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A RAPID TRAJECTORY DESIGN STRATEGY FOR COMPLEX ENVIRONMENTS LEVERAGING ATTAINABLE REGIONS AND LOW-THRUST CAPABILITIES

Abstract

Designing trajectories in dynamically complex environments is challenging and easily becomes intractable. Design space trade-offs and changing requirements also implies a wide array of scenarios and demands a rapid process. For example, Lunar IceCube is a 6U CubeSat that will prospect for water and other lunar volatiles following launch as a secondary payload. Targeting specific lunar science orbit parameters from a concomitant Sun-Earth/Moon system trajectory presents numerous challenges. It is necessary to recast the problem to reduce the design time and offer global solutions by leveraging phase space mapping patterns – available as attainability regions – and the application of search techniques from combinatorics. A computationally efficient search process results that determines potential trajectory concepts to meet unique design requirements over a broad range of mission types, including low-thrust scenarios. A successful framework is based on the general foundational behavior in such regimes and the capability to identify potentially productive links and sequences for path planning. The critical component is an initial guess, one that may incorporate low-thrust arcs, that is subsequently corrected. The framework for the approach is summarized in terms of three components: (i) Discretization—construct sets of base arcs and attainable regions to serve as the design framework. Well known dynamical structures including periodic orbits and manifolds, represented in terms of phase space mapping options, are available. These structures are augmented with the patterns apparent by construction of attainable regions that reflect the complex natural dynamical relationships as well as the shifts available from low-thrust forces. The attainable regions are defined via velocity-domain maps and can be transformed to variables reflecting mission objectives. (ii) Graph Construction—transforming the base set and attainable regions into a searchable 2D or 3D volume or map. The base set of arcs and the attainable regions produce a design space for path planning and assessment. Thus, the sets of arcs and regions are then organized via a suitable data structure to allow a search through the 2D or 3D volumes. A data structure is key to efficiently formulate the problem, particularly for multi-dimensional searches. (iii) Combinatorial search—determination of the transport sequence that delivers the most efficient path employs combinatorics. The transport sequences that evolve may leverage different regions of space in various sequences along the path to support new types of trade-offs. Once the transport sequence is determined as a globally efficient concept, it can be optimized locally by more traditional optimization strategies.