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RAPID TRAJECTORY DESIGN IN COMPLEX ENVIRONMENTS ENABLED VIA SUPERVISED AND REINFORCEMENT LEARNING STRATEGIES

Abstract

Designing trajectories to balance design space trade-offs and shifting requirements in complex environments demands rapid iterations in the design process and swift responses during flight operations. For example, near term cis-lunar activities are constrained by varied technological capabilities as well as the need to coordinate diverse routes through space for differing cargo and crew transport systems. A flexible and robust trajectory design strategy is therefore integral to enabling efficient transport. Likewise, designers would benefit from a computationally efficient and generalizable approach that reveals potential trajectory concepts to meet unique requirements over a broad range of mission types, including both chemical and low-thrust propulsion systems. In this investigation, globally attractive solutions are sought by exploiting artificial intelligence techniques, specifically machine learning methods, to automate exploration of the design space, identify potentially productive links, and exploit techniques from combinatorics to forge sequences for path-planning.

Prior investigations established a successful framework by incorporating a discretized database that served as a library of potential transfer states from an infinite trade-space. Knowledge of the spacecraft performance specifications and automated pathfinding techniques were then exploited to identify and constrain potential combinations of transfer arcs, to seed traditional optimization processes.

The current investigation focuses on techniques to unveil a deeper understanding of the natural dynamics and more effectively exploit its characteristics to address broad-ranging mission objectives and constraints. Approach (I): Free-form search, adopts a receding horizon technique that indiscriminately leverages both chaotic and ordered motion to traverse an infinite trade-space. The designer thus acquires the flexibility to explore unfamiliar design spaces and importantly, discover numerous non-intuitive transfer geometries that may be challenging to uncover via manual or traditional basin-restrictive optimization techniques. This approach also mitigates the time-investment demanded in the prior framework to construct an a-priori knowledge-base of natural solutions and their incorporation into a discretized database. An unrestricted search however, diminishes the capacity to influence specific geometric constraints. Therefore, approach (II): Flow models, introduces the pathfinding agents to known ordered motion constructed via supervised learning methods. Specifically, Support Vector Machines (SVMs), Artificial Neural Networks (ANNs), and probability theory are exploited in unison to selectively restrict the transfer profile. The flow models are less memory-intensive than the prior discretized databases, and also liberates the pathfinding agents from being restricted to the states defined within catalog. Thus, more expansive and complex trajectory design spaces can be explored more rapidly, leading to more robust design and operations processes.