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ON THE USAGE OF MULTI-BEAM LASER ALTIMETRY FOR SMALL-BODY EXPLORATION

Abstract

Planetary exploration missions involve extensive and costly operations in order to plan, program and execute procedures especially during approach, rendezvous and EDL. The main factor for such operational overload is the a priori unknown dynamical environment of the target body: its gravity field, global shape, local topography and the observability conditions of areas of interest, such as a targeted landing site. The restricted capability to deal with the related uncertainties in real time imposes stringent restrictions in the flight-flexibility and operational scheduling, limiting scientific return. Reliable navigation is of major importance to enable science operations in target proximity. In fact, orbit determination itself is the basis for the study of bulk parameters of the target body - i.e., mass, density, gravity field and internal structure.

Light detection and ranging (LiDAR) devices are progressively being considered as advantageous navigation sensors for proximity operations in planetary exploration. The development of rapid LiDAR scanners and flash illumination technology has led to the assembly of two units on NASA's OSIRIS-REx spacecraft to sample asteroid Bennu in 2020. An optical communication terminal could be assembled on ESA's AIM spacecraft to operate as LiDAR altimeter. Future lander missions could introduce imaging LiDAR sensors to support navigation and hazard detection. Further uses of imaging LiDAR for planetary remote sensing are envisioned, especially as technology undergoes significant development.

In this paper, we investigate the orbit navigation performance about small planetary bodies using imaging LiDAR sensors. The navigation performance is assessed through software simulation. Based on current prototypes, a configurable sensor model has been implemented. The sensor model delivers direct altimetry measurements towards the target surface. Measurements are affected by the relative geometry between target and observer, camera-intrinsic parameters and motion dynamics. The sensor model is a configurable module which can be executed in distinctive operational modes: single-beam altimeter, multi-beam altimeter (3 - 4 beams) and camera mode (full-matrix detector).

The positioning performance of a pure LiDAR-based navigation system is evaluated for a spacecraft flying in proximity of selected asteroids. Observations are generated based on an input reference trajectory, spacecraft attitude and target spin. Point-cloud alignment and registration methods inherited from robotic computer vision are evaluated for available asteroid 3D shape models. An extended Kalman filter is used to estimate the spacecraft state in target body-fixed reference frame. The error in the state estimates and the observation residuals are assessed for different orbit scenarios, pointing modes and sensor configurations.