HC3 Mission: Design, Architecture, and System Analysis for CubeSat Operation

Abstract

This paper presents an in-depth analysis of the design, structure, component configuration, and operational capabilities of the HC3 CubeSat. The mission of the HC3 is to capture environmental data while in orbit, relaying critical information to an Earth-based station. The HC3 CubeSat utilizes advanced components, including a robust composite frame, solar power systems, and a LoRa radio communication link, optimized for long-term reliability and operational efficiency in low Earth orbit (LEO).

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1. Introduction

The HC3 CubeSat project was initiated with the primary mission of demonstrating cost-effective, reliable, and versatile CubeSat technology. Designed to collect and transmit environmental data, the HC3 mission focuses on leveraging compact, efficient systems that support remote sensing and data relay applications. The CubeSat integrates cutting-edge materials and technologies, ensuring resilience and functionality in the challenging conditions of space.

2. Mission Overview

The HC3 will deploy into LEO, where it will operate autonomously, collecting data on temperature, humidity, and barometric pressure, among other environmental parameters. Data collected by HC3 will be transmitted to Earth using LoRa radio technology, with a planned mission duration of six months. The mission also seeks to validate the performance of PPA-CF (polyphthalamide carbon fiber) composite material in the CubeSat structure, which may have implications for future satellite designs.

3. Design and Structure

- **Frame Composition**: The HC3 frame is built from PPA-CF composite, offering a high strength-to-weight ratio and excellent thermal resistance. This material is ideal for small satellite construction due to its durability in extreme thermal environments.
- **Thermal Management**: Passive thermal control is achieved through the inherent properties of PPA-CF, which can withstand significant temperature fluctuations. This will maintain system integrity and prevent damage to sensitive internal components.

- **Structural Integrity**: The frame and casing are designed to withstand launch stress, using a compact, lightweight structure that minimizes mass without compromising strength.

4. Power System

- **Battery Storage**: HC3 is powered by a 3.7V 2500mAh Lithium-Ion Polymer Battery, selected for its capacity-to-weight ratio and rechargeability.
- **Solar Energy**: The Solar Lipo Charger ensures continuous power supply, utilizing solar panels that capture and convert sunlight for battery recharge. This dual power source system minimizes reliance on ground-based interventions, maximizing HC3's autonomy.
- **Energy Management**: Efficient power distribution is managed by a microcontroller that monitors power levels, ensuring optimal energy allocation between systems.

5. Communication System

- **LoRa Radio**: The CubeSat employs a FireBeetle LoRa Radio 433MHz module for data transmission. This module is well-suited for long-range communication, capable of transmitting data over significant distances despite the CubeSat’s small size.
- **Transmission Protocol**: LoRa modulation allows for efficient use of power and bandwidth, essential for small satellite applications where power is limited.
- **Ground Control Interface**: Communication with the ground station will occur at scheduled intervals to upload data packets, with redundancy protocols in place for failed transmissions.

6. Control System and Propulsion

- **Attitude Control**: An N20 Worm Gear Motor is used for precise control of the CubeSat's orientation. This motor enables rotation on a fixed axis, facilitating adjustments for optimal solar panel exposure or data collection alignment.
- **Stability**: With the worm gear motor, the CubeSat can maintain a stable orientation during its orbit. This setup is efficient for small adjustments, which are essential in optimizing data acquisition.

7. Sensors and Data Collection

- **Sensor Array**: Equipped with an Arduino Nicla Sense ME module, HC3 can measure environmental parameters such as temperature, pressure, and humidity.
- **Data Management**: The data gathered by the sensors will be processed, stored, and transmitted to the ground station through the LoRa radio link. Collected data helps assess atmospheric conditions and can assist in validating CubeSat resilience in various operational scenarios.
- **Sensor Calibration**: Periodic recalibration of the sensors is managed by on-board software to ensure data accuracy over the mission duration.

8. Processing Unit

- **Processor and Data Handling**: The main processing unit integrates an advanced microcontroller system that coordinates all CubeSat operations. It manages data collection, processing, and transmission, in addition to performing power distribution control.
- **Error Management**: An error-correction protocol is embedded within the processor to handle data transmission interruptions and maintain system stability.

9. Conclusion

The HC3 CubeSat is engineered to meet the challenges of an LEO mission, with a versatile framework and autonomous systems designed for long-term data collection and transmission. The mission provides a practical approach to small satellite applications, utilizing durable composite materials, efficient energy management, and resilient communication protocols. Future developments will explore the application of HC3 technologies in higher orbits and larger satellite platforms.