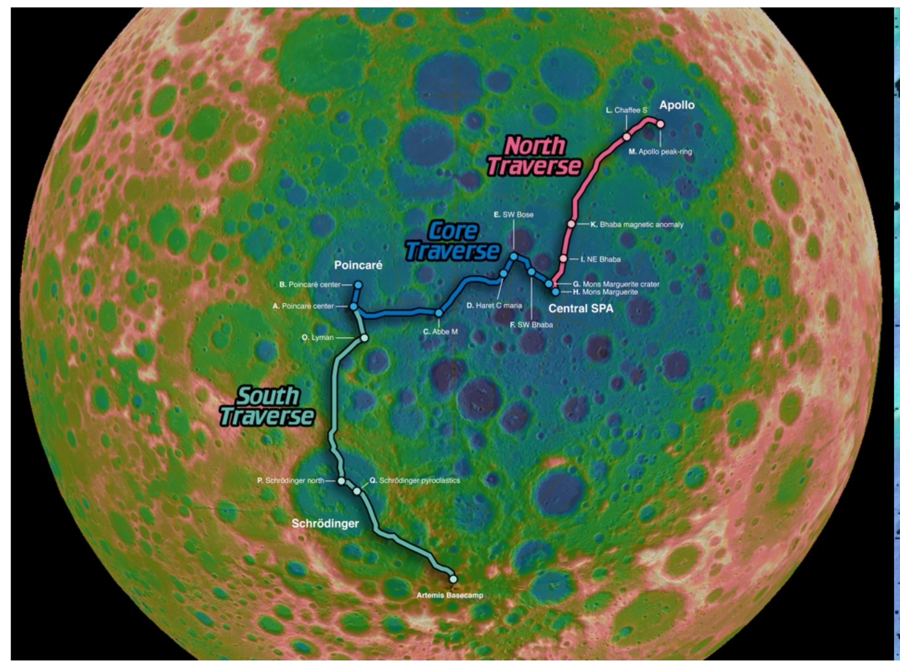
National Aeronautics and Space Administration

Autonomous navigation for fast, long-range surface mobility (ShadowNav)

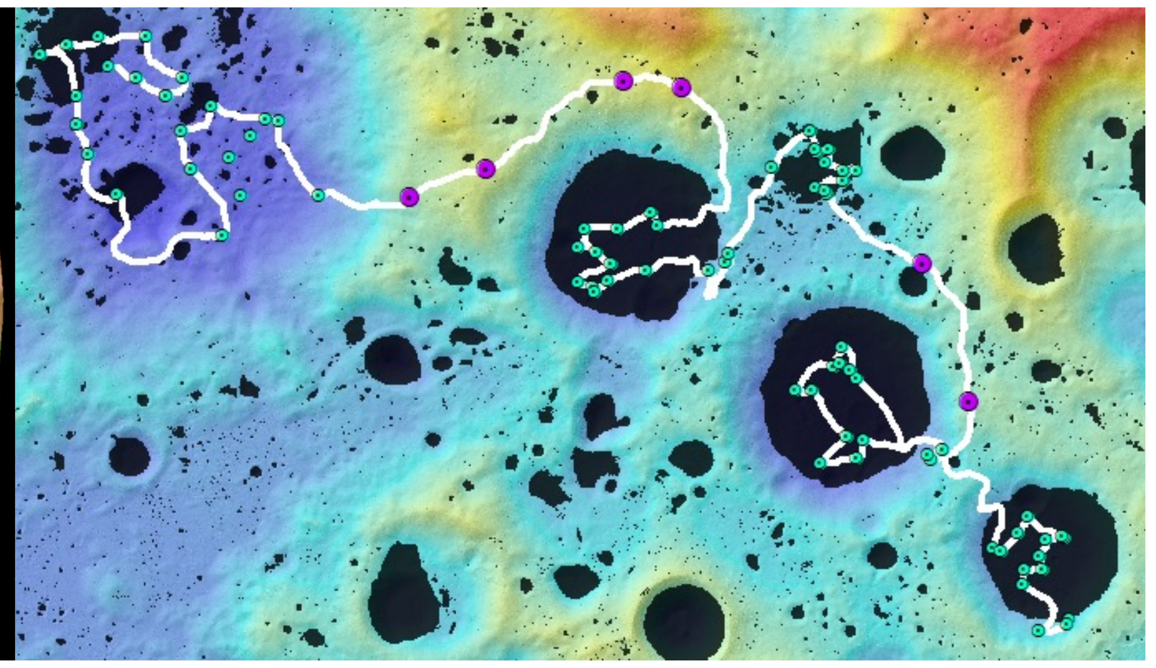
Principal Investigator: Masahiro Ono (347); Co-Investigators: Deegan Atha (347), Robert Swan (347), Shreyansh Daftry (347), Larry Matthies (347), John Elliott (312), Yang Cheng (347)

Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Long Range Lunar/Mars Surface Mobility**

Challenge: Lunar rover concepts studied at JPL involves >1,000 km automated drive in PSR and during night, which requires absolute localization in the dark. JPL does not have such capabilities yet.



Long-range rover mission to the South Pole Aitken Basin, driving over ~2,000 km



Rover mission concept to visit multiple PSR craters with a ~1000 km drive

FY21 Objective 1-A (Data collection): Generate/collect synthesized and real images of topographical features representative of Lunar surface with a simulated lighting condition of PSR.

We newly developed a high-fidelity Lunar surface simulator based on a 3rd party visualization tool, Blender. We implemented the HAPKE model for accurately simulating the opposition effect, which could be a major challenge for night-time imaging. Figure 1 shows representative outputs from the simulator. Meanwhile, we collected real nighttime images, as well as Lidar scans, from Arroyo Seco right next to JPL. The data was acquired at six locations, at 5 and 10 m from the negative topographical features with 45 cm - 180 cm relief. Figure 2 shows representative images.

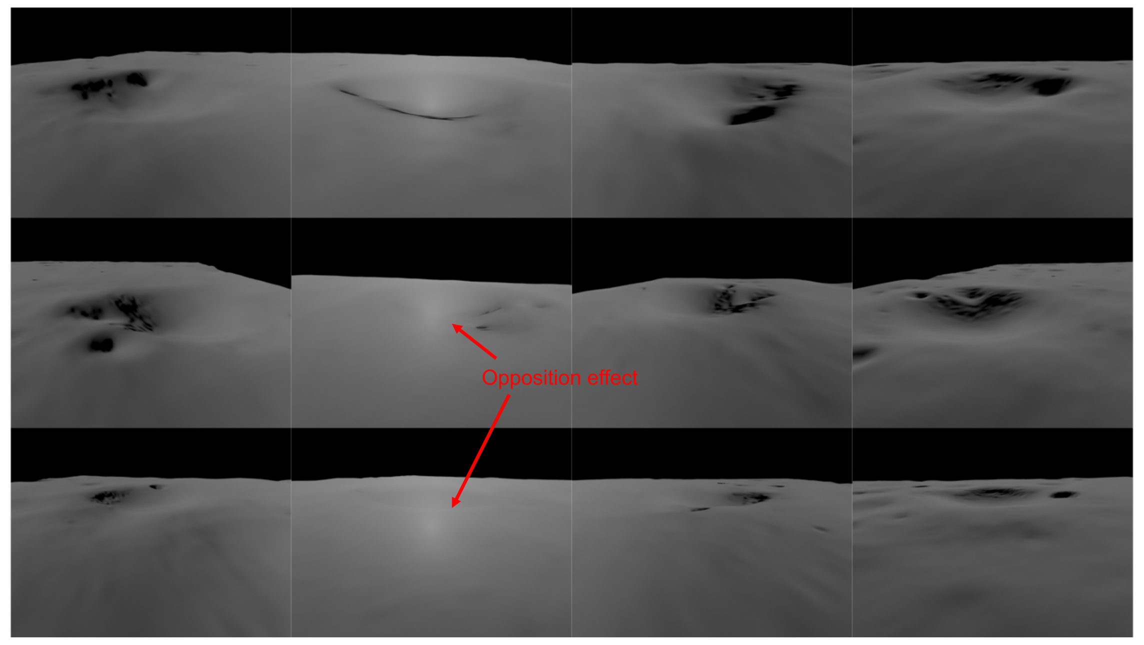


Figure 1. Samples of synthetic camera images. Note the opposition effect is clearly visible.

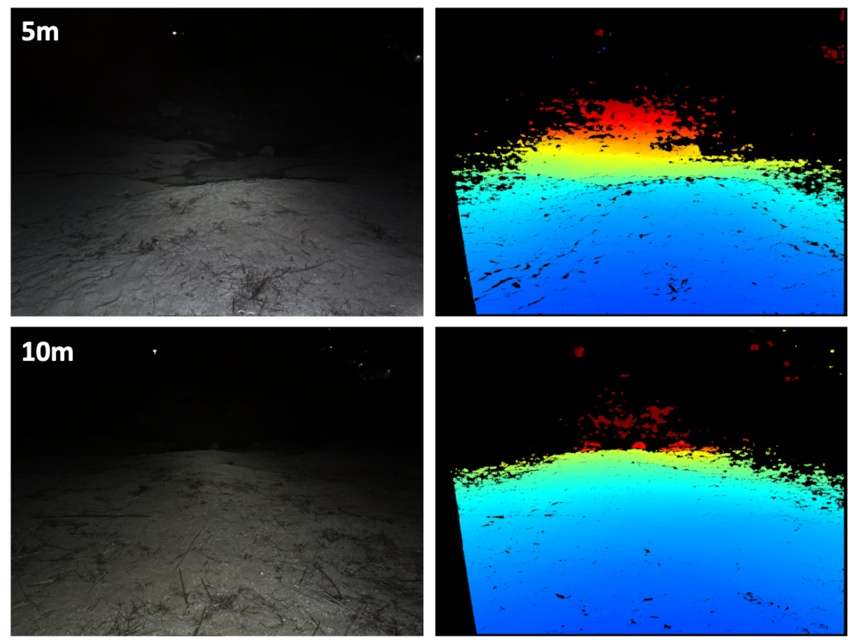


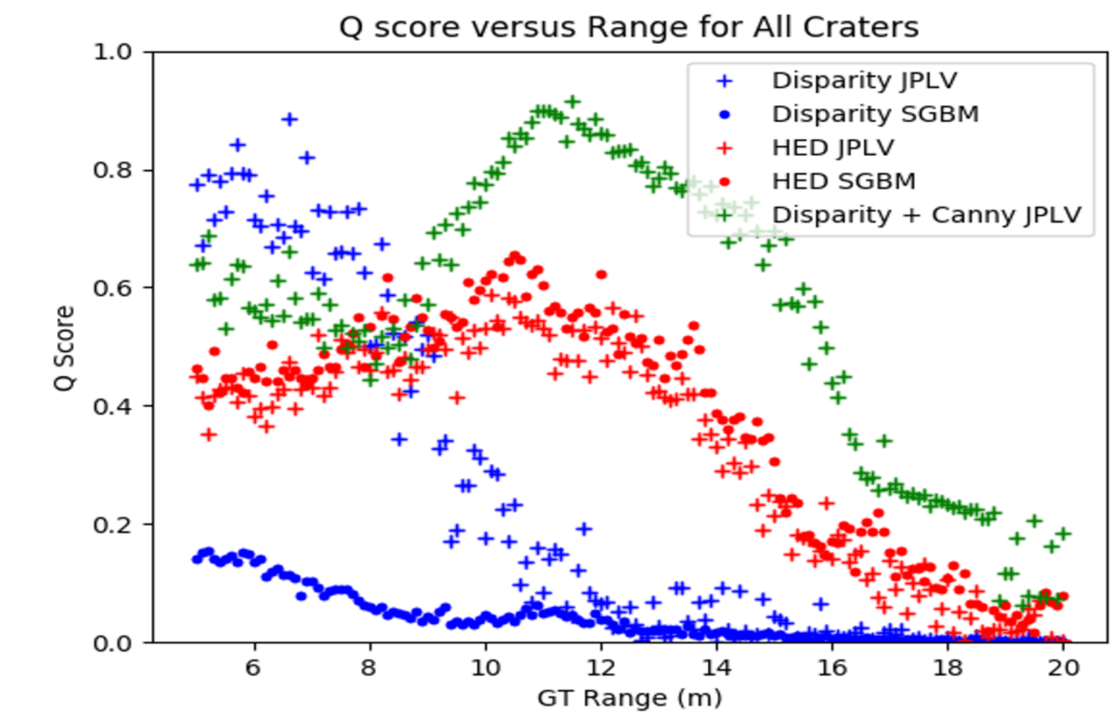
Figure 2. An example of our Arroyo nighttime dataset

Overall Approach for Global Localization in the dark:

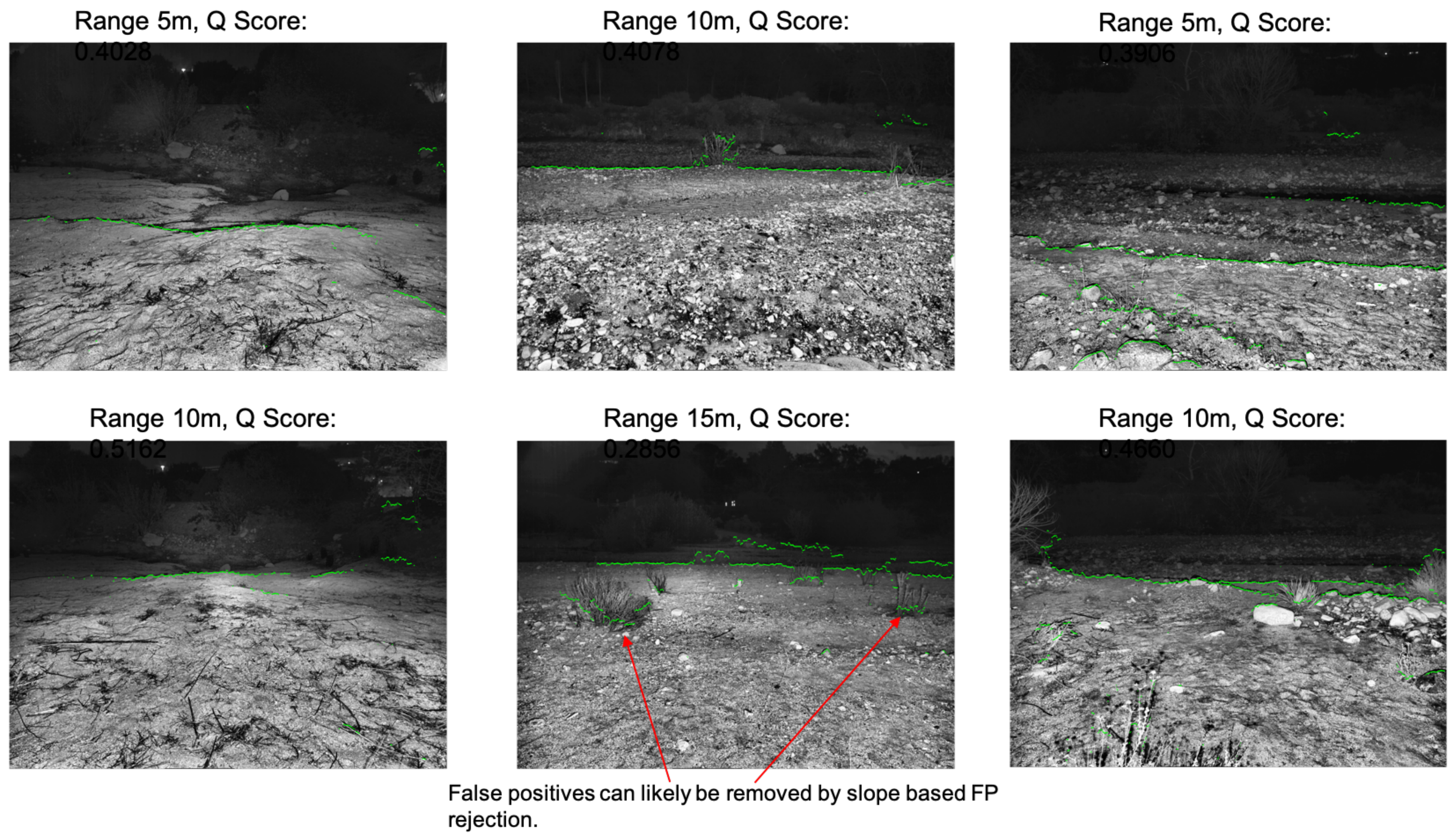
Our idea is to use small craters, which are the dominant feature on the Moon, as landmarks. More specifically, craters are detected onboard and matched with a list of craters crated from orbital observations to localize itself. ASU's ShadowCam (2022 launc) will be able to image the interior of PSRs at 1.7m/pixel resolution, using the scattered light by crater rims. With this resolution, craters greater than ~10 m in diameter should be resolved reliably. Many of the major PSR craters are old (e.g., Shackleton Crater: 3.6 Ga), meaning that the crater density of the interior is comparable to the average Lunar surface. From known crater size/frequency distributions, the average distance between craters of >=10 m in diameter is ~100 m, which is quite frequent. Therefore, we believe that on-board absolute localization against ShadowCam images is feasible by using >=10 m craters as landmarks.

FY21 Objective 1-B (Crater Edge Detection in the Dark): Develop methods for reliably detecting negative topographical features that are representative of the leading edge of craters >=10 m in diameter from the distance of ~10 m.

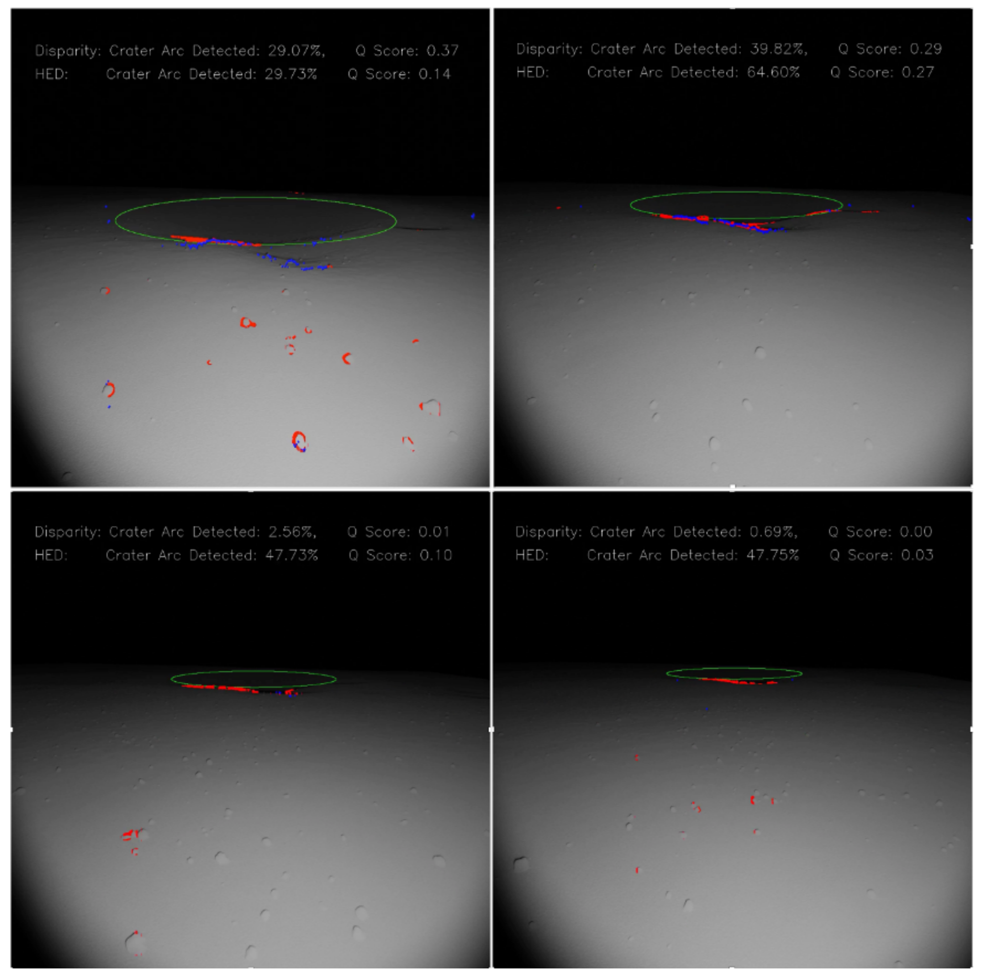
We developed three detection approaches: (A) a disparity-based approach, (B) Holistically-Nested Edge Detection (HED), and C) Hybrid of A and the Canny edge detection. (A) looks for jumps in disparity on vertical lines of an image; (B) is a deep learning-based method and we used it out-of-box without additional training; (C) uses Canny in far-field and the disparity-based method in the near field. To quantitatively assess the performance, we developed a new metric called *Q-score*. Intuitively, it measures how well the observed locations of edges agree with expected locations given a belief in the rover's position and attitude. We chose Q-score because it corresponds to the probability of observation in Bayes filter-based localization approach (such as particle filter). Overall, we found that the hybrid approach (C) is the best performer for both the near and far fields, with a reliable detection range being >15 m.



Quantitative evaluation of edge detection algorithms. The horizontal axis is the distance from the crater edge and the vertical axis is the Q-score (higher is better).



Edge detection results on Arroyo nighttime data. The hybrid method was used.



Edge detection results with various distances from the crater edge. Blue: disparity-basd, Red: HED

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: Masahiro.Ono@jpl.nasa.gov

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