Abstract

The purpose of this thesis is to propose an approach to constrained Nonlinear Model Predictive Control (NMPC) design and solution. Such NMPC framework points the attention on the autonomous guidance and control in space mission applications, by considering both the cases of orbital transfers and rendezvous maneuvers.

The key aspect of the work is a NMPC online solution by taking advantage of the Pontryagin's minimum principle, which, under suitable assumptions, provides the `explicit' control law also in presence on nonlinearities and/or input and state constraints. Thanks to this approach, the optimal control problem turns into a standard two-points boundary value problem, whose solution provides the gains for the explicit optimal control law.

Nevertheless, it is well known that one of the main drawbacks of the Pontryagin-based optimization methodology is the management of state constraints. Indeed, in order to handle such constraints, an a-priori knowledge of the solution structure is required which allow to impose some interior tangency conditions at the junction points between constrained and unconstrained arcs. This issue is hugely enhanced when dealing with on-line NMPC schemes. This drawback is tackled by proposing a methodology for dealing with state constraints by means of penalty functions. Thanks to this methodology, it is possible to account any kind of trajectory constraint (nonlinear and non-convex too) without any significant modification of the solution algorithm with a reduced computational burden.

Furthermore, a study about the mathematical properties of the proposed NMPC scheme has been carried out. In particular, the theoretical study tackles an important argument: the local stability and convergence of the closed-loop. The closed-loop stability is studied by identifying an ad-hoc Lyapunov function, based on the prediction in the future of the state. Event though the proposed closed-loop stability analysis is only 'local', the results is particularly worth of interest since few results are available in literature.

In summary, the thesis aims to propose the following original contributions:

- The definition of a methodology for solving the NMPC optimization problem by means of the Pontryagin's principle with a receding horizon stategy.
- The integration of the state constraints within the optimal control problem through an approach, based on penalty functions, that does not significantly affect the on-line optimization algorithm.
- The study of the local stability and convergence of the closed-loop.

The proposed NMPC novel methodology and the theoretical features are, then, tested and confirmed through an extensive simulation campaign. The simulation test case is focused on two kinds of very common spacecraft orbital maneuvers: the low-Earth orbit – Geostationary orbit non-coplanar transfer and rendezvous proximity and docking maneuver between a chaser spacecraft and a non-collaborative target. The two difference between the two applications relies on the different methodology employed for solving the nonlinear optimal control problem. Indeed, in the first case, a numerical solver, based on sequential quadratic programming is employed, whereas the Pontryagin approach is used for the second applications. Moreover, the rendezvous case study also includes a Monte Carlo campaign, whose goal is to confirm from an `empirical' point of view the results about the stability coming from the developed theory.