RIDDANCE: Removal of Irregular Debris Using Double Assisted Nets with Controlled Enhancement

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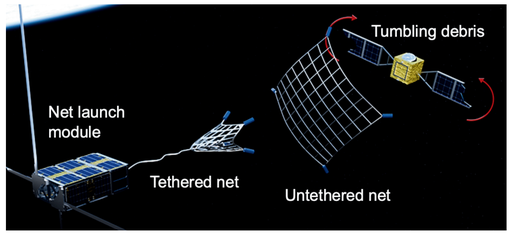
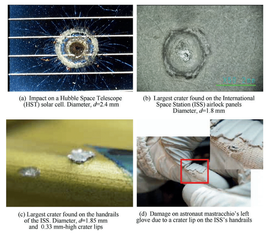
ABSTRACT

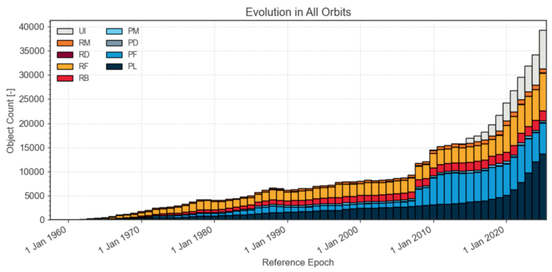
The growing problem of orbital debris is an increasingly critical threat to existing satellite systems and any potential future missions in space. Among different strategies for debris mitigation, net-based Active Debris Removal (ADR) remains a promising method for its passive, durable, and scalable nature for debris capture operations. As part of the development efforts for net-based debris removal activities, simulation work using an LS-DYNA software with a Kevlar net in an orbital debris interception mission has helped understand its dynamic enwrapping phases in debris interception operations.





INTRODUCTION

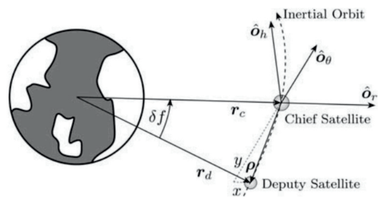
The ever-increasing menace of orbital debris creates critical circumstances for the sustainability of operations in Earth's satellites. There is the possibility of triggered chain reactions referred to as Kessler Syndrome, hence emphasizing the significance of Active Debris Removal.

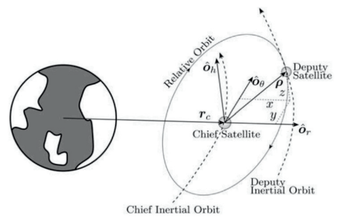


- Explores net-based ADR for its scalability and non-destructive nature in technology implementations.
- Utilizes LS-DYNA simulations for simulating the net debris interactions.
- Analyzes dynamic wrapping behavior and structural response.
- It strives to optimize net geometry and material properties for better capture.
- Enables building lightweight yet robust ADR systems.

METHODOLOGY

A two-stage net-based Active Debris Removal (ADR) system was developed for efficient and controlled orbital debris capture. Two Kevlar 49 nets are deployed sequentially—the first untethered net reduces debris tumbling, while the second tethered net captures both the debris and the first net for controlled deorbit and atmospheric burn-up. Finite element analyses in LS-DYNA examined wrapping dynamics, deformation, and stress response [1]. Meshing and preprocessing were done in Altair HyperWorks, using a 1m × 1m virtual net targeting a 6U CubeSat-sized object.





The figures and formulas represent the nonlinear orbital relations between the deputy satellite and the chief satellite in terms of point mass dynamics [2].

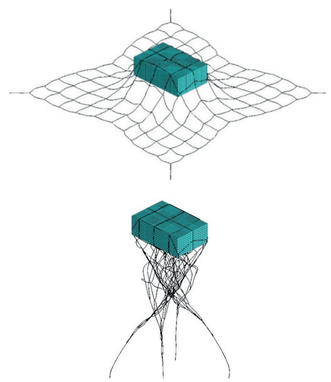
$$\ddot{x} - 2\dot{f}\left(\dot{y} - y\frac{\dot{r}_c}{r_c}\right) - x\dot{f}^2 - \frac{\mu}{r_c^2} = -\frac{\mu}{r_d^3}(r_c + x)$$

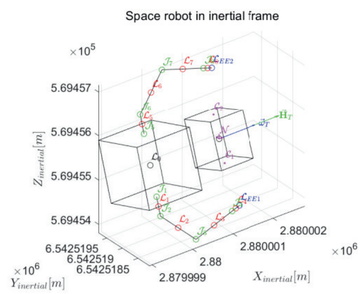
$$\ddot{y} + 2\dot{f}\left(\dot{x} - x\frac{\dot{r}_c}{r_c}\right) - y\dot{f}^2 = -\frac{\mu}{r_d^3}y$$

$$\ddot{z} = -\frac{\mu}{r_d^3}z$$

RESULTS

LS-DYNA simulations shows effective Kevlar net wrapping and entanglement. The figure depicts space robot–RSO interaction, including approach, alignment, and contact.





DISCUSSION

- Simulation results from LS-DYNA reveal that the net effectively covers the debris with its elastic deformation in tension areas.
- Robust capture effectively captures difficult, spinning targets, including tumbling targets, with good consistency in performance.
- Simulation shows the space robot approaching in the angular momentum direction, its extensible manipulators reaching target points for making contacts, then successfully capturing the debris in its spinning, tumbling state [3].
- ADR potential confirms the sustainability and effectiveness of Kevlar netting for Active Debris Removal missions for safe and efficient removal of orbital debris.

CONCLUSION

The rising presence of space debris poses a potential threat to the safety and sustainability of future space operations. Removal is also key to preventing other collisions.

Net-based Active Debris Removal (ADR) is safe and effective in removing space debris, according to research, with simulation results indicating that the net is able to grasp tumbling debris effectively with high structural integrity. LS-DYNA simulation results show that the net is able to grasp tumbling debris effectively with high structural integrity.

In general, the results verify the feasibility of light, flexible, and non-destructive net systems to act as a green technology for a cleaner and secure orbital environment.

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