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Dynamics and Control of a Tethered Solar Sail Spacecraft for Solar Corona Observation Under the Sun-Earth CRTBP Framework

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ABSTRACT

Persistent high-resolution observation of the solar corona is essential for advancing human's understanding of critical solar phenomena, including coronal heating, solar wind acceleration, and the initiation of coronal mass ejections that significantly impact space weather. This study proposes a novel space-based solar corona observation mission concept, which uses a tethered solar sail spacecraft to create a sustained artificial total solar eclipse near the Sun-Earth L2 point. By positioning a probe at the end of Earth's umbra cone and leveraging Earth as a natural occulter, the mission enables uninterrupted observations of the innermost solar corona. To demonstrate the feasibility of this concept, a two-dimensional dynamical model of the tethered solar sail system is established. Based on this model, an artificial equilibrium point near the L2 point, induced by solar radiation pressure, is identified, and critical design constraints are analyzed. A reference spacecraft configuration is proposed, positioning the probe approximately 1,745 km sunward of the umbra terminus. Additionally, periodic orbits resembling Lyapunov orbits are computed, with periods of approximately 176.43 days and x-amplitudes ranging from 1 to 50 km. To ensure stable operation, a nonlinear model predictive control strategy is developed for station-keeping, using the sail's angular position as the control input. Numerical simulations demonstrate the controller's ability to stabilize the spacecraft within the umbra shadow. The system achieves a minimal corona observation radius of about 1.00125 solar radii, significantly below the operational limits of conventional coronagraphs. While the study highlights the mission's potential, it also acknowledges its limitations, such as model simplifications and technological challenges, which require further investigation for practical implementation.

KEYWORDS

Solar corona observation; solar sail; tethered spacecraft; CRTBP; artificial equilibrium point; model predictive control

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