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AI-DRIVEN PREDICTIVE MAINTENANCE FOR NANOSATELLITE POWER SYSTEMS: ENHANCING RELIABILITY THROUGH MACHINE LEARNING

Abstract

Nanosatellites have revolutionized space exploration by offering cost-effective and accessible platforms for scientific research, Earth observation, and deep-space missions. However, their limited power capacity and lack of continuous ground intervention expose them to unexpected system failures, particularly within Electrical Power Systems (EPS), which are crucial for mission success. Conventional fault detection relies on predefined thresholds and rule-based monitoring, which often fail to detect early performance degradation, increasing the likelihood of power failures, reduced mission lifespans, and data loss. To improve the reliability of nanosatellite power systems, an AI-driven predictive maintenance approach is introduced, enabling real-time anomaly detection and fault prediction. By leveraging machine learning (ML) techniques, this method examines historical telemetry data to detect patterns in battery behavior, power distribution variations, and solar panel efficiency changes. The framework implements onboard lightweight AI models that perform two key functions: detecting anomalies in real time by continuously monitoring EPS behavior using telemetry parameters such as voltage, current, temperature, and state of charge (SoC), and enabling predictive fault prevention by anticipating potential failures and taking preventive actions. This approach optimizes power management, extends battery life, and reduces reliance on ground-based monitoring, ultimately enhancing the satellite's autonomy and reliability. Simulations show that this AI-based system achieves more than 90% accuracy in fault detection while reducing false alarms by 40%, significantly increasing system resilience and energy efficiency. Unlike traditional threshold-based methods, the predictive maintenance framework provides an adaptive and robust solution for identifying and mitigating EPS anomalies. The integration of AI in satellite power system monitoring marks a significant advancement in autonomous spacecraft management, allowing nanosatellites to diagnose and address power-related issues without external intervention. This capability is particularly valuable for deep-space missions and large-scale satellite constellations, where immediate operator support is often unavailable. AI-driven predictive maintenance offers a scalable and effective solution to extending mission durations, optimizing energy consumption, and minimizing failure risks, ensuring nanosatellites achieve greater operational reliability in increasingly demanding space environments.