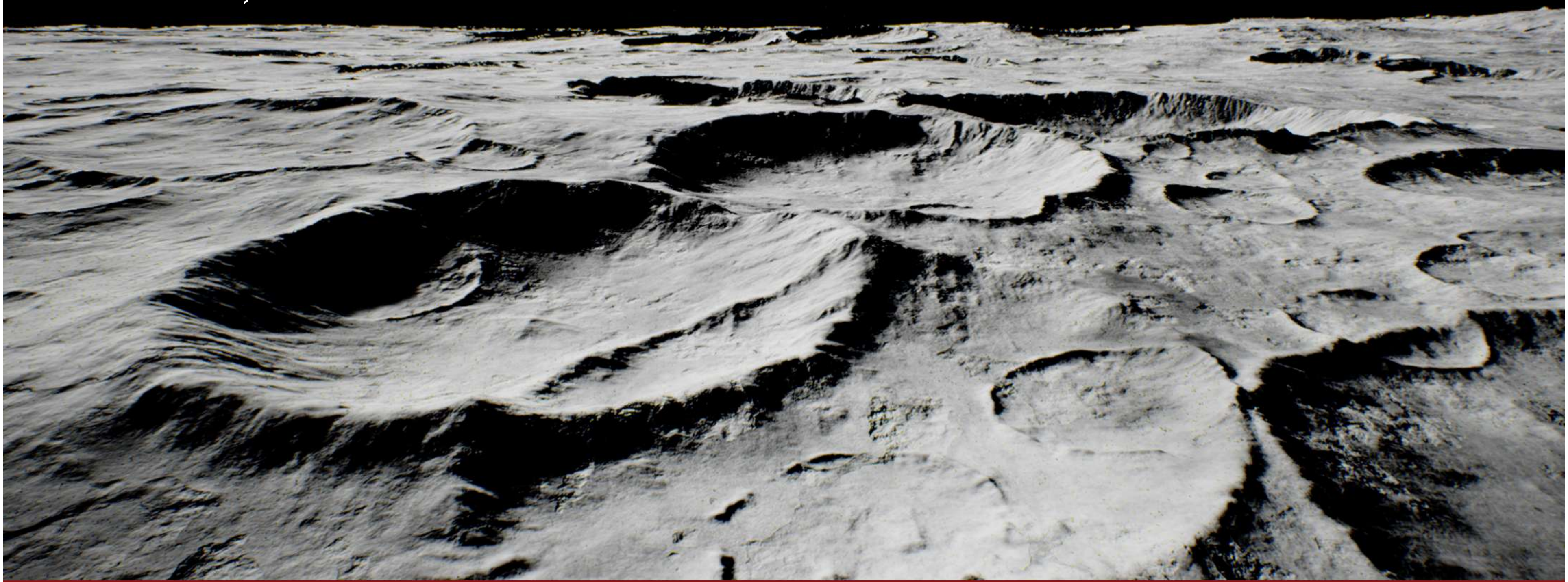
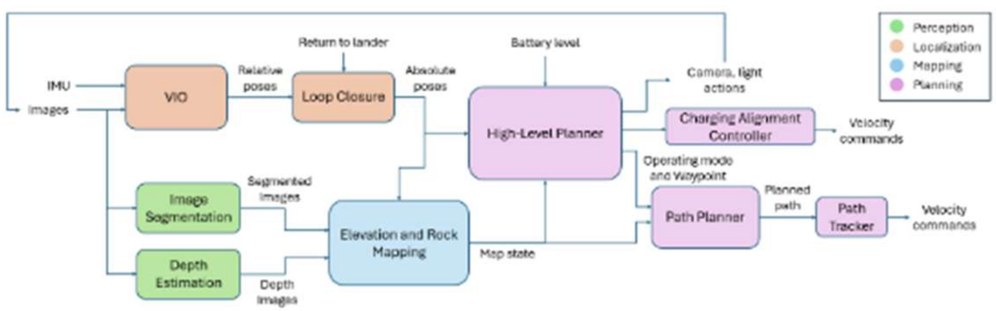
ARC Based Path Planner and Segmentation for Lunar Autonomy Challenge

THOMAS DENG, ADAM DAI



Introduction to Lunar Autonomy Challenge

- Collaboration between NASA and Johns Hopkins Laboratory, aims to develop autonomy solutions for the Artemis missions.
- Requires mapping a 40m x 40m lunar surface while avoiding obstacles and navigating through highly contrasted lit and shadowed regions.
- NAVLab approach: perception, localization, mapping, decision-making, and path planning in a high-level control framework.



Outline/Problem Statement

- The goal: arc-based path planning, leveraging image segmentation and depth estimation to enable autonomous navigation around segmented rocks.
- Develop a planner that effectively avoids obstacles and follows a set of global waypoints with a high degree of consistency.

The Rover and Simulation Environment

- Sensors: IMU, eight monochrome cameras, and four stereo camera pairs (front, back, and both sides)
- Rocky landscapes, highly contrasted lighting conditions, and permanently shadowed regions, reflecting the Artemis mission’s operational constraints.
- Lander with fiducial markers

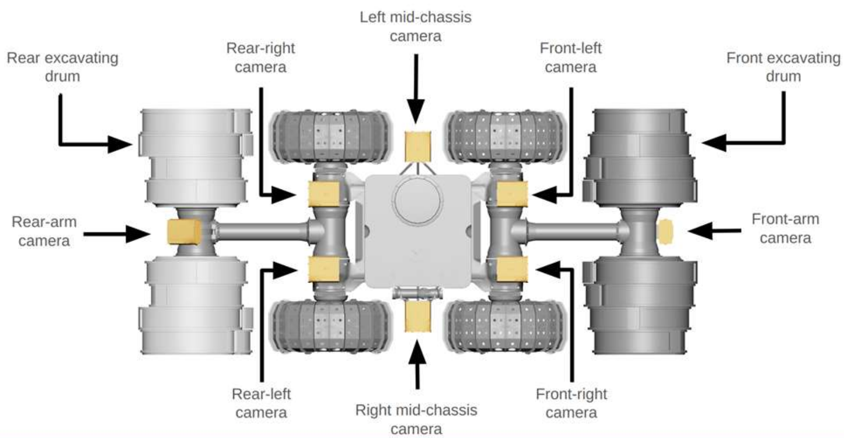
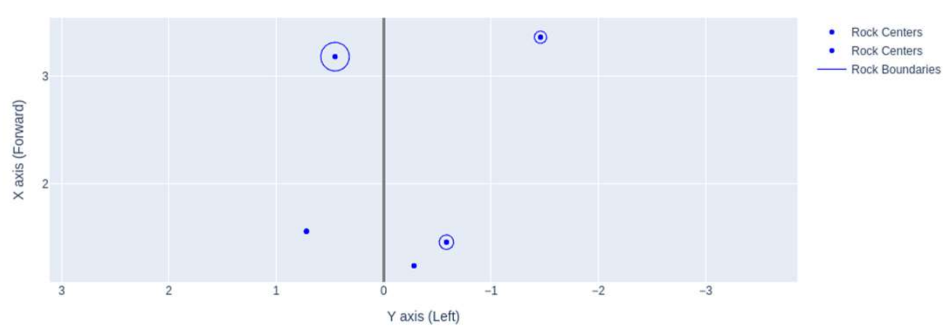
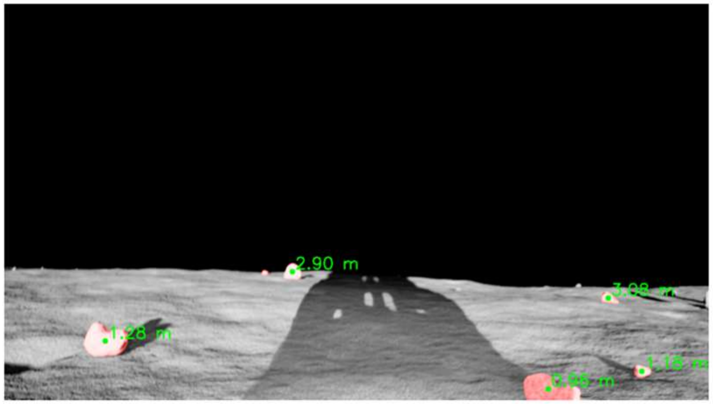


Image Segmentation + Depth Estimation

- Objective: Identify and localize rocks in the camera frame to inform collision avoidance in path planning.
- Utilizes Language Segment-Anything (LangSAM) to segment rocks based on textual prompts.
- Stereo Depth Estimation: Computes rock depths using stereo disparity calculations from paired rover cameras.
- Rock Size Estimation: Determines rock radii using depth, focal length, and pixel width calculations.
- Output: Generates a local 2D rock map that integrates with trajectory planning for real-time obstacle avoidance.

Segmentation and Depth Examples





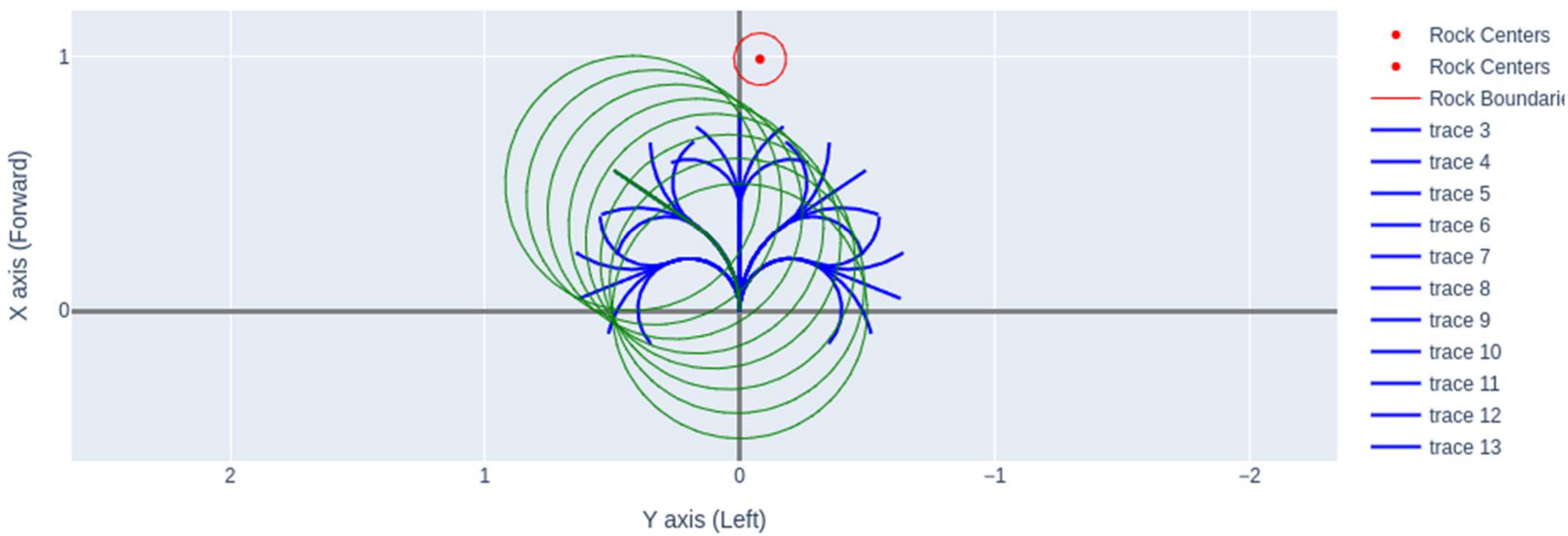
Arc-based Path Planner

- Develop a dynamically feasible, collision-free path planner that enables the rover to navigate around segmented rocks while following global waypoints.
- Uses Dubin's car model to generate smooth, kinematically feasible paths.
- Constructs paths by concatenating two sequential arc segments, each lasting 2 seconds.
- Each arc follows a constant velocity of 0.2 m/s with an angular velocity selected from five discrete values between -1 rad/s and 1 rad/s.
- Incorporates rock segmentation results and depth estimation to determine rock positions and radii.

Path Selection

- Path Selection: Generates 25 candidate arcs (5 initial arcs, each branching into 5 more).
- Eliminates any arcs that result in collisions with segmented rocks.
- Chooses the optimal path by selecting the arc whose endpoint is closest to the next waypoint.
- Runs at 20 Hz, constantly updating the rover's trajectory
- Balances long-term goal progression with optimal short-term local maneuvering.

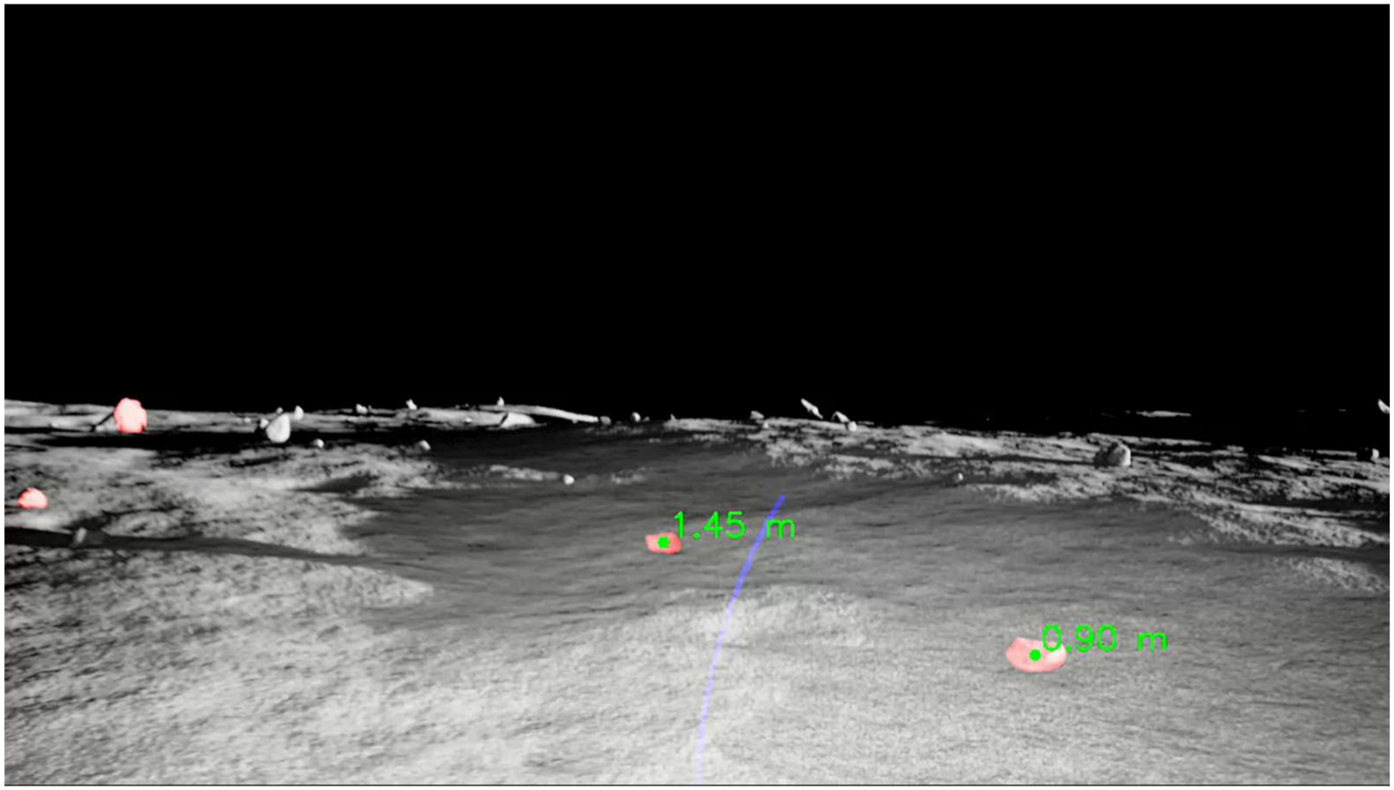
Arc Planner Example



Results

- Was able to successfully follow 16 square waypoints without being stopped by the rocks!
- Took intuitive paths that did not require too much steering and was able to stay directed towards the goal waypoint.

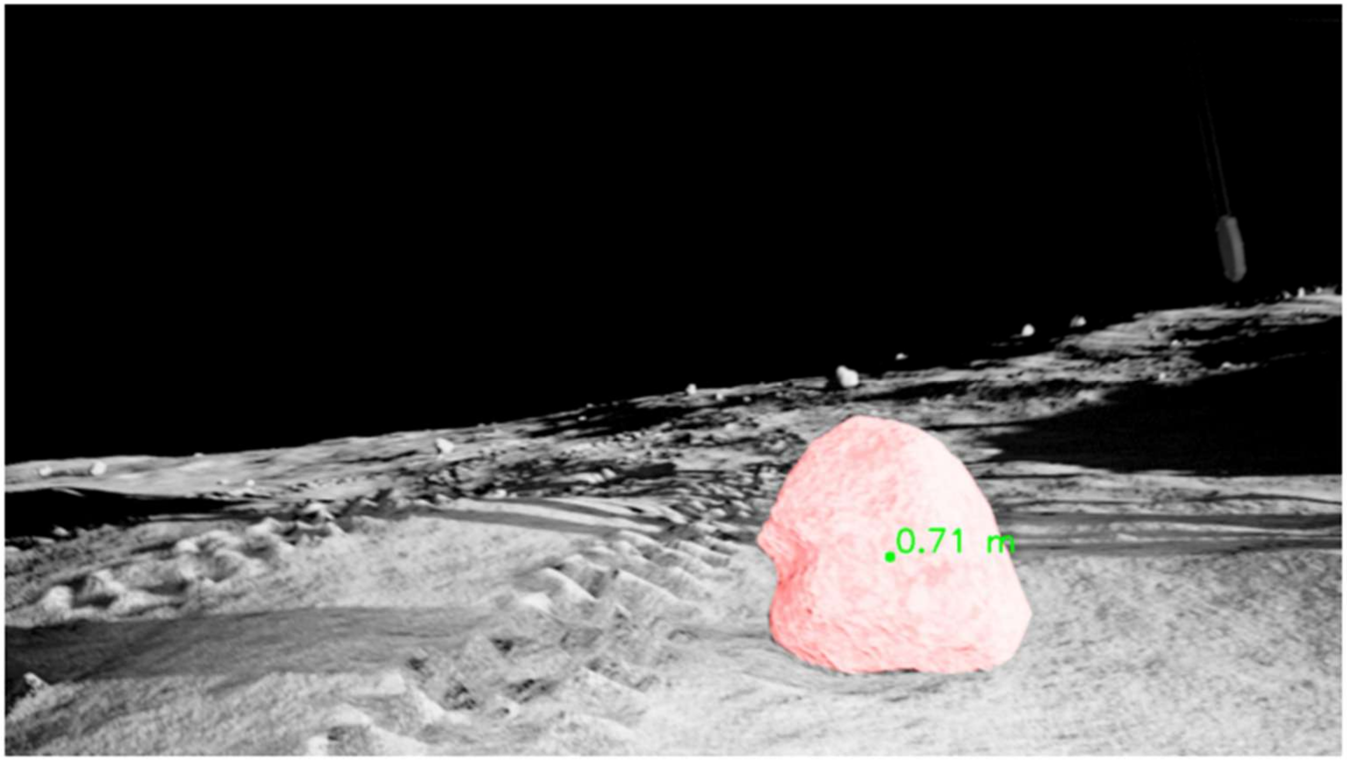
Results



Current Challenges and Future Works

- Enhance the cost function to incorporate additional factors such as slope, energy efficiency etc.
- Add more velocity options
- Fuse the side and rear cameras to provide additional rock information
- Filter out smaller rocks and place higher emphasis on taller rocks
- Incorporate the rock mapping into the path planning
  - EKF or other filtering algorithm and loop closure to avoid creating paths that collide with rocks, not in the camera frame.

A Problematic Rock



Challenges contd.

Thank You!