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Author: Mr. Michele Pagone
Politecnico di Torino, Italy, michele.pagone@polito.it

Mr. Mattia Boggio
Politecnico di Torino, Italy, mattia.boggio@polito.it
Prof. Carlo Novara
Politecnico di Torino, Italy, carlo.novara@polito.it
Mr. Luca Massotti
European Space Agency (ESA), The Netherlands, Luca.Massotti@esa.int
Dr. Simone Vidano
Politecnico di Torino, Italy, simone.vidano@polito.it

A SPARSE NONLINEAR MODEL PREDICTIVE CONTROL FOR AUTONOMOUS SPACE MISSIONS

Abstract

Autonomous guidance and control strategies are key elements in the space industry: they can improve the level of spacecraft autonomy when planning and performing the required maneuvers, reducing the effort in designing space missions on the ground. In this context, Model Predictive Control (MPC) has a great potential for future applications, thanks to its ability to deal with linear and nonlinear systems and input/state constrains, to optimize a wide class of performance indexes and to allow a high level of autonomy. A significant effort is focused on finding new classes of cost functions, promoting the optimization of the satellite propellant budget. From this point of view, the classic quadratic cost used in the MPC optimization problem leads to a sub-optimal propellant consumption and an undesirable continuous thrusting action. In this paper, we propose a novel nonlinear MPC (NMPC) framework for autonomous guidance and control in space missions, involving high-thrust quasi-impulsive maneuvers. The internal NMPC prediction model is based on the Modified Equinoctial Orbital Elements (MEOEs). The advantages are: (i) the reference trajectory can be generated without specifying the satellite desired position along the orbit; (ii) differently from the Keplerian orbital elements, the MEOEs are not significantly affected by singularities. The MEOE equations are intrinsically nonlinear and their linearization may lead to deteriorations of the control performance. This motivates the use of a pure nonlinear MPC approach. Moreover, the proposed NMPC framework is able to employ different kinds of cost functions, leading to a sparse-in-time command input profile and yielding an improvement in terms of fuel consumption in high-thrust maneuvers, with respect to using the classical astrodynamics methods. Indeed, the thrust profiles are based on an unfeasible abstraction: the concept of instantaneous and impulsive maneuver, due to the technical limitations of real propulsion systems. The ESA Sentinel-2 satellite is considered as a case study. The Earth observation missions expect only consecutive orbital plane changes, being a suitable test bench for our NMPC framework. In this case study, the proposed NMPC approach is compared to other two strategies: the ideal and impulsive (but practically unfeasible) strategy and a realistic quasi-impulsive strategy, which can be considered one of the existing state-of-the-art strategies in these kinds of missions. The simulations show that the NMPC algorithm performances are close to the one of the ideal impulsive strategy and significantly better than the one of the quasi-impulsive strategy in terms of propellant consumption and trajectory precision.