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Author: Mr. Marco Nugnes
Politecnico di Milano, Italy, marco.nugnes@polimi.it

Dr. Camilla Colombo
Politecnico di Milano, Italy, camilla.colombo@polimi.it

LOW-THRUST TRAJECTORY OPTIMISATION THROUGH DIFFERENTIAL DYNAMIC PROGRAMMING METHOD BASED ON KEPLERIAN ORBITAL ELEMENTS

Abstract

The optimisation of low-thrust orbital trajectories represents one of the classic non-linear constrained optimal control problems in space applications. Low-thrust systems are getting more involved in the design of new missions, such as for example the all-electric spacecraft, since they grant a greater final operational mass thanks to their high specific impulse.

One of the available methods in solving such difficult problem is Differential Dynamic Programming (DDP), which is based on the identification of optimal feedback control laws by the discretisation of the dynamics and the application of Bellman optimal principle. Colombo et al. presented a modified DDP algorithm for the optimisation of low-thrust trajectories where the problem is discretised in several decision steps, so that the optimisation process requires the solution of a great number of small problems. Lantoine and Russell developed a new second-order algorithm based on DDP, called Hybrid Differential Dynamic Programming (HDDP), which maps the required derivatives recursively through first-order and second-order state transition matrices. Campagnola et al. proposed a Stochastic Differential Dynamic Programming (SDDP) where random perturbations enter the dynamics of the problem and their expected values are computed by the unscented transform. Despite the development of many advanced techniques in the field of DDP, the formulation of the dynamics in all these works has always been in Cartesian coordinates and no attempt was made to couple DDP with Keplerian orbital elements as state variables.

In this paper a low-thrust trajectory optimisation through a DDP approach based on Keplerian orbital elements is derived. Lagrange and Gauss planetary equations are used to model the dynamics of the spacecraft in such a way that orbital perturbations can be included if their disturbing potential is expressed in terms of orbital elements or, in case of aerodynamic drag if the disturbing acceleration is properly modelled. The adoption of orbital elements as state variables presents all the advantages coming from the variational equations for the propagation of the dynamics and the state transition matrix as in Lantoine and Russel can be easily computed.

An interplanetary transfer to a main-belt asteroid is used as example to test the proposed approach since its dynamics is well described by using the variational equations. Finally, a comparison between the new method and the Cartesian based DDP is carried out to enhance the differences and assess the performance.