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Small Bodies Missions and Technologies (5)

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APPLICATION OF DISCRETE MECHANICS AND OPTIMAL CONTROL TO SPACECRAFT IN NON-KEPLERIAN MOTION AROUND SMALL SOLAR SYSTEM BODIES

Abstract

For scientific missions to small solar system bodies and asteroids in particular one might opt to position the spacecraft in non-Keplerian motion around the body. In this paper we propose the use of the discrete mechanics and optimal control (DMOC) approach to find suitable and sustainable trajectories for these missions.

Such trajectories include stand-off hovering orbits and points, which are interesting not only for science but also for deflection strategies involving gravity tractor designs. In such an orbit, the spacecraft has to maintain a small, fixed distance to the asteroid and therefore counteract the asteroid's gravity while being subjected to the orbital dynamics of close proximity operations in a non-uniform gravitational field. The asteroid's shape and gravity field is modeled using spherical harmonics. For capturing the effects of the non-uniform gravitational field it is sufficient to restrict the simulation time to a few revolutions of the asteroid. Hence, orbital motion around the Sun can be neglected, yielding a two body problem. Recent advances in solar sail technology and, especially for station-keeping, the promised reduction in propellant resources lead us to investigate a spacecraft modeled as a bus connected to a rectangular sail through a fixed boom. Solar pressure exerts a force on the sail which is approximated by a realistic optical force model. In order to counter the perturbing forces, the spacecraft is 3-axis stabilized. Due to the conservative nature of the underlying system, we utilize Lagrangian mechanics, leading to a convenient optimal control formulation in DMOC. DMOC is based on a discretization of the Lagrange d'Alembert principle of the dynamical system, as opposed to, e.g., collocation or multiple shooting which rely on discretization of the associated equations of motion. The resulting forced discrete Euler-Lagrange equations respect the variational structure of the system and are used as optimization constraints for a given objective function. The resulting restricted optimization problem is then solved using an SQP solver.

Our approach provides a new and promising perspective on spacecraft operations around arbitrarily shaped bodies and can directly be utilized as a design tool for system engineering. We demonstrate the applicability of DMOC to close proximity hovering and also pave the way to extend this approach to building a library of optimal reactions to variations in unknown gravity fields, thus enabling direct scientific operations without cartographic prerequisites.