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A NEW GUIDANCE AND CONTROL ARCHITECTURE FOR ORBIT DOCKING VIA FEEDBACK LINEARIZATION

Abstract

For future robotic missions (about Earth, Moon, or Mars), automatic rendezvous and docking represents a major challenge and a key operational technology. This research is focused on the analysis, design, and numerical testing of an effective guidance and control architecture for close-range maneuvering of a chaser spacecraft toward a target vehicle. The final goal is in attaining safe approach and docking of the chaser with the target. Docking is feasible only if the chaser can approach the target along a specified direction (with no collision) and finally attain the proper dynamical conditions (on relative position and velocity) that allow a safe connection. To this end, this work considers a chaser vehicle equipped with a single thruster (for trajectory corrections) and an array of single-gimbal control momentum gyroscopes (for attitude control). The relative dynamics of the two vehicles, placed in nearby low Earth orbits, is modeled using the (exact) nonlinear Battin-Giorgi equations of relative motion, with the inclusion of all the relevant perturbations, i.e. harmonics of the geopotential, atmospheric drag, solar radiation pressure, and third body gravitational pull due to Moon and Sun. Unlike several former contributions in the scientific literature, this research considers the orbit perturbing actions on both vehicles, proving that this is crucial for a successful maneuver. Feedback linearization is used as an effective real-time technique, with the intent of identifying the thrust direction and magnitude needed to drive the chaser toward the target, while satisfying the final conditions for docking. Because the thruster has specified orientation relative to the body axes of the chaser, the desired thrust direction leads to defining the commanded attitude. This is pursued using a nonlinear attitude control algorithm, whose convergence properties are guaranteed by the Lyapunov stability theory, in conjunction with the LaSalle invariance principle. A specific (redundant) configuration of single-gimbal control momentum gyroscopes actuates the attitude control action. In this work, the steering law of these devices is based on the Moore-Penrose pseudoinverse, with singular value decomposition of the actuation matrix, employed as an effective approach for singular direction avoidance. Trajectory, attitude, and actuation algorithms are integrated in a unified architecture for guidance and control. Monte Carlo simulations are run, in the presence of random initial attitude and nonnominal flight conditions for the chaser, related to stochastic navigation errors. The numerical results unequivocally demonstrate that the guidance and control methodology at hand is rather effective and accurate for safe orbit docking.