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NMPC-BASED GUIDANCE AND CONTROL FOR AUTONOMOUS HIGH-THRUST NON-COPLANAR LEO-GEO MISSIONS

Abstract

Space missions are based on two fundamental operations. The first one is mission planning, or guidance, which is typically carried out on-ground by employing the classical astrodynamic methods. The second one is spacecraft trajectory/orbital control, that, in many cases, is performed in open-loop, with occasional feedback corrections driven by a human agent. However, the current approach in designing and implementing guidance and control on space vehicles appears to be not suitable for certain future missions, where the spacecraft (S/C) will be required to autonomously perform complex orbital maneuvers, minimizing the human intervention from ground and satisfying many strict mission constraints and requirements. In this framework, Model Predictive Control (MPC) appears to be a key technology, capable to provide significant advantages in terms of autonomous guidance and control strategies. In this paper, we propose a novel nonlinear MPC (NMPC) strategy for autonomous guidance and control in space missions which expect high-thrust maneuvers. The proposed framework introduces two main features: (i) a strong enhancement of the S/C capability in autonomously trajectory planning; (ii) the trajectory optimization from the propellant consumption point of view. To this end, we introduce a modified NMPC cost function in order to obtain a sparse-in-time control input signal, resulting in a bang-bang input profile. Such a behavior is important in view of high-thrust guidance, since the S/C engines are allowed to fire only in those points along the orbit, where maneuvering is cheaper. On the other hand, the sparsity criterion ensures an optimal propellant consumption, avoiding long periods of undesirable low continuous thrust. Furthermore, due to the technical limitations of a real propulsion system, the maneuver budget cannot be delivered in a single infinitesimal-time impulse: gravity and misalignment losses are introduced if no thrust vectoring and maneuver subdivision optimization are performed. The strength of the proposed NMPC approach is that both ΔV sub-division and single burns optimizations are incorporated in a single optimization process. The proposed methodology has been employed for a non-coplanar LEO-GEO transfer. Indeed, if the coplanar GTO (Geostationary Transfer Orbit) transfer has an analytical (and trivial) minimum propellant optimal solution (i.e. the Hohmann transfer), the out-of-plane GTO has not an exact optimal solution and many strategies can be explored and are available in literature. Within this framework, the NMPC-based guidance and control appears to be a suitable technology for optimizing the propellant expenditure and enhancing the S/C autonomy.