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Author: Mr. Riccardo Santoro
Sapienza University of Rome, Italy, santoro.1733475@studenti.uniroma1.it

Dr. Mauro Pontani
Sapienza University of Rome, Italy, mauro.pontani@uniroma1.it

ORBIT ACQUISITION, RENDEZVOUS, AND DOCKING WITH A NONCOOPERATIVE CAPSULE IN A MARS SAMPLE RETURN MISSION

Abstract

The Mars sample return mission is intended to perform autonomous rendezvous and docking, aimed at gathering Mars samples, stored in an orbiting capsule. This study focuses on guidance and control techniques for the three phases of a typical Mars sample return mission: (i) orbit acquisition, (ii) phasing and correction maneuvers, and (iii) rendezvous and docking with the orbiting sample (OS) capsule, which is assumed to be a noncooperative vehicle. The chaser vehicle is assumed to be equipped with both chemical and electrical propulsion. The latter is used in phase (i), in conjunction with nonlinear orbit control. This can be regarded as an autonomous guidance technique also in the presence of nonnominal flight conditions, and leads to defining a saturated feedback law for the thrust magnitude and direction, with remarkable global stability properties. In phase (ii), a phasing strategy and proper correction maneuvers are designed, to reach suitable parking conditions, identified through the orbital commensurability criterion. Then, a guidance, control, and actuation architecture is proposed for phase (iii), split in arc 1 (proximity maneuvers) and arc 2 (final approach and docking). In both arcs, relative motion is modeled using the nonlinear Battin-Giorgi equations, with the inclusion of all the relevant perturbations. Feedback linearization is employed for trajectory control, aimed at tracking a reference path, which is iteratively defined from the estimation of the rotational state of the capsule. The final goal is in approaching the OS capsule with correct alignment with the docking interface. In arc 1, attitude control aims at pointing the main chemical thruster toward the desired direction, while orienting the solar panels to maximize their irradiation. In arc 2, a set of lateral thrusters is used, and attitude is driven toward the correct alignment that allows safe docking. Two distinct, nonlinear feedback control laws, enjoying quasi-global stability properties, are used in arcs 1 and 2 for attitude control. Attitude actuation is demanded to a pyramidal array of single-gimbal control momentum gyros. Their steering law employs singular direction avoidance based on singular value decomposition of the actuation matrix. Chemical propulsion is ignited using pulse width modulation (in both arcs), with a suitable thruster selection algorithm (in arc 2). A large set of perturbations (including navigation and actuation errors) are modeled. Monte Carlo simulations prove that the guidance, control, and actuation architecture at hand is effective to complete safe docking with a noncooperative OS capsule.