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TOWING TETHERS TO CONTROL DEBRIS REMOVAL DYNAMICS

Abstract

Space debris is an urgent and growing issue to be faced for future space operations and space exploitation durability, especially in Low Earth Orbits (LEO). A general-purpose removal system design should effectively intervene on objects different in configuration, materials and possibly in dimensions such as fragments, entire/parts-of dismissed satellites and third stages/fairing elements. Moreover, targets to be captured do not cooperate and have a complex, free, not completely known dynamics. For these reasons, different techniques have been proposed based on capturing debris from a safety distance through the use of either throw-nets or tentacles or harpoons. In contrast with rigid capture mechanisms, these techniques are characterized by establishing a flexible tethered connection between the chaser and the target. That opens new challenges for guidance navigation and control (GNC) design: the chaser GNC system is required to be precise enough to gain stabilized specific relative orbits and to robustly perform de-orbiting operations, while controlling a complex system and damping vibrations of flexible elements and connections. This paper, via numerical results, shows that tethered systems are a promising technology to remove space debris and discusses the main difficulties that are likely to take place during the towing, particularly from a GNC point of view. The composite's tethered dynamics is explored using a discretized viscoelastic tether model attached to six degrees of freedom end-bodies with flexible appendages. The spatial motion of the system is studied in the Earth gravity field, under the action of chaser de-orbiting thrusters, aerodynamic drag and gravitational torque. Initial orbital configurations (V-bar or R-bar alignment) and propulsion systems (chemical versus electric), as well as the tether material, length and diameter strongly affect the mission feasibility: fallouts are presented for both the cases of de-orbiting and re-orbiting. It is demonstrated how closed-loop control laws significantly reduce the likelihood of post-burn collisions, as well as multi-burn strategies and large initial separation distance do. The possibility of critical modes of the system motion leading to entanglement of the tether is also shown by means of numerical simulations. Performances, safety and costs of such de-orbiting missions and robustness of implemented GNC algorithms against system uncertainties and non-perfect, non-aligned tether connection points are presented: influences of initial conditions and tow-tether physical properties on the system dynamic behaviour and controllability are studied. Finally, the controlled re-entry of a large space debris from LEO to the Earth's surface is studied, being significant for such a technology.