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NEAR-EARTH ASTEROID RENDEZVOUS MISSIONS FOR IMPACT AVOIDANCE USING SOLAR SAILCRAFT

Abstract

Near-Earth asteroids (NEAs) pose significant risk to life on Earth. The recent discovery of 2012 DA14, scheduled to miss Earth by a mere 27,000 km on February 15th 2013, highlights the need for new missions to demonstrate NEA trajectory modification technologies. In this paper, we propose flying a solar sailcraft to an NEA. The spacecraft would use its solar sail to both rendezvous with the NEA, as well as attach its sail to the asteroid's surface in order to alter its trajectory. Unlike previous proposals that use solar sails for kinetic energy impacts, such a spacecraft could travel from potentially hazardous object (PHO) to PHO, modifying their trajectories in order to avoid Earth.

Solar sails, large aluminized Kapton films that utilize the Sun's radiation pressure for propulsion, are attractive for this application. As some NEAs have low delta-vs with respect to Earth and small gravity, a solar sail can readily provide the required mission delta-v. Additionally, as a low cost propulsion technology with free delta-v provided by the Sun, many such spacecraft may be deployed to multiple PHOs far in advance. Lastly, the solar sail can be attached to the asteroid's surface, utilizing the same solar radiation pressure in order to nudge the NEA off of its current course.

The challenge of using solar sails for rendezvous with NEAs on elliptic heliocentric orbits is that they only permit thrust vectoring in a half-space orthogonal to the light source. We present a new proof of controllability in this case based on the linear time-varying Tschauner-Hempel (TH) equations for relative motion on elliptic orbits.

As the TH equations are time-varying, we employ our recently developed forward-integrating Riccati (FIR) controller in order to stabilize the spacecraft to a desired orbital position. Unlike the backwards-in-time Riccati controller arising in optimal control theory, the FIR controller can achieve stabilization of a linear time-varying system without requiring future knowledge of time-varying model parameters. In addition, the FIR controller does not require knowledge of the perturbation forces acting on the spacecraft, such as the NEA's gravitational field, and is robust to many error sources including severe thrust direction constraints.

We demonstrate via numerical simulations that the FIR controller successfully rendezvous the solar sailcraft with various NEAs headed towards Earth impact, and that the sail effectively alters their trajectories.