Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria Aerospaziale

DEVELOPING SOLUTIONS FOR ACTIVE SPACE DEBRIS REMOVAL

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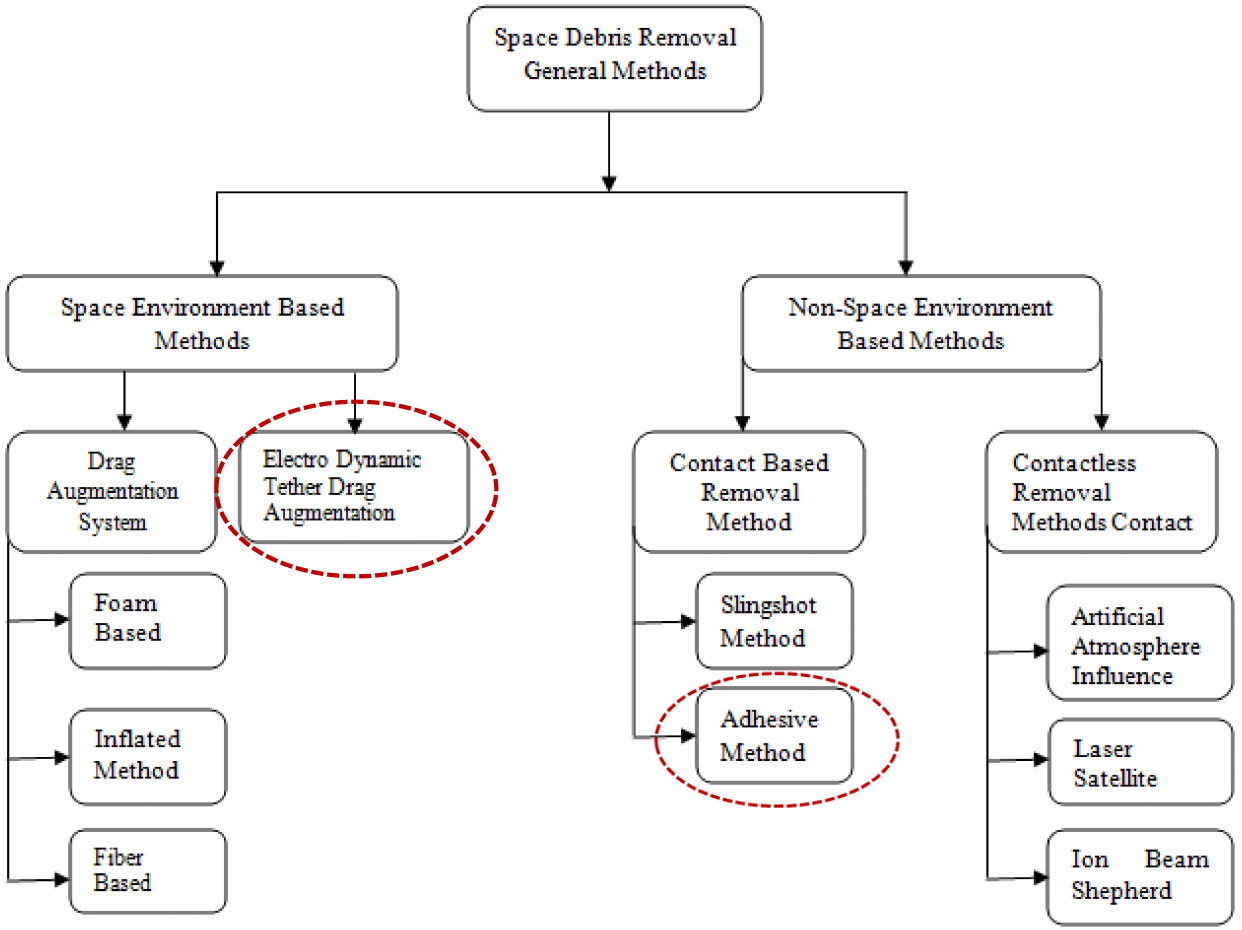
THE PROBLEM OF SPACE DEBRIS

Distribution of space debris. Credit: ESA

- Kessler Syndrome
- Sources of space debris
  - explosions of satellites and rocket bodies
  - anti-satellite test
  - missing equipment
  - defunct satellites
  - natural sources
- Hypervelocity impact → phenomena occuring when a spacecraft collides with an object with a relative velocity exceeding the speed of sound in solid material
- Inter-Agency Space Debris Coordination Committee (IADC)
- Active Debris Removal (ADR) developing solutions

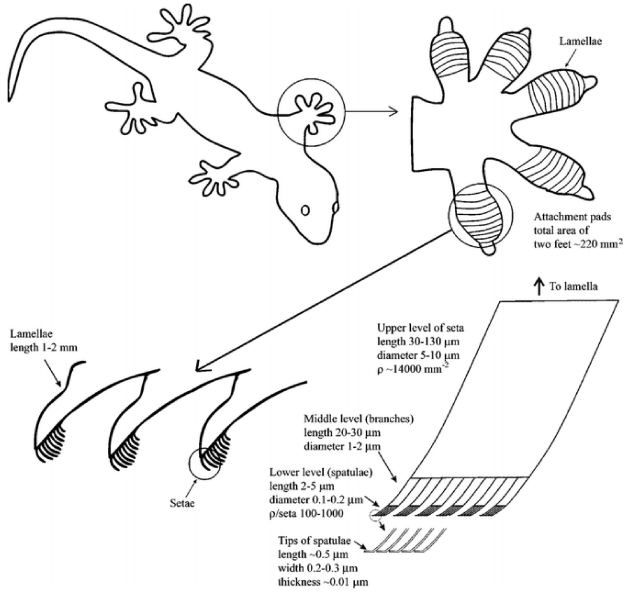
ACTIVE DEBRIS REMOVAL SOLUTIONS



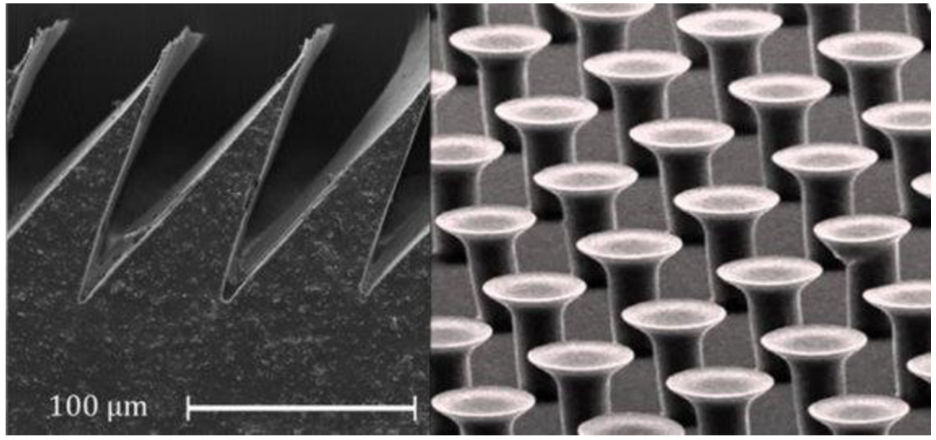
Summary diagram of different ADR methods.
Credit: P. Singh, D. Singh Chand, S. Pal, A. Mishra (2021)

GECKO-BASED ADR

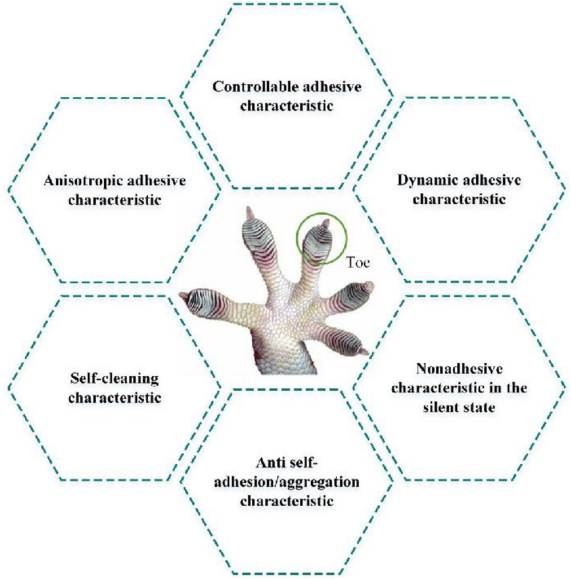
- Contact-based capture method, based on the discovery of the presence of millions of fine hairs or fibrils in gecko's skin
- Kind of adhesives, based on their shape:
  - Anisotropic wedges, composed of asymmetric fibrils
  - Mushroom-shaped fibres
- Several properties
- Manufacturing process: moulds made by lithography techniques or micromachines
- Tested gecko materials: polyurethane and silicone based materials



Schematic structure of gecko foot, with cross-sectional view of the lamellae and individual seta. Bhushan (2007b)

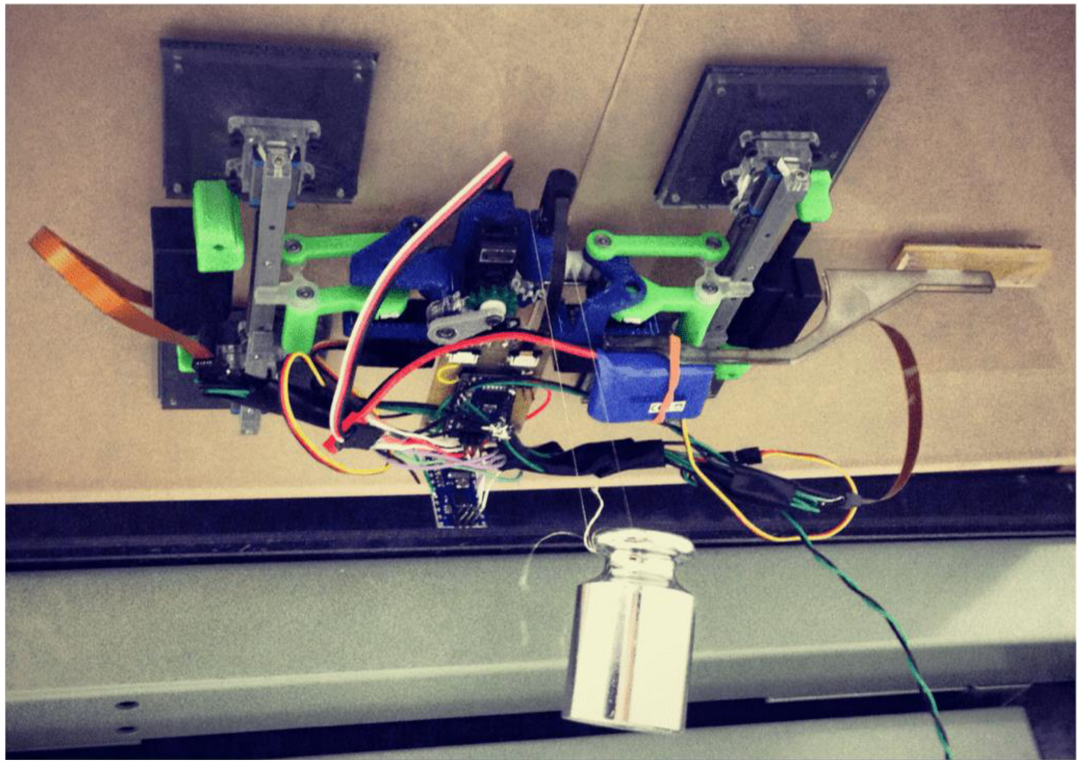


Micro-wedge-shaped adhesive (left) and mushroom-shaped adhesive (right). M. Cutlosky (2020)



Adhesive characteristics of gecko's foot. Wei Wang, Yang Liu, Z. Xie (2021)

ACROBOT



ACROBOT climbing upside down.
S. Kalouche, N. Wiltsie, Hai-Jun Su, A. Parness (2014)

An important example of implementation of gecko adhesives was produced by a group from Stanford University that developed a robot

- capable of climbing surfaces in any gravitational orientation or in vacuum
- pads composed of two-tiered structure
- suspention layer compensating misalignments
- array of wedges with directional mushroom ends
- small actuator that generate a shear load

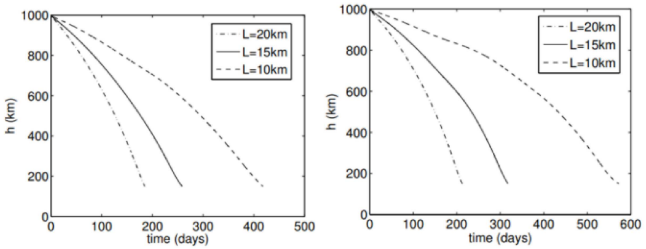
ELECTRODYNAMIC TETHERS (EDT)

- EDT supply power and propulsion using the Lorentz force generated by the interaction between the electric current and the geomagnetic field

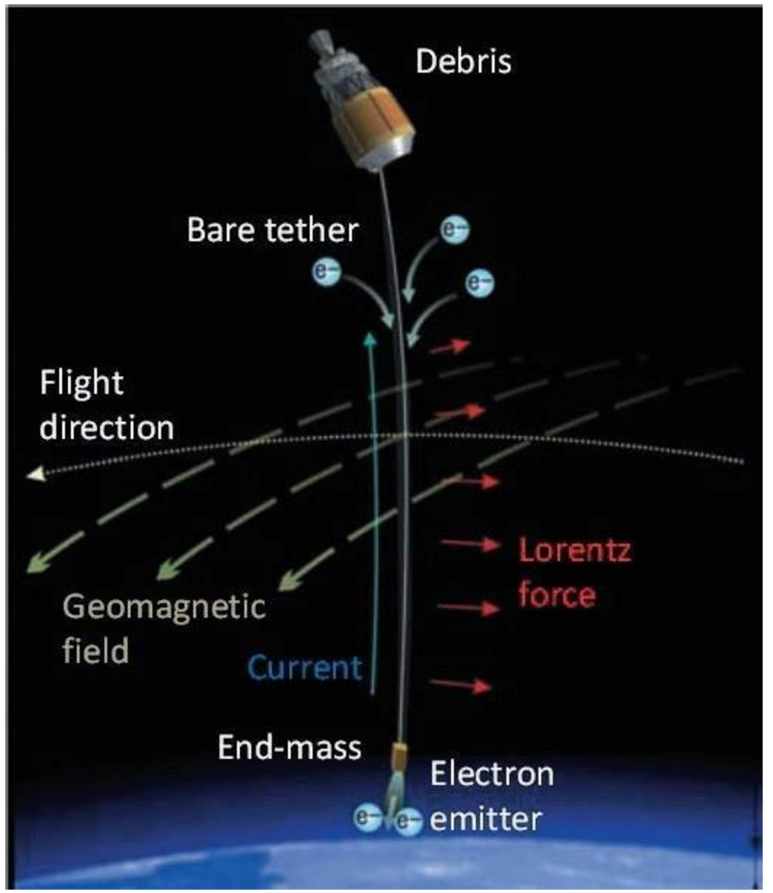
$$\vec{F} = \int_0^L I(l)d\vec{l} \times \vec{B} \qquad \Longrightarrow \qquad P = \vec{F} \cdot \vec{v}$$

With a maximum average current flowing through a passive EDT $I_{av} = \frac{3}{5}\eta_{th} I_{ch}$ (estimated by C. Bombardelli and his teamwork)

- Implemented using two models:
  - Single tether model
  - Flexible tether model
- IADC Action Item 19.1 computational approaches:
  - ISTI/CNR approach → $P = 1 - e^{-R_F \Delta t}$ (given the number of impacts that can cut a single line tether during a certain time interval)
  - KU method → $X_T(t) = \left(X_1(t) + X_2(t)\right)^N \left(X_{knot}(t)\right)^{N+1}$ Where $X_1(t)$ and $X_2(t)$ are probabilities referred to two different conditions of wires in a loop after collision
  - NASA/JSC method → follows the Anz-Meador model
- Deorbiting performance



Deorbiting curves for a Zenith 2nd stage under maximum (left) and minimum (right) solar activity. C. Bombardelli (2010)



Working principle of Electrodynamic Tethers. Surajit Mondal (2018)

CLEARSPACE-1

ClearSpace-1 approaching the VESPA module with the four deployed tentacles. Credits: ESA

- Developed by a Swiss start-up financed by ESA
- Target: upper stage of Vega Secondary Payload Adapter (VESPA)
- Mission operations
  - Separation from the fairing
  - Parking orbit for commissioning and critical targeting tests
  - Far range rendezvous
  - Close range rendezvous
  - Capture
  - Deorbiting
  - Atmospheric re-entry

CONCLUSIONS

ADR concept	Reusability	Complexity	Detumbling possibility	Adaptability	Risk of creating new debris
Gecko-based	++	+	+	+	+
Electrodynamic tethers	++	o	+	++	+
Robotic arms	--	--	++	o	--

Overview of the ADR concepts analysed, where the key is the following: "++" = very good, "+" = good, "o" = medium, "--" = unsuitable

The goal that must be set for the future is to find increasingly complete and boastful solutions, providing the possibility to reduce the problem of space debris, improving the orbital environment, and preserving the safety of present and future space missions.

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