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CubeSAT

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Abstract: *CubeSat missions have democratized access to space by offering a relatively low-cost platform for scientific research and technology demonstration. However, the current success rate of CubeSat missions, particularly for first-time developers, remains a concern. This paper discusses the structured life-cycle of CubeSat development, using the authors' experience in creating and operating the 2U CubeSat, qbee50-LTU-OC, as part of the QB50 mission, while also critiquing common poor practices observed in the CubeSat development process. A critical factor in CubeSat mission success is the cohesion and organization of the development team. Inexperienced teams often underestimate the complexity of coordination across technical and managerial tasks, leading to delays or failure. A cohesive team with clearly defined roles is essential to meeting deadlines and achieving mission milestones*

Their success is often measured by publishable results, which may not always align with industry-driven milestones. On the other hand, industrial partners focus on meeting short-term, financially driven goals. It is crucial for all stakeholders to understand each other's pace of work, priorities, and limitations.

The authors' experience in the QB50 mission illustrates both the strengths and weaknesses of CubeSat projects. Many teams cut corners on testing due to limited time and funding, which often leads to mission failures that could have been avoided with more thorough preparation.

Keywords: *CubeSat, miniaturized satellite, nanosatellite, small satellite development*

I. INTRODUCTION

CubeSat projects encompass the design, development, and deployment of miniaturized, standardized satellites primarily intended for space research, in-orbit technology validation, and academic training. A typical 1U CubeSat measures 10 × 10 × 10 cm and has a mass between 1 and 1.33 kg. These units can be modularly expanded to form larger configurations such as 2U, 3U, or 6U systems. Due to their compact form factor and relatively low development costs, CubeSats offer a highly accessible platform for universities, research institutes, and private organizations to conduct space missions.

Despite a growing interest from commercial and governmental sectors in utilizing CubeSats for demonstration of space technologies, the platform remains predominantly educational. As such, unless mission development is informed by lessons learned from prior projects and space-grade practices, CubeSats may fall short of the reliability required for long-term, high-stakes operations in space.

The evolving paradigm in satellite mission development emphasizes the delivery of increased capability at reduced cost, often summarized by the "Smaller, Cheaper, Faster, better" approach. While this methodology has enabled broader access to space, it has, in several instances, involved scaling down conventional mission architectures without substantial innovation in design philosophy. Such an approach has been cited as a contributing factor in the failure of certain recent NASA deep space missions.

To enhance mission performance while maintaining cost-effectiveness, there is a growing trend toward reducing spacecraft dimensions by orders of magnitude. This direction is increasingly viable due to rapid advancements in the miniaturization of electronics, which now provide high computational performance, low power consumption, and reduced volume. These technological improvements directly contribute to lowering overall mission costs, particularly

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through decreased launch mass and associated launch expenses. This shift presents new opportunities for scientific exploration, especially in missions where mass, volume, and cost are critical constraints.

CubeSats have emerged as an accessible platform for space research and technology demonstrations due to their compact size, standardization, and relatively low cost. While traditionally used in academic environments for educational purposes, there is a growing shift toward using CubeSats for scientific research and prototype testing. This trend is supported by advancements in miniaturized electronics, increased processing capabilities, and low-power sensors.

Despite these advances, designing a fully integrated CubeSat system requires addressing challenges related to data acquisition, communication, power management, and system integration. This paper presents a functional prototype that replicates these key subsystems on a small scale using off-the-shelf hardware. The implementation includes environmental sensing via a DHT11 sensor, real-time geolocation tracking via GPS, wireless telemetry using NRF24L01 modules, and live video streaming using ESP32-CAM. This integrated platform serves as a practical and educational model for developing real-world satellite subsystems.

N. Chahat et al. (2019) conducted a comprehensive review of CubeSat antennas for deep-space and Earth science missions, emphasizing the growing complexity and communication demands for missions beyond low Earth orbit (LEO). Their study highlighted significant advancements in deployable antennas, high-gain phased arrays, and miniaturized reflectors, which have enabled CubeSats to maintain reliable communication links over large distances [1].

Integrating antennas into CubeSat solar panels offers an efficient method to maximize the surface area without hindering other critical systems. In 2019, S. K. Podilchak and colleagues proposed a circularly polarized meshed patch antenna that could be embedded into the solar panels. This design-maintained antenna performance while allowing solar energy collection owing to its lightweight and flexible mesh structure, which is an ideal solution for the limited space and mass constraints of CubeSats [2].

Abulgasem et al. (2020) developed a wideband metal-only patch antenna for CubeSats, which enhanced both bandwidth and radiation efficiency. The metal-only structure eliminates the need for dielectric substrates and increases durability in harsh space environments. Its wideband performance supports communication missions that require multiple frequencies or high data rates, making it a robust solution for CubeSat applications [3].

J. Wang et al. (2020) introduced a compact, high-efficiency tightly coupled dipole reflect array antenna using a variant-coupling-capacitance method. This design improves the gain and directivity, making it suitable for CubeSat missions requiring long-distance communication. Its compact form addresses the space and weight limitations of small satellites, thereby demonstrating the adaptability of advanced antenna technologies for CubeSat applications [4].

II. METHODOLOGY

A. Sensing Subsystem

The payload included two primary sensors for onboard data acquisition.

- DHT11 Temperature and Humidity Sensor

The DHT11 is a digital sensor that outputs calibrated temperature and humidity data. It is connected to the Raspberry Pi via a single digital GPIO pin using a custom Python script to read and store the data at regular intervals (every 10 s during testing).

- GPS Module (NEO-6M or similar)

The GPS module provided real-time geolocation data (latitude, longitude, altitude, and UTC time). It communicates with the Raspberry Pi through a serial interface (UART). A dedicated script continuously parses the NMEA sentences and extracts positional data, which are time-stamped and logged for further analysis.

B. Data Processing and Wireless Transmission

- Raspberry Pi 4

Serving as the central processing unit, the Raspberry Pi 4 collects, processes, and formats data from the DHT11 and GPS modules. A lightweight Python-based software stack handles the following issues:

- Sensor polling
- Data logging in CSV format

• Transmission formatting

- NRF24L01 Transceiver Module

To simulate telemetry communication, Raspberry Pi uses an NRF24L01+ module to transmit data wirelessly to the ground station. The transceiver was configured using the Spidey library for SPI communication. A transmission loop sends sensor and GPS data packets every 10 s using error checking and retransmission for reliability.

C. Ground Station Communication and Monitoring

- ESP32 Microcontroller (NRF Receiver)

ESP32 at the ground station was programmed using the Arduino IDE and RF24 libraries to receive data packets via an NRF24L01 module. The received data were parsed and displayed in real time through a serial monitor and optionally forwarded to an LCD display for field visualization.

- LCD Display (16x2 or 20x4)

A character LCD is interfaced with the ESP32 via I2C to provide real-time feedback of telemetry data, such as temperature, humidity, and GPS coordinates. The display updates dynamically for each new data packet.

D. Live Video Streaming Subsystem

- ESP32-CAM Module

An ESP32-CAM module was used for live video streaming to simulate the optical payload functionality and onboard surveillance. The module is configured to act as a Wi-Fi access point and hosts an MJPEG video stream that is accessible via a web browser. The live stream is initialized through ESP32's internal camera web server, which allows remote clients to connect to the IP address and view real-time footage.

The ESP32-CAM operates independently of the telemetry system to reduce the load and interference. Its video frame rate ranges between 10 and 15 fps at the QVGA resolution, depending on the network bandwidth. The module is powered separately to ensure stable current delivery and reduce the power draw from the main battery.

E. Power Management Subsystem

- Battery Pack

rechargeable lithium-polymer (Li-Po) battery powers onboard electronics. The capacity used in the testing was 5,000 mAh, providing approximately 2–3 h of continuous operation depending on the load from live streaming and data transmission.

- Voltage Regulation

A step-down transformer (buck converter) ensures stable voltage output (5V for Raspberry Pi, 3.3V for NRF24L01, and ESP32 modules). Voltage levels were monitored using a digital voltmeter, and the current draw was minimized through power-efficient coding practices and optimized sensor-polling intervals.

F. Integration and System Workflow

The system follows a synchronous workflow.

1. The sensors collect environmental and GPS data.
2. Raspberry Pi processes and formats the data.
3. Data were wirelessly transmitted via NRF24L01 to the ground station.
4. Ground station ESP32 receives and displays the data.
5. The ESP32-CAM simultaneously streams live videos into a web browser.

This modular approach allows for the independent testing and scaling of subsystems for future integration into a high-altitude or orbital CubeSat deployment.

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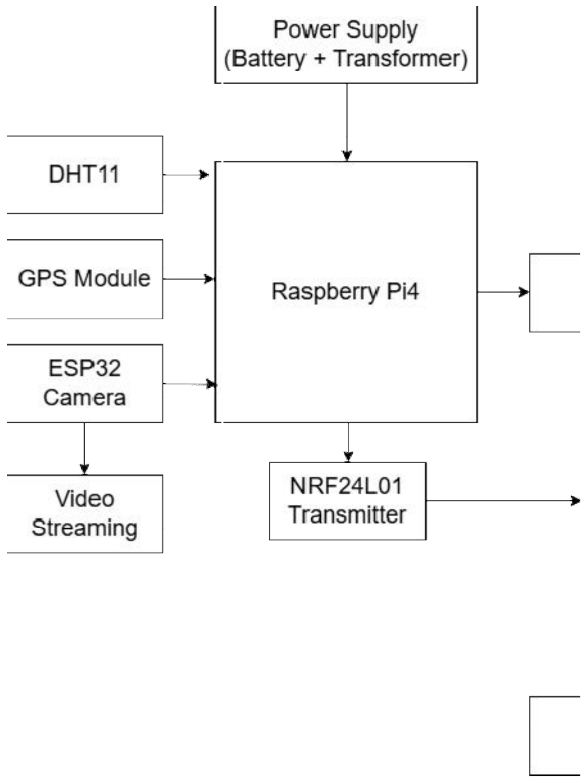

Figure No 1. Block diagram of cubeSAT

III. RESULTS

The CubeSat prototype was assembled and tested in controlled indoor environments and in limited-range outdoor settings. Data from the DHT11 sensor were successfully logged and transmitted at intervals of 10 s to provide accurate temperature and humidity readings. The GPS module maintained a stable fix in open areas, achieving a positional accuracy within ±5 m.

Wireless transmission using NRF24L01 modules was tested for up to 50 m in open space. The link was stable with minimal packet loss, owing to the retransmission and checksum mechanisms implemented in the code. The ESP32 receiver parsed the incoming data in real time and displayed it on a 16 × 2 LCD for quick field observation.

The ESP32-CAM module streamed video over Wi-Fi at a frame rate of 10–15 fps and 320 × 240 resolution. Although some latency was observed under heavy network conditions, the stream remained consistent and visually informative. Power consumption tests revealed that the entire system operated for approximately 2–3 h on a 5000 mAh battery, with power usage primarily dominated by Raspberry Pi and ESP32-CAM.

Overall, the results confirmed the viability of the system as a functional, low-cost satellite prototype capable of fulfilling basic telemetry and imaging tasks. The modular architecture also allows for future upgrades, such as extended-range communication, SD card logging, and solar power integration.

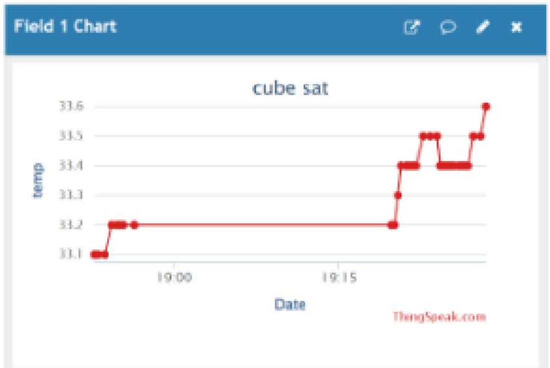

Figure No 3.1 Temperature line chart

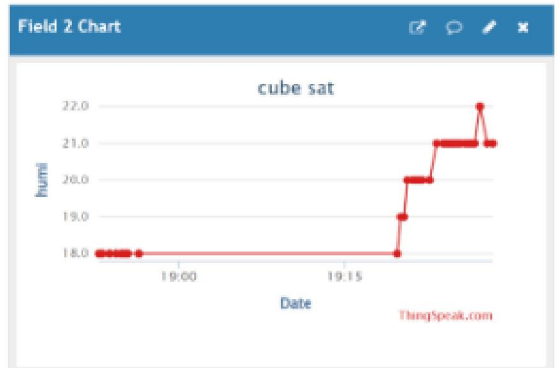

Figure No 3.2 Humidity line chart

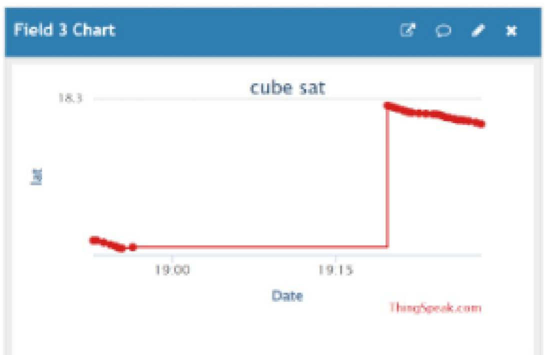

Figure No 3.3 latitude line chart

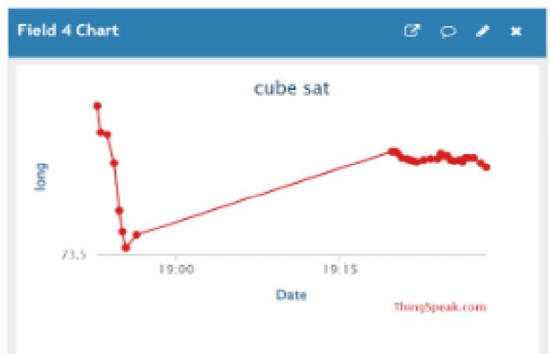

Figure No 3.4 longitude line chart

IV. CONCLUSION

This study demonstrates a compact CubeSat prototype capable of performing real-time environmental monitoring, GPS-based positioning, telemetry, and live video streaming using widely available low-cost components. The system proved effective in laboratory and short-range field testing, offering a promising platform for educational use, prototype testing, and deployment on high-altitude balloons.

Future work will include extending the communication range, improving power efficiency with solar input, and environmental shielding to enable operation in near-space conditions. This project highlights the potential of CubeSat-inspired systems for hands-on aerospace education and rapid prototyping of satellite technologies.

V. ACKNOWLEDGMENT

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