IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation and Control (2) (4)

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FORMATION KEEPING IN VERY LOW-EARTH ORBIT: THE VULCAIN MISSION CASE STUDY

Abstract

In recent years, Very Low Earth Orbits (VLEO) are becoming more and more attractive to answer the challenging Earth Observation data resolution needs. On the other hand, space traffic increase asks for space assets to move towards on board autonomy to relieve ground segment congestion. Model Predictive Control (MPC) represents one of the most promising guidance and control techniques to increase spacecraft autonomy and respond to this need, due to its capability of generating optimal control profiles directly on board in compliance with operational and technological constraints. The paper proposes the MPC strategy designed to cope with the autonomous control of the two formation-flying VULCAIN CubeSats, designed to orbit on VLEO. VULCAIN is an Earth Observation scientific mission to image in VIS-IR the Earth volcanoes by means of two 12U CubeSats in train formation. The embarked scientific cameras need for instruments co-pointing to ensure that their footprints overlap. Therefore, an onboard optimal Station Keeping plan shall be generated on board to cope with the perturbed dynamics according to scientific acquisitions time windows, along which active control is forbidden. Complexity is added by the low authority of the actuator – namely an electric thruster for CubeSat applications – which is limited in both thrust magnitude and vectoring. The proposed controller compensates the relative orbital deviations from the reference slots exploiting the system linearized and convexified dynamics expressed in quasi-nonsingular Relative Orbital Elements (ROE). That choice allows expressing fast and efficient solvers for the online optimization while including orbital perturbations in the prediction. Due to the MPC strong dependence on the state estimation quality, ROE are computed onboard with the desired accuracy from simulated GNSS measurements integrated with state information coming from the inter-satellite link via appropriate filtering techniques exploiting the knowledge of the absolute and relative orbital dynamics. Numerical simulations run with the controller in closed loop with a high-fidelity orbital propagator including major perturbances in VLEO and considering realistic measurement errors for GNSS receivers. Two particularly meaningful scenarios for VULCAIN and VLEO missions are discussed in the paper, namely, the optimized formation keeping and a maneuver to change the Local Time of Ascending Node. Results highlight good accuracy of the designed GNC scheme in maintaining the reference slot with feasible control profiles for the formation, while prescribing control actions only when no other operation is foreseen. Furthermore, light computational times confirm the applicability of this solution for on board implementation.