IAF MATERIALS AND STRUCTURES SYMPOSIUM (C2)
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OPTIMIZING MEMS SENSOR NETWORKS IN IOT ARCHITECTURES FOR REAL-TIME STRUCTURAL HEALTH MONITORING OF SPACECRAFT

Abstract

This research introduces a new model for integration of Micro-Electro-Mechanical Systems (MEMS) sensors in Internet of Things (IoT) architectures for real-time structural health monitoring (SHM) of spacecraft. In the proposed system, a carefully designed network of radiation-tolerant, low-energy MEMS sensor nodes is placed in key locations in spacecraft structures. Designed specifically for monitoring key parameters such as strain, vibration, and temperature, these nodes form a critical part of spacecraft structures, and these key parameters are important for assessing structural integrity in the midst of changing dynamics during spacecraft operations. The MEMS sensor nodes have edge processing capabilities, allowing for early processing of collected data, such as filtering and anomaly detection, through incorporation of lightweight machine learning algorithms. Edge processing reduces requirements for transmission and lessens latency, allowing for near real-time creation of critical alerts. Communication between nodes is supported through a high-performance, low-latency IoT network infrastructure with protocols specifically optimized for withstanding extreme environments in space, including custom adaptations of LoRa or Zigbee, augmented with additional error checking and redundancy for countering radiation and extreme temperature fluctuations during transmission. A complex simulation environment was developed for testing and evaluation of performance under a range of operational scenarios, including mechanical vibrational loads, thermal cycling, and high-radiation environments. Simulated performance of MEMS-IoT platform proves its ability to accurately predict impending failures and detect structural abnormalities with high accuracy, enhancing overall spacecraft system safety and durability. The conclusion drawn in this work identifies a high level of potential for integration of MEMS technology with IoT architectures for developing a scalable and reliable real-time SHM system for spacecraft, opening doors for increasingly autonomous and proactive maintenance in future spacecraft operations.