Paper ID: 42474
oral
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IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IP)

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VISION BASED STATE ESTIMATION USING A GRAPH-SLAM APPROACH FOR PROXIMITY OPERATIONS NEAR AN ASTEROID

Abstract

Autonomous navigation of the spacecraft around smaller celestial bodies is a challenging task because of the low dynamic environment and non-gravitational perturbations. Each asteroid poses a set of distinct characteristics that are described by its orbital motion, rotational axis, rotation duration, dynamics, shape, emissive properties and mineral constituents, etc. Small body exploration missions offer enough time to process the navigational information on-board favored by the low dynamic environment. Successful autonomous navigation depends on the spacecraft's knowledge of its environment and robust prediction of the dynamics near the asteroid. Also, the estimation approach must be robust enough to accommodate the changes in environmental conditions and common errors emerge from false data associations.

In this paper, we present a graph-based SLAM (Simultaneous Localization and Mapping) framework to estimate the state of the spacecraft, asteroid as well as landmark locations to help navigate a spacecraft in the proximity of a rotating asteroid. While most SLAM approaches use a wide array of sensors, the proposed visual SLAM framework uses registered images from the navigation camera and altimeter data for the depth perception. Prediction and estimate are two key elements of a robust SLAM approach. To predict, spacecraft's motion and asteroid's motion are represented by rigid body dynamics and used while constructing the motion model. The simulated images from the navigation camera is used to extract the locations of the distinct features available on the asteroid's surface and used in the measurement model. The motion and measurement data during each key-frame combined to construct the graph where each variable depends on a few state nodes and constrained by the conditional probabilities extracted from the models. The graph is solved through iterative optimization techniques over the entire duration to estimate the optimized trajectory of the spacecraft, asteroid's pose and landmark location. Experiments are performed on a simulated asteroid dataset through different realistic orbital conditions, including shadowing from the sun. Apart from a reconstructed 3D point cloud of the asteroid and the trajectory of the spacecraft, the estimates also include other unknown parameters such as center of rotation, rotational axis. The detailed results from the simulation on the accuracy of the spacecraft's state, asteroid's state and landmark's position are presented.