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ADAPTIVE ORBIT DESIGN AND CONTROL OF SOLAR SAILS IN COMPLEX AND UNCERTAIN SPACE ENVIRONMENTS

Abstract

Solar sails have emerged as a promising propulsion technology for spacecraft, utilizing solar radiation pressure without consuming fuel. However, there are still several technical difficulties before the solar sail can fully exert its advantages in engineering practice. These challenges arise from the diverse and harsh space environment, causing disturbances such as optical degradation of the sail material, orbit injection errors, and deformation of the sail surface. These factors are complex and even time-varying, making them difficult to predict and model. The above interferences are directly related to the propulsion performance of the solar sail, and further directly determine the completion of the mission. In summary, it is necessary to identify complex and unknown parameters of solar radiation pressure force model online, and further adaptively adjust the design and control of orbit.

Take optical degradation of solar sail materials as an example, although some studies have focused this phenomenon (Dachwald, 2007), they mostly relied on linear simplified models of optical parameters without considering uncertainties, which are not accurate in modeling nonlinear and complicated degradation in real space. To overcome these challenges, this paper proposes an adaptive orbit control method based on parameter identification for solar sails in the complex space environment. Firstly, a general parameterized model is developed to widely describe the changes and interference of the multi-type parameters of the solar sail, and the identification is realized by an improved least square method. Then through the analysis of the error dynamics model, an evaluation index is designed to determine the parameter change threshold beyond which redesign of the reference orbit is required. The proposed method, supplemented by a feedback control law, improves the solar sail's ability to achieve the desired propulsion effect in the complex interstellar environment with multiple uncertainties.

In this study, a scheme with adaptive adjustment and reconfiguration of the mission orbit is designed for solar sails. When the model parameters change that the original mission orbit is unreliable, the trajectory and orbit control can be re-designed according to the new model parameters online. With this approach, solar sails can play a promising role in missions that require high precision and are difficult to control, such as orbital maintenance on a stable position near inner-planets or asteroids under strong perturbations for long-term observation. To evaluate the feasibility and performance of this technology, numerical simulations are conducted based on specific mission scenarios.