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LOW-ENERGY TRAJECTORY DESIGN AND AUTONOMOUS NAVIGATION TO FLYBY NEAR-EARTH ASTEROIDS USING CUBESATS

Abstract

CubeSat technology is rapidly evolving and now the first missions beyond LEO have been planned. These first 6U interplanetary CubeSats will pave the way for future missions and reach far destinations such as the Moon, near-Earth asteroids, and even Mars. Interplanetary CubeSats represent today an attractive solution for planetary exploration since the implementation and development costs of CubeSat missions are largely reduced compared to those of traditional missions. Ground segment operations, however, remain a key challenge for CubeSats in deep-space travel. Large costs and extensive workforce are required for the use of ground stations such as the Deep Space Network (DSN), and ground operations still represent a very significant fraction of the mission budgets.

In response to the current interest in CubeSats and in their potential applications for planetary science, this work studies the feasibility of using autonomous CubeSats to flyby near-Earth asteroids. Two main matters are addressed in this study: (1) low-energy (impulsive and low-thrust) trajectories to encounter asteroids using 3U and 6U CubeSats are designed in a high-fidelity ephemeris model, and (2) the flyby accuracies (i.e., flyby altitudes) that could be achieved using autonomous optical navigation are evaluated.

In preparation for future piggyback opportunities, this study specifically considers the possibility of deploying a CubeSat from a larger spacecraft in a periodic orbit around the first (L1) or the second (L2) Sun-Earth Lagrange points. These orbits are common destinations for missions to observe the Sun and outer space, and two more missions will be launched to L2 by 2020. Despite the limited propulsive capabilities of CubeSats, quasi-unstable invariant manifold trajectories provide low-energy solutions to encounter near-Earth asteroids. Flyby trajectories are initially designed here in the CR3BP, and their dynamical substitutes are then computed in a full ephemeris model.

Preliminary results show that 11 near-Earth asteroids could be encountered by a 3U CubeSat between 2019 and 2025. However, considering no navigation support from NASA's DSN, only 6 of them feature favorable enough illumination conditions for a successful optical navigation campaign. Considering uncertainties in the asteroid ephemerides, and the limited performance of sensors and actuators, flyby altitudes of $\sim$500 km are shown possible via Monte-Carlo simulations.

This work ultimately assesses the capability of current CubeSat technology to provide a real low-cost

solution for small-body exploration. The trajectory design, upcoming flyby opportunities, achievable flyby altitudes, and proposed navigation strategies for autonomous CubeSat missions are presented and discussed here in detail.