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Author: Mr. Aditya Nath Roy
Indian Institute of Technology Kanpur, India

Mr. Mridul Sengupta
Indian Institute of Technology Kanpur, India
Mr. ABHILASH KARAN
Indian Institute of Technology Kanpur, India
Mr. Aman Bhavsar
Indian Institute of Technology Kanpur, India
Dr. Dipak Kumar Giri
Indian Institute of Technology Kanpur, India

METHODICAL ANALYSIS OF VARIOUS CONTROL ARCHITECTURES FOR ATTITUDE STABILIZATION IN A 3U CUBESAT EQUIPPED WITH A 3-AXIS REACTION WHEEL SYSTEM

Abstract

Ground-based satellite testing and control architecture testing are paramount for successful satellite missions. Testing and validation of hardware and software components under simulated space conditions identifies and rectifies potential design flaws before launch. Thorough control architecture testing ensures seamless command execution. By addressing the potential failures, these tests significantly reduce the risk of in-orbit failures, saving resources and safeguarding mission objectives. This paper, developed at the Space Dynamics and Flight Control Laboratory, IIT Kanpur, presents an in-depth analysis of Attitude Determination and Control System (ADCS) architectures for attitude stabilization in a 3U CubeSat equipped with a 3-axis reaction wheel system, aimed at achieving high-precision attitude control and robustness. The primary actuators consist of a 3-axis reaction wheel assembly and magnetorquers used as the secondary actuators. The study explores the real-time operating systems and different control architectures to evaluate their effectiveness in multitasking, data management, and communication capabilities. The first architecture leverages RTOS on a microcontroller, leveraging on its multitasking and multi-threading capabilities, ensuring deterministic execution and efficient resource management. The second configuration integrates Micro-ROS on a Raspberry Pi, utilizing XRCE-DDS middleware to facilitate reliable, low-latency communication between control modules, with ROS providing high-level abstraction and ease of system integration. Finally, we implement a NuttX-based architecture on an STM32 microcontroller, which offers real-time guarantees and streamlined hardware interaction to support critical control tasks. We are aiming to conduct comprehensive ground-based testing in a simulated magnetic field environment using a Helmholtz cage and a hardware-in-the-loop setup to validate the performance and reliability of each architecture. The analysis examines key metrics such as actuator response time, computational overhead, data communication latency, and fault tolerance under various operating conditions. Furthermore, we assess the robustness of sensor fusion algorithms, employing Kalman filters for noise reduction and optimizing PID control loops to enhance attitude determination and control accuracy. Our research aims to provide comparative data analysis that highlights the strengths and limitations of each architecture, guiding future implementations for CubeSat missions requiring efficient, real-time ADCS solutions. This work contributes to the field by offering insights into scalable, high-performance ADCS designs capable of meeting stringent requirements for Earth observation and satellite missions.