Design and characterization of map-based lunar rover localization

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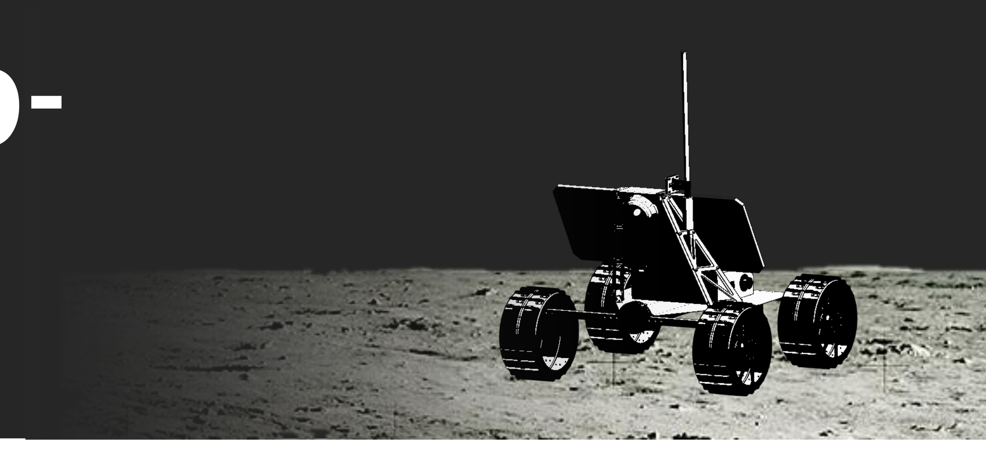


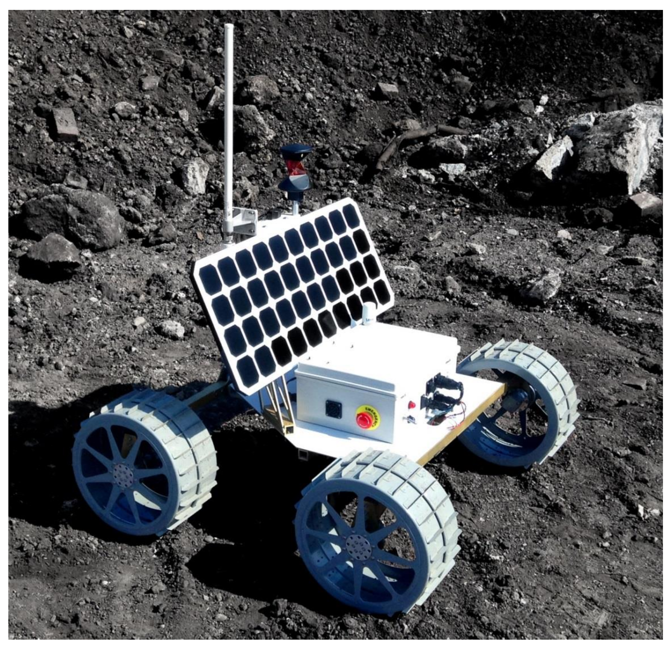
Motivation

Need for accurate positioning and distance determination for lunar rover missions

- Currently: To verify 500m traverse for Google Lunar X-Prize
- Subsequently: For strategic lunar exploration and science missions

Challenges of lunar localization:

- Lack of absolute positioning system (no GPS)
- Wheel odometry: Error from integration and wheel slip



The Andy Rover will explore Lacus Mortis, a pit on the Moon

Strategy

Available data: wheel turns, onboard monocular camera, aerial landing map

Determining Distance Traveled:

1) On-site calibrated wheel odometry

- updates continuously throughout traverse to account for changing wheel slip

$$distance = wheel\ turns * odometry\ factor$$

$$odometry\ factor = \frac{\#wheel\ turns\ between\ aerial\ map\ features}{distance\ between\ features}$$

2) Map-based feature-matching

- uses feature matches between onboard camera and aerial map
- finds straight-line distances between features for conservative distance estimate

Determining Rover Position - visual odometry

- finds SIFT features between monocular camera images for structure from motion reconstruction w/ bundle adjustment for error minimization
- Scales reconstructed ribbon with aerial map

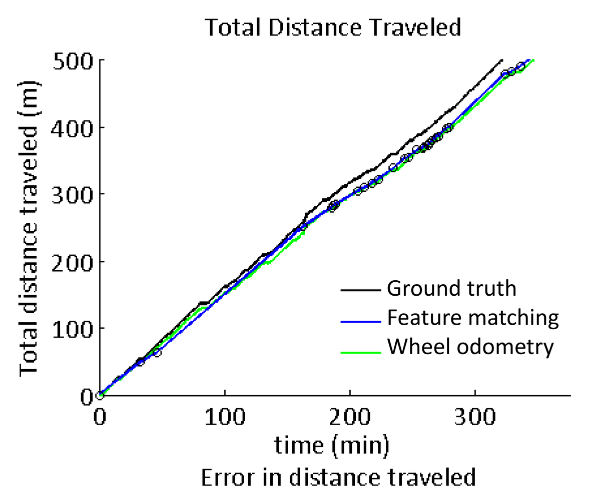
Analog Test – Performance and Results

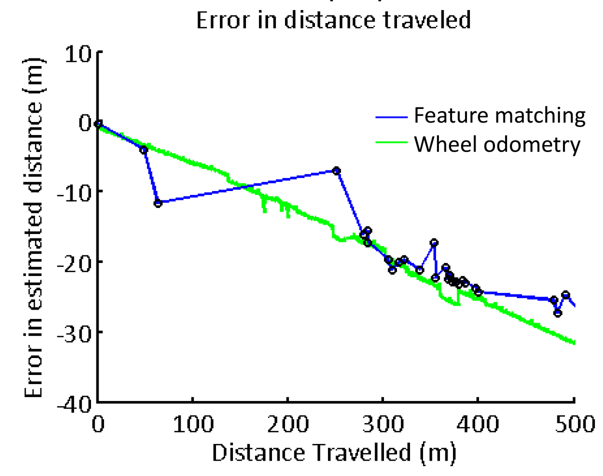
In situ calibrated wheel odometry

- Using single calibration: +/- 31m distance estimate @500m
- Provides conservative distance estimate

Map-based feature matching

- Feature matches between 3D aerial map onboard camera (see right): +/- 21m distance estimate @ 500m
- Provides conservative distance estimate and rough position map

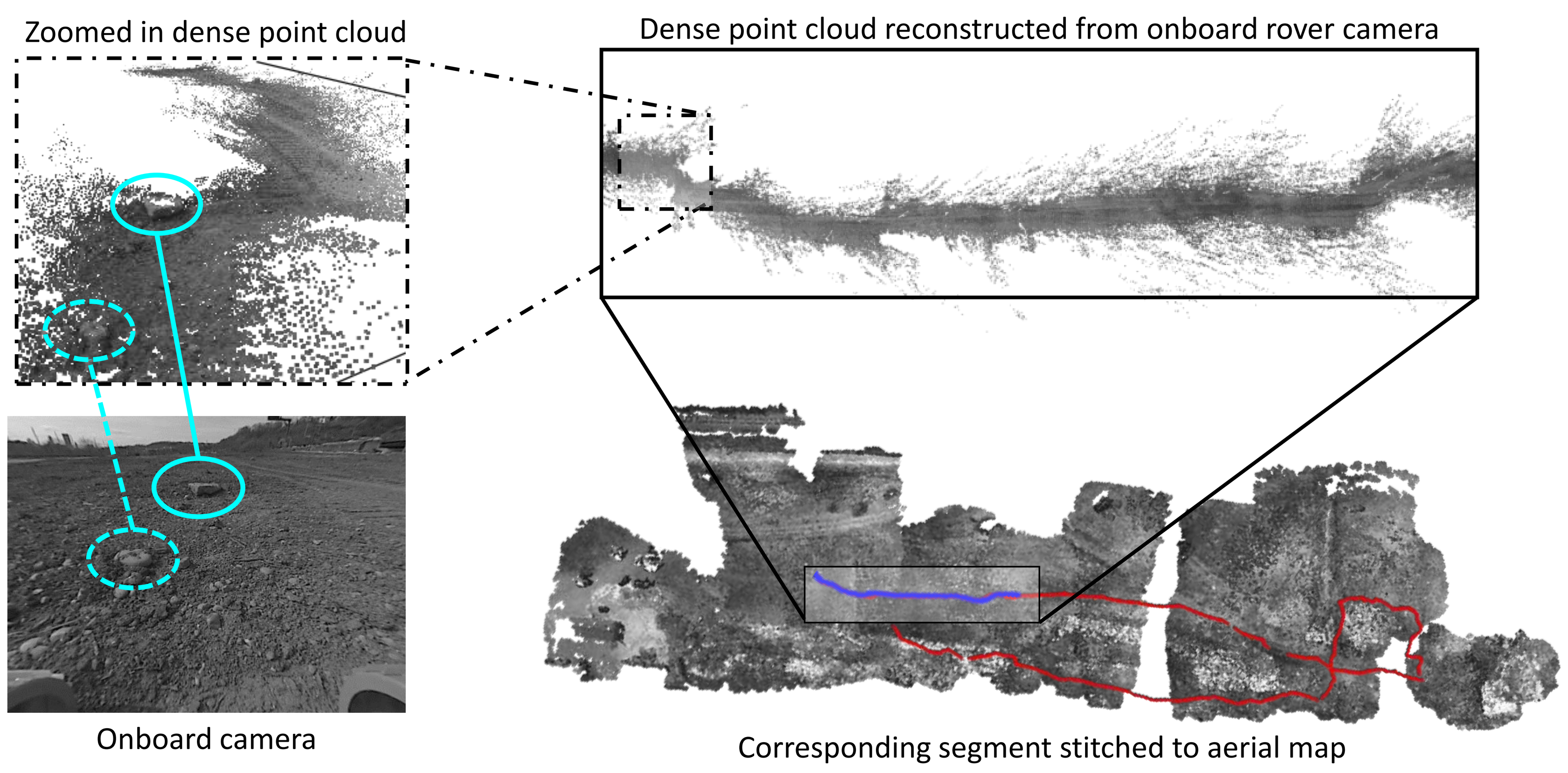




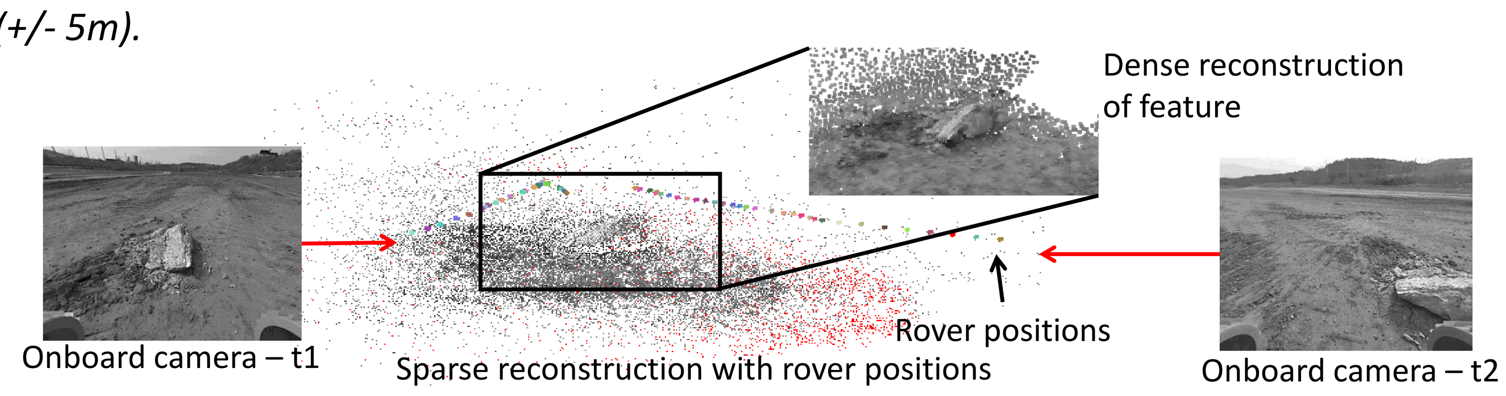
Plot showing total distance traveled estimate for both methods compared to ground truth. Both methods provide conservative estimate.

Visual odometry

- Dense point cloud with rover positions – scaled with aerial map
- Can be used for loop-closure at end of traverse



Visual odometry process: dense point cloud constructed from sequence of camera images (left). This point cloud is scaled using the aerial map (right), providing a position estimate very close to the ground truth (+/- 5m).



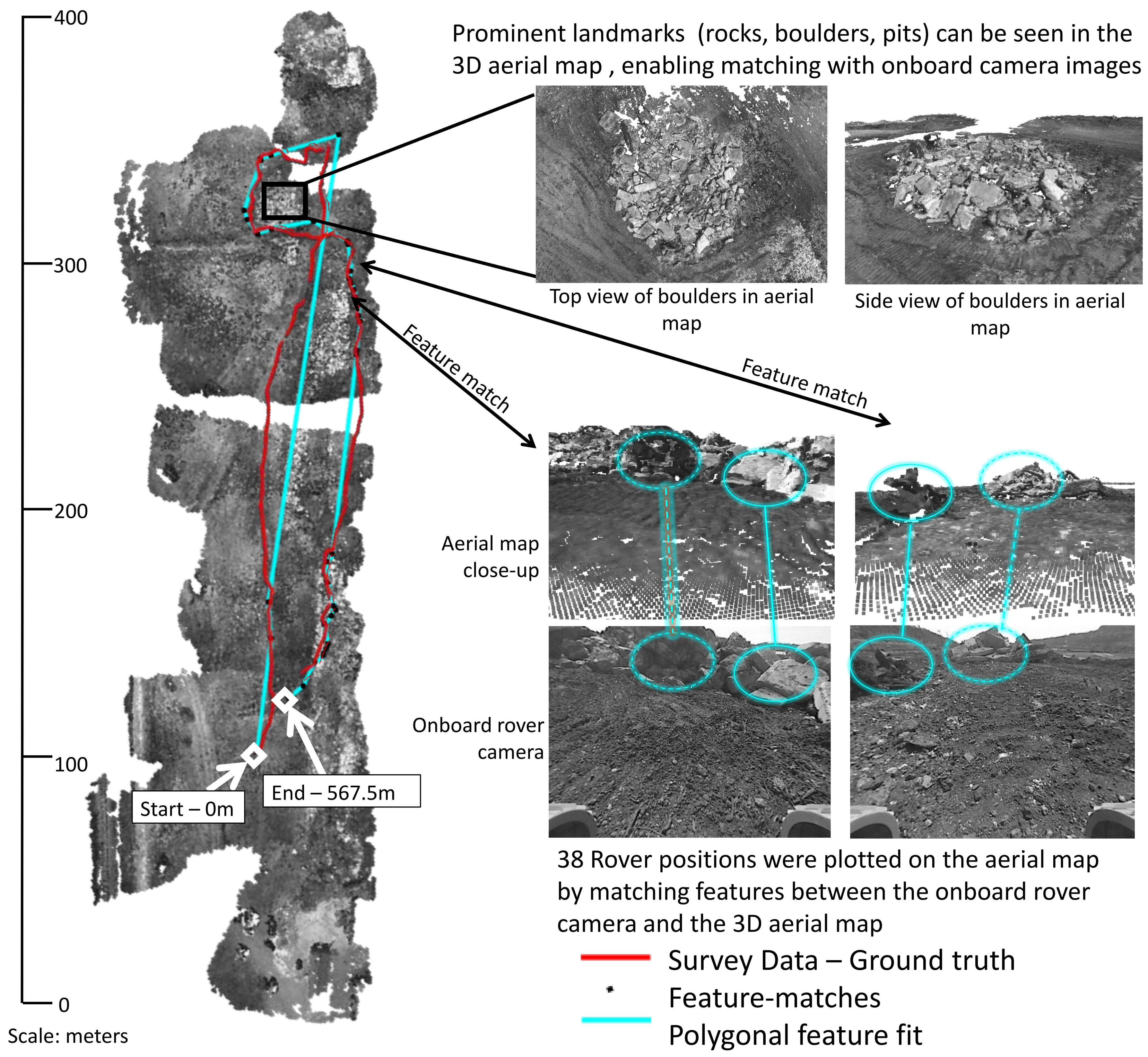
Loop closure: Same feature identified at beginning and end of traverse. Dense point cloud constructed using both data sets, showing automatic rover position reconstruction from both sides.

Simulated Rover Mission: Robot City Analog Test Site

UAV utilized for mapping with raw overhead image

FARO laser scanner with raw scan, used for scaling

Aerial Map – 3D point cloud reconstruction of test site using UAV flyover and FARO laser scanner. This is similar in resolution and quality to a planetary landing map generated upon descent.



Aerial map of Robot City Analog test site. The rover drove a total of 567.5m and the ground truth position (red) is plotted on the map. Black dots represent feature matches in which certain landmarks were registered to the onboard rover camera images (shown). Cyan lines show the straight-line interpolations between points – these were used to determine total distance traveled.

Future Work

- Extended Kalman Filter (wheel odometry + visual odometry + IMU) for better localization and distance accuracy.
- Real-time visualization of rover position on 3D map.

Acknowledgements

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References

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[3] Matthies, Larry H, "Visual Localization Methods for mars Rover using Lander, Rover, and Descent Imagery", JPL, http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/22227/1/97-0695.pdf