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OPTIMAL CONTROL OF TETHERED SPACE-TUG SYSTEM FOR SPACE DEBRIS REMOVAL USING TIMESCALE SEPARATION

Abstract

With the dramatically growing number of states capable of launching their own satellites into orbits, the near earth orbits are becoming increasingly crowded. Among all possible solutions of space debris removal, the tethered space-tug (TST) carrying a space net to capture and deorbit the space debris by a tether appears one of the most effective and promising methods. However, it is challenging to prevent the TST system from failures due to the tether slack, tether libration and the attitude motion of the tug during the propulsion stage. This work concerns the dynamic stability of TST systems in the propulsion phase of a Hohmann orbital transfer that raises space debris from the geostationary orbit to the graveyard orbit by 300km. Operational constraints, such as bounded motion both for the tether libration and the tug attitude motion, positive tension and constant propulsion, are considered. The stability control of the tug system is achieved by regulating the reel-in/out acceleration of tether, the control toque and the orientation of the propulsion force acting on the tug. The authors develop a computationally efficient algorithm to solve the optimal control problem of the Hohnmann transfer for onboard implementation. Studies show that the orbital and libration motions of tethered space systems change at different timescales. Based on their time variation rates, the states and control inputs are separated into fast and slow categories and they are discretized by Legendre-Gauss-Lobatto method with different discretization grids. The resulted open-loop optimal control generates an optimal trajectory with minimum propulsion time and stable states of TST systems (zero libration of tether and zero attitude of tug) at the end of propulsion stage of the Hohmann transfer. Then, a closed-loop sliding mode controller is used to reduce errors introduced by the approximation of timescale separation and the direct discretization using polynomials. Finally, the efficiency and accuracy of the timescale separate optimal control strategy is demonstrated by numerical simulation. Furthermore, It is demonstrated that the proposed timescale separation scheme is effective in reducing the computational burden of the optimal control by about 30 percent with acceptable control accuracy.