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REGULARIZATION AND A HYBRID PSEUDOSPECTRAL, SHAPE-BASED SOLVER FOR LOW-THRUST OPTIMAL CONTROL

Abstract

Regularization, without doubt, is one of the major theoretical and practical contributions in modern Astrodynamics. The current understanding of the Kepler problem is definitely cemented on the work of Kustaanheimo, Stiefel, Moser or Deprit, among others. Moreover, the advent of computer-aided orbital propagation rapidly put into manifest the significant benefits of regularization from the numerical, navigation perspective.

Still, the use of regularization techniques in pure guidance and control applications is not that common, despite recent efforts within the Astrodynamics community. Just as for navigation, in terms of accuracy, regularized formulations of orbital optimal control (OC) are promising. However, these are usually more complex than traditional approaches, which further complicates the already problematic task of mission design optimization.

In fact, OC is another major realm of active research, specially oriented for onboard implementations, enabled now by modern computational resources. While convex optimization copes most efforts for efficient OC these days, significant advancements have been achieved by the state-of-the-art pseudospectral and shape-based solvers. Both families seek for efficient yet accurate techniques of solving general OC: while the former bridges the gap between direct and indirect techniques by means of the celebrated Covector Mapping Theorem and orthogonal polynomials and collocation, the latter prescribes the solution to be in the form of a particular analytical expression, whose defining parameters are appropriately selected to comply with the problem's constraints.

Precisely, the aim of this investigation is to explore regularization, in combination with a recently-introduced hybrid pseudospectral, shape-based solver for cost-effective, enhanced performance in low-thrust mission design. The novelties of this communication are three-fold. First, the state-of-the-art regular, universal DROMO formulation, whose application to OC has not received extensive attention, is hybridized with this novel solver for optimal low-thrust transfer design. Thanks to the common goals and synergies between the two, we demonstrate the capabilities of DROMO not only for its initial intended use, but also for OC. Secondly, in a similar way, we combined the solver with the Kustaanheimo-Stiefel (KS) transformation for OC low-thrust transfers. In this second case, the gauge freedoms of the KS transformation are leveraged to increase the performance and accuracy of the solver. Finally, the performance of the introduced methodologies is compared to standard techniques for OC, such as sequential convex optimization.

The above studies and results are framed within several mission design test scenarios, including both low-thrust near-Earth orbit, asteroid interception and cislunar optimal transfer applications.