Investigations into Vision-based Hazard Estimation During Autonomous Lunar Landing
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Motivation
One of the major challenges in landing an autonomous spacecraft on the Moon, or any other planetary body, is to ensure that it does not land on any rocks, lunar, or slopes that can damage the lander and prevent it from carrying out its surface mission. The danger presented by landing hazards can be particularly high for a small lander with a low ground clearance. A hazard detection and avoidance (HDA) system would enable small spacecraft missions to safely and efficiently land on the Moon.

Approach
In order to investigate estimation and guidance strategies, a simulation framework has been developed in MATLAB with the capability of generating and processing synthetic images of lunar terrain. The simulation environment employs a six degree-of-freedom (DoF) dynamics model, driven by lunar environment and actuator models. In addition to the image measurements, an IMU and radar altimeter are modeled. All these sensor measurements are incorporated into an online estimation and guidance system, with retargeting capability to adjust the landing point.

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The simulation can generate a rock field of varying densities based on the Golombok model. Mars rock densities [1] using a total rock area coverage parameter of 10%. For convenience, generated rocks are cubes. An image is created using a projective camera model and the center location of the spacecraft camera. Pixel intensity is proportional to object height, as long as it is above the camera's spatial resolution. A representative image, taken at a different altitude, is shown in Figure 2. The lander pose and intersection of this image with the ground plane are shown in Figure 2.

The primary method to be used for detecting rocks in orbital and descent imagery is based on a technique developed at JPL, which detects rocks based on the shadows cast [2]. The method segments the image, based on entropy measures, into regions of light and shadows. The shadow region can then be differentiated into individual rocks. Rock position and size can be estimated if the sun vector and spacecraft altitude are known.

A comparison between rocks detected in both synthetic and gantry-collected images is shown in Figure 3. Correct detections are shown in green, false positives identified in white and false negatives shown in red.

One shortcoming of the current implementation of synthetic imaging is that the ground plane has no texture or elevation changes other than the rock hazards. The testbed images show the shadow-based method changes in local slope when a shadow is visible. These non-textured rocks, these depressions or ridges could potentially be hazardous to the lander.

Future work will integrate additional slope estimation strategies [2] with a fine investigation of the depression estimation performance of the shadow technique.

Rock Detection in Images
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Recursive Estimation Framework
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Hypothesis: We can improve the chances of successfully detecting and avoiding hazards if we fly a trajectory that not only steers the spacecraft to the landing point, but also actively gathers hazard information.

A closed-loop simulation has been run with the rock detection and filtering techniques described previously. These maps, shown in Figure 4, show the evolution of the hazard as they are detected, images matched in a database, and finally added to the filter state. Rocks found in images are shown in magenta. As the camera altitude decreases, the accuracy of rock detection increases. Small rocks, which might previously have been identified as one large rock, can be differentiated from each other. Objects that are consistent with new information, such as these large rocks, are deleted in the database and can be seen in dashed red, as in Image 7. The object must be observed at least twice in order for it to be added to the filter state, which are then shown in black.

References