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Dynamics and Control of Electrodynamic Tether for Spacecraft Deorbit

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The fast growing numbers of non-operational satellites, spent rockets and other debris produced objects and the relatively concentrated distribution of the space debris in orbits make the space around the Earth extremely crowded, especially in the Low Earth Orbit (LEO). Every year, new satellites have been launched into orbits around the Earth, which adds to the burgeoning profusion of space debris. Fragmentation of debris due to tidal forces or collisions makes the problem worse by increasing the number of stray particles, whose orbits become increasingly harder to track and predict as their spatial density increases and size decreases. This will eventually lead to a collisional cascading effect, known as the Kessler Syndrome, which could eventually render certain orbits completely useless for generations. The objective of the current work is to study the dynamics and stability control of electrodynamic tether (EDT) for spacecraft deorbit. EDT is an innovative propulsion technology that can perform deorbit maneuver without consuming propellant. However, it is intrinsically unstable due to the time-varying excitation of the electrodynamic force. The study shows that the stability of EDT is sensitive to the geomagnetic field model, especially in orbits with high inclination angles, and the high-order geomagnetic model must be used. To ensure the successful spacecraft deorbit by EDT, a piecewise two-phased optimal control scheme is proposed. The first phase concerns the open-loop control trajectory optimization, where the optimal control problem is formulated for the tether libration motion only by assuming the slow-varying orbital elements of the electrodynamic tether system as constant within a discretized interval. The second phase deals with the closed-loop optimal control for tracking the derived optimal reference trajectory subject to multiple major orbital perturbations. The finite receding horizon control method is used in the optimal trajectory tracking. Both optimal control problems are solved by a direct collocation method based on the Hermite–Simpson method using discretization schemes with coincident nodes. The resulting nonlinear programming problem significantly reduces the problem size and improves the computational efficiency. Numerical results for fast nanosatellite deorbit by an electrodynamic tether in both equatorial and highly inclined orbits show the proposed method achieves high control accuracy and efficiency.