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Author: Mr. Dario Sanna
Sapienza University of Rome, Italy

Mr. Leonardo Russo
DLR (German Aerospace Center), Germany
Mr. David Paolo Madonna
Sapienza University of Rome, Italy
Dr. Mauro Pontani
Sapienza University of Rome, Italy
Prof. Paolo Gasbarri
University of Rome "La Sapienza", Italy

CONSTRAINED RENDEZVOUS AND MATING WITH GATEWAY USING NONLINEAR CONTROL TECHNIQUES

Abstract

Gateway will represent a logistic outpost with a vital role for the future lunar and deep space exploration, as well as for a variety of onboard experimental activities. Orbit dynamics in the proximity of Gateway is strongly perturbed, and in this research it is modeled in a high-fidelity multibody dynamical framework, with the inclusion of all the relevant orbit perturbations. Orbit motion relative to Gateway is described using a modified Battin/Giorgi approach that considers Gateway as the reference vehicle, unlike former contributions that usually assume that the reference spacecraft travels a Keplerian orbit. The rendezvous and mating maneuver is split in two phases: (a) close-range rendezvous, starting from a relatively short distance, and (b) final approach and mating. Phase (a) includes coordinated trajectory and attitude control and is aimed at driving the spacecraft toward Gateway, with final conditions such that in phase (b) the spacecraft naturally drifts toward Gateway, with no propulsion. In this way, in phase (b) attitude maneuvering has no effect on trajectory and can be designed in order to achieve the final correct orientation. In phase (a), a novel hybrid nonlinear control technique is proposed and tested, and includes two arcs, i.e. (i) saturated-thrust arc with control gain adaptation, and (ii) time-varying-thrust-magnitude arc, yielded through feedback linearization. Strict collision avoidance constraints, with the definition of a suitable exclusion region, are included in the real-time iterative update of the tracked trajectory. The time-varying thrust components identify the commanded pointing direction of the spacecraft, and a nonlinear control algorithm, which enjoys global stability properties, is used. Actuation is demanded to an array of momentum exchange devices. In phase (b), attitude maneuvering is carried out (while trajectory naturally drifts), and two distinct scenarios are considered, i.e. (1) docking and (2) berthing. Scenario (1) requires that the spacecraft arrives at the Gateway docking port with near-zero relative velocity and angular rate. Scenario (2) assumes that the Gateway is equipped with a robotic arm, able to grasp the spacecraft, provided that the latter reaches the final correct position and attitude. In this research, arm manipulation is also described, using the Kane's approach for multibody spacecraft. Trajectory planning of the end effector of the manipulator is addressed as well, aimed at efficient and safe grasping. Numerical simulations, in both nominal and nonnominal flight conditions, show that the nonlinear control techniques developed in this study are effective for spacecraft rendezvous and mating with Gateway.