Autonomous Navigation of a Formation of Spacecraft in the Proximity of a Binary Asteroid

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Binary asteroids are systems composed of two asteroids orbiting around their common barycentre. Some of them are part of the Near Earth Object population, like 2000 DP107, or 65803 Didymos (1996 GT),an Apollo asteroid discovered on April 11, 1996, that is now the target of the AIDA mission.

Navigating in the proximity of an asteroid is in itself a challenging task due to the complex dynamics induced by the irregular gravity field of the asteroid, the gravity of the Sun and solar radiation pressure. Even more challenging is to navigate a formation of spacecraft with heterogeneous sensors. Recent work by one of the authors demonstrated the possibility to autonomously navigate a formation of spacecraft with a distributed fault-tolerant autonomous system [1].

The complexity increases even further in the case of a binary due the complex interaction between the primary and the secondary.

This work extends, to the case of a binary system, previous results on the navigation of single spacecraft and of a formation of spacecraft in the proximity of an asteroid [1][2]. The paper will focus, in particular, on the maintenance of a subset of periodic solutions that can be of particular interest for the exploration of a binary system or to conduct deflection and prospection experiments. Of particular interest are periodic solutions around the dynamic equivalent of the Lagrange points L4 and L5 of the binary system and quasi-satellite orbits. Some of these periodic solutions were shown to be of particular interest to extract surface and subsurface material with laser ablation[3].

The dynamical model in the proximity of the binary system includes the gravity of the two asteroids, the gravity of the Sun and solar radiation pressure. Each spacecraft is equipped with a minimum set of sensors under the assumption of low power and low computational capabilities. Following previous work from the authors each spacecraft is assumed to carry a laser range finder, a camera and an inter satellite link that allows sharing information with other spacecraft in the formation and provides range and range rate information.

Two scenari will be considered in this study: one in which one spacecraft operates as master and provides data relay with the Earth, the other in which all spacecraft are identical and the navigation is fully distributed. It will be shown how distributing the navigation and state estimation process increases the resilience of the formation and allows for a partial or full failure of one or more sensors. Given the nonlinear nature of the dynamics the paper will present a novel filtering and state estimation algorithm based on a generalised polynomial algebra[4] that expands the state dynamics and the measurement model in Chebyshev polynomials. This filtering process will be compared to a more traditional Unscented H-infinity Filter. Both filtering techniques will rely and a common pool of measurements shared, asynchronously, among the members of the formation.

References

[1] Vetrisano M., Vasile M. Autonomous Navigation of a Spacecraft Formation in the Proximity of an Asteroid. Advances in Space Research, Volume 57, Issue 8, 15 April 2016, Pages 1783–1804.

[2] Vatrisano M., Vasile M., Colombo C., Asteroid Rotation and Orbit Control via Laser Ablation. Advances in Space Research, Volume 57, Issue 8, 15 April 2016, Pages 1762–1782.

[3] Thiry, N. and Vasile, M., Binary Asteroid Manipulation with Laser Ablation. HPLA/DE, Santa Fe, 4-6 April 2016.

[4] Riccardi, A., Tardioli, C., Vasile, M., An Intrusive Approach to Uncertainty Propagation in Orbital Mechanics Based on Tchebycheff Polynomial Algebra. Astrodynamics Specialists Conference, AAS 15-544, Veil, Colorado, USA, 9-13 August 2015