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SMART SATELLITES AI-DRIVEN PREDICTIVE MAINTENANCE FOR SUSTAINABLE SPACE OPERATIONS

Abstract

This paper explores the implementation of AI-driven predictive maintenance to enhance satellite longevity and sustainability. Satellites are vital for communication, Earth observation, scientific research, and defense, but their operational lifespan is compromised by extreme space environments, unforeseen failures, and resource depletion. Traditional maintenance methods are reactive, leading to premature mission failures, increased operational costs, and growing space debris. To address these challenges, this paper presents an AI-based predictive maintenance framework that enables satellites to autonomously monitor health, predict failures, and optimize operations, reducing downtime and extending mission lifespans.

The paper details how real-time telemetry analysis, AI-driven fault detection, and autonomous optimization can be integrated to enhance satellite resilience. Onboard sensors continuously monitor critical subsystems such as power distribution, propulsion, thermal regulation, and communication, collecting real-time telemetry data. Advanced machine learning algorithms analyze historical and live data to detect anomalies, predict failures, and diagnose issues before they escalate. Supervised learning models classify faults based on past mission data, while unsupervised learning techniques identify novel anomalies in system behavior. AI-driven decision-making algorithms then determine the most effective corrective measures, such as power redistribution, thermal control adjustments, or configuration modifications, ensuring continued functionality. In critical cases, satellites can autonomously adapt operations or send alerts to ground control for assessment.

Additionally, the paper advocates for the integration of sustainable composite materials to enhance satellite durability and reduce environmental impact. By selecting lightweight, radiation-resistant materials with improved thermal insulation, satellite structures can better withstand space conditions. AI-driven material degradation models further enhance reliability by predicting wear and tear, enabling proactive maintenance strategies.

This research demonstrates that AI-driven predictive maintenance significantly improves satellite sustainability by minimizing premature failures and mitigating space debris. By reducing mission costs and operational risks, this approach contributes to sustainable space exploration and helps prevent the Kessler Syndrome, where accumulating debris threatens future missions. The paper highlights how intelligent fault detection, real-time optimization, and advanced materials can revolutionize satellite operations, ensuring long-term functionality, resource efficiency, and environmental responsibility in space missions.