



Lunar ROADSTER

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

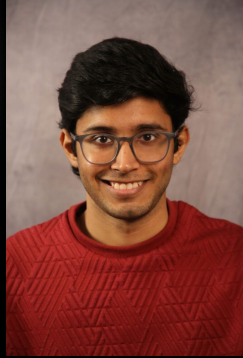
“Starting with a foothold on the Moon, we pave the way to the cosmos”



The Team



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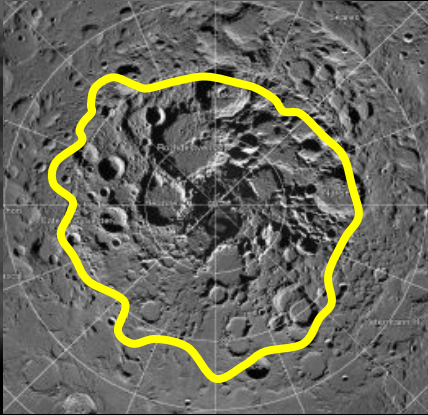


Boxiang (William) Fu

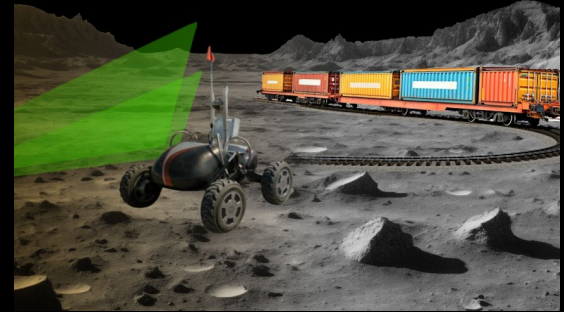
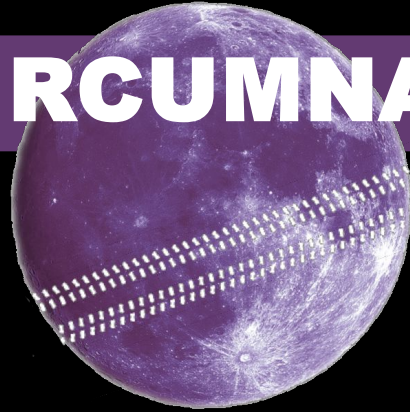


Dr. William "Red" Whittaker

Motivation: The Lunar Polar Highway



CIRCUMNAV



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

Motivation: The Lunar Polar Highway

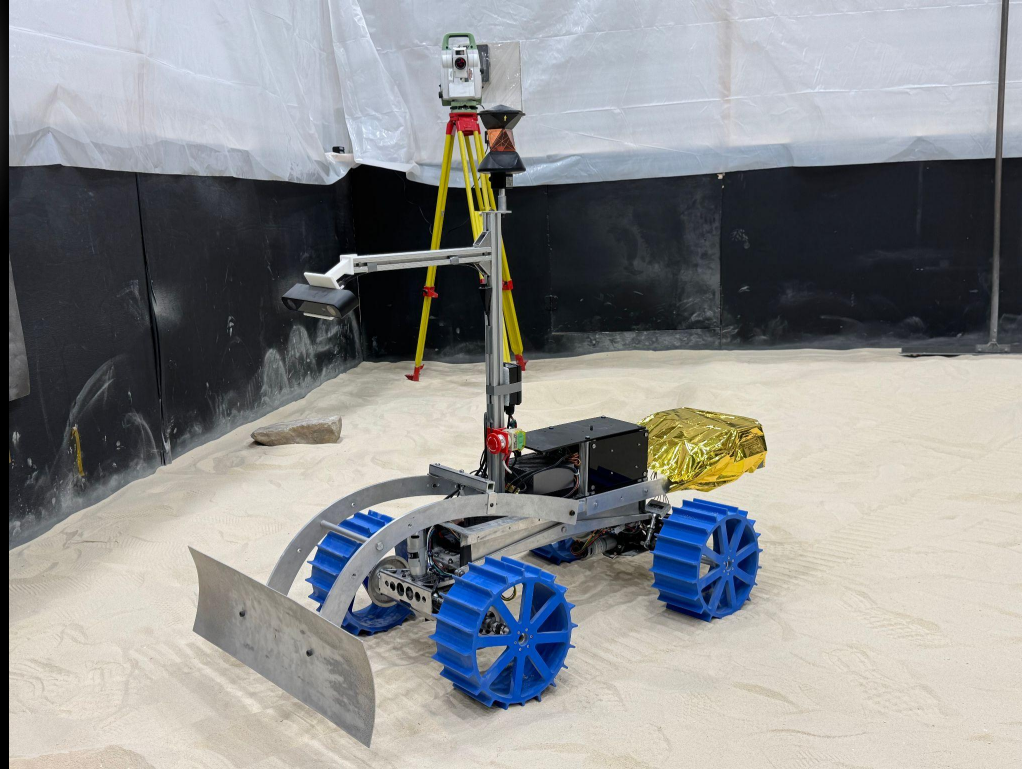
Sun-synchronous circumnavigation around Moon at
28 days x 24 hr = 672 hour sun rotation

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

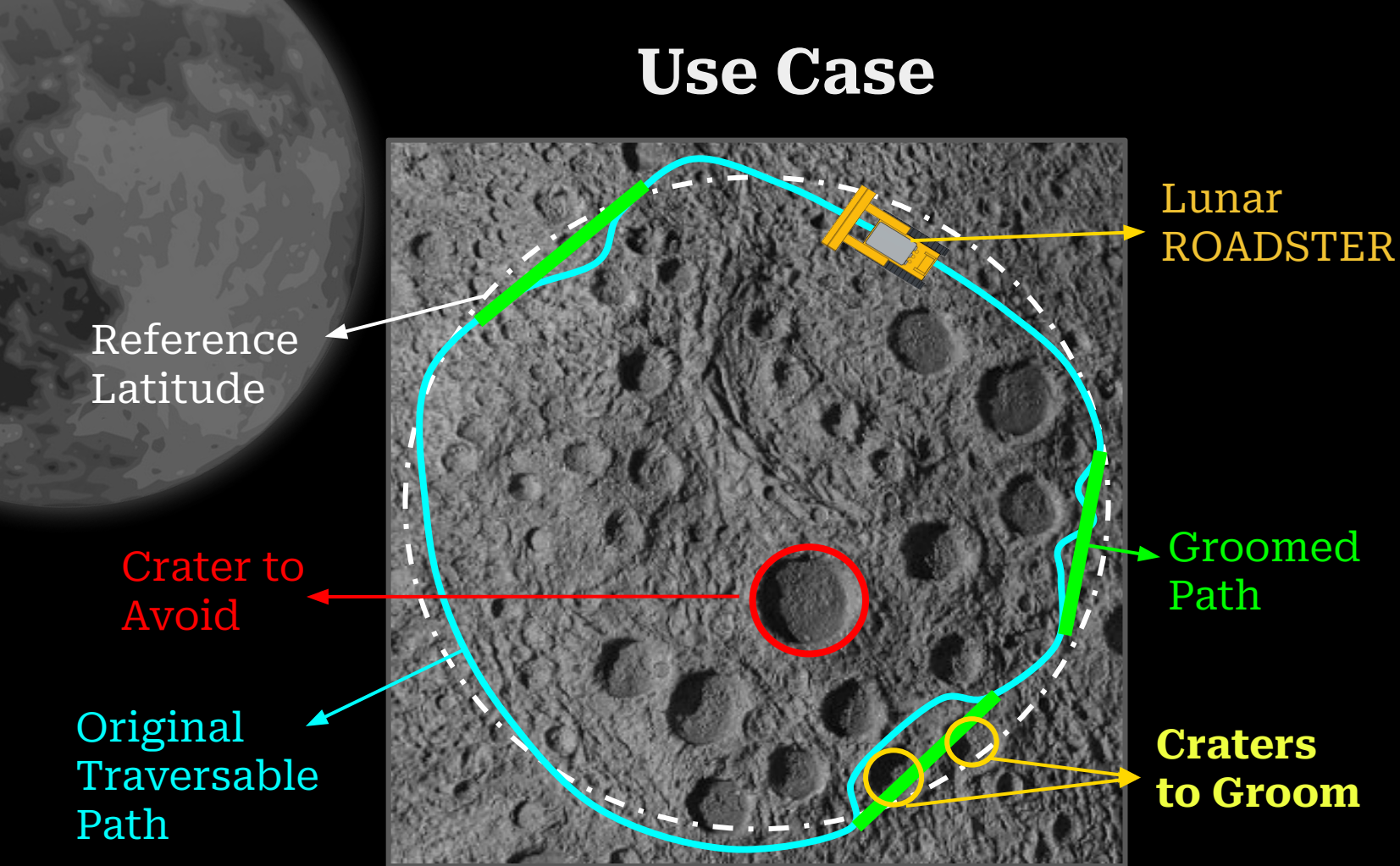


The Project: Lunar ROADSTER

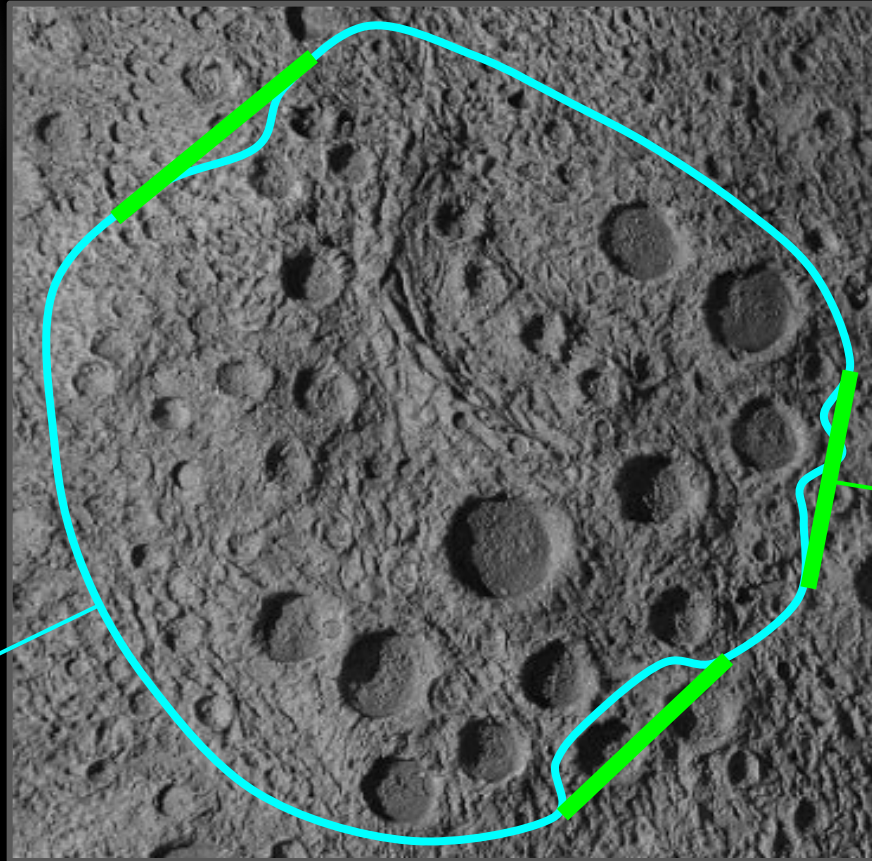
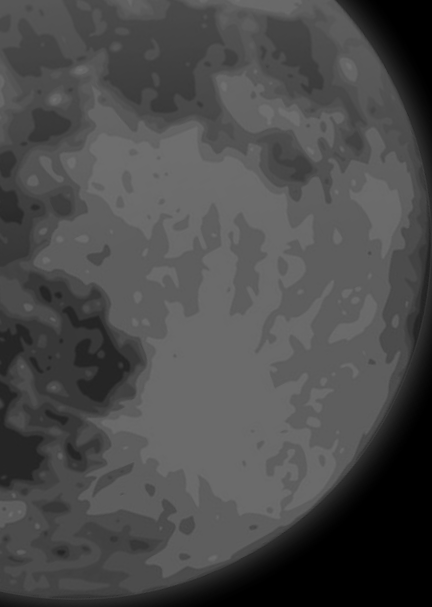


An **autonomous moon-working** rover capable of **finding ideal exploration routes** and **creating traversable surface trails**

Use Case



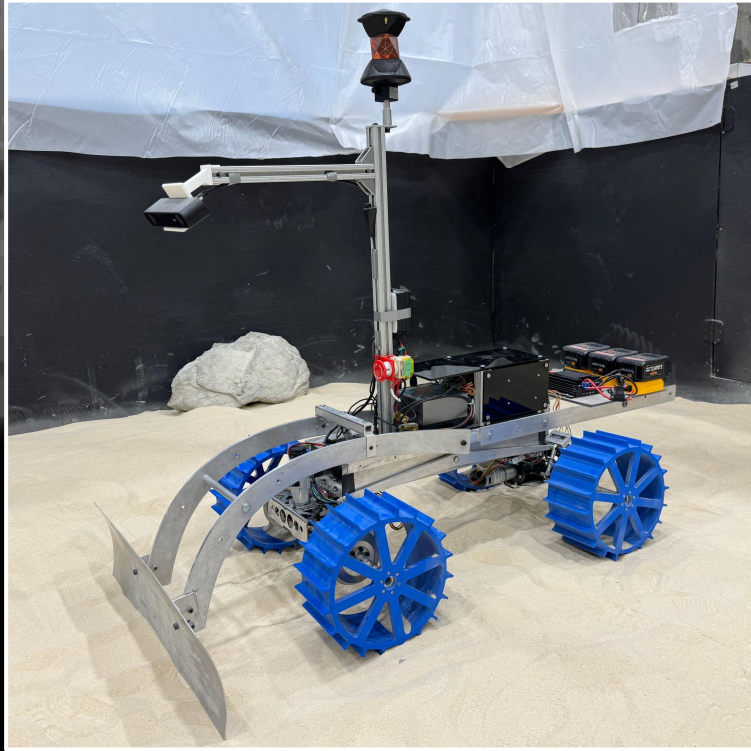
Use Case



Original
Traversable
Path

Groomed
Path

ROADSTER



An autonomous mechatronic bulldozer for the Moon

- 60cm dozer width (3 times the predecessor)
- High tool actuation strength (can lift the whole ROADSTER)
- Custom wheels with high rimpull and maximised grip
- 135 kgf-cm drive actuators (2 times the predecessor)
- Superior pushing power (high drawbar pull)
- Reliable circuitry
- Efficient power distribution
- **An optimal, specialized machine for crater grooming**



Demonstration

Demonstration

Mission Statement: The ROADSTER uses the excavator to groom multiple craters and create a traversable, circuitous path around the Moon Yard.

Procedure

Pre-Demo Setup

Prepare test environment - **create craters**

Obtain **global map** using laser scanner

Setup **Total Station**

Calibrate localization

Setup **GUI** and **Operations Terminal**

Send Start Mission command

During Demo

Start Mission

ROADSTER traverses to target crater

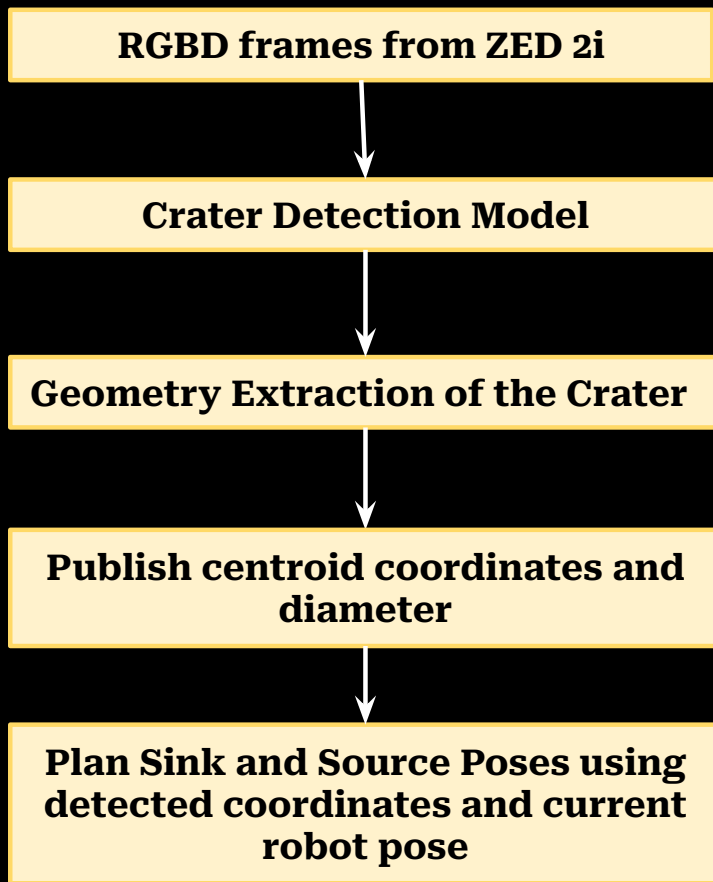
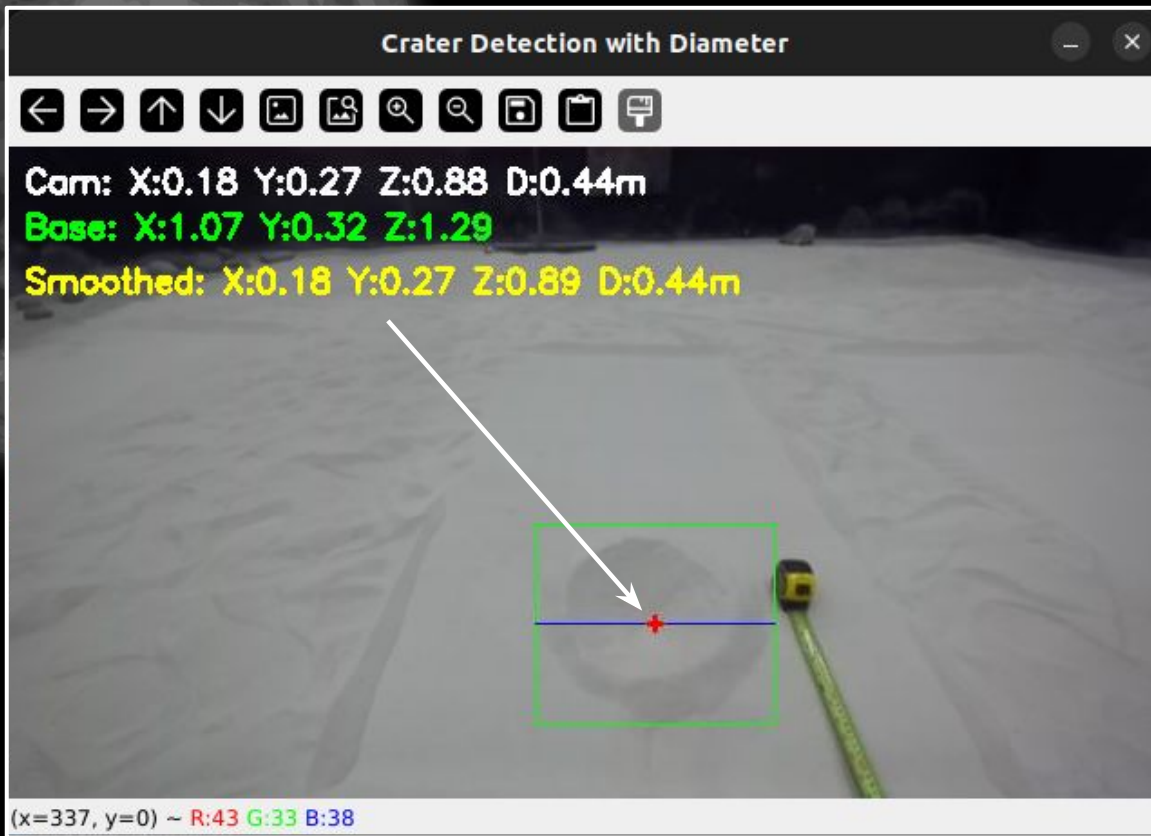
ROADSTER perceives and manipulates

ROADSTER validates

ROADSTER moves to next crater until end

End Mission

Perception



YOLO v8 model trained on custom dataset

Manipulation

Current Rover Pose

Tool Up

Source Pose

Tool Down
(Grading)

Sink Pose

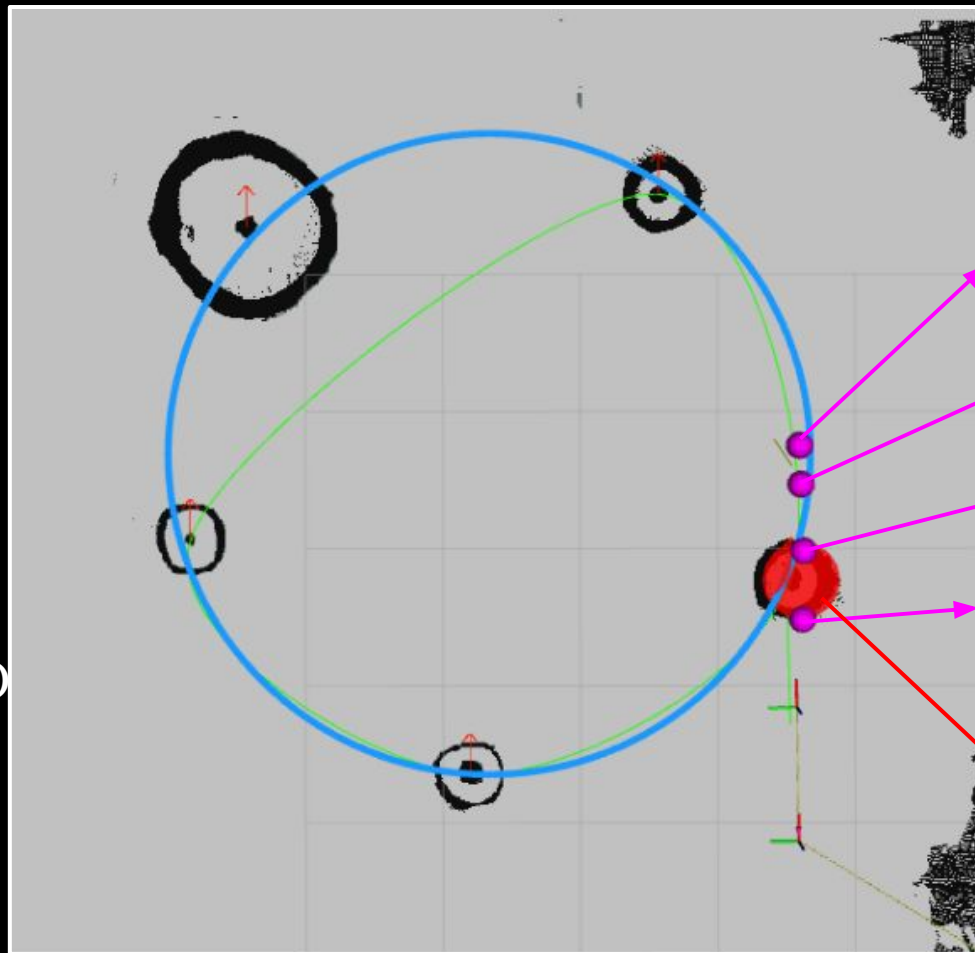
Tool Up

Source_Backblade Pose

Tool Down
(Backblading)

Sink_Backblade Pose

Next Crater



**Source
Backblade**

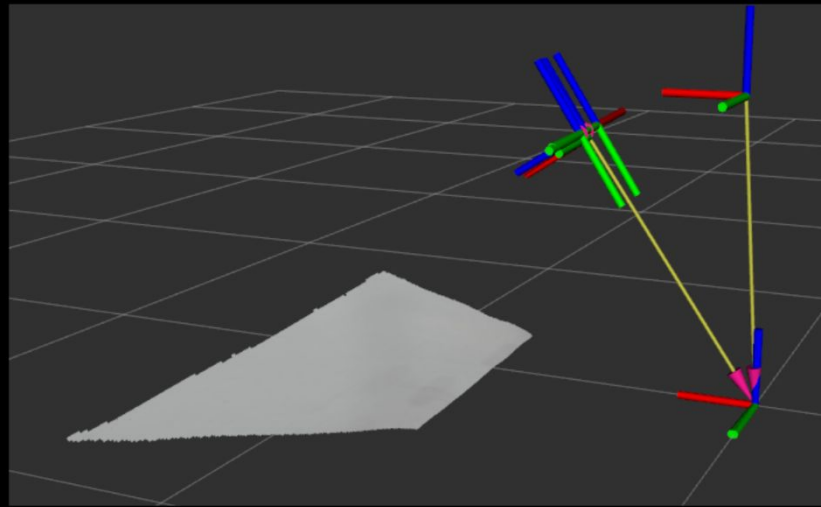
Sink

Source

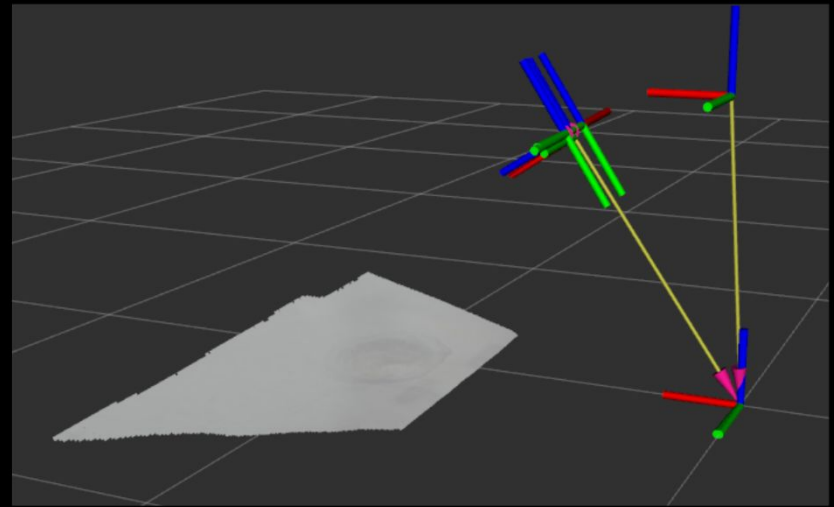
**Sink
Backblade**

**Detected
Crater
Location and
Geometry**

Validation



Validation on Flat Terrain
Grading Success = True, Slope = 1.44 deg



Validation on 15 Degree Crater
Grading Success = False, Slope = 14.78 deg

Get Point Cloud

Voxel Downsample

Estimate Normals

Compute Averages

Mask Ghost Points

Get Point Slopes

Localization



Leica TS16
Total Station



VectorNav
VN-100 IMU



Wheel
Encoders

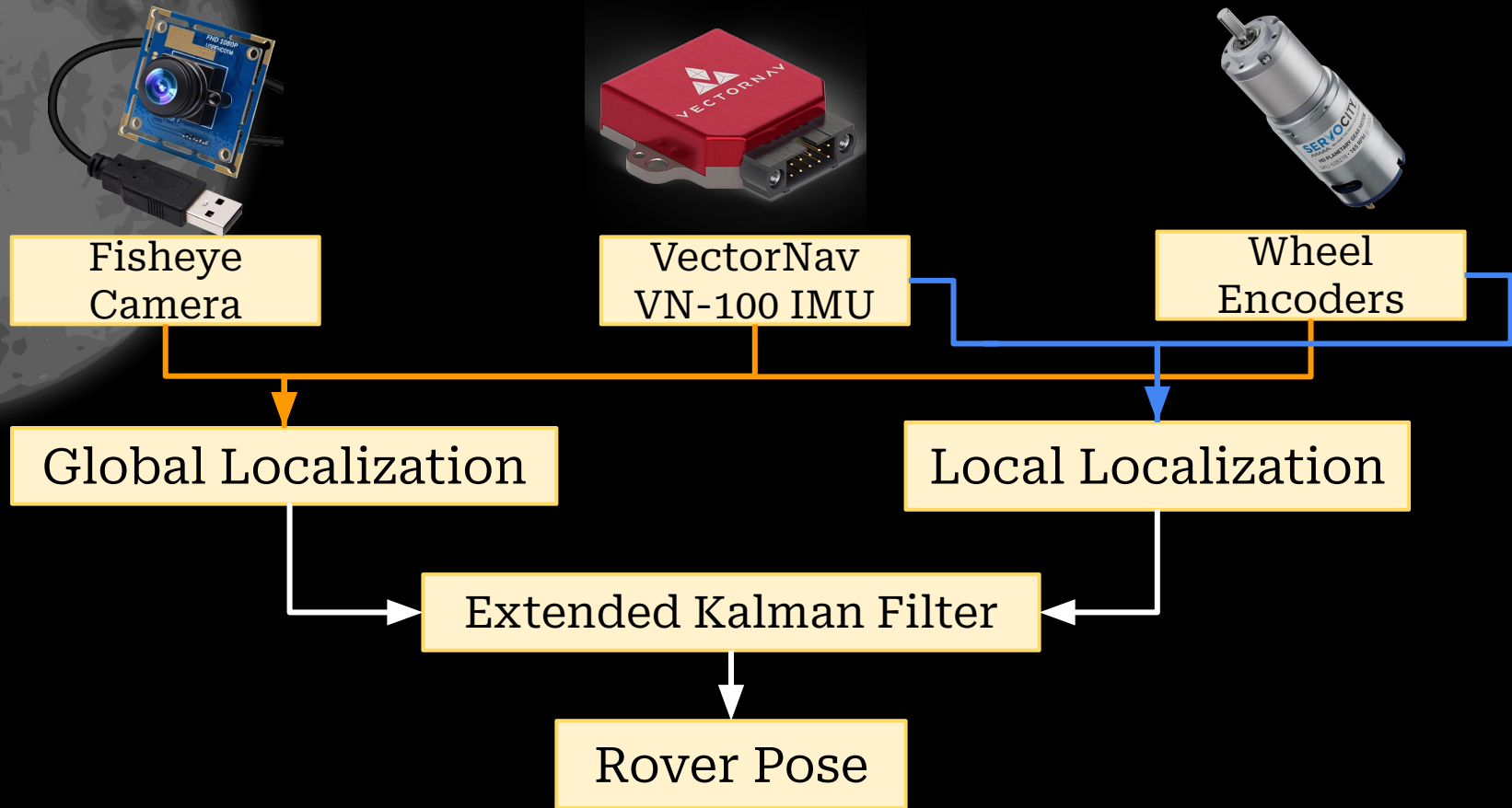
Global Localization

Local Localization

Extended Kalman Filter

Rover Pose

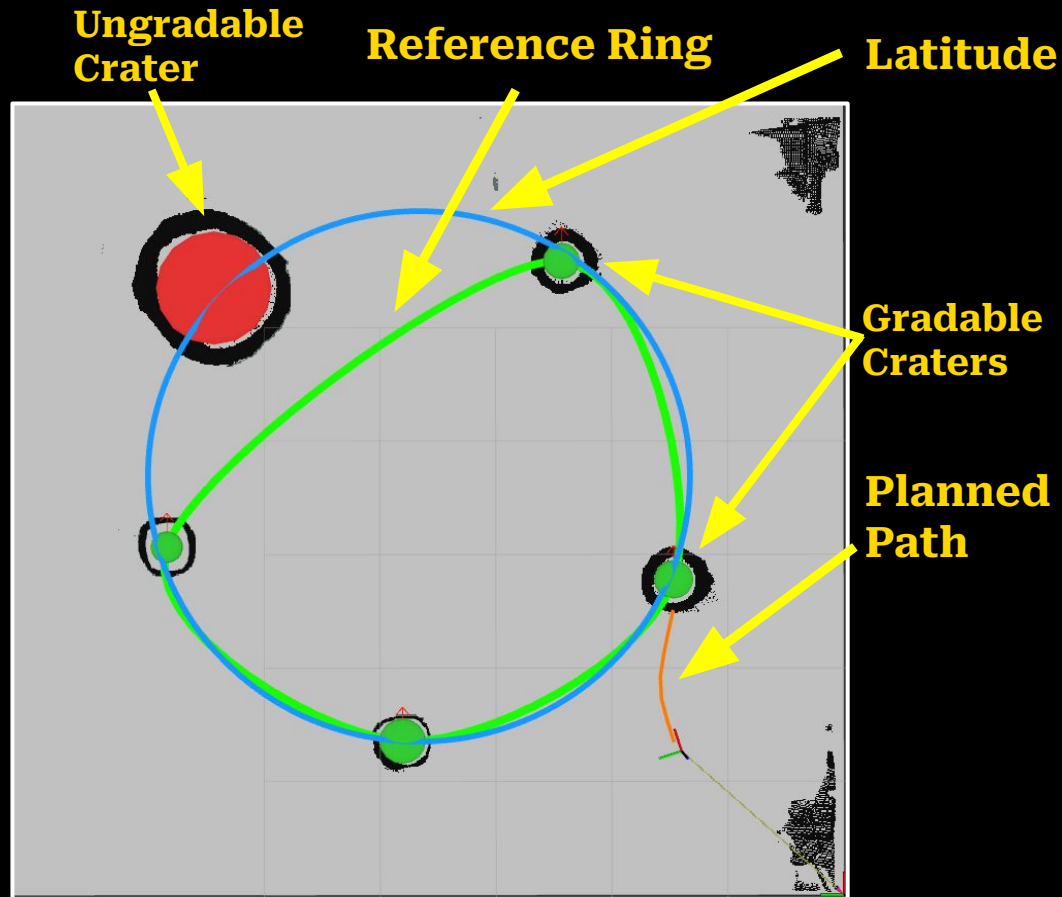
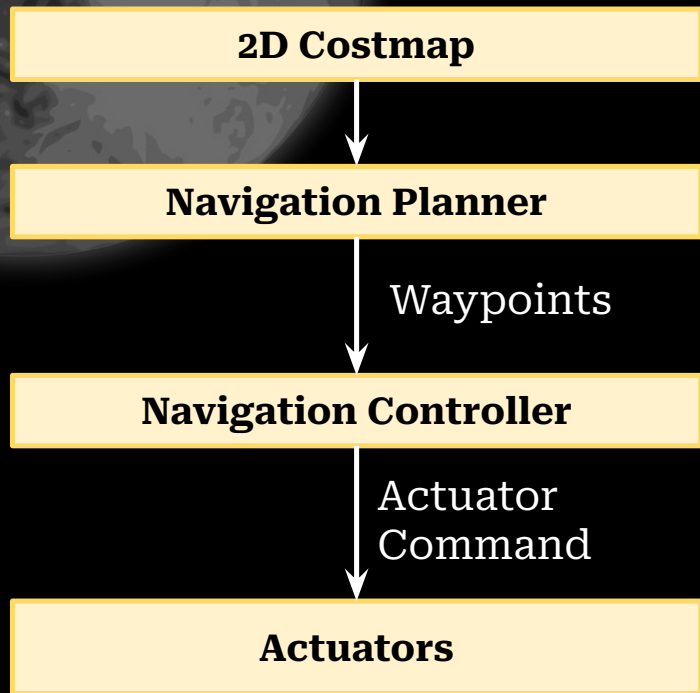
Localization (Encore)



Navigation

Navigation Planner: Lattice A* with Ackermann Primitives

Navigation Controller: Pure Pursuit



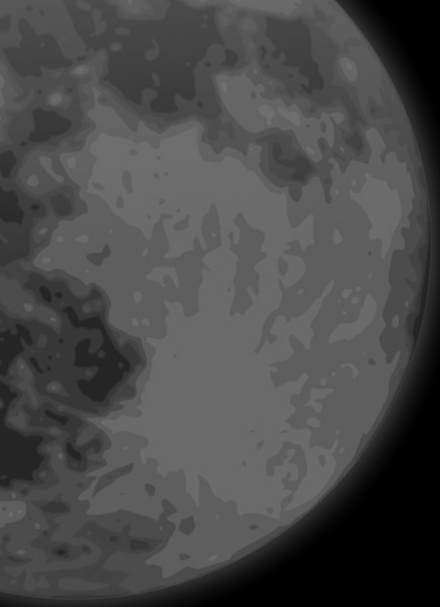
Behaviour Executive Node



Demonstration Video



2x Speed



Results

M.P.1: Plans a path with cumulative deviation of $\leq 25\%$ from chosen latitude's length (due to untraversable terrain)

Radius of reference latitude = 2.33 m

Reference Latitude length = 14.66 m

Planned Path Length (m)	Deviation (m)	Deviation %
11.09	3.57	24.34%
11.51	3.15	21.47%
11.11	3.55	24.20%
11.51	3.15	21.47%
11.29	3.37	22.97%

Least: 21.47%

Max: 24.30%

Mean: 22.89%

Result: Satisfies requirement and rover plans path with average deviation of **22.89%** from reference latitude.

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

Radius of reference latitude = 2.33 m

Reference Latitude length = 14.66 m

Planned Path Length (m)	Actual Traversed Path (m)	Deviation (m)	Deviation %
11.09	9.65	1.44	12.98 %
11.51	12.97	1.46	12.68 %
11.11	11.42	0.31	2.79 %
11.51	10.76	0.75	6.52 %
11.29	11.28	0.01	0.09 %

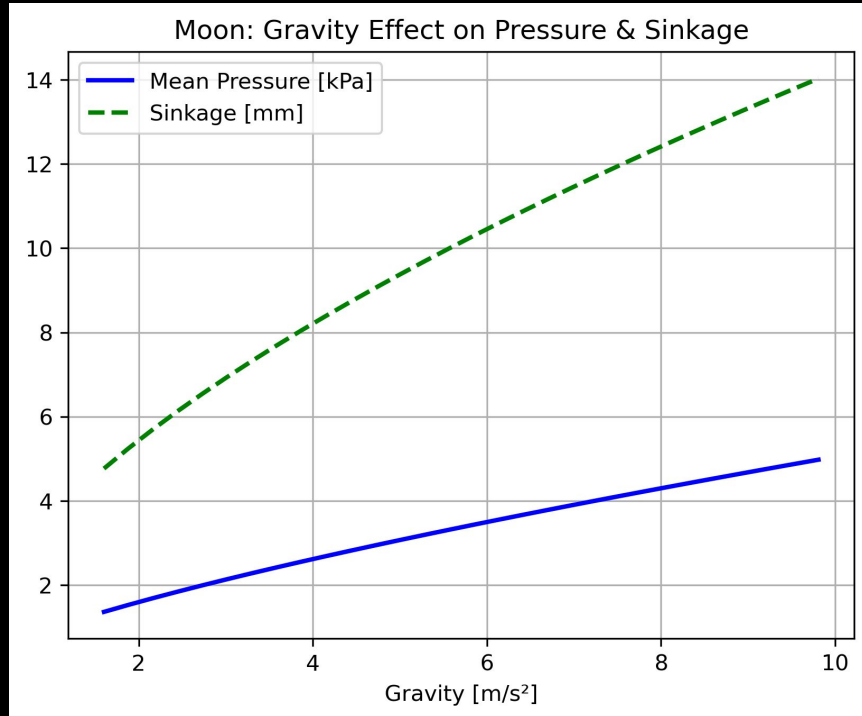
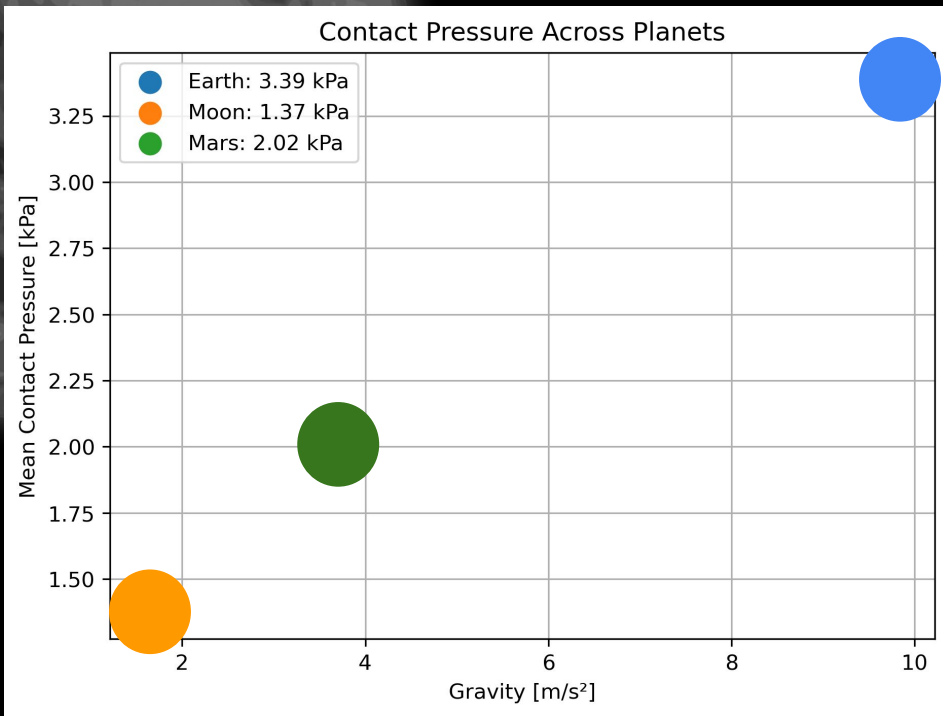
Least: 0.09 %

Max: 12.98 %

Mean: 7.01 %

Result: Satisfies verification criteria and rover follows planned path with average deviation of **7.01 %**.

M.P.3: Has a **contact pressure $\leq 1.5\text{kPa}$**

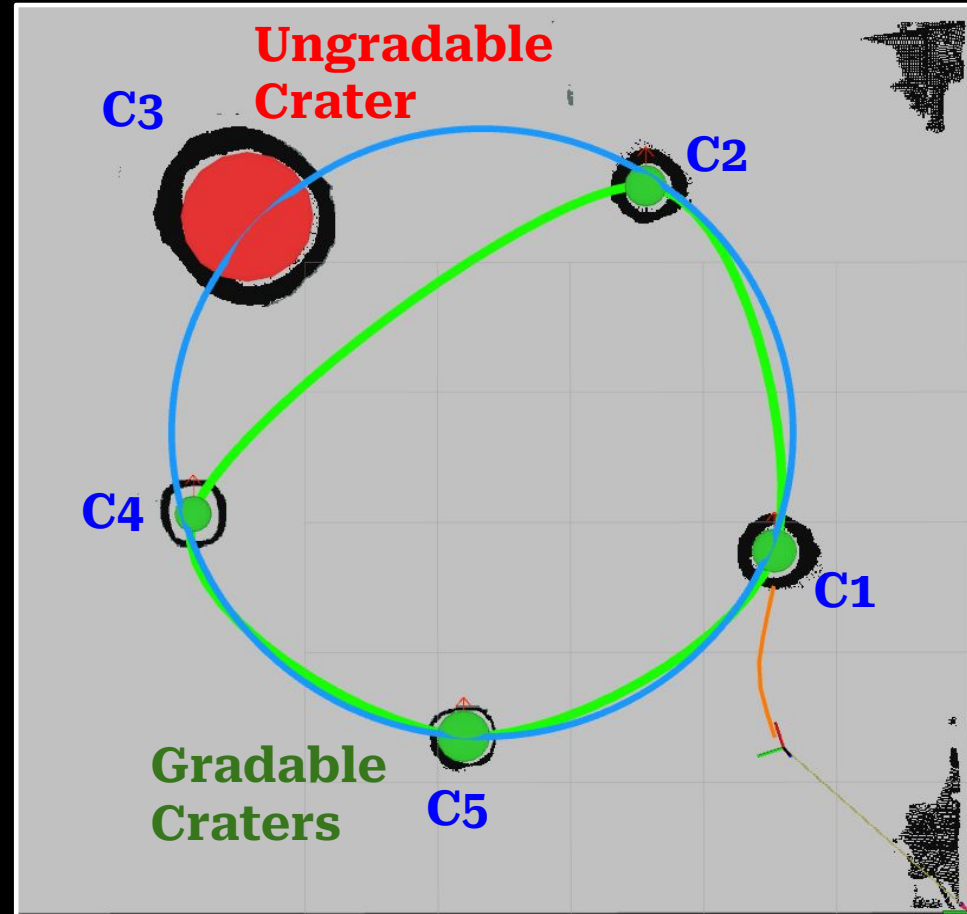


Contact Pressure of the ROADSTER on the Moon - **1.37kPa (0.199 psi)**

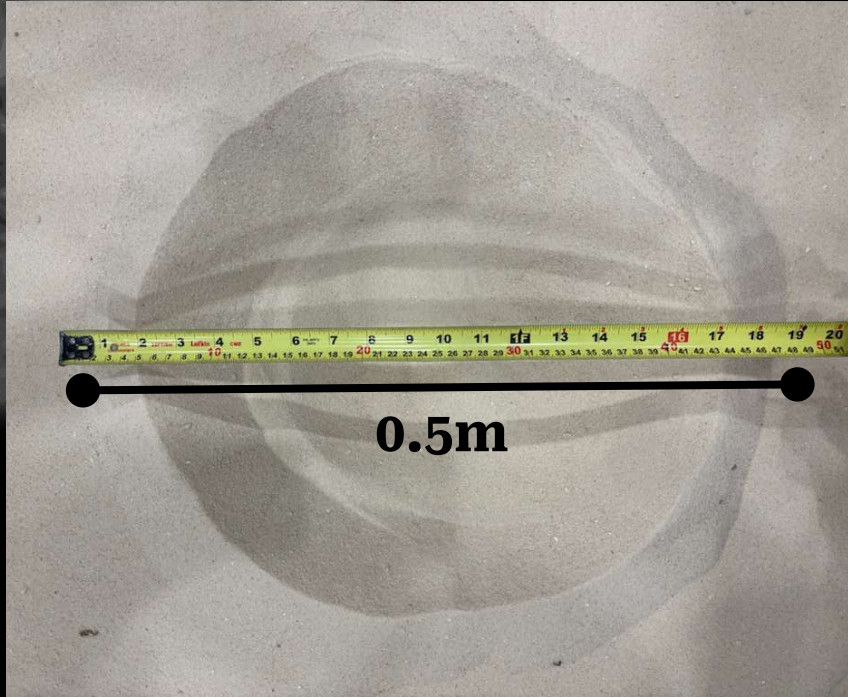
M.P.4: Avoids craters ≥ 0.5 meters

Gradable Craters Diameter and Location (Centroid):

- **Crater C1:**
Diameter: 0.34 m
Centroid: X=2.78 m, Y=1.466 m
- **Crater C2:**
Diameter: 0.32 m
Centroid: X=5.58 m, Y=2.431 m
- **Crater C4:**
Diameter: 0.28 m
Centroid: X=3.043 m, Y=6.126 m
- **Crater C5:**
Diameter: 0.4 m
Centroid: X=1.372 m, Y=3.803 m



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



Grading craters with diameter $\leq 0.5\text{m}$ and Depth $\leq 0.1\text{m}$

Functional Requirements

Sr. No.	Mandatory Functional Requirement	Result
M.F.1	Shall perform trail path planning	✓ Demonstrated
M.F.2	Shall operate autonomously	✓ Demonstrated
M.F.3	Shall localize itself in a GPS denied environment	✓ Demonstrated
M.F.4	Shall navigate the planned path	✓ Demonstrated
M.F.5	Shall traverse uneven terrain	✓ Demonstrated

Functional Requirements

Sr. No.	Mandatory Functional Requirement	Result
M.F.6	Shall choose craters to groom and avoid	✓ Demonstrated
M.F.7	Shall grade craters	✓ Demonstrated
M.F.8	Shall validate grading and trail path	✓ Demonstrated
M.F.9	Shall communicate with the user	✓ Demonstrated

Non-Functional Requirements (Mandatory)

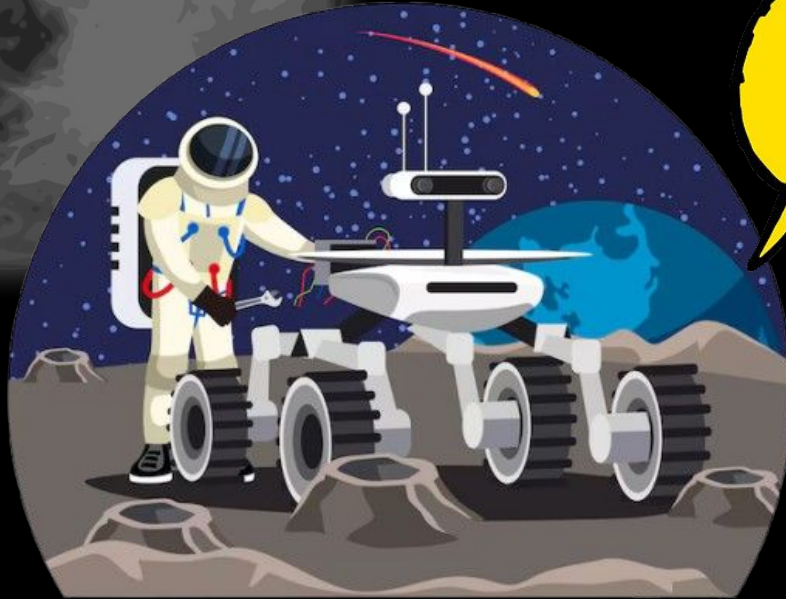
Sr. No.	Parameter	Description	Result
M.N.1	Weight	The rover must weigh under 50kg	✓ Achieved - 23.8 kg
M.N.2	Cost	The cost for the project must be under \$5000	✓ Achieved - \$4,995 (MRSD Budget)
M.N.3	Computing Capacity	The onboard computer should be able to run all required tasks	✓ Achieved (Shown in appendix)

Non-Functional Requirements (Desirable)

Sr. No.	Parameter	Description	Result
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	✓ Achieved - Code comments and Notion page
D.N.2	Aesthetics	Requirement from sponsor, the rover must look presentable and lunar-ready	✓ Achieved - Verified with Sponsor
D.N.3	Modularity	To enable tool interchangeability , the tool assemblies must be modular	✓ Achieved - The tool assembly can be mounted and re-mounted easily
D.N.4	Repeatability	The system will complete multiple missions without the need of maintenance	✓ Achieved - Several test runs without maintenance

Colonize the Moon!

- *Team Lunar ROADSTER*



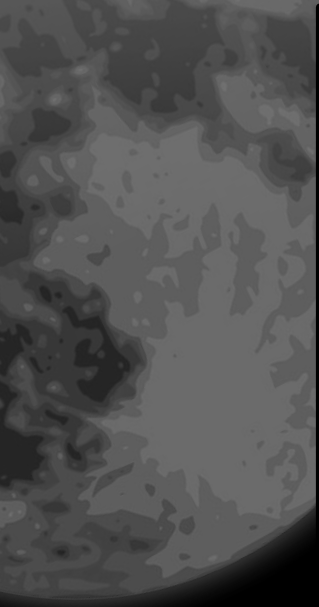
Acknowledgements

- Professor William 'Red' Whittaker - **Project Advisor**
- Dr. John Dolan and Dr. Dimitrios Apostolopoulos - **Course Advisors**
- Tim Angert - **Workshop Supervisor**
- Team CraterGrader
- Dr. Wennie Tabib
- Warren 'Chuck' Whittaker
- Dr. David Wettergreen

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

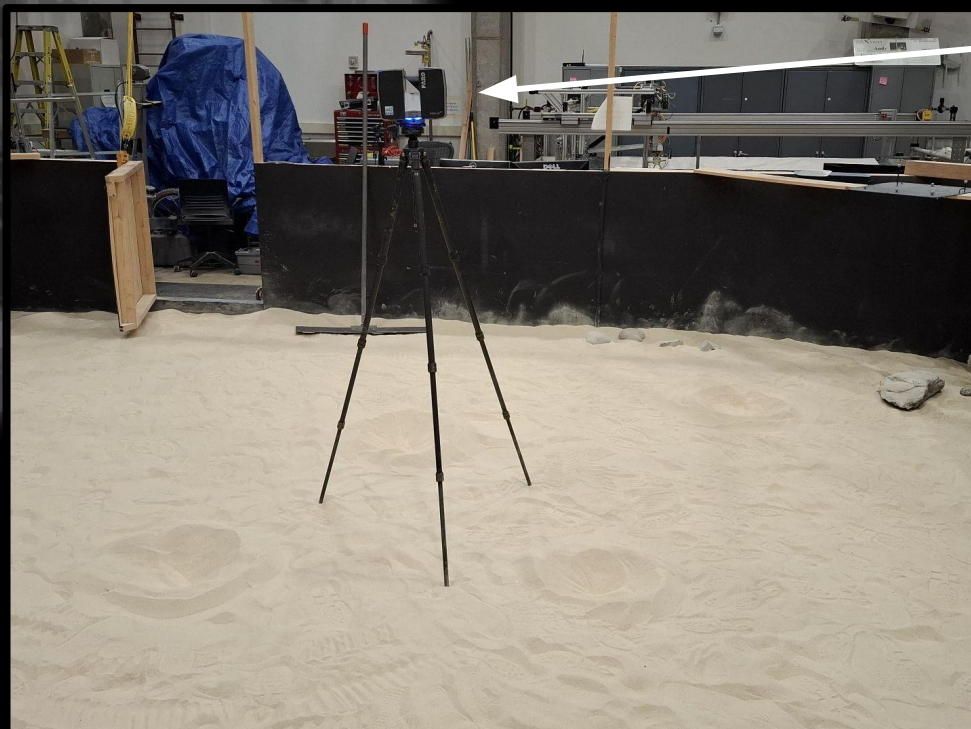


Appendix



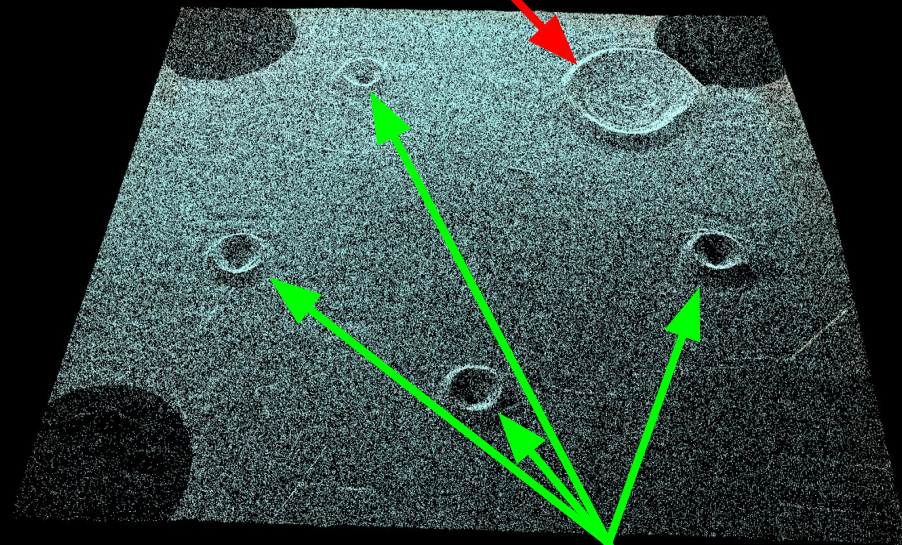
Prepare test environment (Moonyard)

FARO Scanner



**FARO
Scanner**

**Ungradable
Crater**



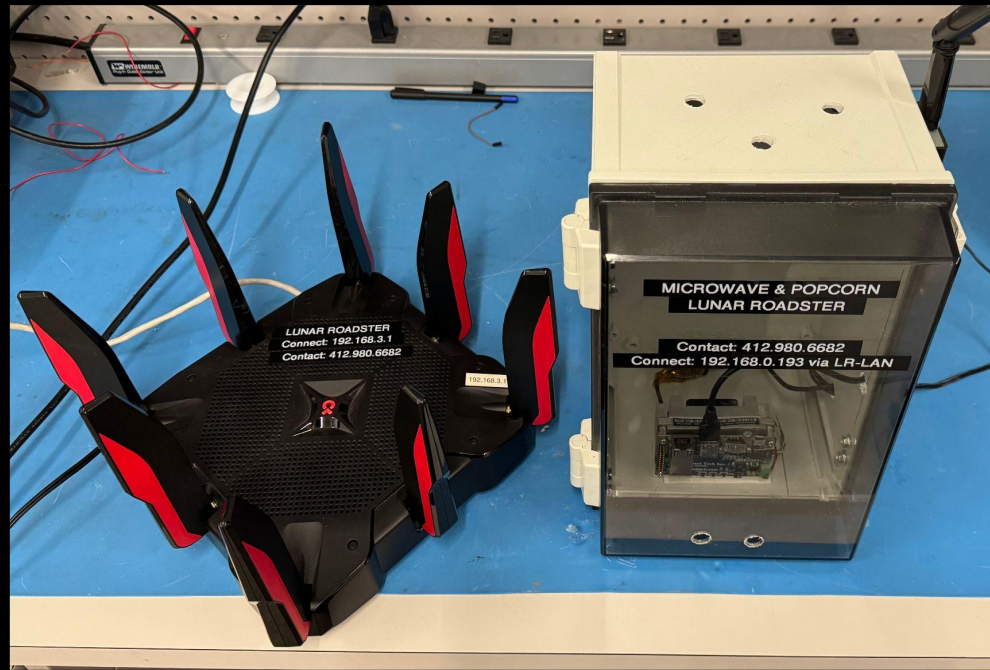
**Gradable
Craters**

Obtain global map using FARO Scanner

Localization Setup



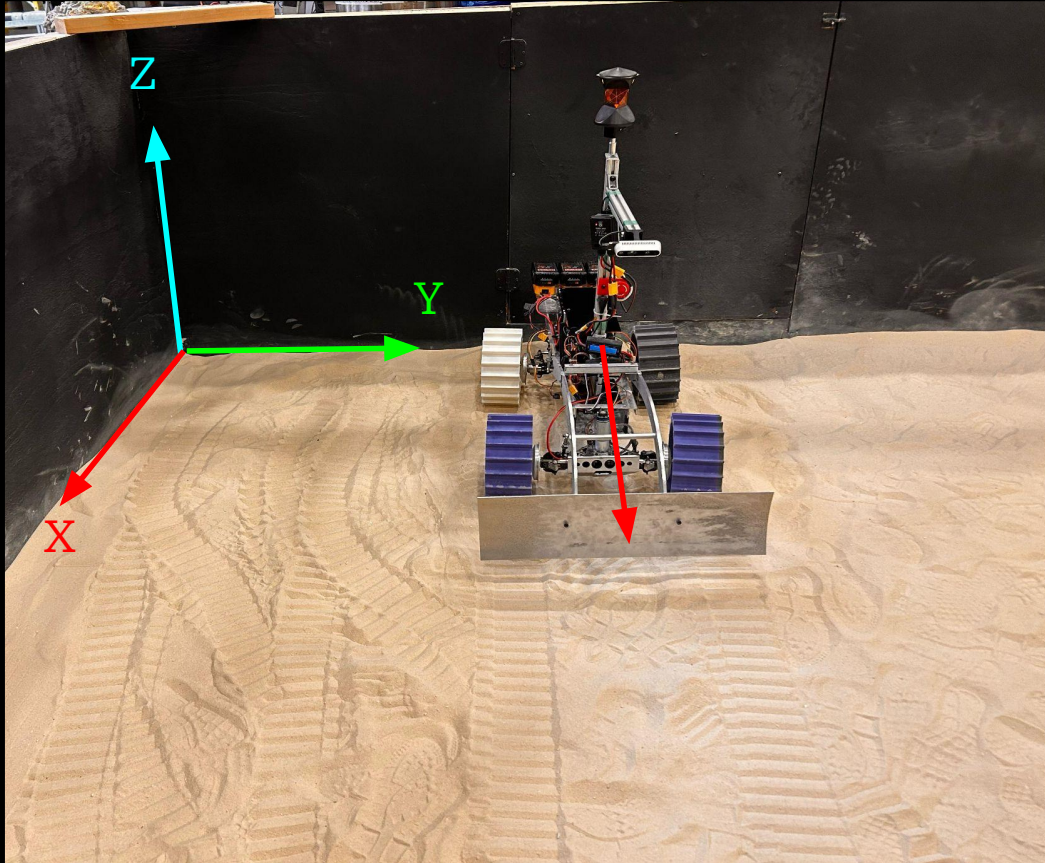
Leica TS16 Total Station



LAN Router & TX2 Relay

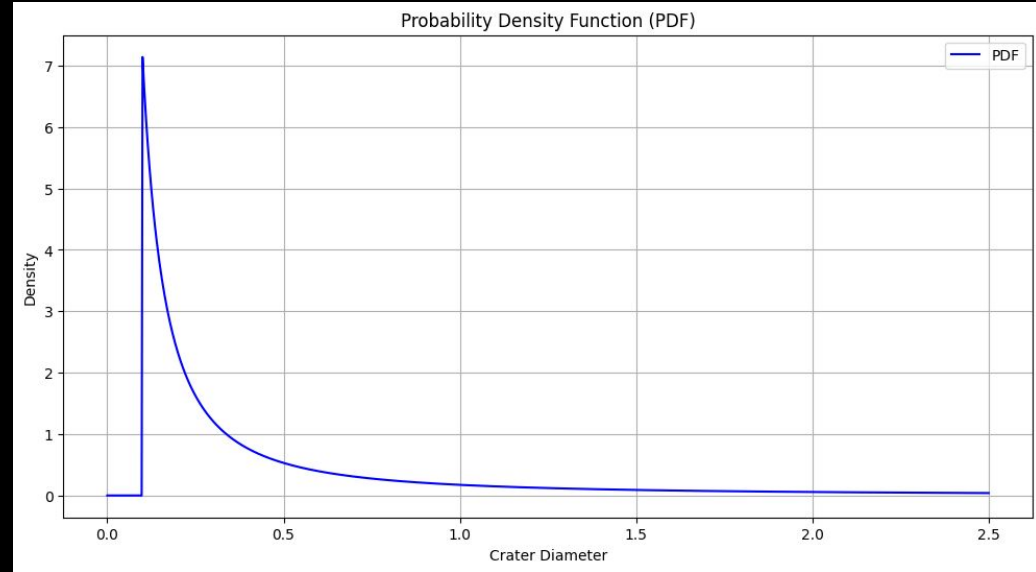
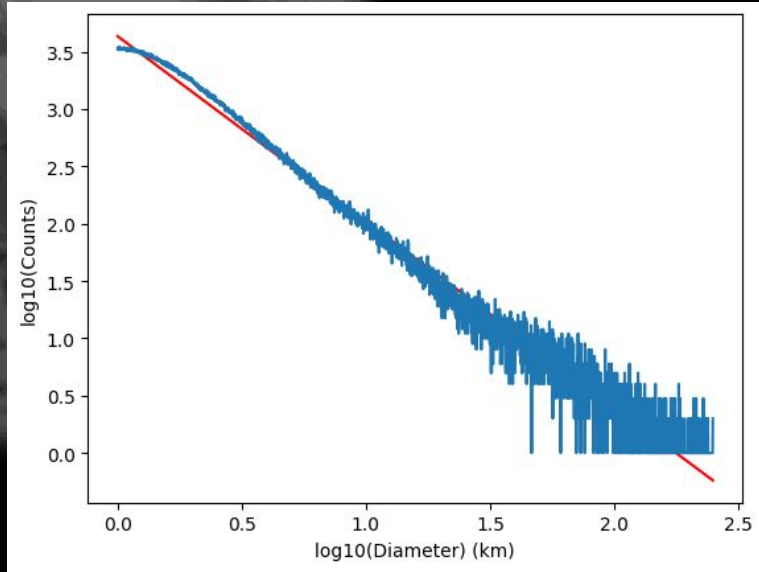
Set up external infrastructure

Yaw Calibration



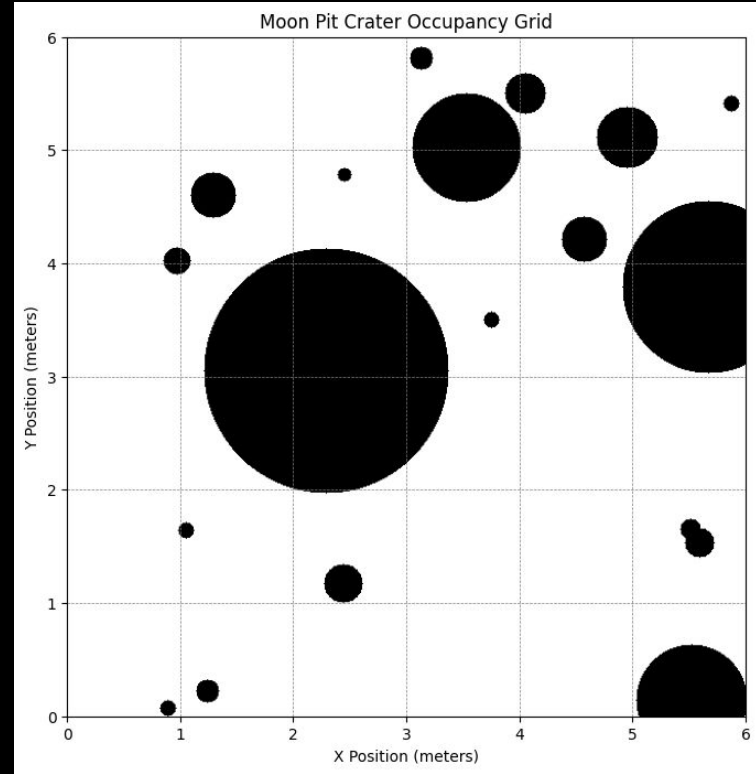
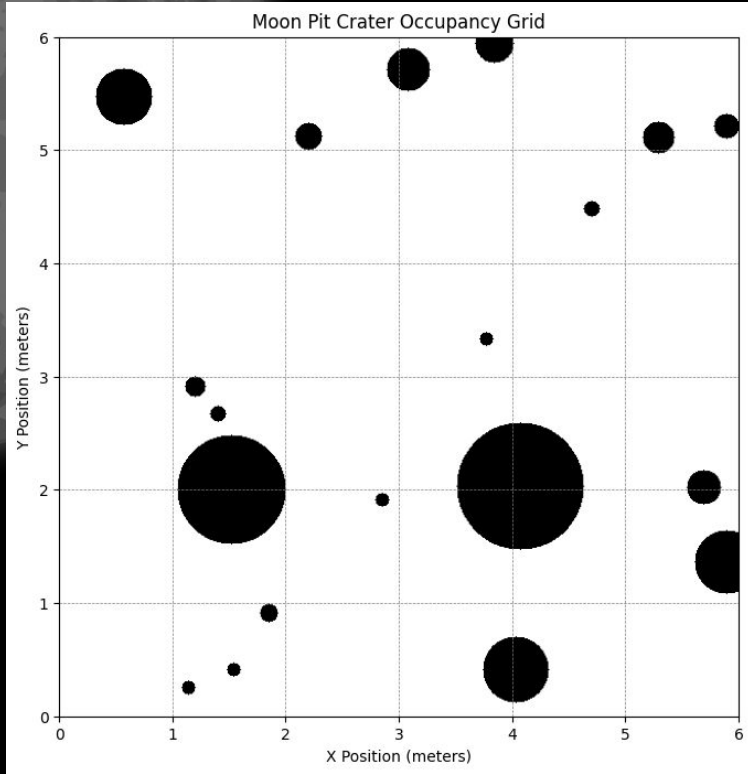
Calibrating relative heading angle (yaw)

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).

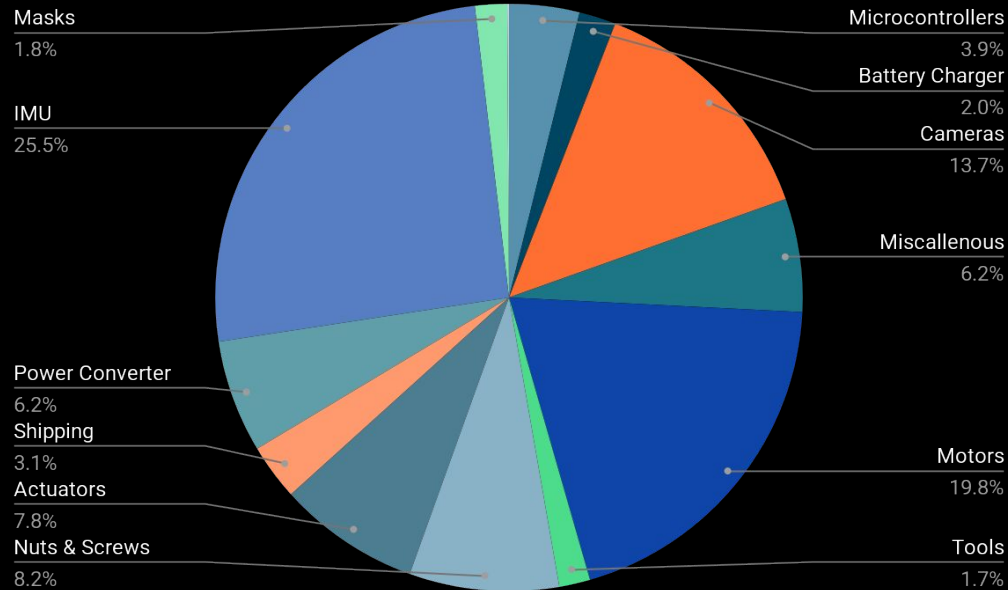
Moon Pit Crater Size Distribution



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

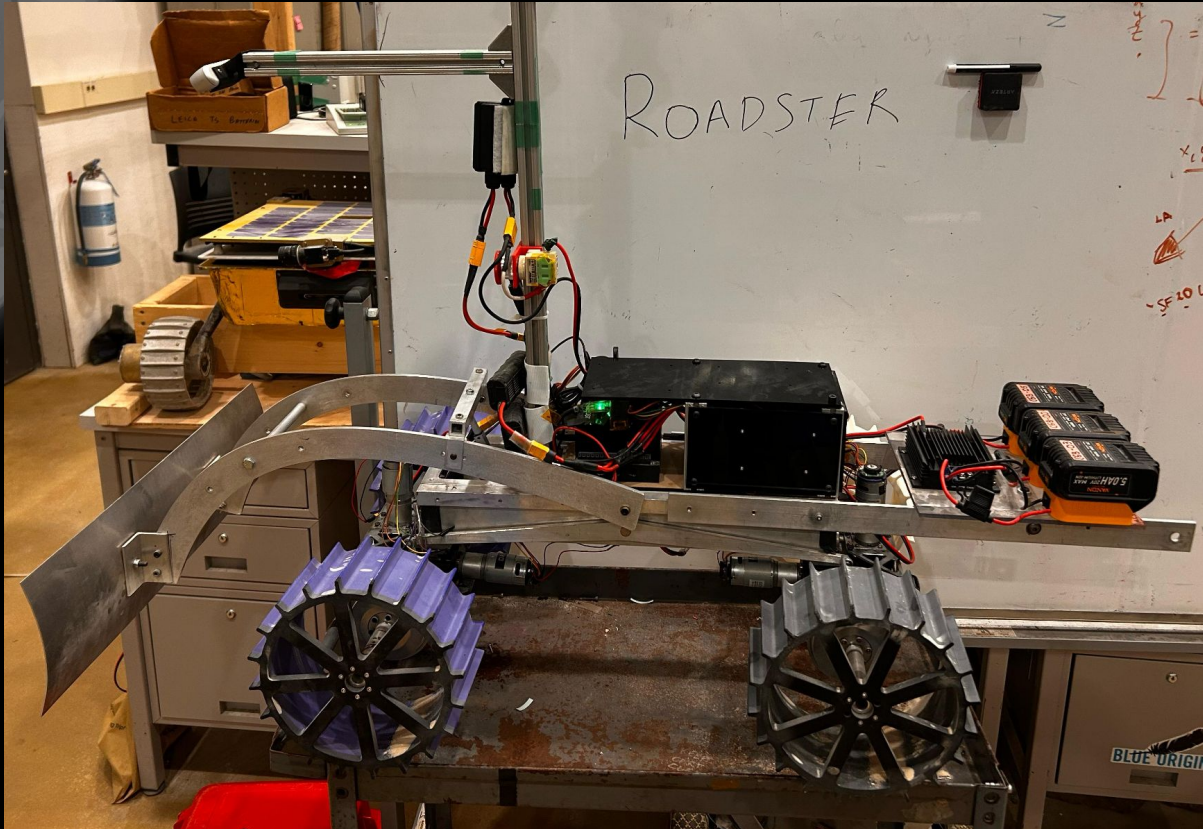
Cost

MRSD Budget	MRSD Budget Spent (\$)	MRSD Budget Spent (%)	Total Budget Spent*	Remaining Balance
\$5,000	\$4,995.09	99.90%	\$8,065.09	\$4.91

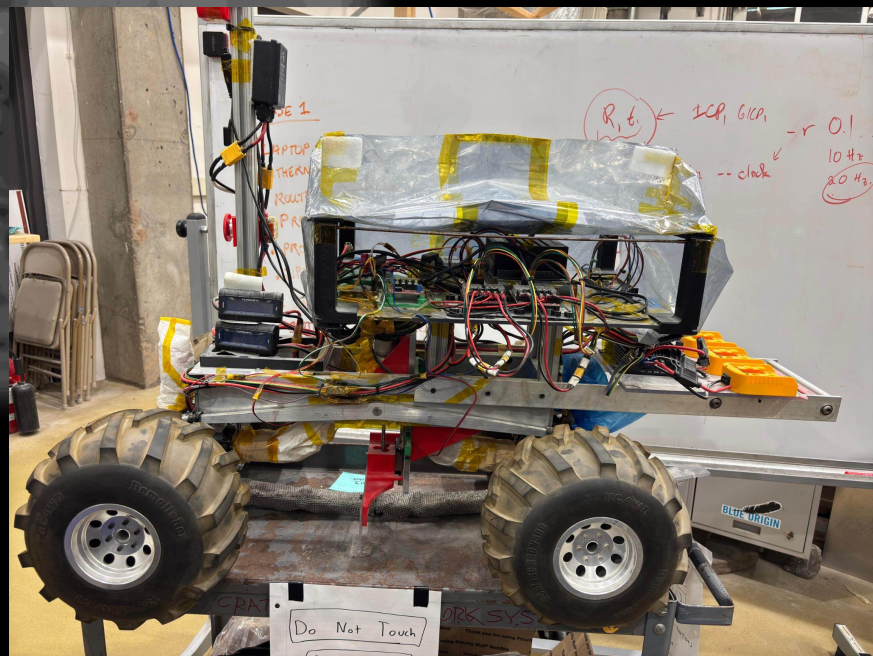


* Includes \$3,070 worth of items inherited from Crater Grader and Supervisor

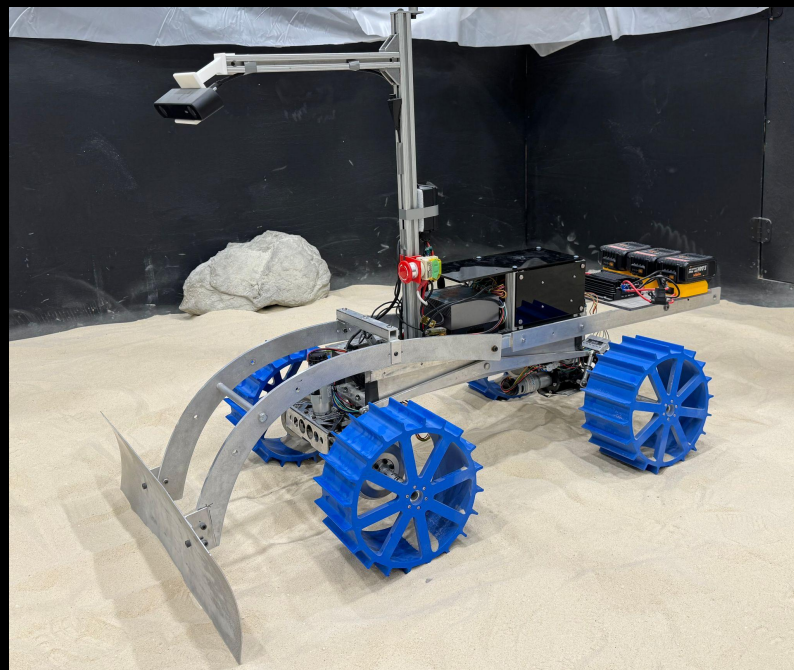
Ontwiththemew!..



CraterGrader - - - - → Lunar ROADSTER



Before

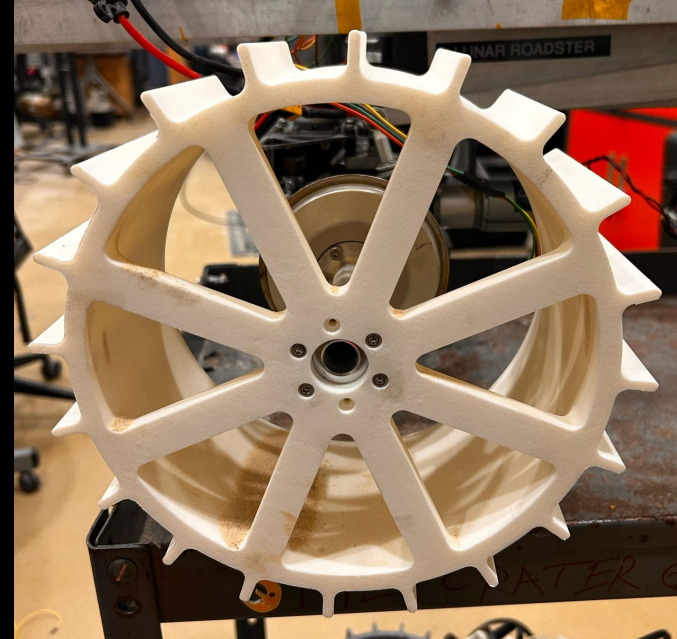


After

Stock Wheels - - - - → Lunar Wheels



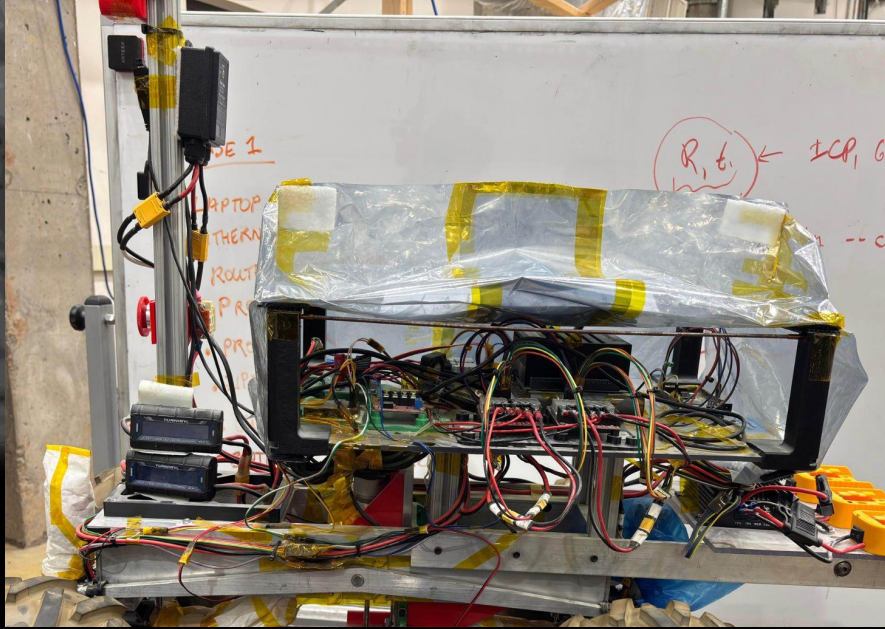
Before



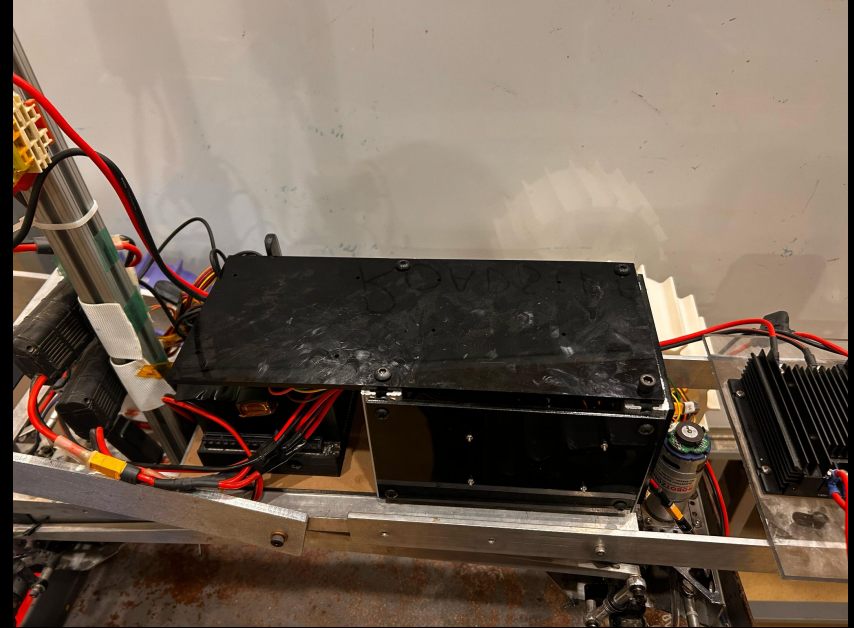
After

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

Cluttered Wiring - - - - → Compact E-Box



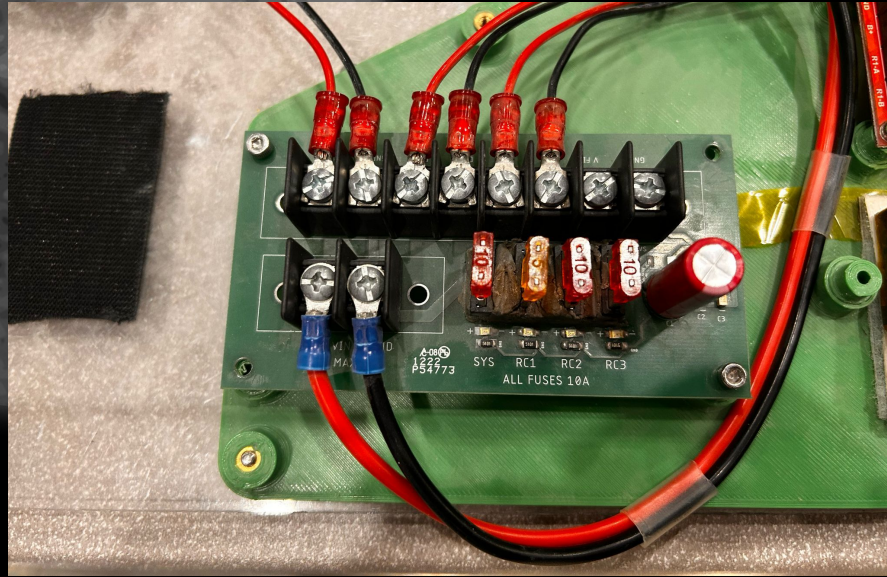
Before



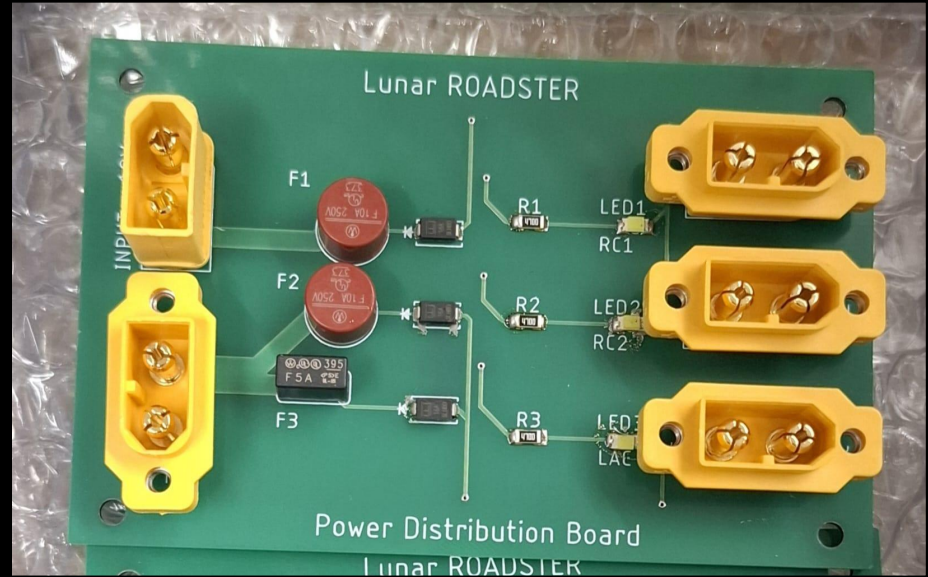
After

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

Improved Power Distribution Board



Before



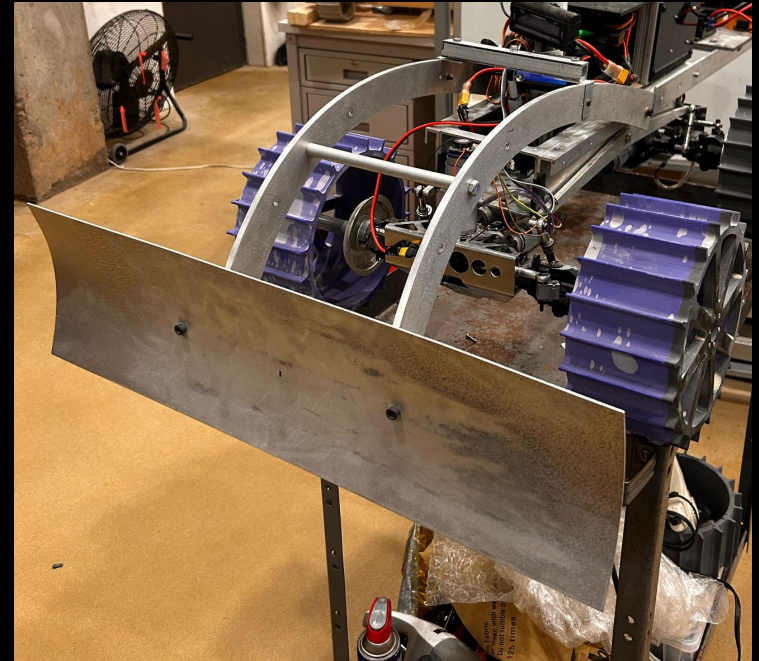
After

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

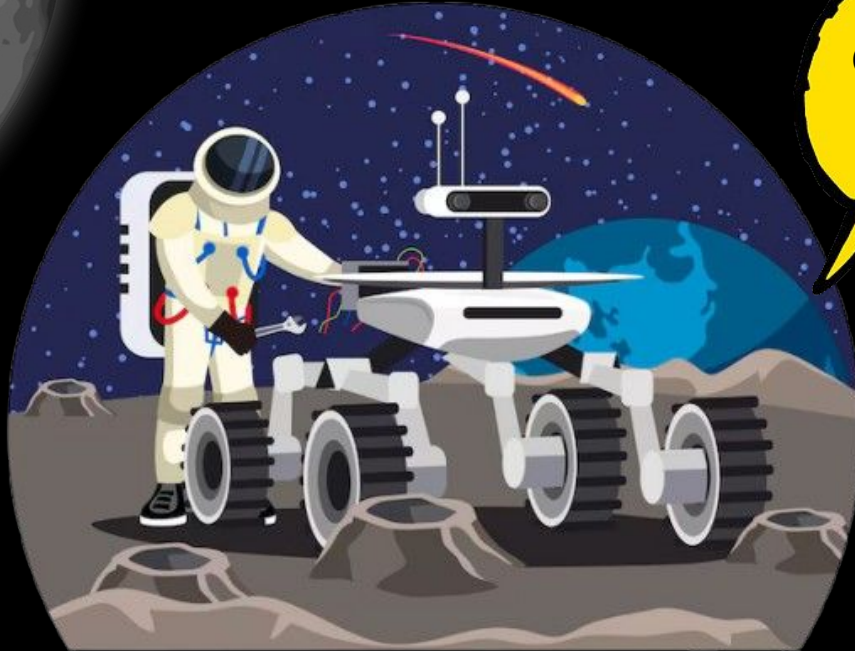


After

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

Colonize the Moon!

- *Team Lunar ROADSTER*



Questions?



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