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AUTONOMOUS NAVIGATION OVER UNEXPLORED CELESTIAL BODIES

Abstract

Space missions aimed at orbiting arbitrary Small Celestial Bodies (SCB) that have not been previously examined, like most asteroids, would undergo significant navigation challenges. These challenges are mainly due to the lack of knowledge about the SCB gravitational field, which entails high uncertainties in the dynamical model of translational motion (DMTM) of the spacecraft with respect to the SCB. For orbiting a previously unexplored SCB, there will not be a predefined coordinate system to which the taken measurements could be associated, which adds complexity to the problem. This situation raises the need to devise strategies that can concurrently solve the problems of autonomous navigation of spacecraft around these bodies and estimation of a DMTM appropriate for navigation purposes.

This work proposes a novel approach that can accomplish both tasks autonomously, solely based on the cooperative interaction of multiple spacecraft using computational vision and range measurements. Assuming the spacecraft are equipped with stereo-cameras and range finders, we propose a measurement scheme that allows us to solve for the unknowns sought for navigation (position and velocity resolved in an arbitrary well defined frame) and those pertaining to the DMTM (coefficients characterizing the gravitational field of the SCB, its angular velocity and possibly its rate of change). Onboard stereo-cameras would track landmarks on the surface of the SCB, determining their position, velocity and acceleration, in the camera frame. We show that combining measurements taken by three spacecraft provides sufficient information to estimate the mentioned unknowns with a 2×2 associated gravitational field. Furthermore, using measurements taken by a higher number of spacecraft would provide information to estimate a gravitational field of higher degree and order. A sequential estimator is presented that efficiently determines the aforementioned quantities. Although we show that determining the rate of change of the angular velocity of the SCB would be feasible in this scheme, the small values that this quantity might have makes this endeavor highly challenging considering the accuracy of existing sensors. Hence, an alternative approach that assumes this quantity to be negligible is also elaborated.

This autonomous approach could greatly benefit deep space exploration missions where there is no a-priori knowledge about the gravitational fields of the orbited celestial bodies.