LEVERAGING TERRESTRIAL TESTING TO DESIGN AND TEST LUNAR TERRAIN RELATIVE NAVIGATION

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Abstract. *Testing and verifying optical terrain relative navigation (TRN) algorithms for Lunar terrain is challenging since all testing must be done on Earth before depending on these algorithms at the Moon. Draper has done extensive terrestrial testing of their image-based absolute localization (IBAL) TRN algorithms to quantify its robustness and performance. Leveraging that testing experience, the IBAL algorithms are under development for TRN with Lunar terrain alongside developing optimal landmark database generation, and high-fidelity simulated imagery. This poster presents an overview of the terrestrial testing and preliminary Lunar orbit results.*

Introduction. Draper began developing algorithms for Lunar Terrain Relative Navigation (TRN) in 2005 under a Draper Internal Research and Development (IRAD) effort.[1,2] Since then, Draper has developed TRN algorithms and approaches for numerous applications, many of which include terrestrial field testing activities and flight. These activities have produced TRN algorithms for terrestrial-based programs, and for GPS-denied environments. Flight testing of the core TRN algorithms include parachute testing [3], quadcopters, fixed-wing aircraft, high-altitude balloon testing, and suborbital rocket testing.[4]

The Lunar terrain provides a challenging problem to test and verify TRN algorithms that are developed on Earth. The algorithms must be tested only on simulated and canned lunar image data before trusting them to land a spacecraft safely on the moon. While the database of Lunar Reconnaissance Orbiter (LRO) images is extensive, one must match the canned images with the lighting conditions and resolution that the navigation system expects to operate in. Testing must account for terrain parameters such as lighting conditions, ground sample distance (GSD), and lunar surface properties.

This poster illustrates the testing and verification efforts of Draper's core TRN algorithms, image-based absolute localization (IBAL). Flight test results from terrestrial projects are presented to illustrate the TRN performance and robustness. Piggy-backing off of the experience from terrestrial flight testing, we present the adaptation of IBAL for the Lunar TRN problem. The poster presents on Lunar landmark database generation, simulated lunar imagery, and preliminary TRN performance results in a simulated low Lunar orbit.

IBAL Basics. Draper's IBAL algorithms are based on matching known landmark templates to observed images, and provide absolute position and attitude knowledge of the camera state. The main phases of IBAL involve (1) a landmark database search, (2) landmark matching, and (3) geometric outlier rejection.

The core image processing algorithms in IBAL first estimate the location of a landmark in the expected camera image ground footprint using the current camera pose and elevation data, and the landmark database is queried for any landmark feature in view at each resolution level. The landmark is warped into the camera image plane, and match scores are computed for the template with camera subregions. Thresholding checks retain the strongest matches, and produce a candidate landmark list that is passed into a random sample consensus (RANSAC) outlier-rejection algorithm. The output is the pixel location and geo-registered coordinates of the landmark measurement. [3,5]

Terrestrial Testing. In a collaboration effort with the U.S. Natick Soldier Research, Development and Engineering Center, Draper tested its IBAL algorithm with a guided parafoil to support navigation in GPS-denied environments. Testing IBAL on a parafoil resulted in matching a multitude of ground landmarks spatially, and even matching the same landmark at different altitudes. With IBAL, the navigation solution converged with the "truth" trajectory based on GPS data.[3]

To support using TRN in a Lunar landing scenario, Draper's IBAL algorithms were tested on a Masten rocket in Fall 2019 to test their performance at altitudes lower than 1 km and in a rocket-powered lander environment. Furthermore, the testing quantified the degradation in performance when using different GSD levels between landmarks and observed camera image. IBAL was able to match landmarks down to a map resolution of 4 m/pixel (Figure 1). [5]

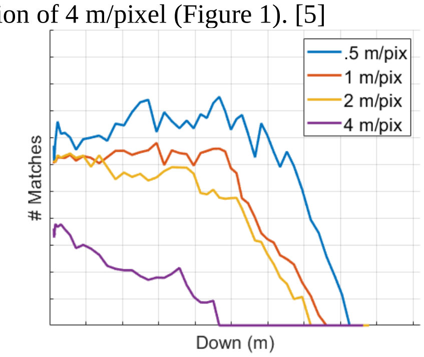

Figure 1. Average number of landmark matches against the estimated vehicle altitude, separated by resolution levels for the 2019 Masten test flight. The x-axis is plotted in reverse with the largest altitude located on the left-most part of the x-axis.[5]

Lunar Landmark Database Generation. The landmark templates for IBAL are sourced directly from Lunar Reconnaissance Orbiter (LRO) images. Draper created an automated landmark generation pipeline from the NASA Planetary Data System (PDS) archives for global or trajectory-specific databases. The pipeline automatically selects candidate landmarks based on their high-contrast feature content, extracts landmarks at multiple image resolutions, and optimally balances between landmark uniqueness and spatial dispersion to maximize database information content. The LRO QuickMap tool[6] was used to visualize the nominal trajectory, camera field of view (FOV) and landmarks in the database at different resolution (pyramid) levels. Figure 2 shows an example of a nominal lunar trajectory, the camera FOV every 25th frame, and the outlines of the landmarks in the database at different resolutions.

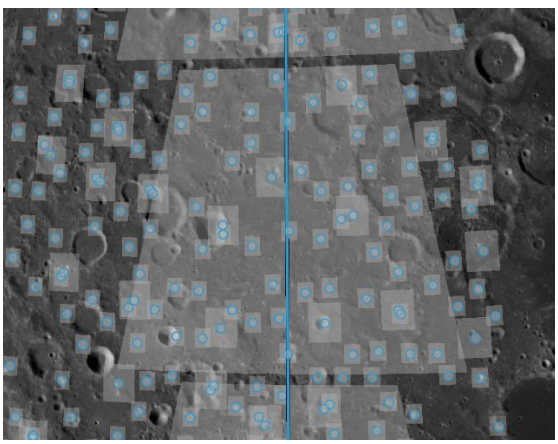

Figure 2. Detail view of a portion of the landmark database. Circles depict the reference points of the landmarks and squares depict the boundaries of the landmark image patches, which were generated at two resolutions (pyramid levels). The trajectory ground track (blue line) and the camera field of view for every 25th frame are additionally shown for relative scale.

Lunar Imagery Simulation. Draper is working with Diamond Visionics and their GenesisMoon software package to develop simulated lunar image generation. The simulated images are a combination of LRO images and high-fidelity digital elevation maps (DEMs). With an inputted trajectory, GenesisMoon is able to quickly render observed images in real-time.

Lunar Orbit Simulated Testing. Using the Lunar landmark database created from LRO images by the automated database pipeline, and observed images from the GenesisMoon simulation, Draper's IBAL algorithm is tested in a low Lunar orbit. The number of measurements matched is greater than 12 for every frame, with the majority of the frames producing at least 20 matching measurements. The accuracy of landmark matches are approximately 5 pixels in error.

References.

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[6] LRO quick map tool https://quickmap.lroc.asu.edu/