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ADVANCING DIGITAL TWIN IMPLEMENTATION FOR CUBESATS: INTEGRATING THEORETICAL INSIGHTS WITH REAL-WORLD APPLICATIONS

Abstract

The evolution of CubeSats from a technical demonstrator to a reliable platform for scientific missions has introduced a new era of space operations. However, mitigating technical risks remains predominant, necessitating comprehensive test facilities tailored to small satellites, allocating vast amounts of personnel and financial resources. Digital Twins present a promising solution for streamlining the life cycle, enabling accelerated development and more reliable operations. Despite its potential, limited research prevents broader application in the CubeSat sector.

This study introduces the implementation of a Digital Twin for a CubeSat, using a 6U-CubeSat as a case study for in-depth analysis, delving into both theoretical and practical aspects of the Digital Twin implementation. The theoretical considerations offer insights into tailoring the Digital Twin process to the characteristics of CubeSats, short development cycles, limited space, power, and computing resources. In comparison, the practical side showcases the hardware and software components utilized in the implementation. Furthermore, the study examines the impact of these components on the overall Digital Twin process, providing valuable insights into its effectiveness.

Tailoring the Digital Twin for the CubeSat market involves identifying key challenges and system requirements, emphasizing subsystem detail fidelity, and prioritizing modeling scope across the life cycle. The focus is on the integration, exchange, and verification of data to ensure the accuracy and reliability of the Digital Twin. Implementing Digital Twins in the design and operational phases improves design progress. It shifts the focus from safety factor-based to instantiation-based designs, using integrated data to make informed decisions.

The exploration of the feasibility of practical implementation includes a specific focus on data integration from multiple sources, such as models, simulations, and components of different subsystems, and the verification throughout the design stage with a focus on enhancing data-driven decision-making and operational efficiency. Various implementation strategies, including standard software packages and open-source alternatives, are evaluated regarding their data management, analysis, and optimization capabilities. Through this research, strategies, limitations, and areas for improvement will be identified, with insights gained from an industry perspective through interviews and collecting end-user feedback. Conclusively, the research aims to bridge the gap between theoretical concepts and practical implementation to ensure the effective use of Digital Twin technology in the development and operation of CubeSat.