Tailoring stochastic predictive schemes for on-orbit control of space platforms

Martina Mammarella[1]

[1] Institute of Electronics, Information Engineering and Telecommunications, National Research Council of Italy, Torino, Italy

In the last decades, model predictive control (MPC) has become one of the most successful advanced control techniques for industrial processes, thanks to its ability to handle multi-variable systems, explicitly taking into account state and equipment constraints. However, moving horizon schemes like MPC might incur significant performance degradation in the presence of uncertainty that arises in the modelling phase, and in some others it is intrinsic to both the system and the operative environment. Furthermore, ignoring modelling errors and disturbances can lead to constraint violation in closed loop and the online optimization being infeasible. Hence, it is crucial to include underlying stochastic characteristic of the framework and eventually accept a violation of constraints with a certain probability level, in order to improve the coherence of the model and reality. Recently, for processes where a stochastic model can be formulated to represent the uncertainty and disturbance and constraints violation does not correspond to compromise the application or lose the mission, Stochastic Model Predictive Control (SMPC) approaches have gained popularity. Indeed, a probabilistic model allows to optimize average performance or appropriate risk measures, and the introduction of so-called *chance constraints*, which seem more appropriate in those applications where allowing a (small) probability of constraints violation provides a higher cost-effectiveness of the application itself. Furthermore, chance constraints lead to an increased region of attraction and enlarge the set of states for which MPC provides a valid control law. On the other hand, the classical criticism of MPC schemes, especially in their robust/stochastic instantiations, is their *slowness*. Indeed, typically this widely recognized shortcoming is mainly due to the computational effort required in the on-line solution of the ensuing optimization problem, and to the difficulty of embedding a real-time solver for MPC implementation. In space applications, the available processors provide limited on-board computational power. This constrains the level of spacecraft autonomy because even relatively simple autonomous operations require complex computations to be performed in near real time. The implementation of classical MPC on low-cost hardware, such as micro-controllers, is already quite demanding. In this talk, we will present an offline sample-based strategies for addressing in a computationally tractable manner SMPC, able to cope simultaneously with additive random noise and parametric stochastic uncertainty. Then, we show the real-time implementability of the proposed scheme, addressing two different control problem arising in aerospace applications: i) attitude control during Earth-observation missions, and ii) the autonomous rendezvous maneuver among spacecraft. Numerical simulations and experiments will show that the approach provides probabilistic guarantees on the success of the mission, even in rather uncertain and noisy situations, while improving the spacecraft performance in terms of fuel consumption. Last, we will present two tools that have been developed as an extension to the previous SMPC scheme, tailored to deal with current and future challenges of space applications, thus further reducing the computational burden of on-board implementation on one side and on the other to face uncertainties inherent to the application itself, for example in the framework of debris removal with unknown/uncooperative targets.

Bio: Dr. Mammarella obtained her Ph.D. in Aerospace Engineering from the Polytechnic of Turin in 2019. She is currently a research fellow at the IEIIT Institute of the National Research Council, a role she has held since 2019, and adjunct professor at the Politecnico di Torino since 2017. In 2021, she obtained the National Scientific Qualification for Associate Professor in the Aeronautical, Aerospace and Naval Engineering sector (09/A1). Her competencies are focused on spaceflight mechanics and control system design for aerospace systems. In the area of automatic controls, her expertise is mainly focused on advanced robust and stochastic predictive control techniques for constrained systems. Her research includes the experimental validation in the laboratory and in the field of these algorithms, designed for satellites and aerial drones, the latter used in various application fields, including precision agriculture. Currently, she is Guest Associate Editor for the special issue "State-of-the-art Applications of Model Predictive Control" on the IEEE TCST journal and Associate Editor for the IEEE CSS TCEB. She is member of IEEE CSS TC on Aerospace Control, IEEE RAS TC Committee on Agricultural Robotics and Automation, IFAC TC on Robust Control, IFAC TC on Control in Agriculture, and AIAA GNC TC.