IAF ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations - IAF ASTRODYNAMICS SYMPOSIUM (IP)

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# ROBUST LOW-THRUST GRAVITY-ASSIST TRAJECTORY OPTIMIZATION

**Abstract**

The electric propulsion (EP) and planetary gravity-assist (GA) maneuver are facilitating deep space exploration. Nevertheless, the low maneuverability makes EP spacecrafts necessitate long thrust arcs and susceptible to uncertainties and disturbances. To cope with the potential uncertainties, such as state uncertainties, observation uncertainties and execution uncertainties, robust low-thrust optimization is usually performed, and Reinforcement learning (RL) is a promising alternative. Considering that the solution by RL is hardly capable of satisfying constraints of GA on spacecraft position accuracy, this paper combines reinforcement learning (RL) with numerical algorithms for robust low-thrust GA trajectory optimization. Firstly, the low-thrust trajectory before GA is divided into two segments, with a longer segment from the beginning of the mission and a shorter one near flyby planet. For the longer segment, RL is utilized for robust low-thrust trajectory optimization, which is recast as a time-discrete Markov decision process, and Proximal Policy Optimization is used to train a deep neural network. As for the shorter segment, an efficient numerical algorithm is used to guide the EP spacecraft to reach the flyby planet, achieving a compensation for the accuracy of control policy by RL. Further, the dynamical effects due to different incidence velocity in GA are analyzed, i.e., the uncertainty of the initial conditions of subsequent mission segment after GA. Similarly, the low-thrust trajectory after GA is separated into two segments with different time durations, and the corresponding robust trajectory optimization processes are the same as those for the segments before GA. To demonstrate the utility of the proposed method, a Mars gravity-assist mission is considered, and the simulation results are expected to show that the method can achieve efficient robust low-thrust GA trajectory optimization.