Contact-less Active Debris Removal: the Hybrid Propulsion Alternative

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The space debris removal and generation containment in Earth orbits is a well-known and urgent issue to be faced to mainly preserve the safety of the current and future active space systems. From a removal system design point of view, the more the general purpose it is the more cost effective would be. On the other side, the more general purpose it is, the less effective it may turn to be. In fact, a general purpose removal system design should effectively intervene on objects completely different in configuration, materials and possibly in sizes such as fragments, entire/parts-of dismissed satellites and third stages/fairing elements. Moreover, elements to be managed do not cooperate and have a complex, free, not completely known dynamics.
Different techniques are being proposed in literature, starting from the classical robotic arm, dedicated to a narrow and specific class of debris which present parts the robotic arm can grasp to, up to action-reaction principle exploitation with no contact at all, such as gas plume impinging on the non-cooperative element to change its momentum. The latter is, at some extent, less constrained by the target features and gives room for a multi-debris disposal with single chaser scenario analysis. The contact- less solution has the main benefit of being almost independent on the target configuration and free motion: no docking maneuver is required, no grasping device must be a hoc sized and realized.
On the other hand, possible chemical interactions between the target material and the exhausted gas molecules should be avoided or, at least, known to correctly evaluate the maneuver efficiency; the plume must be kept in line with the target all the maneuver long and correctly pointed not to generate side effects on the rotational dynamics; depending on the impinging plume efficiency the chaser might follow the target for quite a long time span. Differently from the solutions offered in literature so far, which propose the electric propulsion plume exploitation to control the target debris momentum change, the paper discusses the benefits in exploiting the plume of a hybrid propulsion unit embarked on the chaser vehicle, to remove dead objects with no contact. Thanks to the high thrust level the exploitation of a chemical propulsion plume allows drastically reducing the target-chaser interaction up to few minutes: as a consequences the GNC unit effort to keep the plume pointing the chaser is definitely softened. The exhausts are neutral particles that have no chemical reaction with the metallic debris surface, therefore the mechanism efficiency is preserved. More, the chemical propulsion is a high TRL technology, therefore costs to potentially develop this solution for ADR is cheaper than others.
The chemical propulsion solution, however, has its most relevant limitation in the small specific impulse that affects the fuel mass required for a given maneuver: the solid-liquid hybrid propulsion offers reasonable specific impulses levels, it is light, simple and cheap and throttleable: features definitely appealing for a multi-removal mission. The paper presents the feasibility study results for an ADR mission for large debris critically discussing the sensitivity of the mission design to the features of the alternative chemical propulsion units solutions and to the size, mass and number of the potential targets to remove.
The proposed contact-less ADR hybrid propulsion solution is analyzed in deep by applying the thruster features currently under development at the SPLab (Space Propulsion Lab) of the Aerospace Science and Technologies Dept. of Politecnico di Milano. A possible technology roadmap to implement and test the proposed strategy with an In-Orbit Demonstration is also presented.