Model Predictive Control Applications for Planetary Rovers

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Model Predictive Control (MPC) is a well known method for control of processes with low or moderate dynamics as found in power or chemical plants. Within space applications the typical domain of MPC is spacecraft attitude and orbit control. MPC for control of planetary rovers is a quite new technology and was recently investigated in the frame of the RobMPC project, under ESA contract. In this context the Robust-MPC approach was applied to three layers of the rover control hierarchy dealing with medium to high dynamics control tasks: 1) Guidance, 2) trajectory control and 3) traction and steering control. The selected reference rover is ESA's four-wheel EGP rover with rear axle steering and a mass of approximately 800 kg.

The MPC control design flow is based on the MPCSofT Toolbox for MATLAB, a novel toolbox developed within the RobMPC project. The MPCSofT toolbox provides an environment for design and simulation of MPC controllers, based on a quite general class of linear time-varying models, constraints, and quadratic costs, possibly equipped with integral action to increase robustness. As MPC prediction models are easily specified by the user in Embedded MATLAB code, generation of C-code can be automatically generated within the MATLAB/Simulink environment for immediate rapid prototyping.

The highest control level is shared between the nominal path planner (computed offline) and the MPC guidance function. When the rover slips outside the safety corridor around the nominal path, the guidance function continuously builds obstacle-free optimal contingency paths to bring back the vehicle to the nominal path, without the need of stopping the rover to compute a new nominal path. The LTV model included in the MPC optimization engine is used to reconstruct the guidance path from the computed optimal sequence of actions.

The MPC trajectory control acts on the velocity vector of the vehicle in order to keep the vehicle within the nominal (guidance) path. This level takes into account the non-holonomy characteristics of the rover and implements a kinematic LTV model of the vehicle.

The lowest MPC level is dedicated to traction and steering control. This layer is controlling the steering angle and wheel velocity coordination and replaces typically the Ackermann control. Here, the MPC solution is based on a multi-body system model of the rover including the wheel-soil interaction dynamics. It is implemented as a stepwise LTI class problem with corresponding online linearization of the model.

The paper will introduce the architecture of the entire control hierarchy together with selected details of the MPC specific implementation. The performance and robustness analyses are presented based on results of comprehensive Monte Carlo simulations. A profiling of the code will give an outlook regarding readiness state in terms of controller implementation on space qualified computer hardware.