LunarNav: Lunar Rover Navigation Using Craters as Landmarks.

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Introduction: The Artemis program requires robotic and crewed lunar rovers for resource prospecting and exploitation, construction and maintenance of facilities, and human exploration. These rovers must operate in sunlit and shadowed areas at high latitudes and must support navigation for 10s of kilometers (km) from base camps. Similarly, a lunar science rover mission concept ("Intrepid") [1] is under study that would traverse approximately 1800 km over four years at low latitudes, driving at speeds in daylight (30 cm/s) that are about 6 times faster than Mars rovers to date and doing short drives at night to maximize science productivity.

These rover mission scenarios require functionality that provides onboard, autonomous, global position knowledge ("localization"), in sunlight, shadow, and during the lunar night. However, planetary rovers have no onboard global localization capability to date; they have only used relative navigation [2], by integrating combinations of wheel odometry, visual odometry, and inertial measurements during each drive to track position relative to the start of each drive. At the end of each drive, a "ground-in-the-loop" (GITL) interaction is used to get an absolute position update from human operators in a more global reference frame. As a result, autonomous rover drives are limited in distance so that accumulated relative navigation error does not risk the possibility of the rover driving into a "keep-out zone"; in practice, drive limits of a few hundred meters are to be expected.

Technical Approach: In this work, we are developing algorithms and software to enable lunar rovers to estimate their global position on the Moon with error less than approximately 10m in sunlit areas and 15m in permanently shadowed areas. This new capability will eliminate the need for ground-in-the-loop interactions with human operators for lunar rover global position estimation, which will substantially increase operational productivity of lunar rovers and will reduce operations costs.

This will be achieved autonomously onboard by detecting craters in the vicinity of the rover and corresponding them to a database of known craters mapped from orbit. As craters are ubiquitous on the surface of the Moon, our approach is applicable everywhere, does not require high resolution stereo imaging from orbit as some other approaches do [3, 4], and has potential to enable position knowledge with order of 10m accuracy at all times.

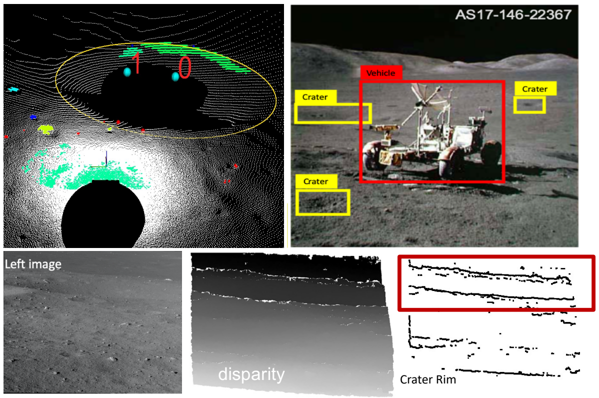

Figure 1: Examples of crater detection algorithms using different sensing modalities: **(top-left)** Using LiDAR. The colored regions identify potential crater back walls based on point normals; numbers identify potential locations after processing; the yellow ring shows the final estimated location of the known crater landmark. **(top-right)** Using monocular images. A convolutional neural network was trained to detect craters (in yellow. Using stereo images. **(bottom)** Disparity cues were used to detect the front and back rim of the crater (in red).

The overall technical LunarNav framework consists of three main elements: 1) crater detection, 2) crater matching, and 3) state estimation. This year the focus of our work has been on the first element. We developed crater detection algorithms based on three different sensing modalities: (1) 3-D point cloud data from lidar, (2) 3-D point cloud and image data from stereo camera pairs, and (3) image appearance from monocular images using.

These algorithms were demonstrated on a dataset of both real and simulated lunar images, in a representative environment. Figure 1 shows qualitative examples of crater detection using the 3 modalities. Furthermore, performance evaluation was done as a function of varied crater sizes, distances to craters and illumination conditions.

References: [1] Robinson M. et al., (2019) AGU. [2] Parker et al., (2010) LPSC. [3] Nefian et al., (2017) LPSC. [4] Scholten et al., (2012) J. of Geophysical Research: Planets, Vol. 117.