Flash LIDAR Based Relative Navigation around Small Bodies

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Missions to small bodies, such as asteroids and comets, are important for furthering our understanding of planetary science, hazardous asteroid mitigation, and resource utilization. Spacecraft have already flown to small bodies, such as the Hayabusa mission to the asteroid Itokawa and the Rosetta mission to comet 67P/Churyumov-Gerasimenko, and several missions are currently in development, such as OSIRIS-REx to the asteroid Bennu, and the Asteroid Redirect Mission. The small size of these bodies, and their distance from Earth, hinder ground-based observations and initial characterization of them, and once arriving at the small body, there is a lag in communications that can range from 15 to 30 minutes. This directs engineering research towards spacecraft autonomy such that the spacecraft can respond quicker in these uncertain situations, and enable more interesting missions profiles such as landings or touch-and-go missions.

The current state-of-the-art for relative navigation is the use of optical images (OpNav), which has heritage on missions such as Rosetta, DAWN, Hayabusa, and NEAR. This technique requires processing thousands of images to create "landmark maps" of the surface, while an onboard altimeter is required to resolve the scale bias of the 2D images. Creating these maps involves an iteration process, which can take significant processing time and must be performed on the ground.

This research focuses on using a flash LIDAR instrument for relative measurements around a small body for orbit determination (OD). The flash LIDAR measurement returns an array of altimetry measurements, and can be treated as a three-dimensional picture in which each pixel is a range. Unlike optical images, the relative distance from the spacecraft to the surface of the body is already included in the measurement, and flash LIDAR can be used in any lighting conditions. The measurement processing technique used in this work only requires a well-defined onboard shape model, and sidesteps the image correlation process within OpNav. Therefore, these measurements show promise for reducing the processing power for relative navigation and increasing spacecraft autonomy.

Previous work has studied using flash LIDAR for OD in stable terminator orbits about the asteroids Itokawa and Bennu, as well as a descent orbit to the surface of Itokawa, while utilizing an unscented Kalman filter (UKF) for the state estimation. This research expands on these studies to test the robustness of using flash LIDAR measurements by introducing errors in the asteroid shape modeling and sensor pointing. The focus is to delineate the shape model resolution needed onboard, and the maximum pointing error allowed in order to provide an accurate OD solution. Different resolutions of facet/vertex asteroid shape models are investigated for OD, using a lower fidelity model for the computed measurements, and a higher fidelity model for the truth measurements.

In addition, this work explores the measurement processing techniques chosen. The current method compares the range of corresponding pixels in the observed and computed images to determine a state update. While this is simple to implement, it requires an overlap of corresponding pixels between the observed and computed images. This work explores how to process these three-dimensional images, the limitations, and the ease of implementation. It also compares the performance of a linearized Kalam estimation filter with the UKF.

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