

Weather Imaging CubeSat For Real Time Environmental Monitoring

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Abstract- The MicroSat Weather Observer is a compact CubeSat prototype designed for real-time environmental monitoring and weather observation from low Earth orbit (LEO). It integrates a set of sensors, including a high-resolution camera, infrared (IR) sensor, temperature sensor, and magnetometer, managed by an STM32 microcontroller. The system operates on solar power with energy stored in a rechargeable battery, enabling autonomous data acquisition during its orbit. MWO captures Earth images and environmental parameters, processes them onboard using simple image filtering algorithms, and compresses the data to optimize bandwidth. The processed data is transmitted to a ground station via a 2.4 GHz RF link, where it is displayed for further analysis. The project focuses on efficient power management, robust communication, and intelligent data selection, simulating real satellite functionalities. This work provides hands-on experience in satellite systems development, demonstrating how CubeSats can contribute to environmental research and space technology. It highlights the potential of integrating intelligent features such as onboard decision-making and energy-efficient designs in small-scale space missions.

Keywords: CubeSat, Environmental Monitoring, Weather Imaging, Onboard Image Processing, Data Transmission, Infrared Sensor, STM32, Low Earth Orbit, Solar Power, Microcontroller, RF Communication.

I. INTRODUCTION

In recent years, environmental monitoring has become an important area of research due to the increasing impact of climate change and atmospheric variations. Accurate measurement of parameters such as temperature, radiation, and environmental conditions helps in better understanding weather patterns and predicting natural changes. Traditionally, large satellites are used for this purpose, but their high cost and complexity make them difficult to implement for academic-level projects. Small satellite platforms such as CubeSats have gained popularity because of their compact size, low cost, and ease of development.

These systems provide a practical way to study satellite-based applications without the need for complex infrastructure. Early developments in

CubeSat technology mainly focused on basic satellite structures and deployment mechanisms, which helped in establishing a standard model for small satellite design [1– 3]. Further advancements in this field introduced the use of embedded systems and microcontrollers for handling onboard operations. Researchers have explored different control units and subsystems to improve data acquisition and system reliability. These works mainly focused on improving communication and processing capabilities in small satellite platforms [4– 5]. In addition, several studies have emphasized the importance of integrating environmental sensors into small-scale systems.

These approaches demonstrated that low-cost hardware can be effectively used for real-time data collection [6–8]. With the development of wireless communication technologies, many systems have incorporated RF-based transmission methods for sending data to ground stations. At the same time, researchers also explored different methods for

reliable data transfer under limited communication conditions [9–11]. Another important aspect considered in recent works is onboard data storage. Since continuous communication is not always possible, storing data locally becomes necessary. Various storage solutions such as flash memory and SD card modules have been used to ensure data safety and retrieval at later stages [12–14]. Recent developments have also focused on integrating imaging systems into environmental monitoring platforms. Camera modules have been used to capture visual data, which adds additional information compared to sensor readings alone.

This combination of sensing and imaging improves the overall understanding of environmental conditions [15–17]. Moreover, the use of IoT platforms and cloud-based visualization tools has made it easier to monitor data in real time. Applications such as web dashboards and mobile-based interfaces allow users to observe environmental parameters in graphical formats and analyze changes over time. These systems enhance user interaction and data interpretation [18–19]. Although many existing systems focus on individual aspects such as sensing, communication, or imaging, only a few works attempt to combine all these features into a single platform. There is still a need for a simple and integrated system that can perform environmental sensing, image capture, wireless transmission, and data storage in a coordinated manner [20–21].

II. RELATED WORK

Several research efforts and academic projects have focused on the development of small satellite systems and CubeSat platforms for environmental monitoring and educational purposes. Due to their standardized structure and low development cost, CubeSats have been widely adopted to demonstrate satellite subsystems such as sensing, onboard processing, data storage, and communication. Early studies on CubeSat-based weather monitoring systems primarily focused on measuring atmospheric parameters such as temperature and humidity using basic sensor payloads. These systems demonstrated the feasibility of using compact

satellites for environmental data collection, while emphasizing low power consumption and simplified payload integration. With the advancement of embedded systems, researchers have integrated microcontrollers and sensor modules to enhance data acquisition capabilities in small satellite platforms. Several works proposed sensor-based payloads capable of collecting environmental parameters and transmitting the data to ground stations using wireless communication modules.

These implementations highlighted the importance of efficient data handling and telemetry in satellite missions. In recent years, IoT technologies have been increasingly adopted in environmental monitoring applications. IoT-based weather monitoring systems utilize sensor networks, embedded controllers, and wireless communication to enable real-time data collection and visualization. While these systems are typically ground-based, their architectural principles are applicable to CubeSat-based platforms, especially in terms of sensor integration and data transmission.

Some researchers have addressed the limitations of continuous wireless communication by introducing onboard data storage mechanisms such as flash memory and SD card modules. These approaches ensure reliable data logging during communication outages or limited transmission windows. Onboard data storage is a critical requirement in real satellite missions, where uninterrupted communication with ground stations cannot always be guaranteed. A few studies have also explored the integration of camera modules in CubeSat payloads for Earth observation and imaging applications. These systems demonstrated the ability to capture visual data along with sensor readings, enhancing the overall monitoring capability of small satellites. Although existing works have successfully demonstrated individual aspects such as environmental sensing, wireless communication, or imaging, many implementations are either simulation-based or focus on specific subsystems. The proposed work differs by integrating environmental sensors, imaging capability, wireless communication, and SD card-based onboard data storage into a single CubeSat prototype. This integrated approach

provides a practical and educational demonstration of real CubeSat payload and telemetry operations.

III. PROPOSED METHOD

The proposed methodology for the Weather Imaging CubeSat for Real-Time Environmental Monitoring is designed to simulate the basic working of a small satellite system in a simple and practical way. The system mainly focuses on collecting environmental data, capturing images,

and transmitting the information wirelessly to a ground station. For better understanding and implementation, the overall operation is divided into different stages such as power management, sensor data collection, image handling, data storage, and wireless communication.

[1] Power Management

Power management is an important part of the system to ensure continuous and stable operation. In this project, the components are powered using a regulated power supply, which can be extended to a solar-based system in real-time applications. The power is properly distributed to the STM32 microcontroller, sensors, RF module, and other peripherals.

Voltage regulation is used to maintain a constant supply level and avoid fluctuations that may affect system performance. Basic filtering components are also used to reduce noise in the circuit. This setup ensures that all modules work smoothly without interruptions during operation.

[2] Sensor Data Acquisition

The system uses multiple sensors to collect environmental information. These sensors are directly connected to the STM32 microcontroller, which acts as the central unit for data collection. A temperature sensor is used to measure ambient conditions, while an infrared sensor helps in detecting heat-related variations. A magnetometer is included to observe orientation and directional changes.

The STM32 reads the data from these sensors at regular intervals using communication methods such as I2C and digital input pins. The raw values obtained from the sensors are then converted into meaningful data so that they can be used for monitoring and display purposes.

[3] Image Capture and Handling

In addition to sensor data, a camera module is integrated into the system to capture images of the environment. This provides visual information, which helps in better understanding of the surrounding conditions. The STM32 controls the image capturing process and manages the data along with sensor readings.

Since image data occupies more memory, it is handled carefully before storage or transmission. This ensures that the system performance is not affected and memory usage is optimized. The captured images can also be used for live viewing through the receiver side.

[4] Data Processing and Storage

After collecting data from sensors and the camera module, the STM32 processes the information into a suitable format. This includes organizing the data, reducing unwanted variations, and preparing it for transmission.

An SD card module is used for storing the collected data and images. This storage feature is very useful when wireless communication is not available. Even if the data is not transmitted immediately, it can be saved and accessed later without any loss. This improves the reliability of the system.

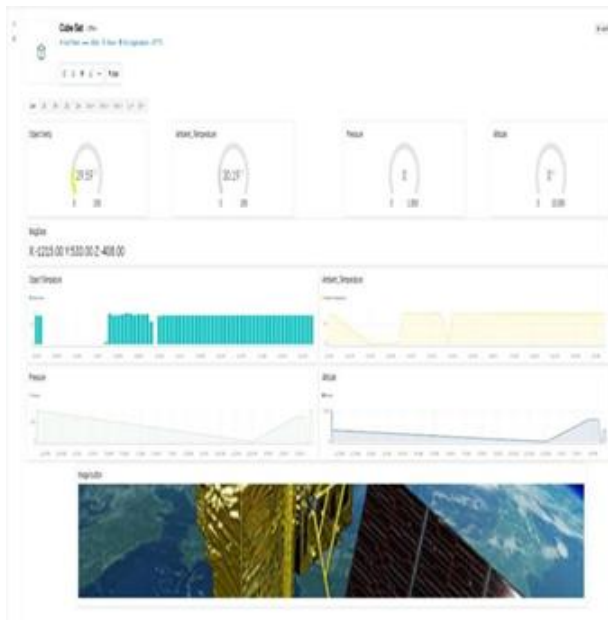
[5] Wireless Data Transmission

Wireless communication is achieved using an NRF24 RF module, which transmits the collected data from the transmitter side to the receiver side. The NRF24 module is chosen because of its low power consumption and reliable communication. On the receiver side, another NRF24 module receives the data and passes it to the ESP32 microcontroller. The ESP32 then sends the data to a laptop, where it is displayed using the Blynk platform. The values are shown both in numerical form and graphical form,

operation, the STM32 controller manages both sensing and communication tasks without interrupting the data flow. Priority is given to sensor data collection to ensure that environmental parameters are updated regularly. At the same time, the system maintains synchronization between data acquisition and transmission, which helps in avoiding delays or data mismatch.

This coordinated functioning improves the overall efficiency of the system. Another important aspect of the flow is its ability to maintain stability during temporary failures. If there is any interruption in RF communication or Wi-Fi connectivity, the system does not stop functioning completely. Instead, it continues collecting data and stores it locally until the connection is restored. Once the link becomes available, the stored data can be transmitted again. This approach ensures that no important information is lost and makes the system more reliable for real-time monitoring applications.

V. RESULTS AND DISCUSSION



The proposed system was tested under normal conditions to evaluate its performance in terms of data collection, transmission, and visualization. The system was able to operate continuously without major interruptions, showing stable behavior during the testing process.

The environmental sensors connected to the STM32 microcontroller provided consistent readings for temperature and other parameters. The values obtained were reasonable and showed slight variations based on the surrounding conditions, which indicates that the sensors are functioning properly. The infrared sensor was able to detect changes in heat levels, while the magnetometer produced stable orientation values in X and Y directions.

The collected data was successfully transmitted from the transmitter side to the receiver side using the NRF24 RF module. The communication between transmitter and receiver was reliable within the tested range, and the data was received without noticeable delay. This shows that the RF module is suitable for short-range wireless communication in this type of application.

On the receiver side, the ESP32 processed the incoming data and sent it to the Blynk platform. The data was displayed clearly on the interface, where parameters were shown in both numerical form and graphical format. The graphical representation helped in understanding how the values were changing over time. It also made it easy to compare previous and current readings, which is useful for monitoring environmental changes.

The camera module worked as expected by providing visual data of the surroundings. Live streaming was achieved through a Wi-Fi link, where the user could access the camera feed using a provided link. The image capture option allowed saving images when required, which adds flexibility to the system.

The SD card module was also tested for data storage. The system was able to store sensor readings and images successfully. This feature ensures that data is not lost even if there is any interruption in wireless communication. The stored data can be accessed later, which improves the reliability of the system. Overall, the system performed well by combining sensing, communication, visualization, and storage in a single setup. The results show that

the proposed design can effectively demonstrate the working of a CubeSat-based environmental monitoring system in a simple and practical manner.

VI. CONCLUSION

The proposed Weather Imaging CubeSat system successfully demonstrates a simple and effective approach for real-time environmental monitoring. By integrating multiple sensors, a camera module, wireless communication, and SD card storage, the system is able to collect, transmit, and display data efficiently. The use of STM32, NRF24, and ESP32 ensures smooth operation and reliable performance. Overall, the project shows how CubeSat concepts can be implemented at a small scale for educational and practical purposes.

REFERENCES

1. J. Puig-Suari, C. Turner, and W. Ahlgren, "Development of the standard CubeSat deployer and a CubeSat class pico- satellite," IEEE Aerospace Conference, pp. 347–353, 2001.
2. S. Bouwmeester and J. Guo, "Survey of worldwide pico- and nanosatellite missions, distributions and subsystem technology," Acta Astronautica, vol. 67, no. 7–8, pp. 854–862, 2010.
3. M. Swartwout, "CubeSat database," Saint Louis University, 2019.
4. D. Selva and D. Krejci, "A survey and assessment of the capabilities of CubeSats for Earth observation," Acta Astronautica, vol. 74, pp. 50–68, 2012.
5. A. Toorian, K. Diaz, and S. Lee, "The CubeSat approach to space access," IEEE Aerospace Conference, 2008.
6. M. A. Swartwout, "The first one hundred CubeSats: A statistical look," Journal of Small Satellites, vol. 2, no. 2, pp. 213–233, 2013.
7. A. H. Johnston and J. F. Osborn, "Small satellite power systems," IEEE Aerospace and Electronic Systems Magazine, vol. 26, no. 5, pp. 3–11, 2011.
8. K. Woellert, P. Ehrenfreund, A. Ricco, and H. Hertzfeld, "Cubesats: Cost-effective science and technology platforms for emerging and developing nations," Advances in Space Research, vol. 47, no. 4, pp. 663–684, 2011.
9. J. Heidt et al., "CubeSat: A new generation of picosatellite for education and industry low-cost space experimentation," AIAA/USU Conference on Small Satellites, 2000.
10. STM Microelectronics, "STM32 ARM Cortex-M microcontroller datasheet," 2022.
11. Aosong Electronics, "DHT11 temperature and humidity sensor datasheet," 2018.
12. Melexis Technologies, "MLX90614 infrared thermometer sensor datasheet," 2019.
13. Honeywell, "HMC5883L 3-axis digital compass ICdatasheet," 2017.
14. OmniVision Technologies, "OV2640 CMOS camera module datasheet," 2016.
15. Texas Instruments, "Low-power RF transceivers for 2.4 GHz ISM band," 2020.
16. N. F. Alshurafa et al., "Wireless sensor networks for environmental monitoring," IEEE Sensors Journal, vol. 15, no. 6, pp. 3339–3347, 2015.
17. S. Khan et al., "Design and implementation of low-cost weather monitoring system using IoT," International Journal of Engineering Research & Technology, vol. 9, no. 4, 2020.
18. A. Gupta and R. Johari, "Satellite communication using RF modules for data transmission," IEEE International Conference on Communication Systems, 2018.
19. P. Tortora et al., "Onboard data handling systems for small satellites," IEEE Aerospace Conference, 2016.
20. M. R. Patel and J. Wang, "Applications, challenges, and prospective in emerging body area networking technologies," IEEE Wireless Communications, vol. 17, no. 1, pp. 80–88, 2010.
21. A. Al-Fuqaha et al., "Internet of Things: A survey on enabling technologies, protocols, and applications," IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347–2376, 2015.