LunarNav: Lunar Rover Navigation Using Craters as Landmarks

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Introduction

- Artemis program requires robotic and crewed lunar rovers that must support **long-range navigation for 10s of kilometers** from the base camp. Similarly, a lunar science rover mission concept ("Intrepid") is under study that would traverse ~1800 km over four years.
- These rover mission scenarios require functionality that provides **onboard, autonomous, global position knowledge ("absolute localization"),** in both sunlit and permanently shadowed regions (PSRs)
- However, planetary rovers to date have no onboard global localization capability; they have only used relative navigation. 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 this work, we are **developing algorithms and software to enable lunar rovers to estimate their global position on the Moon with less than 10m in sunlit areas and 15m in PSRs**

System Concept

- **Key Idea: Use Craters as Landmarks** - Detect craters in the vicinity of the rover and autonomously correspond 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, and does not require high-resolution stereo imaging from orbit.
- The LunarNav system frameworks consists of three main elements: (1) Crater Detection, (2) Crater Matching, and (3) State Estimation; this year's work focused on the development of crater detection algorithms.

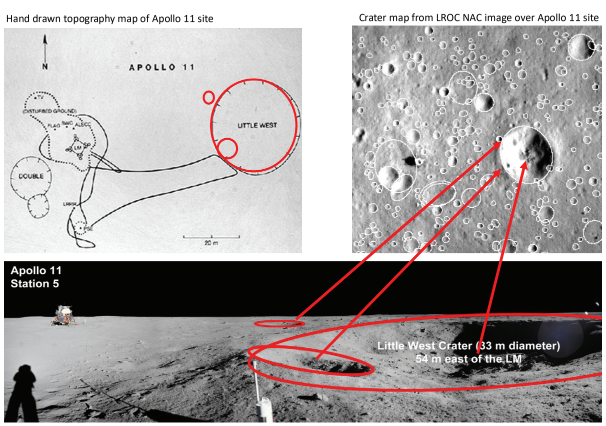

Figure: LunarNav System Concept

Technical Approach

- Developed crater detection algorithms for three different sensing modalities – (1) Using 3D point clouds from LIDAR, (2) Using 3D point clouds from Stereo Point Cloud, and (3) Using deep-learning based pattern recognition with monocular images

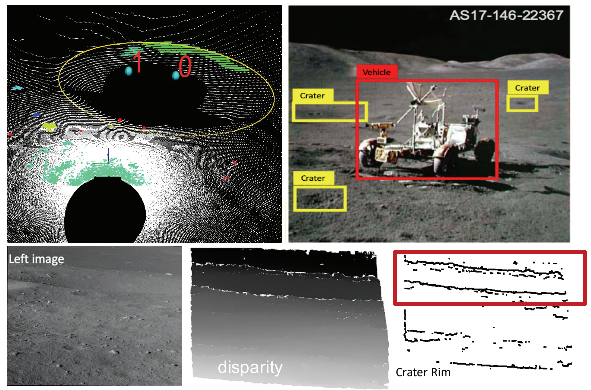

Figure: Crater Detection algorithms using 3 different sensing modalities

- Used both real and simulated sensor data for development and performance evaluation; a large dataset of stereo pairs (1000+) available from Chang'e 3 and 4 missions. Lunar scene simulator was developed using Blender, and a custom implementation of the HAPKE model

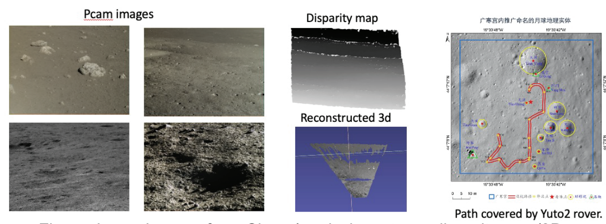

Figure: Lunar Images from Chang'e mission, stereo disparity map/3D renderings and orbital image with reconstructed rover traverse

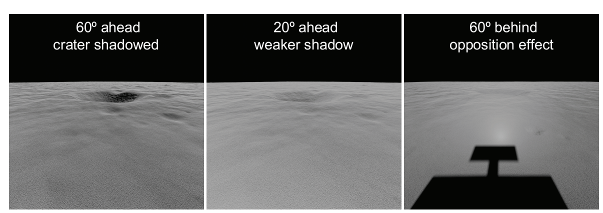

Figure: Simulated images with different sun zenith angles

Experiments and Results

- Studied the performance of crater detection algorithms as a function of crater sizes, distance from the rover, and illumination conditions
- Performed qualitative performance evaluation of algorithms based on stereo and monocular imagery using real lunar data.

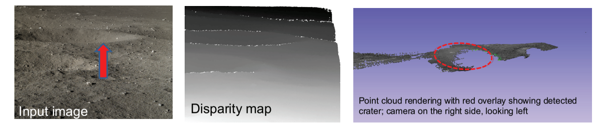

Figure: Qualitative Stereo-based Crater Detection Result

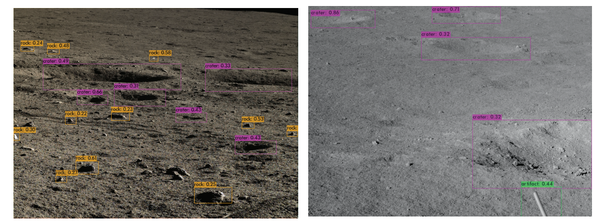

Figure: Qualitative Monocular-based Crater Detection Result

- Performed quantitative evaluation of algorithms using simulated data; Key performance metrics used were : (1) Probability of correctly detected crater landmarks (**P$_d$**), and (2) standard deviation (**σ_p**) of the error in estimating crater position relative to the rover.
- Results from LIDAR-based algorithm shown below; error tends to increase as a function of crater diameter and distance from rover; was able to reliably detect craters within about 15m from the rover

Statistical results suggest rover localization with an error less than 5m is highly probable

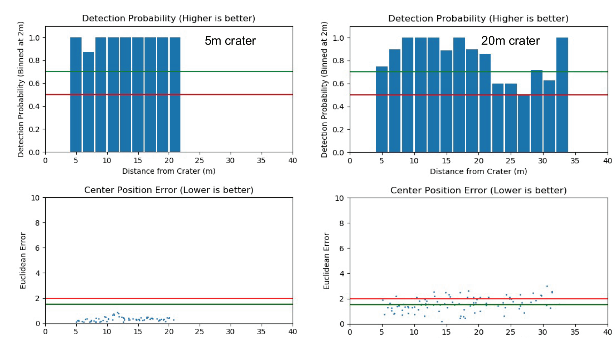

Figure: Quantitative LIDAR-based Crater Detection Result