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ENERGY-OPTIMAL RENDEZVOUS SPACECRAFT GUIDANCE VIA THEORY OF CONNECTIONS

Abstract

Rendezvous and Close-Proximity Operations (RCPOs) are critical maneuvers that are implemented to execute guided relative motion between spacecraft. RCPOs generally refer to the set of maneuvers needed by a chaser to reach the target spacecraft either for docking or to accomplish the mission objectives (e.g. flying around for inspection and servicing). RCPOs require the spacecraft to execute on-board planning. As such, the spacecraft needs to generate in real-time trajectories that are both safe and optimal without the need for ground intervention. Planning and executing such set of maneuvers in an optimal fashion requires the formulation and solution of an optimal control problem. The latter requires setting up a cost function (i.e. the objective of the optimization) and the desired control and state constraints. Usually, two methods are available to solve the abovementioned optimal control problem, i.e. direct and indirect methods. Direct methods aim at discretizing the continuous states and controls thus transforming the problem in a non-linear programming problem. The latter can be cast as a finite constrained optimization problem that can be solved via any of the available numerical algorithms that have the potential to find a local minimum. Conversely, a second approach to solve optimal control problems has been historically proposed and implemented. Named indirect method, the approach applies optimal control theory (i.e. Pontryagin Minimum Principle) to formally derive the first-order necessary conditions that must be satisfied by the optimal solution (state and control). The problem is cast as a Two-Point Boundary Value Problem (TPBVP) that must be solved to determine the time-evolution of state and costate from which the control generally depends.

In this paper, we apply a newly developed method to solve boundary value problems for differential equations to solve the energy-optimal problem for planning and guidance in relative motion. The method relies on the least-squares solution of differential equations via orthogonal polynomial expansion and constrained expression as derived via Theory of Connection (ToC). The application of the optimal control theory to derive the first order necessary conditions for optimality, yields a TPBVP that must be solved to find state and costate. Combining orthogonal polynomial expansion and ToC, we solve the TPBVP for optimal rendezvous of a spacecraft chasing a target. We will show that the approach yields fast and accurate solution with the potential to implement the algorithm in a real-time, closed-loop fashion.