Paper ID: 73704
oral
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation and Control (1) (3)

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MULTI-REVOLUTION LOW-THRUST TRAJECTORY OPTIMISATION USING DIFFERENTIAL DYNAMIC PROGRAMMING IN ORBITAL ELEMENT FORMULATION

Abstract

Space planetary missions' analysis with low-thrust propulsion includes orbit raising and de-orbiting manoeuvres which can involve multiple revolutions resulting in a spiralling motion of the satellite. The launch of large constellation satellites is increasing the number of satellites launched per month and the design of their trajectory to be positioned in their operational orbit. This problem is particularly relevant when low-thrust satellites are considered that are characterised by a continuous thrust and are getting more involved in the design of new missions since they grant a greater final operational mass thanks to their high specific impulse.

The optimisation of low-thrust trajectories involving a larger number of orbit revolutions is a challenging problem. Differential dynamic programming is one of the techniques that can be used to solve nonlinear optimal control problems. This method based on the application of Bellman principle of optimality defines a feedback control law solving necessary optimality conditions during the backward sweep discretising the overall problem in several decision steps and checks for the functional cost reduction during the forward integration to accept or reject the computed control law. In the last years, differential dynamic programming technique evolved thanks to the formulation of the hybrid differential dynamic programming proposed by Lantoine and Russell which maps the required derivatives recursively using state transition matrices and the stochastic differential dynamic programming which introduces random perturbations that can affect the dynamics. However, all past works deal with orbital dynamics expressed in terms of Cartesian coordinates and in only one paper orbital elements are used as state representation, but the rendezvous problem is not solved.

This paper presents a systematic procedure for the optimisation of multi-revolution low-thrust trajectories using the differential dynamic programming technique based on orbital elements as state representation of the dynamics. Lagrange and Gauss planetary equations are used to model the spacecraft dynamics to include both conservative and non-conservative accelerations.

Some planetary missions like orbit raising and deorbiting for large constellations and Geostationary transfer orbit considering the engine specifics of actual satellites are used to test the proposed approach including also J_2 orbital perturbation. Finally, a comparison between the proposed method and state-of-art optimisation techniques for multi-revolution low-thrust trajectories is carried out to stress the pros and cons in terms of accuracy and computational efficiency.