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LASER ACTIVATED COMPLIANCE EMBEDDED NETWORKS (LACEN): QUANTUM-PHOTONIC AUTONOMY FOR PREEMPTIVE DEBRIS MITIGATION

Abstract

Introduction

The proliferation of space debris in low-Earth orbit poses an existential threat to satellites, crewed missions, and future space operations, over 36,000 tracked debris objects 10 cm currently orbit Earth, with collision risks escalating annually due to megaconstellations and legacy satellites. Conventional mitigation strategies (propulsion based deorbit systems, drag sails, or AI-driven collision avoidance) face critical limitations: dependence on onboard power/electronics, high costs, and incompatibility with defunct or passive objects, the aerospace industry urgently requires preemptive, passive, and verifiable solutions aligned with Space Environment Management (SEM) guidelines to ensure long-term orbital sustainability.

Objective

This research proposes Laser-Activated Compliance Embedded Networks, a novel quantum-photonic framework integrating metamaterials and laser physics to passively enforce SEM compliance.

LACEN aims to:

-Enable autonomous, propulsion free deorbiting of satellites via laser-induced quantum-photonic momentum transfer.

-Provide real time verification of debris mitigation measures without telemetry.

-Establish a universal, low cost standard for future spacecraft design.

Methodology

The LACEN framework is being developed through three interconnected phases:

Theoretical Modeling

Quantum dot matrices are engineered to amplify photon momentum via electron delocalization under targeted laser wavelengths (1064–1550 nm). Computational simulations quantify force generation (0.1–0.5 mN) required for controlled orbital decay, laser interaction protocols are optimized using radiative transfer equations, accounting for atmospheric attenuation and orbital dynamics.

Material Synthesis Testing

Prototype LACEN coatings, embedded with wavelength-tunable quantum dots, are applied to CubeSat-grade aluminum panels. Ground-based testing at the CNES Microgravity Center validates reflectivity modulation (15–25

System Integration

A global verification network is designed using existing astronomical telescopes to detect LACEN's photonic “compliance signatures”.

Expected Outcomes Progress

Preliminary simulations indicate that LACEN-enabled satellites could achieve controlled deorbiting within 2–4 weeks using terrestrial lasers (10–20 kW). Theoretical models predict a 90

Conclusion

LACEN represents a paradigm shift in SEM by addressing mitigation proactively at the design stage, eliminating reliance on post-deployment active systems, its passive, physics-driven approach aligns with global SEM priorities, while circumventing risks associated with AI or propulsion.