Paper ID: 88888
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IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM (B2)
Interactive Presentations - IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM (IPB)

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A PHYSIC-INFORMED NEURAL NETWORK-BASED THRUST MODELING AND ORBIT DETERMINATION METHOD FOR LOW THRUST SPACECRAFT PROPULSION

Abstract

This paper proposes a Physics-Informed Neural Network (PINN)-based method for thrust modeling and orbit determination in low thrust spacecraft, aiming to address the issue of navigation error accumulation which caused by thrust control deviations. The low thrust propulsion method can not only effectively enhance the spacecraft's re-orbiting capability but also reduce mission costs. It is widely employed in tasks such as satellite constellation deployment and small celestial body exploration. The mission cycle under low thrust propulsion mode is often lengthy, requiring the thrust system to maintain the scheduled working state for an extended duration throughout the mission. Nevertheless, the issue of thrust deviation presents challenges for low-thrust control in actual detection missions. For example, a control interruption of approximately 3 days occurred during the electric thrust start-up process in the BepiColombo mission, resulting in a thrust deviation of up to 5% in this arc segment. However, the accurate modeling of time-varying low thrust is a challenging task, and current research is insufficient, while the error of thrust model during a long-cycle mission can seriously affect the accuracy of spacecraft orbit determination. To address this problem, a PINN-based thrust modeling and orbit determination method for low thrust spacecraft is proposed, which introduces Fourier series to construct a parameterized thrust model. By utilizing the powerful data processing and parameter fitting capabilities of neural networks, a parameter optimized analytical low thrust model is obtained through PINN processing of observed data, while concurrently improving the orbit. Firstly, the spacecraft orbital dynamics model considering the complex perturbation force and low thrust is established. The initial dynamic low thrust acceleration model is then constructed by fitting the Fourier series to the nominal thrust, and the dynamics differential equations are established by taking the Fourier coefficients as the to-be-estimated parameters in the augmented and generalized state variables. Then, a regularizing term representing the physical constraints is added to the PINN method which is introduced to solve the differential equations, on the basis of which the low thrust model coefficients are fitted to the observed data while the orbital parameters are optimally determined. Finally, the accuracy of parameterized fitting for thrust model and orbit determination results is analyzed and evaluated. The effectiveness and robustness of the method are verified through simulation tests using various forms of measurement data.