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EARTH MULTI-TARGET TRAJECTORY DESIGN WITH ARTIFICIAL NEURAL NETWORK

Abstract

The growth of satellites in space mirrors their crucial role in modern society, driving navigation, telecommunication, and Earth observation services. As new satellite constellations emerge, missions such as active debris removal, multi-injection, and in-orbit servicing gain prominence. A recurring theme in their mission analysis is the multi-target aspect, enabling a single spacecraft to visit multiple objects in one mission, enabled by using high-impulse, low-thrust propulsion systems. However, the trajectory design presents challenges, including identifying optimal target combinations within a vast search space and the computational demands of designing low-thrust trajectories. In this paper, a trajectory design methodology is proposed, that uses artificial neural networks to estimate propellant mass consumption and time of flight related to orbit-to-orbit transfers. Each transfer is composed of three parts: the first and the third are low-thrust legs, calculated using a three-dimensional shape-based algorithm. This algorithm is based on non-linear interpolation of consecutive orbits, allowing it to function even in scenarios involving hundreds of revolutions typical of Earth-centered missions. These two are connected by a coasting arc, which exploits the J2 perturbation to change the Right Ascension of Ascending Node. Particle Swarm Optimisation (PSO) is used to optimise the altitude and inclination of the intermediate drifting orbit. Initially, a pool of optimal transfers between randomly-generated earth orbits is created. These are used to train an artificial neural network through supervised learning. The structure and key parameters of the network are optimised using Optuna. The trained neural network exhibits higher error rates compared to those typically reported in the literature, around 15% on propellant mass and 45% on mission duration. However, it offered significant advantages in terms of computational speed, estimating a single transfer in a few milliseconds while the technique used for the database generation required 5 minutes per transfer in average.

Finally, a breadth-first tree search is employed to tackle the combinatorial aspect of the problem. Considering an in-orbit servicing mission involving a search space of 200 randomly-generated objects, the proposed methodology successfully explored the entire space within 25 minutes. The best sequence obtained exhibited error margins of 5% for propellant mass consumption and 22% for mission duration, compared to the coupling of the shape-based algorithm and PSO used for database generation. Notably, employing the latter method instead of the neural network would necessitate 10 days to explore the same search space, underscoring the efficiency of our proposed approach in lowering computational burden and time.