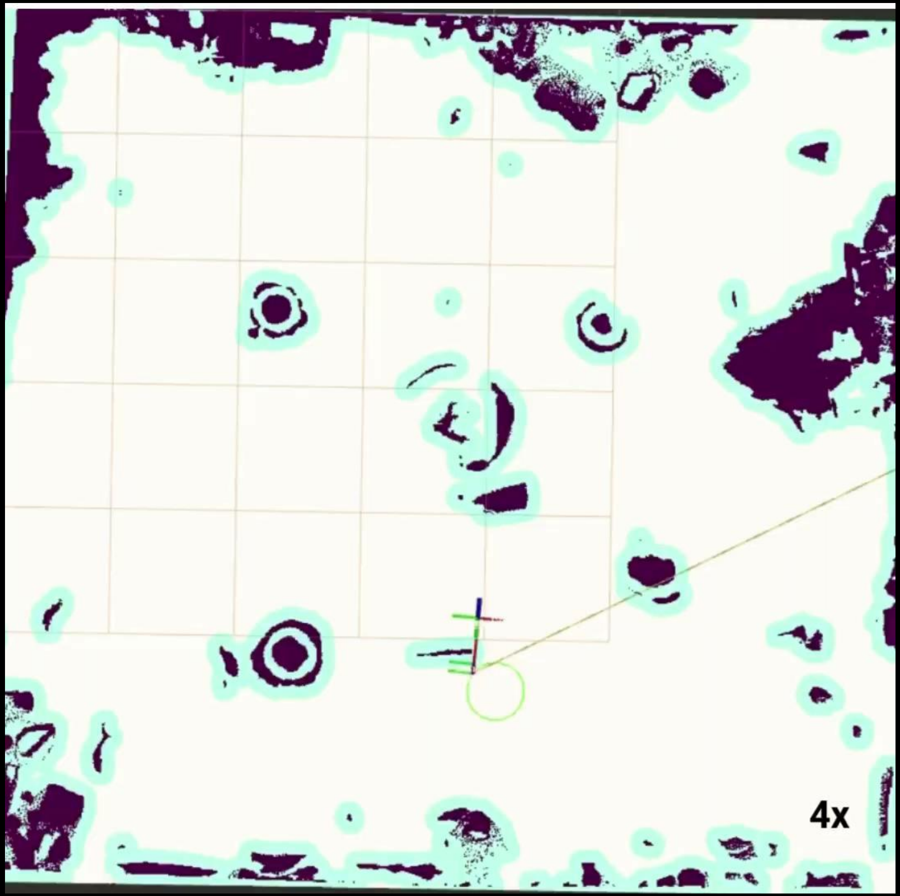
Average Deviation - 8.16%

M.P.4 (Part 1): Will avoid craters **>= 0.5 meters** (shown in global navigation plan)

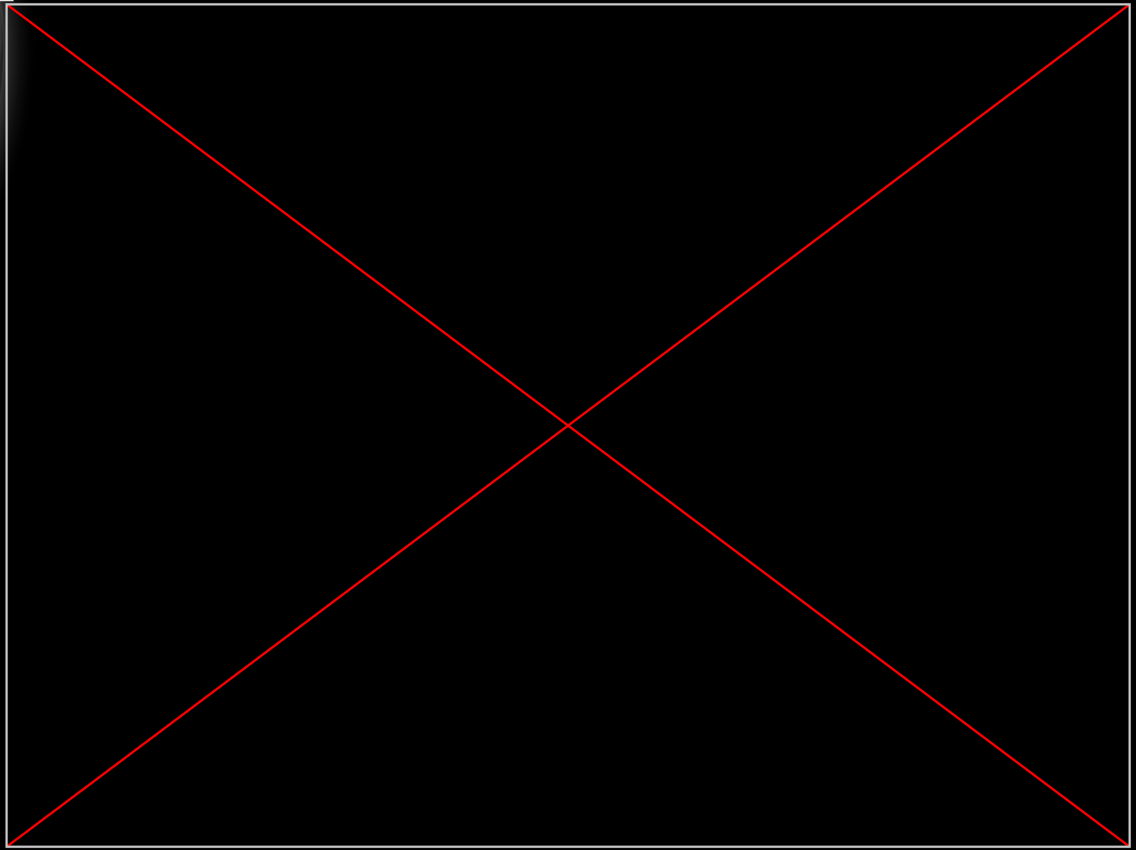
```
Gradable Craters Location
Crater C1: Diameter = 0.300 meters
  Centroid of Crater C1: X = 2.380 m, Y = 2.289 m


Crater C2: Diameter = 0.360 meters
  Centroid of Crater C2: X = 5.131 m, Y = 2.443 m


Crater C3: Diameter = 0.600 meters


Crater C4: Diameter = 0.280 meters
  Centroid of Crater C4: X = 2.453 m, Y = 4.909 m


Crater C5: Diameter = 0.400 meters
  Centroid of Crater C5: X = 4.421 m, Y = 5.335 m
```



M.P.4 (Part 1): Will avoid craters >= 0.5 meters (shown in global navigation plan)



M.P.5: Will fill craters of up to **0.5 meters** in diameter and **0.1 meters** in depth



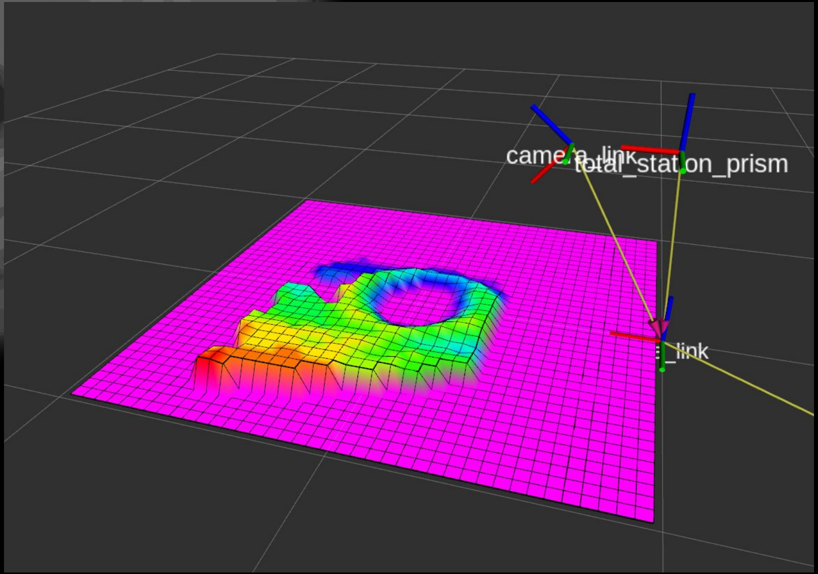
M.P.5: Will fill craters of up to 0.5 meters in diameter and 0.1 meters in depth

Before

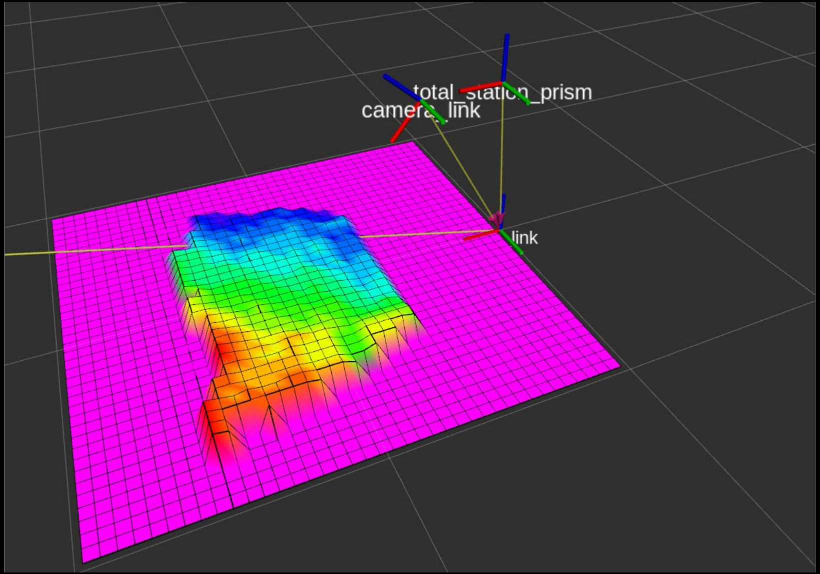
After

M.P.5: Will fill craters of up to 0.5 meters in diameter and 0.1 meters in depth

Before

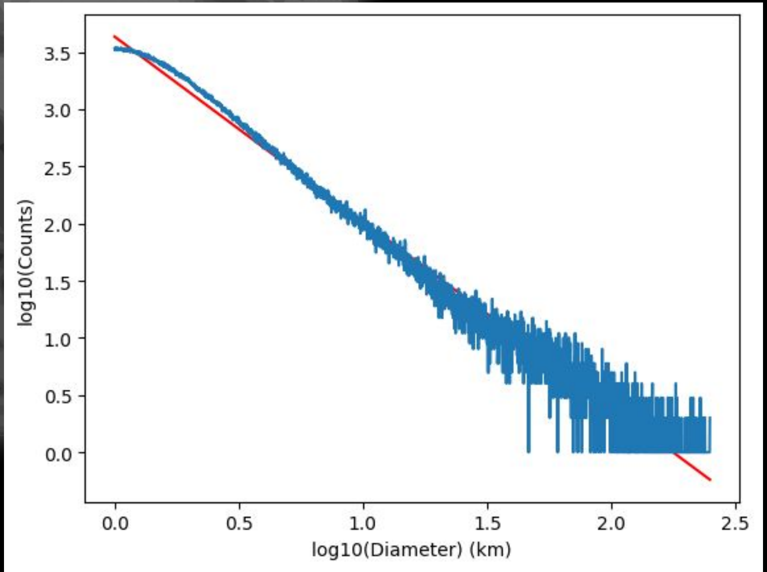


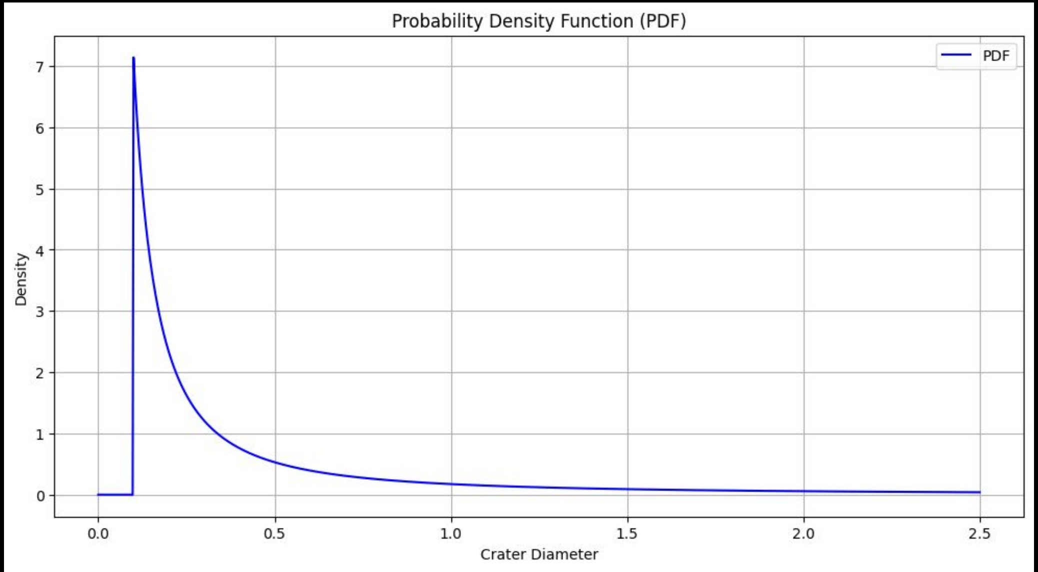
After




```
[info_logger_node-1] [INFO] [1745446813.600659910] [info_logger_node]: Mean Elevation:     1.41 cm
[info_logger_node-1] [INFO] [1745446813.600924924] [info_logger_node]: Elevation RMSE:     2.91 cm
[info_logger_node-1] [INFO] [1745446933.590001611] [info_logger_node]: Mean Elevation:     0.99 cm
[info_logger_node-1] [INFO] [1745446933.590321099] [info_logger_node]: Elevation RMSE:     1.90 cm
```

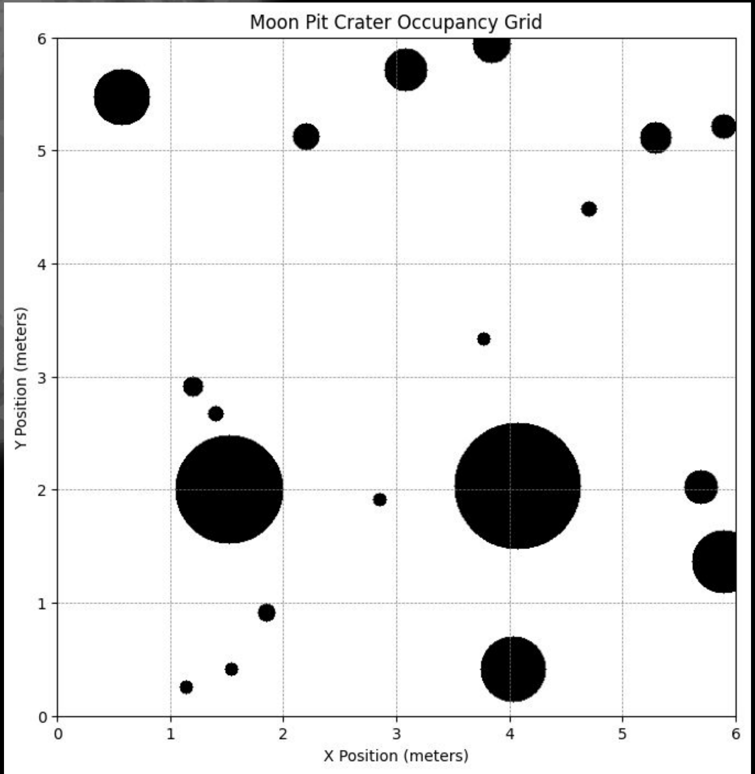
Moon Pit Crater Distribution

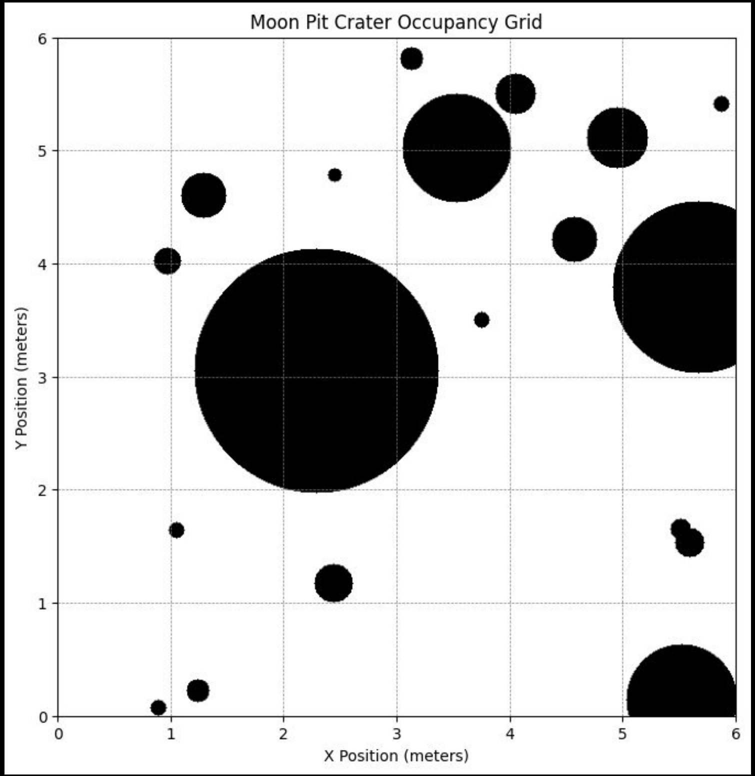




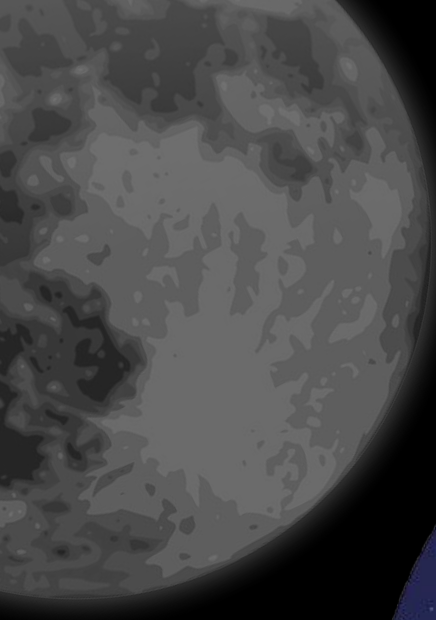
1. Raw data is read from the Lunar Crater Database (Robbins 2018)
2. A PDF and CDF is calculated based on a log-log fit linear regression model.
3. Then, we estimate the number and size of craters that would occur in a 6x6m area (assuming the size of craters to be restricted between 0.1 and 2.5m diameter).

Moon Pit Crater Distribution



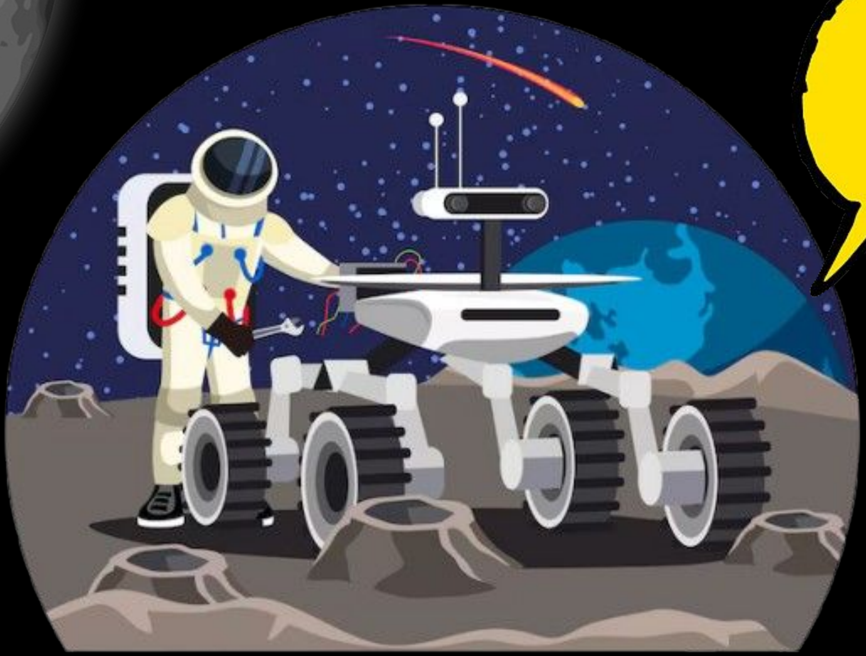


The majority of the data collection and processing is attributed to the Moonshot Circumnav Pathfinding team, and the crater generation code is attributed to Guo Ning (Andrew) Sue. William adapted it to fit the project scope.



Colonize the Moon!

- *Team Lunar ROADSTER*



Any Questions? 🤖🦾🚀

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