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OPTIMAL LOW THRUST DEBRIS REMOVAL USING A TETHERED SYSTEM CONSIDERING COLLISION AVOIDANCE

Abstract

A low-thrust tethered spacecraft system for debris removal considering collision avoidance is studied and simulated. Population data of the debris environments of the ESA- MASTER using statistical analysis are considered in the transfer analysis. The probability for collision of the tethered system with the debris fragments is integrated and an upper limit is set as a constraint during optimization. Study of the optimal low-thrust tethered system is complicated by its extreme sensitivity to the initial guess and the system's pitch oscillations. With an appropriate control strategy using low-thrust propulsion, it is possible to keep the oscillations of the system within an envelope with a magnitude of around 5 degrees and properly transfer the debris to a specified altitude.

Two major methods are used in this research work to tackle the complex optimal control problem of oscillation and collision avoidance. A radius basis function-based surrogate is used to model and analyze collision probability with complicated shaped population density surfaces. The highly efficient surrogate is integrated into the optimization and set to constraints to be satisfied. Considering the collision avoidance constraints, costate equations and boundary conditions for the low thrust tethered system are developed. Time-varying transversality conditions for the probability constraints are constructed accordingly. A relaxed boundary technique is used to reformulate the indirect optimal control problem into a quadratic form optimization problem. The boundary condition to be met is relaxed and expressed using expected values and variance. In the technique, the area-based metric is used instead of the conventional distance-based metric concerning the expected boundaries of transverse conditions. The costate initial guess is recursively optimized using a gradient optimizer, leading to a highly efficient solution process.

The optimal trajectory transferring a debris using a tethered system, with a collision probability lower than 1.0e-4, is determined using the above mentioned methods.