Paper ID: 46264
oral
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimization (1) (8)

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AN INTRUSIVE POLYNOMIAL ALGEBRA MULTIPLE SHOOTING APPROACH TO THE SOLUTION OF OPTIMAL CONTROL PROBLEMS

Abstract

This paper proposes an approach to the solution of optimal control problems, that extends the classical direct multiple-shooting method by replacing real numbers with polynomial expansions, over a limited compact support, and all algebraic operations among real numbers with algebraic operations among polynomials.

The proposed approach to the expansion in polynomial series generalises the more common use of Taylor polynomials (generally found in Differential Algebra or Jet Transports) and allows the use of any polynomial representations. With this extension, one can exploit the properties offered by polynomials other than Taylor, like min-max or uniform convergence. In this paper, states are expanded in Chebyshev polynomials that were shown to exhibit a superior global convergence and robustness in a number of cases.

The inclusion of this polynomial representation in the framework of a direct multiple-shooting transcription of the optimal control problem starts with a discretisation of the time domain in sub-intervals. At the beginning of each sub-interval, the state spatial distribution is modelled with a polynomial expansion. Continuity conditions are then imposed at the boundary of two adjacent segments. This operation is critical because it requires the continuity of two extended sets, one at the end of one segment and the other at the beginning of the following segment. The enforcement of the continuity between two generic hyper-dimensional sets affects the accuracy of the result and the computational complexity of the algorithm. Two approaches are presented: a conservative and fast one based on box-delimitation of the propagated state, and a more expensive and refined one that provides a more accurate matching of the two sets.

The Intrusive Polynomial Algebra aNd Multiple-shooting Approach (IPANeMA) proposed in this paper can find application in the solution of stochastic optimal control problems in which no a-priori distribution needs to be defined, or the probability distribution is affected by imprecision and only the upper and lower boundaries on the expectations of the quantity of interests can be computed. Another important area of application is the definition of families of control laws for swarms of spacecraft that start from a given set of initial conditions and need to reach a target set without the need to specifically track any particle in the swarm.

In this paper, the approach is applied to the design under uncertainty of a low-thrust trajectory to a Near-Earth Object. Uncertainty is considered in the initial conditions and model parameters.