Paper ID: 71120
oral
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IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IPB)

Author: Mr. Claudio Vela
University of Naples "Federico II", Italy, claudio.vela@unina.it

Mr. Vincenzo Porrino
Università degli Studi di Napoli "Federico II", Italy, v.porrino@studenti.unina.it
Prof. Roberto Opromolla
University of Naples "Federico II", Italy, roberto.opromolla@unina.it
Dr. Giancarmine Fasano
University of Naples "Federico II", Italy, g.fasano@unina.it

COORDINATION AND REACTIVE CONTROL OF MULTI-SPACECRAFT FORMATIONS FOR EARTH OBSERVATION

Abstract

The interest in the realization of distributed space systems has been flourishing for the last decades, fostered by the notable advantages they grant. Formations, in particular, are enabling advanced capabilities in every context to which they are applied (from Earth Observation and Geodesy to Space Sciences), as well as increased systems' flexibility and maintainability. Accurate autonomous guidance, navigation and control (GNC) solutions are essential to fully exploit formations' potential, with stronger independence from ground control and immediate and safer response to contingencies. Within the framework of Earth Observation missions based on distributed radars, this work presents an innovative approach to formation control able to deal with any number of assets, exploiting a combination of a Finite State Machine (FSM) for decision making and a robust Proportional-Derivative (PD) controller. Underlying assumptions include the use of low-thrust propulsive systems, the presence of inter-spacecraft communication links and the employment of carrier-phase differential GNSS for relative navigation. The states of the FSM define task-assignment rules and compute the required manoeuvres for each member of the formation, based on periodic estimates of navigation states. The latter are exploited for predictive propagations to allow collision detection and consequent prompt reactions. When a spacecraft is commanded to manoeuvre by its FSM, robustness to temporary failures and uncertainties on thrusting actions is enforced through the PD controller, ensuring that each asset follows the assigned trajectory through the designation of an error box. As the spacecraft crosses it, the PD control is activated to bring it back on the nominal path. The performance of the system is evaluated in an integrated simulation environment, exploiting NASA's open-source General Mission Analysis Tool for orbital propagation and MATLAB for task-assignment and control action's evaluation. A contingency scenario is simulated, in which two spacecraft of a larger formation are in route for collision. Thanks to the FSM, they can determine which of them must perform a collision avoidance manoeuvre and later return to its slot within the formation. The PD controller is tested applying random perturbations on thrusts' magnitude and orientation for the manoeuvres defined by the FSM. The control system promptly deals with the contingency and allows the formation's nominal state to be autonomously recovered with a contained cost. The FSM correctly performs formation's guidance while the PD controller efficiently limits the effects of thrust errors on the manoeuvring spacecraft, with residual position and velocity errors at cm and mm/s levels.