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OPTIMAL CONTROL OF THE SPACE TETHERED TUG-DEBRIS SYSTEM WITH FUEL RESIDUALS DURING DEORBIT

Abstract

In characterizing the problem of space debris, it's shown that an amount of most dangerous debris is dominated by upper rocket stage left behind in orbit, because the breakup of this rocket body will produce more debris when propellant tanks with residual fuel in them explode. Fortunately, one promising approach to remove the upper rocket stage actively is to tow it into graveyard orbit or a low orbit with non-negligible atmospheric resistance by a spacecraft-tug, and there's a tether connecting the upper rocket stage and the spacecraft-tug. The combination of the upper rocket stage, tether, and spacecraft-tug is commonly known as the space tethered tug-debris system with fuel residuals. Unlike debris in most deorbit studies, the sloshing of fuel in the upper stage has a significant impact to the stabilization of this system, even makes it chaotic. For the convenient of dynamic analysis, small- and medium-amplitude of the sloshing is assumed, so the fuel can be equivalent to a pendulum approximatively. Detailed dynamics of the system has been analyzed in previous studies, however, suppression for its libration is not fully studied, especially with the condition of minimal fuel consumption of the spacecraft-tug. Therefore, the purpose of this work is to propose an optimal control scheme for mitigating the libration of the space tethered tug-debris system with fuel residuals, namely the attitude of the spacecraft-tug, the tumbling of the upper stage and the sloshing of its fuel. Based on this scheme, magnitude and direction of thrust force generated by spacecraft-tug can be obtained in real-time, which suppress the tumbling of the upper stage indirectly through a tether and satisfy the energy optimal condition. In the dynamics modeling, the spacecraft-tug and the upper stage are both considered as rigid bodies, and equations describing the motion of the system is constructed by Lagrange formalism. At the next level of control, the optimal control scheme mentioned above includes two steps, open-loop control step and closed-loop control step respectively. Based on Gauss pseudospectral method, the open-loop control step designs an optimal reference trajectory by solving an optimal fuel consumption deorbit problem. Considering the uncertainty of the dynamic model of the system and space perturbations, the closed-loop control step for tracking the trajectory using nonlinear model predictive control method is proceeded subsequently. Numerical simulations indicate that the proposed scheme can suppress the libration of the space tethered tug-debris system successfully and economically.