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HYBRID DIFFERENTIAL DYNAMIC PROGRAMMING ALGORITHM FOR LOW-THRUST TRAJECTORY DESIGN USING EXACT HIGH-ORDER TRANSITION MAPS

Abstract

Optimal orbital trajectories are obtained through the solution of highly nonlinear large scale problems. In the case of low-thrust propulsion applications, the spacecraft benefits from high specific impulses and, hence, greater final spacecraft mass. However, these missions require a high count of orbital revolutions and, therefore, display augmented sensitivity to many disturbances. Solutions to such problems can be tackled via a discrete approach, using optimal feedback control laws. Historically, differential dynamic programming has shown outstanding results in tackling these problems. The state of the art software Mystic, that implements a variation of DDP, has been developed by Whiffen and is used by NASA's Dawn mission. One of the latest techniques implemented to deal with these discrete constrained optimizations is the Hybrid Differential Dynamic Programming (HDDP) algorithm, introduced by Lantoine and Russell. This method integrates the reliability and efficiency of classic nonlinear programming techniques with the robustness to poor initial guesses and the reduced computational effort of DDP. The key feature of the algorithm is the exploitation of a second order state transition matrix procedure to propagate the needed partials, decoupling the dynamics from the optimization. In doing so, it renders the integration of dynamical equations suitable for parallelization. Together with the possibility to treat constrained problems, this represents the greatest improvement of classic DDP. Nevertheless, the major limitation of this approach is the high computational cost to evaluate the required state transition matrices. Analytical derivatives, when available, have shown a significant reduction in the computational cost and time for HDDP application. This work applies differential algebra to HDDP to cope with this limitation. In particular, differential algebra is introduced to obtain state transition matrices as polynomial maps. These maps come directly from the integration of the dynamics of the system, removing the dedicated algorithmic step and reducing its computational cost. Moreover, by operating on polynomial maps, all the solutions of local optimization problems are treated through differential algebraic techniques. This approach allows to deal with higher order expansions of the cost, without modifying the algorithm. The leading assumption of this work is that, treating higher than second order expansions, grants larger radii of convergence for the algorithm, improved robustness to initial guesses, hence faster rates of convergence. Examples are presented in this paper to assess the performance of the newly constructed algorithm and to test the assumptions.