National Aeronautics and Space Administration

Autonomous navigation in dark for long-range surface mobility

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Objectives:

The overall objective of this task is to develop and test absolute localization in dark. Specifically, to develop absolute localization methods that under the lighting condition of Lunar PSRs/night, aiming for position knowledge error of less than 10 meters relative to an orbital map.

Significance/Benefits to JPL and NASA:

The new Decadal Survey recommends the Endurance-A Lunar rover mission should be implemented as a strategic medium-class mission as the highest priority of the Lunar Discovery and Exploration Program.

- Endurance will need to conduct ~70% of drive during the night because the majority of day hours must be spent for science and sampling.
- Key capabilities needed for autonomous surface operations include navigation, pose estimation, instrument deployment/placement, and global localization (i.e., determining the vehicle's location relative to orbital maps).
- Global localization is necessary to maintain an error of < 10 m relative to the orbital maps.

Approach and Results:

Craters are the most abundant terrain features on the Lunar surface and therefore are promising to use as landmarks for absolute localization. To perform this localization using craters, we propose an approach in which crater rims are detected in surface imagery and matched with known craters within an orbital map. To detect the crater rims within surface imagery, we propose using a headlight on the rover that is mounted below a stereo camera. Using the imagery, craters can be detected by both discontinuities in the disparity map and monocularly using the shadows on the crater rim. To localize these detections in the context of an orbital map, we utilize a particle filter with each particle representing a possible pose of the rover. Based on each pose, the detected rims are compared to the orbital map and evaluated for overlap. The particle filter predicts both the position of the rover and an uncertainty based on the scores of all of the particles.

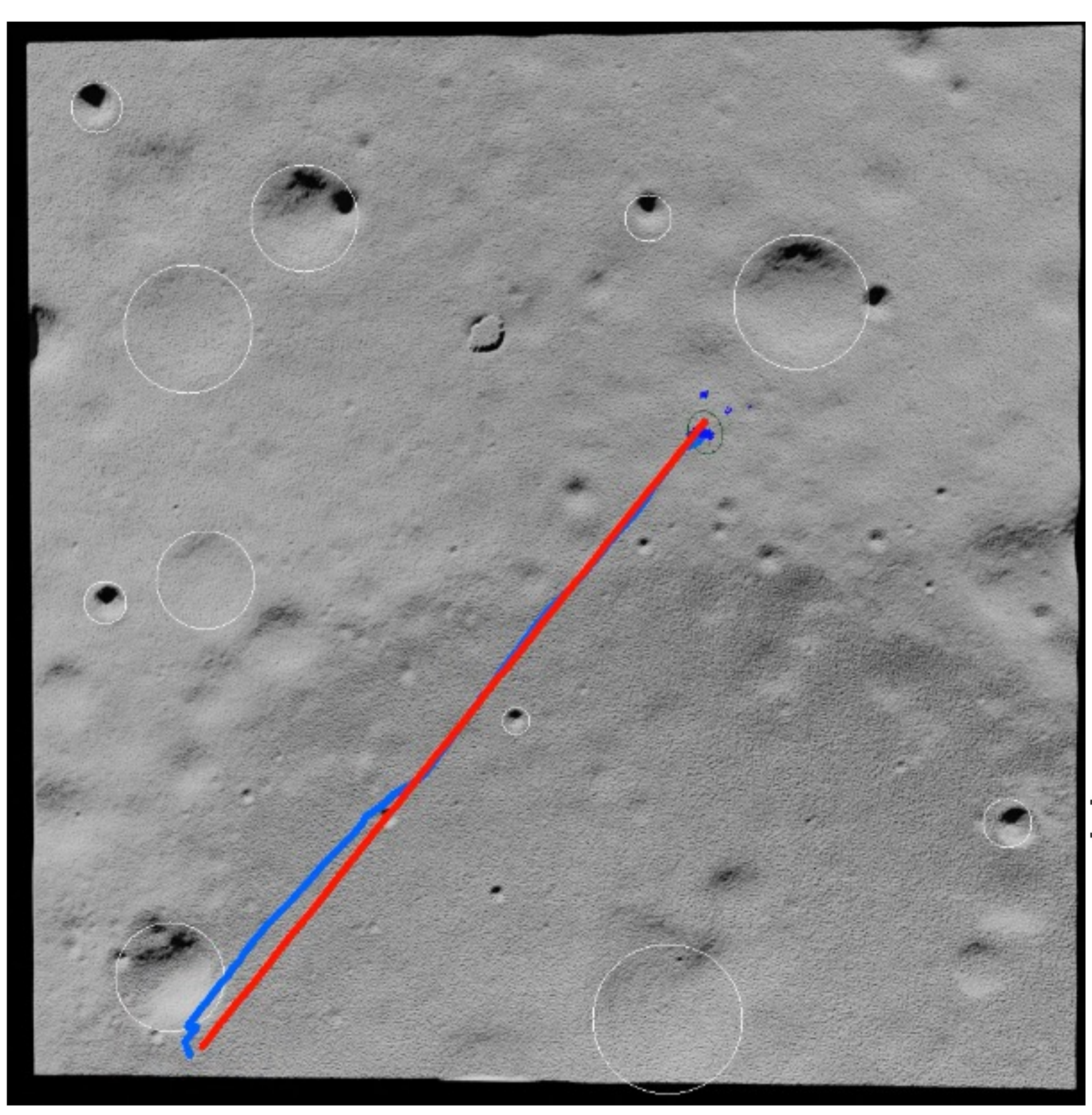

Figure 1: A sample trajectory within an orbital map. Red Line: Ground truth position. Blue Line: Predicted position. Blue Dots: Particles. Black Circle: Uncertainty ellipse. White Circles: Ground truth orbital craters.

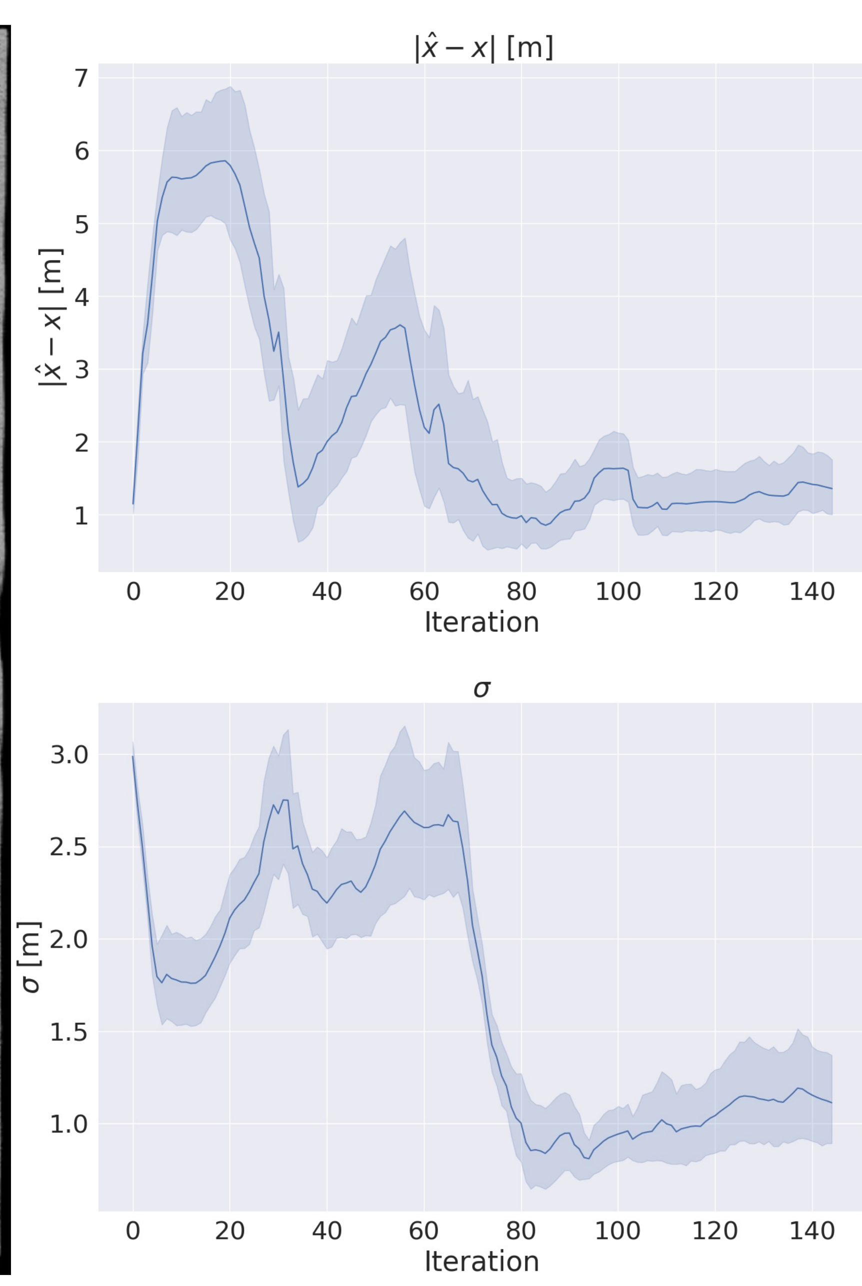

Figure 2: Sample Monte Carlo results with 10 random seeds, 200 particles, initial uncertainty of 3sigma = 3m and odometry noise of 4%..

Background:

JPL conducted three Planetary Mission Concept Studies on long-range Lunar rovers as inputs to the 2022 Decadal Survey: (1) Endurance [2], a long-range rover mission for exploring and collecting, caching, and returning samples from the South Pole-Aitken (SPA) basin, which would traverse ~2,000 km in under four years, (2) Inspire, another long-range (~1,000 km) rover mission to visit multiple permanently shadowed craters (PSRs) for understanding the origin and evolution of Lunar volatiles in three years, and (3) Intrepid, a 1,800 km-long roving mission to visit a diverse set of geological units representing 4 billion years of Lunar history. ~70% of the total distance of Endurance-A and ~75% of Inspire must be driven at night to allow sufficient time for day-time science activities. Therefore, the Endurance and Inspire studies found that both of these rovers need onboard absolute position estimation against orbital map at night and in shadow, which does not exist today.

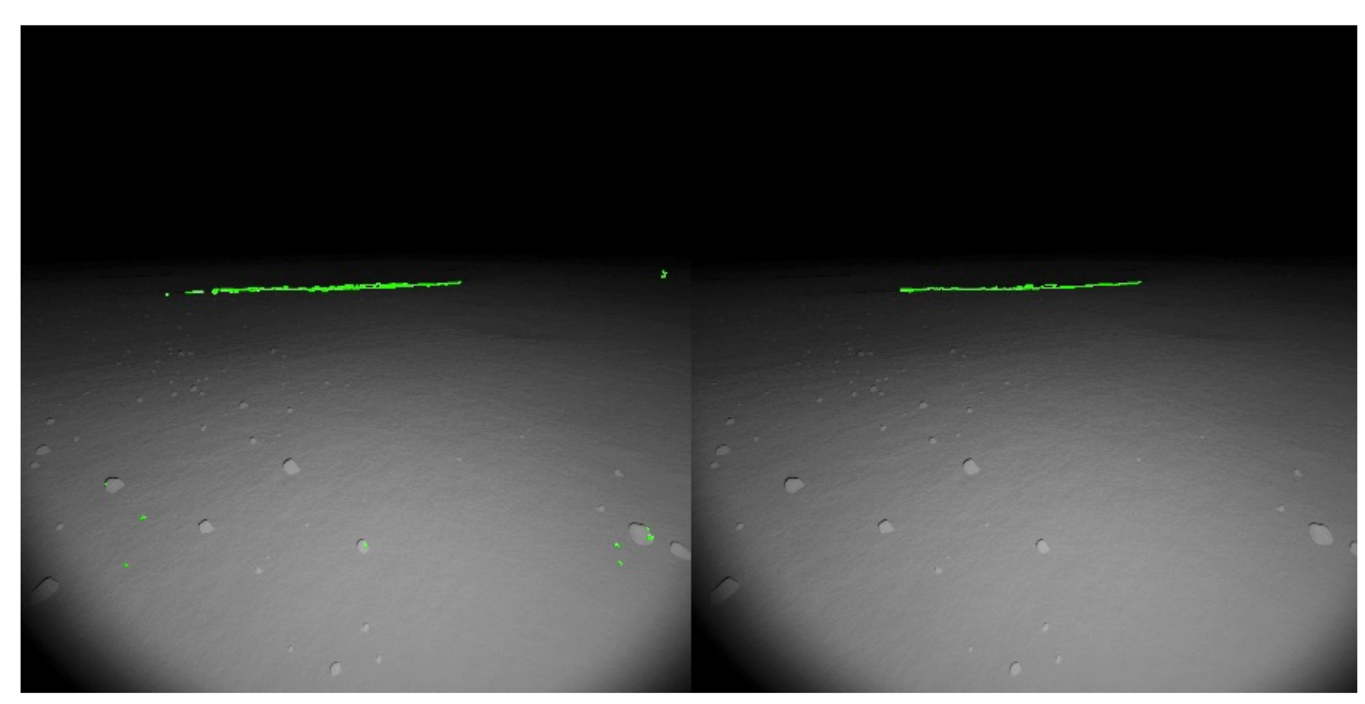

Figure 3: Crater detections with (left) no contour filtering and (right) with contour filtering.

Figure 1 demonstrates a sample trajectory within our simulation with a successful localization upon seeing a crater. Figure 2 contains the error and uncertainty plots which demonstrate a successful localization to 1m error and 1m uncertainty. Figure 3, displays a successful surface crater detection and false positive filtering using contours. Figure 4 contains a table of Monte Carlo simulations using different number of particles and their impact on final convergence error of the particle filter.

Num. Particles	Final Error [m]	Final Mahalanobis Distance
25	2.13±1.07	3.80±4
50	2.03±1.11	3.87±4
75	1.94±1.52	2.55±2
100	1.44±0.85	1.61±1
200	1.63±0.81	2.22±1

Figure 4: Table of Final error +- final uncertainty and final Mahalanobis distance for different number of particles. There were 25 random seeds and 2% odometry noise and 3m initial uncertainty.

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