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SPACE DEBRIS SYMPOSIUM (A6)
Space Debris Removal Issues (5)

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SPACE DEBRIS REMOVAL WITH AN ION BEAM SHEPHERD SATELLITE: DYNAMICS AND CONTROL

Abstract

Among the different strategies proposed to actively remove space debris from low and geostationary Earth orbits, the use of a highly collimated neutralized plasma beam pointed at a generic debris from a nearby "shepherd satellite" has been proposed recently. The beam would transfer enough momentum to modify the orbit and/or attitude of the debris from a safe distance in a controlled manner without the need for docking. Although in principle conceptually simple, the proposed removal approach involves new and interesting challenges from the dynamics and control point of view. Most importantly, the debris shepherd and the space debris should be simultaneously de-orbited (or re-orbited) in a controlled and reliable way, keeping a safe distance between each other and avoiding collisions. This implies not only the need for advanced sensors, actuators and control strategies, but also, and first of all, the need for accurate models describing the dynamic interactions between the debris and the plasma beam. The present article studies such interactions and their implications on the relative position control problem of the debris with respect to the shepherd satellite. First we model the axial evolution of a collimated axisymmetric quasi-neutral beam consisting of singly-charged highly-supersonic ions and isothermal electrons. Plasma beam characteristics of state-of-the-art ion thrusters are considered. Next we integrate the transmitted force and torque by the beam on a debris of spherical and cylindrical shape as a function of its position and attitude with respect to the beam axis. We then proceed with the relative equations of motions of the shepherd-debris system with respect to a local orbiting frame including the beam force perturbation, and the attitude dynamics of the orbiting debris with the disturbing torque exerted by the beam. The coupled relative dynamics and relative attitude equations are integrated numerically with the aid of an in-house custom developed simulation software. After demonstrating that the beam force does not add stability to the (already unstable) relative dynamic problem, we design a simple PD control strategy for the shepherd satellite and compute the boundary of the stable region in the control parameter space. Results show that under the assumption that an accurate relative position estimation is available, the proposed control scheme provides relative position stability for quasi-circular or mildly eccentric low Earth orbits.