Orbital Strategies of Space-TUG for Space Debris Remediation in Low Earth Orbit

Abstract: Space debris is the most important issue of today's space age. It includes both naturally occurring meteoroids and anthropogenic debris from human activity in Earth's orbit. Donald Kessler first observed the phenomena of increasing debris and noted that the accumulation of already present orbital debris would begin to create new debris due to collision and that this cascading process would severely impede human activities in space – a phenomenon known as Kessler Syndrome. Today, the space segment is constantly threatened by orbital debris, including rocket bodies and defunct satellites. As of March 2023, the Space Surveillance Network (SSN) has traced about 33680 pieces of space debris greater than 10cm in size. Additionally, an estimated 1 million pieces between 1 to 10 cm and 130 million fragments smaller than 1 cm are also orbiting Earth. Thus, space safety in today's scenario requires two essential approaches – the space debris mitigation (SDM) and space debris remediation (SDR). Unless both approaches are employed simultaneously, the likely possibility of space catastrophes will continue to rise steadily. While the SDM is being managed through InterAgency Space Debris Coordination Committee (IADC), the SDR remains essentially unresolved.

The SDR process can be best undertaken by performing Active Debris Removal (ADR) missions. These highly complex and risky missions need to be designed with utmost accuracy so that debris removal can be conducted without affecting the safety of the SDR spacecraft. At the AstroFlux research facility, there is an ongoing pursuit for developing mission strategies for small affordable Space Tugs with limited orbital life, that use robotic end-effectors for undertaking SDR operations of preselected debris in Low Earth Orbit. The alternative mission strategies for the space tugs are based on the minimal energy maneuvers, thus drastically reducing the cost of mission operations. The methodology for affordable SDR mission is based on a three-step approach. The first step involves selection of space debris for SDR. For this a dimensionless mission efficiency parameter is defined to select the debris items that cause minimal losses for SDR mission. In the second step a suitable parking orbit and several alternative mission sequences are evolved. The parking is a Sun-synchronous orbit as the spacecraft's secondary objective can be to function as an Earth observation satellite during its waiting period. In the final step the most suitable mission concepts are fully developed. Following the concurrent engineering approach, two novel mission strategies have been developed namely, the Home capture and the Nodal capture. In Home capture the debris is grabbed from its orbit by phasing the chaser's orbit. The chaser enters the debris orbit, grabs it, and then de-orbits it. The Nodal capture is however designed to be less risky and energy efficient in which the debris trajectory crosses the parking orbit at the intersecting node at which point debris is captured. Thus, neither the chaser nor the debris changes its orbit. These missions are designed to be performed by a dedicated spacecraft bus supported by a LIDAR-based tracking that assists the robotic arm for capturing the debris.

Keywords: Kessler Syndrome, Space debris Remediation (SDR), Active Debris Removal (ADR), Robotic Manipulator, Home Capture strategy, Nodal Capture strategy, Sun-synchronous Orbit.