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Advanced Technology for Space Debris Removal

Team Details :

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Problem Statement: **Space Debris Removal (Individual Category)**

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SHAPE MEMORY ALLOYS (SMAS)

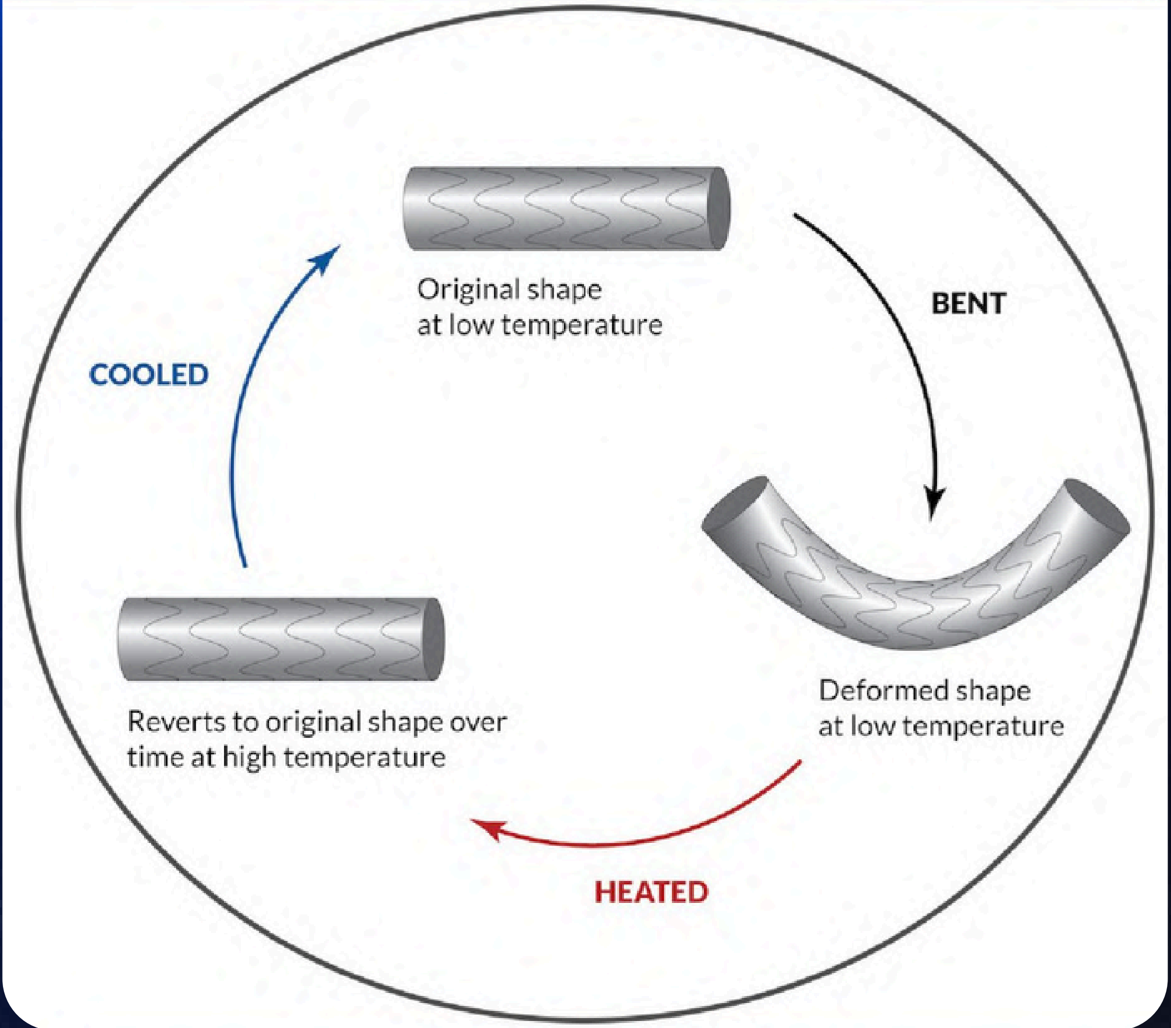
WHAT IS SHAPE MEMORY ALLOY?

- **Smart materials** that return to their original shape when heated or stress is removed.
- Composed of metals like **Nickel-Titanium (NiTi)**, **Titanium-Tantalum (Ti-Ta)**, **(NiTiHf)** or **(NiTiNb)** for high-temperature stability in space.
- Used in **robotic actuators**, **aerospace structures**, and **adaptive gripping systems**.

WHY USE SMAS IN SPACE?

- **High Strength-to-Weight Ratio:** Ideal for space missions where every gram counts.
- **Durability:** Capable of withstanding harsh space environments, including extreme temperatures and radiation.
- **Minimal Power Consumption:** Energy-efficient actuation mechanisms that are crucial for long-duration missions.

Transformation of Shape Memory Alloy



APPLICATIONS IN AEROSPACE

- **Adaptive Grippers:** SMA-powered for precise debris capture.
- **Deployable Arms:** Extendable and retractable mechanisms for handling debris of varying sizes.

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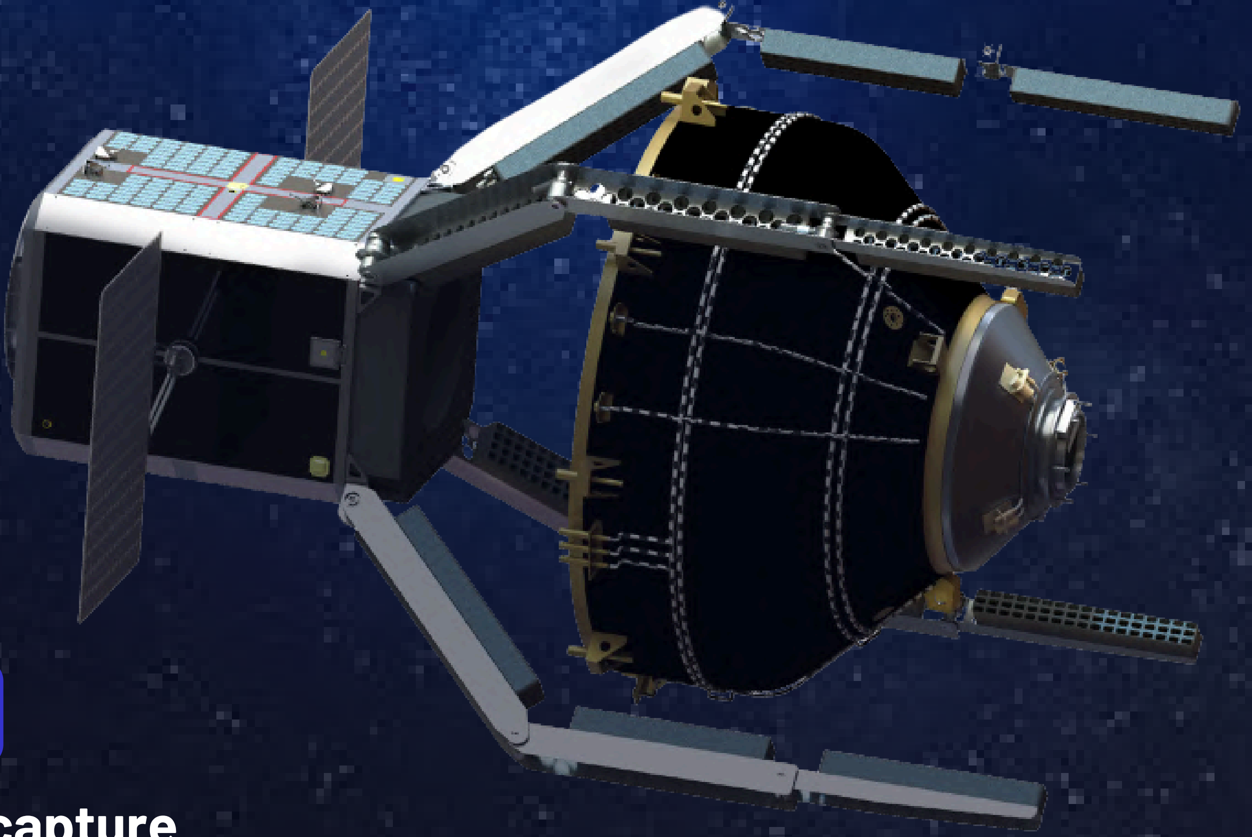
INTEGRATION OF SMA IN DEBRIS REMOVAL

Integrating Shape Memory Alloys into robotic arms for space debris removal presents a promising advancement, enhancing efficiency, reducing energy consumption, and lowering costs while maintaining high capture effectiveness. This innovation could significantly improve the viability of ADR missions in addressing the growing space debris challenge.



SMA-Based Actuators for Grippers

- **Facilitate flexible and adaptive gripping of irregularly shaped debris, ensuring effective capture without damaging the debris or the capture mechanism.**

Deployable SMA-Driven Structures

- **Extendable booms and arms can position capture tools precisely, allowing for versatile approaches to debris of varying sizes and shapes.**

Thermal Activation Mechanism

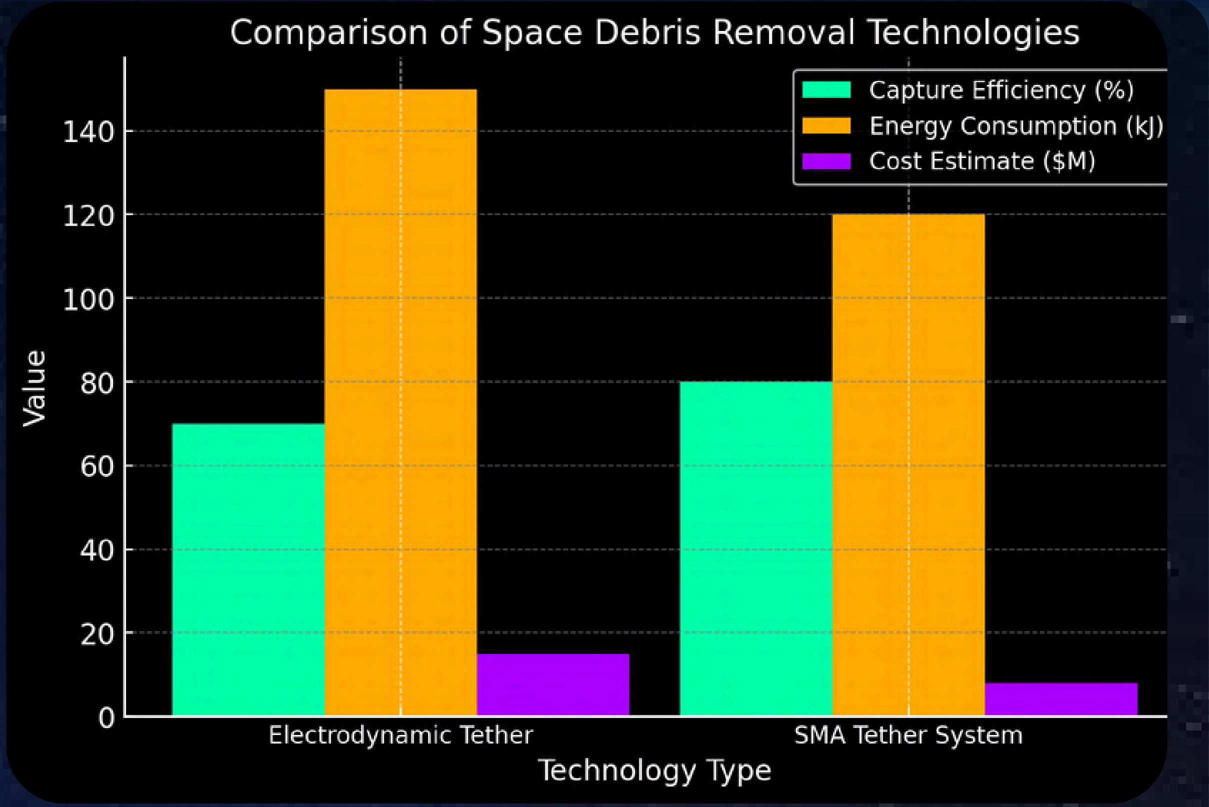
- Utilizes **onboard power sources** to activate SMAs, enabling shape transformation that is responsive to environmental conditions or mission requirements.

Robustness Against Space Conditions

- SMA mechanisms are designed to function reliably under **extreme conditions**, including vacuum and temperature fluctuations typical in **space environments**.

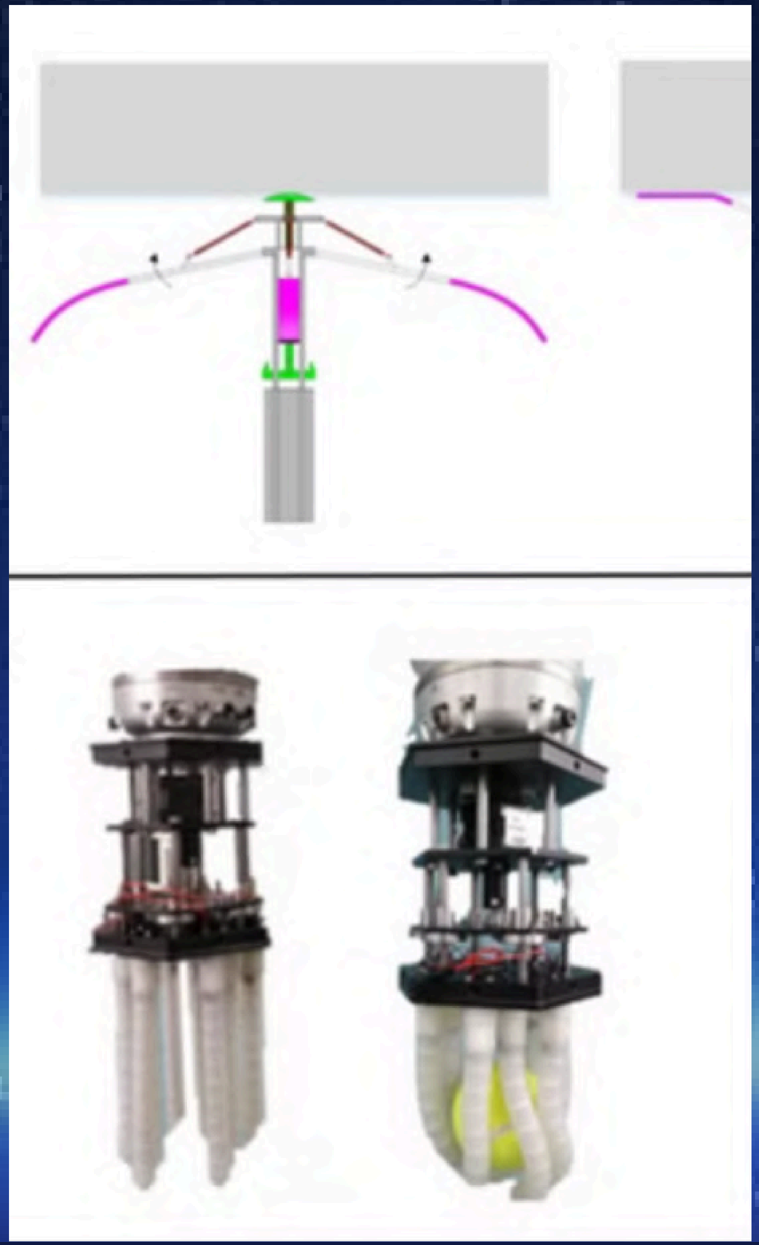
SHAPE MEMORY ALLOY (SMA) ROBOTIC ARM

Integrating Shape Memory Alloys into tether systems presents a promising advancement in space debris removal technology, enhancing efficiency, reducing energy consumption, and lowering costs while maintaining high capture effectiveness.



Advantages of SMA:

- Adaptability: Shape-shifting for dynamic capture adjustments.
- Energy Efficiency: Potentially lower energy use via passive actuation.
- Impact Resistance: Enhanced energy absorption, reducing debris.
- Capture Efficiency: Potential 80% efficiency due to adaptability and energy absorption.
- Energy Consumption: Estimated 120 kJ.



LImitations of Current Technology

- Power Requirements: High power needs for electromagnetic forces increase mission complexity and cost.
- Limited Range: Effectiveness decreases with distance and high debris velocities.
- Control Complexity: Controlling EDT orientation and operation is challenging, especially in dynamic environments.
- Cost: High development and deployment costs limit widespread us

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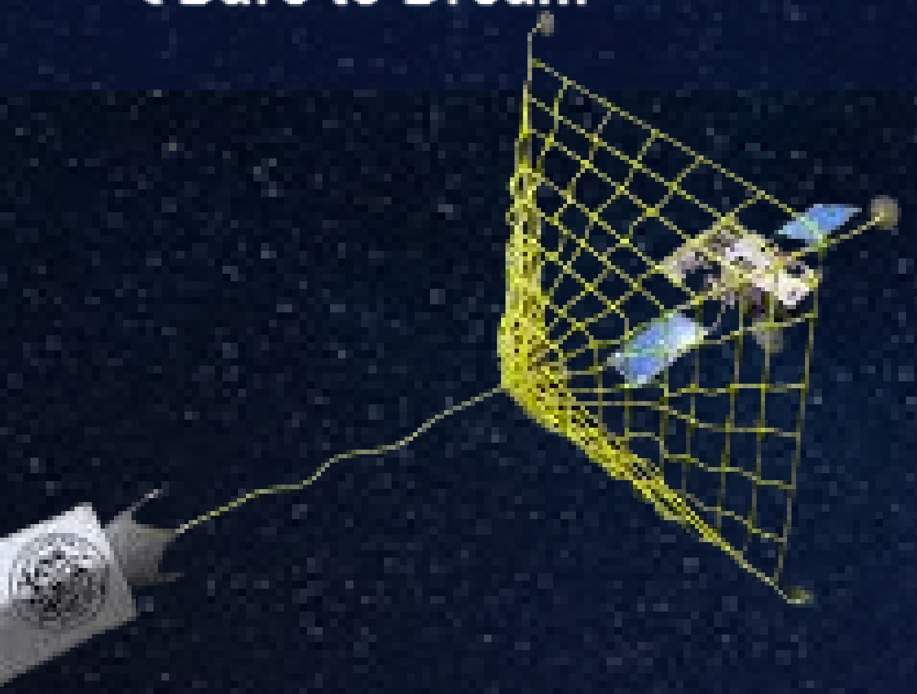


SMA-Based Net for Space Debris Capture

1. Compact Storage

- The SMA net is packed in a **controlled temperature** environment inside the spacecraft.
- Ensures **maximum space efficiency** before deployment.

2. Deployment Using Electricity

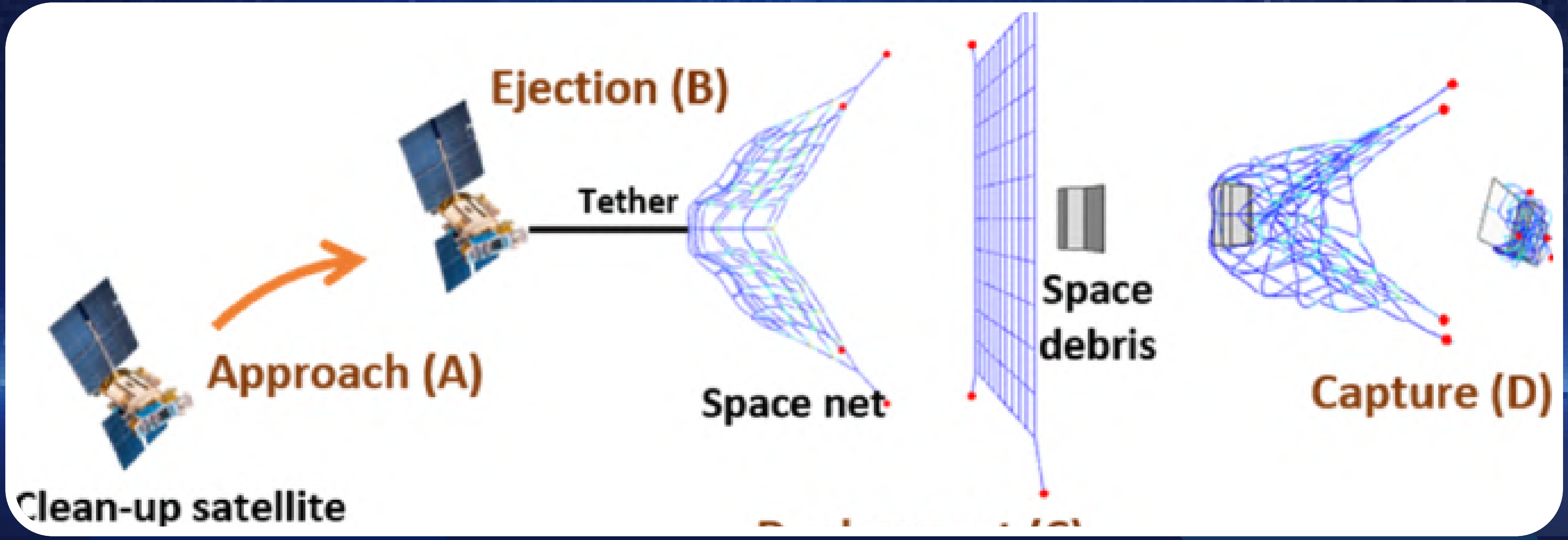
- Once outside the spacecraft, an **electric current** is applied.
- **The SMA net expands and flattens automatically, preparing for capture**

3. Capture Mechanism

- As the **net approaches debris, electricity is turned off.**
- The **SMA contracts, wrapping tightly around the object, ensuring a secure hold.**

4. Debris Removal

- **The captured debris can then be deorbited** or transported safely.
- Example: Similar to a fishing net that spreads out and then closes around a fish, the SMA net expands and contracts to trap space debris.



AI AND MACHINE LEARNING INTEGRATION TECHNOLOGIES

Trajectory Prediction

- **Hybrid Model → LSTM + Kalman Filter + Transformer** to analyze **orbital data** to predict **debris paths** and **velocity with high accuracy**.
- Adaptive algorithms optimize **interception points in real-time**.

Collision Avoidance

- AI ensures the satellite **navigates safely while engaging debris**.
- **Minimizes risks** of unintended collisions during operations.

Object Detection

- Custom-trained **YOLOv8** achieves **99.7% accuracy** for precise space debris detection
- **Real-Time Performance** – <20ms inference time on space-hardened hardware enables instant tracking and response.

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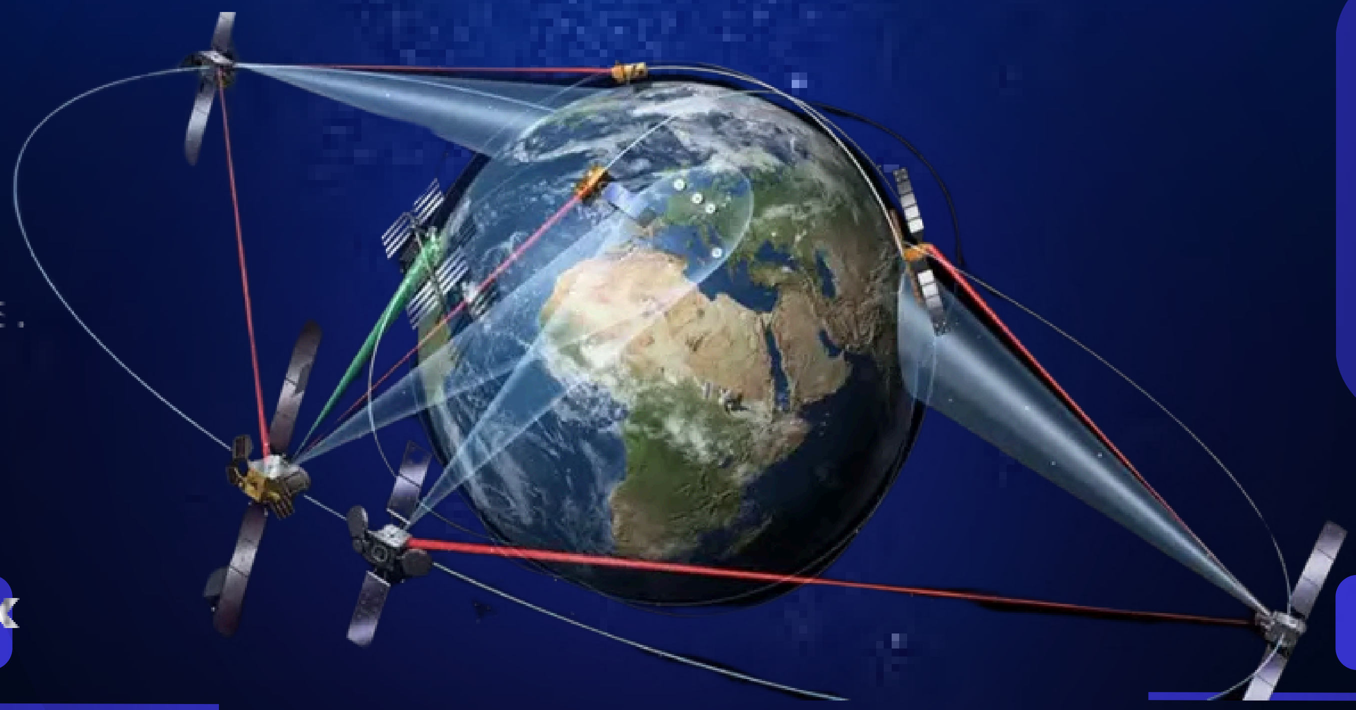
Advanced Sensors and Communication Systems

High-Resolution Cameras and LiDAR

Deliver ultra-precise imaging and 3D mapping for accurate debris tracking and identification
Enhance navigation and obstacle avoidance in dynamic space environments.



Multi-Spectral and Hyperspectral Imaging

Differentiate materials based on spectral signatures for enhanced object characterization.
Support automated debris categorization and risk assessment.

Robust Communication Framework

Enable low-latency, high-bandwidth data transmission for real-time mission updates.
AI-driven autonomous decision-making ensures uninterrupted operations in case of signal loss.
Secure, encrypted communication prevents data breaches and cyber threats.

Infrared Sensors

Detect and classify thermal signatures to identify camouflaged or low-visibility objects.
Improve detection accuracy in extreme lighting conditions, such as deep space or planetary shadows.

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CUTTING-EDGE MATERIAL INNOVATIONS FOR SPACE APPLICATIONS

1 LOW-OUTGASSING, SPACE-GRADE MATERIALS

- Minimize contamination risks, preserving the functionality of optical and electronic systems.
- Ensure compliance with stringent aerospace standards for reliability in space environments.

2 RADIATION-HARDENED SMA ALLOYS

- Engineered with advanced coatings to resist cosmic radiation and extreme temperature fluctuations.
- Maintain structural integrity and shape memory properties in prolonged deep-space missions.

3 EXTREME DURABILITY & IMPACT RESISTANCE

- SMA components designed to withstand micrometeoroid impacts and prolonged vacuum exposure.
- Enhanced resilience against thermal cycling, preventing material degradation over time.