Feedback Guidance Laws for Orbital Maneuvering of Solar Sail Spacecraft by Lyapunov Methods

This project aims to develop a guidance law for planetocentric orbital transfers with a solar sail spacecraft, using a simplified feedback approach derived from Lyapunov control theory.

Orbital maneuvering of solar sail spacecraft poses unique challenges compared to conventional spacecraft with high thrust chemical rocket engines. Firstly, solar sail spacecraft possess low thrust-to-weight ratios [1], meaning that classical impulse-based orbital maneuvering theory is not applicable. Secondly, the availability of thrust in a given direction depends on the direction of incoming sunlight, which cannot be controlled. For example, a solar sail spacecraft cannot produce thrust directly towards the Sun, akin to a sailboat sailing directly into the wind.

Low-thrust guidance has been approached using both global and local methods [2]. Global methods struggle with planetocentric orbits when many revolutions are needed to reach the final orbit, due to the highly "winding" nature of trajectories around a planet. Local methods are a prominent choice for these types of analyses [3]. A class of local feedback guidance laws developed from Lyapunov control theory has seen success through producing near time-optimal planetocentric orbital transfers [3, 2, 4].

Solar sail guidance has been approached using a variety of local feedback approaches, using both ad-hoc [5] and more generalized methods [6]. These borrow ideas from low-thrust guidance theory, and apply special considerations for solar sails. Lyapunov-derived guidance laws have been demonstrated for solar sails, but with a high degree of specialization accounting for sail reflectivity characteristics and sun orientation angles [6].

A key appeal of feedback guidance laws is their relative independence from system parameters. Therefore, it would be interesting to see if a Lyapunov-derived guidance law for a solar sail spacecraft can be developed with minimal regard to the special considerations needed for a solar sail.

Such a guidance law will facilitate trajectory analysis for unique and esoteric spacecraft designs, and remain applicable as better reflection models for solar sails are developed. It will also help bridge the gap between solar-sail-specific guidance research and the broader field of low-thrust guidance research.

The goal of this project is to develop a simplified planetocentric orbit transfer guidance law for solar sail spacecraft derived using Lyapunov methods, with a minimal set of considerations for spacecraft configuration and Sun direction.

An analytical mathematical model of the guidance law will be developed, based on a well-known control-Lyapunov potential function introduced by [2]. A computer model will be implemented in MATLAB to test and validate the performance of the guidance law though simulations. Simulations will vary spacecraft thrust-to-weight ratios, initial/target orbits, and planetary distances from the Sun to determine if the guidance law is convergent and performant under a variety of conditions.

References

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