Interactive Presentations (IP)
Topic 7 - Interactive Presentations (7)

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A TUTORIAL ON MODEL PREDICTIVE CONTROL FOR SPACECRAFT MANEUVERING PROBLEM WITH THEORY, EXPERIMENTATION AND APPLICATIONS

Abstract

This tutorial paper discusses the recent advances and future prospects of spacecraft position and attitude control using Model Predictive Control (MPC). First, the challenges of the space missions are summarized, in particular, taking into account the errors, uncertainties, and constraints imposed by the mission, spacecraft and, onboard processing capabilities. The summary of space mission errors and uncertainties provided in four categories; initial condition errors, unmodeled disturbances, sensor, and actuator errors. These previous constraints are classified into two categories: physical and geometric constraints. Lastly, real-time implementation capability is discussed regarding the required computation time and the impact of sensor & actuator errors based on the Hardware-In-The-Loop (HIL) experiments. The rationales behind the scenarios definition are also presented in the scope of space applications as formation flying, attitude control, rendezvous & docking, rover steering, and precision landing. The objectives of these missions are explained, and the generic constrained MPC problem formulation are summarized. Three key design elements used in MPC design: the prediction model, the constraints formulation and the objective cost function are discussed. The prediction models can be linear time invariant or time varying depending on the geometry of the orbit, whether it is circular or elliptic. The constraints can be given as linear inequalities for input or output constraints which can be written in the same form. Moreover, the recent convexification techniques for the non-convex geometrical constraints (i.e. plume impingement, Field-of-View (FOV)) are presented in detail. Next, different objectives are provided in a mathematical framework and explained accordingly. Third, because MPC implementation relies on finding in real-time the solution to constrained optimization problems, computational aspects are also examined. In particular, high-speed implementation capabilities and HIL challenges are presented towards representative space avionics. This covers an analysis of future space processors as well as the requirements of sensors and actuators on the HIL experiments outputs. The HIL tests are investigated for kinematic and dynamic tests where robotic arms and floating robots are used respectively. Eventually, the proposed algorithms and experimental setups are introduced and compared with the authors' previous work and future plans. The paper concludes with a conjecture that MPC paradigm is a promising framework at

the crossroads of space applications while could be further advanced based on the challenges mentioned throughout the paper and the unaddressed gap.