Journal of Education and Practice
ISSN 2222-1735 (Paper) ISSN 2222-288X (Online)
Vol.15, No.12, 2024

Spacebox CubeSat: Elevating High Schoolers from Learners to Space Innovators

Ali Can Caliskan[1], Devrim Ruzgar Turkmen[1], Arya Ergin[1], Ege Erdogan[1], Omer Suner[1], Yusuf Emir Acar[1], Semih Mete Unal[1], Emir Eroglu[1], Yagmur Cimenkaya[1], Eren Yuce[1], Ata Karakas[1], Aylin Defne Ozer[1], Almina Yildiran[1], Aras Atilgan[1], Ayse Eylul Dilmen[1], Cansu Saglam[1], Cagan Busan[1], Diego Burak Braida Fernandez[1], Doruk Yazici[1], Ece Saglam[1], Ekmel Kerem Celik[1], Irem Boz[1], Kaan Alabas[1], Kerem Yigit Simsek[1], Koray Ege Yalcin[1], Mahir Cinar Akdemir[1], Melis Guven[1], Nehir Yilmaz[1], Omer Efe Kiris[1], Zeynep Onkal[1], Mustafa Alpan[1], Ömer Coşkun[1], Yiğit Karaoğlan[1], Emir Kaan Perçin[1], Burak Gencay[1], Taner Kayis[1], Mehmet Serhan Kal[1], Cihat Arslan[1], Emre Sezer[1], Çiğdem Terzi[1], Sude Ergin Levent[2],
Dr. Vecdi Emre Levent[2]*

1. Bahçeşehir College, Istoza Mevkii, İstanbul 34072, Turkey
2. AvionChip Inc, DES 2. Cad No:8, İstanbul 34775, Turkey

* E-mail of the corresponding author: emre@levent.tc

This project was made possible through the generous support and funding provided by Bahçeşehir College. The commitment of Bahçeşehir College to advancing educational initiatives and fostering innovation enabled the development of the CubeSat deployment system.

Abstract

This study describes the SpaceBox CubeSat project, which introduces high school students to the world of satellite technology by guiding them through the full process of building, testing, and deploying a small satellite called a CubeSat. CubeSats are compact, standardized satellites often used in educational and research projects to make space exploration more accessible. In this project, students learn to create a mission computer on a specialized electronic platform (AMD FPGA), gaining hands-on experience with the basics of space technology, such as using sensors, managing power, and communicating with Earth. For testing, the team developed a custom balloon control system that uses a tethered weather balloon to lift the CubeSat to various heights, allowing students to test its functions under controlled conditions. The CubeSat sends data back to a ground station in real-time, where students can monitor its status, navigate, and control it. The project shows that the CubeSat's mission computer can run efficiently on limited power, lasting up to 7 hours without sunlight, making it suitable for educational missions. Overall, this project not only highlights the CubeSat's technical abilities but also shows the power of hands-on learning in inspiring future innovators.

Keywords: CubeSat, FPGA, High School STEM Education, Mission Computer, Telemetry, Balloon Control Unit

DOI: 10.7176/JEP/15-12-10
Publication date: December 30th 2024

1. Introduction

CubeSats, standardized and compact satellites, have transformed access to space, particularly within the educational and research sectors. Initially developed to offer low-cost, accessible space technology for smaller institutions, CubeSats allow students, researchers, and even developing nations to participate in real-world space missions within the scope of educational budgets (Heidt et al. 2000). These small satellites, often measuring 10 cm on each side and housed in standardized units, leverage Commercial Off-The-Shelf (COTS) components, which are far more economical than radiation-hardened, space-qualified parts. As a result, CubeSats have become the platform of choice for experimenting with new ideas, technologies, and concepts that may eventually be applied to larger, more complex space systems (Carrara et al. 2017). The ITASAT project, for instance, demonstrates how CubeSats can serve as technological development platforms, testing advanced Attitude Determination and Control Systems (ADCS) using a 6U configuration for on-orbit stability and precise payload pointing.

Inspired by this trend, the SpaceBox CubeSat project was designed as an educational platform aimed at bridging theoretical knowledge with hands-on practice for high school students. Students involved in SpaceBox gain exposure to various engineering principles, from embedded systems and sensor technologies to power management and data communication. This approach aligns with current research advocating for integrated STEM activities in education, emphasizing real-world application and interdisciplinary problem-solving (English 2017). Within the project, students work in specialized teams on the CubeSat's mission computer, communications systems, and power distribution, simulating the interdisciplinary collaboration characteristic of professional satellite development. Such experience fosters not only technical skills but also critical thinking and teamwork, which are essential for success in both research and industry.

To facilitate controlled testing on Earth, SpaceBox includes a custom-designed balloon control unit that enables the CubeSat to be tethered and raised to various altitudes, mimicking orbital operations. This system allows for real-time telemetry data collection and altitude adjustments, providing students with valuable insights into the complexities of altitude control, signal transmission, and environmental interactions. Through this hands-on experience, students can make iterative adjustments to the CubeSat, building resilience and problem-solving skills as they work to refine their design. Moreover, this approach encourages students to engage in experimental learning, reinforcing their theoretical understanding of space technology in a controlled, ground-based environment. As educational CubeSat programs like SpaceBox continue to expand, they underscore the profound impact that CubeSat projects can have on inspiring the next generation of engineers, scientists, and technologists.

2. Literature Review

The educational use of CubeSats has transformed access to space technology, enabling schools and universities to provide hands-on satellite experience to students at relatively low costs. Pioneering CubeSat projects like Nayif-1, the UAE’s first CubeSat, showcased the potential of CubeSats as educational tools, providing students with opportunities to develop and operate their own satellite systems. Nayif-1’s mission involved undergraduate students and included outreach activities, allowing high school students to calculate orbital velocity, demonstrating the CubeSat’s value in STEM education (Al Qasim et al. 2016).

Similarly, the TJREVERB project, developed by high school students, tackled component integration and communication issues, underlining the importance of accessible, structured mentorship for student teams navigating complex engineering tasks (Kucko et al. 2023). Another example, Illinois’ Educational Development Unit (iEDU), provides an educational platform emulating CubeSat operations, allowing students to experiment with mission concepts through hands-on lessons involving real sensors and data (Thompson et al. 2023).

High-altitude balloons offer an alternative to full orbital launches, as seen in the Missouri University CubeSat platform, which allows CubeSat payload testing at near-space altitudes. This approach provides students with experience in satellite operations and data collection under conditions similar to those in space (Davis et al. 2019). The TJREVERB project further showcased innovative solutions to operational challenges, such as using a global network of amateur radio volunteers to maintain communication with the satellite, a method that broadened the reach of CubeSat projects beyond traditional ground stations (Dinh et al. 2023).

CubeSat innovation continues to evolve with initiatives like MakerSat, designed for in-space 3D printing and assembly aboard the ISS, allowing flexible CubeSat frames for microgravity environments. MakerSat provides a model for reducing launch costs and preparing customized payloads, expanding the scope of what student-led CubeSat missions can accomplish (Grim et al. 2016). Additionally, the ITASAT CubeSat project has demonstrated the potential of advanced payloads and control systems, showing how CubeSats can support increasingly sophisticated missions in educational settings (Carrara et al. 2017).

Another dimension of CubeSat education includes platforms like iEDU, enabling rapid prototyping and sensor integration on a modular CubeSat framework, preparing students to understand satellite subsystems and mission planning. The project also aligns with programs like MakerSat and TJREVERB in emphasizing technical training, which is essential for student-led CubeSat projects (Thompson et al. 2023).

Collectively, these projects underscore CubeSat technology's critical role in equipping students with essential skills in satellite engineering, system design, and data communication. By engaging students directly in mission planning, testing, and operations, these initiatives effectively bridge the gap between theoretical STEM education and practical application.

3. Cubesat Development

Cube satellites, as is known, communicate wirelessly with ground units at an altitude of approximately 400 km above the ground. In this study, a CubeSat was developed and designed to communicate with a ground station unit on the ground via RF wireless signals. During development process, established 5 different teams. Each team has specific responsibilities to ensure the success of the mission. The Public Relations (PR) team handles outreach, including creating media content, managing relationships, and promoting the CubeSat through articles and media channels. The Mission Computer team is responsible for designing the CubeSat's central processing unit, developing hardware in Verilog, verifying designs, and managing interfaces. The Software team creates the operating software and a "ground station" application to visualize and control data from the CubeSat on Earth. The Electronics team builds the CubeSat's electrical infrastructure, connecting the mission computer, sensors, solar panels, and other components, while ensuring safe power distribution. Finally, the Mechanical team designs and fabricates the CubeSat's chassis, utilizing 3D design tools and materials such as plastic and resin to house all components securely. The test environment resulting from the developments is given in Figure 1 below.

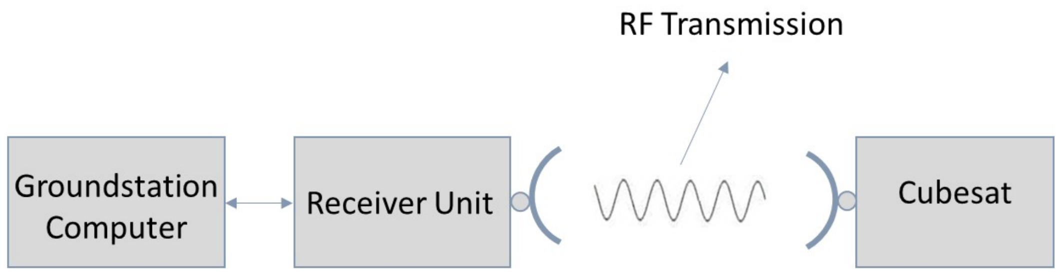

Figure 1. Cubesat and Groundstation Computer Communication Bird's Eye View

The CubeSat's internal architecture is designed to integrate key subsystems that support its operations in space. At the core of its power system are the solar panels and a LiPo battery, which work in conjunction to provide a steady energy supply. The solar panels capture energy from sunlight and direct it to the Power Management Unit, which regulates the charging and discharging of the battery. This ensures that the CubeSat has a stable power source, even when it passes through periods of darkness, thereby maintaining continuous functionality.

Central to the CubeSat's control is the Mission Computer Board, which acts as the main processing hub. This board not only manages tasks and data flow across the satellite but also connects to both the power system and various sensors. The Mission Computer Board is critical for coordinating the CubeSat's activities, processing sensor data, and executing commands received from the ground.

The CubeSat is equipped with a set of sensors that enable environmental monitoring and navigation. Among these are a GPS with an antenna for determining its position and navigating in space, and a gyroscope that helps with attitude control, keeping the satellite oriented correctly. Environmental sensors, such as those for measuring outdoor gas quality and temperature, provide valuable data about the CubeSat's surrounding environment, which can be crucial for mission-specific objectives, like atmospheric studies.

For communication with ground stations, the CubeSat relies on an RF Transceiver connected to the Mission Computer Board. This transceiver facilitates two-way communication, allowing the CubeSat to transmit collected data back to Earth and receive new commands from mission control. This communication capability is essential for telemetry and ensuring the CubeSat remains operational and responsive to mission adjustments.

The internal architecture of our CubeSat, as illustrated in Figure 2 below, showcases the integration of essential subsystems designed to support space operations. This figure highlights the interactions between the power management components, the mission computer board, various environmental and navigational sensors, and the RF transceiver. Together, these components ensure a stable and efficient operational flow, allowing the CubeSat to perform its designated tasks and communicate effectively with ground stations. This diagram provides a clear visual overview of the CubeSat's core functions and connectivity.

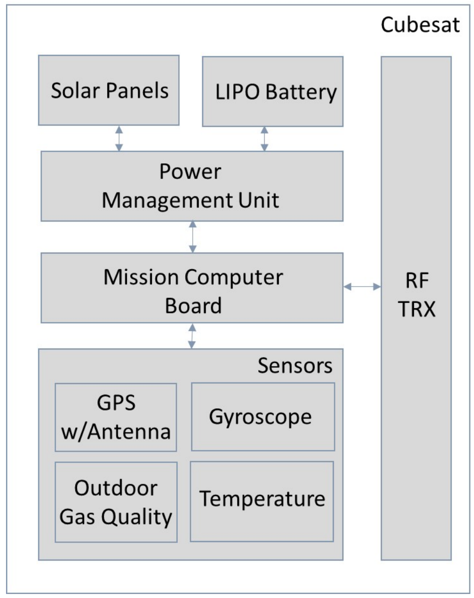

Figure 2. Cubesat Internal Units

The following figure provides a more detailed view of the CubeSat's internal structure, illustrating the placement and interaction of key components such as the power management system, sensors, and mission computer. This configuration optimizes the CubeSat's ability to perform its designated tasks efficiently and maintain reliable communication with ground stations.

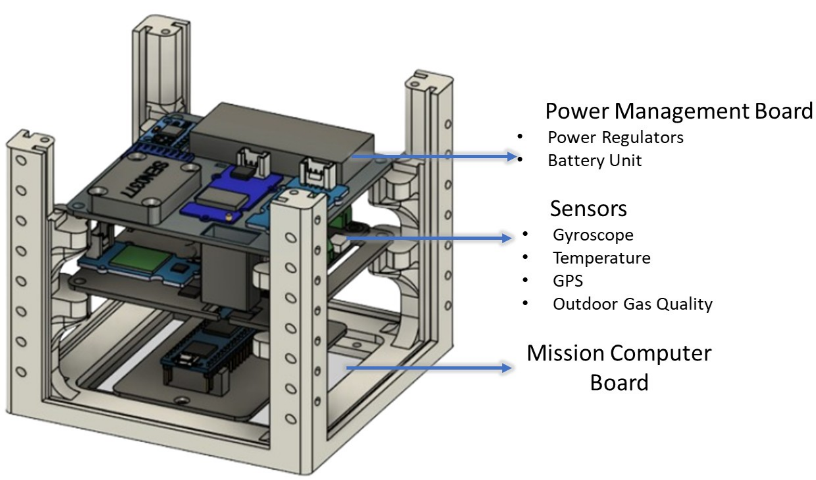

Figure 3. Cubesat Internal Architecture

CubeSat Internal Architecture: showing the layered arrangement of the Power Management Board, Sensors, and Mission Computer Board.

- Power Management Board: Houses power regulators and the battery unit to meet the CubeSat's energy requirements.
- Sensors: Includes various sensors, such as gyroscope, temperature, GPS, and outdoor gas quality, to gather environmental data.
- Mission Computer Board: Serves as the CubeSat's central processing unit, coordinating tasks and managing data flow.

This internal structure provides a stable operational framework, supporting the CubeSat's mission objectives and ensuring seamless integration of all essential subsystems.

3.1 Power Management

The power management unit (PMU) in the CubeSat, shown in Figure 4, is designed to manage the energy flow from the solar panels to the LiPo battery, ensuring a reliable and stable power supply for all onboard systems. This system utilizes a CN3065 chip as the primary charge controller, which efficiently regulates the charging of the battery from the solar input. Additionally, the MT3608 boost converter adjusts the output voltage to meet the CubeSat's operational requirements, allowing it to function effectively across varying environmental conditions. This configuration ensures continuous power delivery, supporting the CubeSat's mission-critical functions.

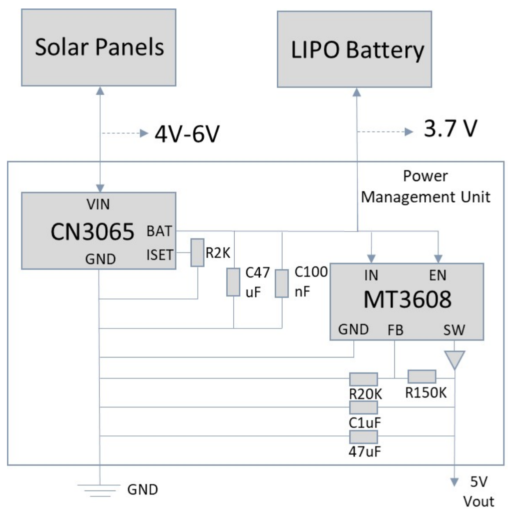

Figure 4. Power Management Unit

3.2 Mission Computer Board

The Mission Computer Board in the CubeSat, depicted in Figure 5, is built around an AMD (Xilinx) FPGA A7-35T, which acts as the primary processing unit, executing the CubeSat's core computational tasks. Power to the FPGA is managed by the RTC3569 power management IC, providing the necessary voltage levels (3.3V, 1.8V, and 1.0V) to ensure stable operation.

For communication and programming, an FT2232 module is integrated, supporting UART for serial communication and JTAG for programming and debugging the FPGA. Additionally, an SPI Flash memory is included for storing the FPGA's configuration data, enabling non-volatile storage that allows the FPGA to retain its programming across power cycles. The board also includes 2.54" header pins, providing GPIO access to facilitate interfacing with external components and sensors.

This configuration of the Mission Computer Board ensures a versatile and robust platform capable of managing various mission requirements and interfacing with other CubeSat subsystems.

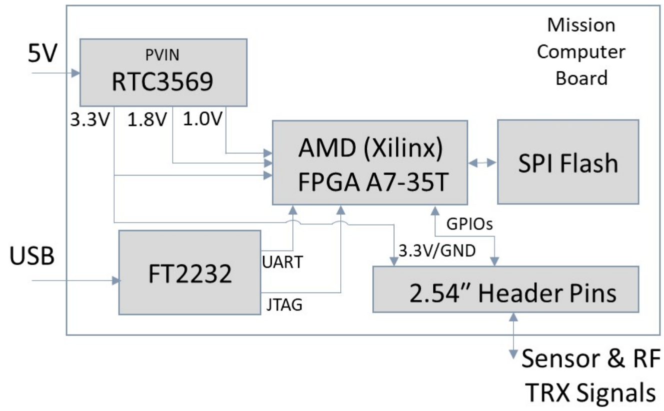

Figure 5. Mission Computer Board

3.3 Sensor Board

The CubeSat's Sensor Board, shown in Figure 6, integrates various sensors essential for navigation and environmental monitoring. This board connects to the main system via 2.54" header pins, allowing for streamlined communication and power access. Key sensors on the board include a GPS module with an antenna for satellite positioning, a gyroscope for attitude control, an outdoor gas quality sensor for environmental data, and a temperature sensor for monitoring ambient conditions. The sensors utilize I2C and UART protocols for data transmission, enabling efficient and reliable data flow to the Mission Computer Board. This setup ensures that the CubeSat has access to critical navigational and environmental information, which supports mission objectives and operational stability.

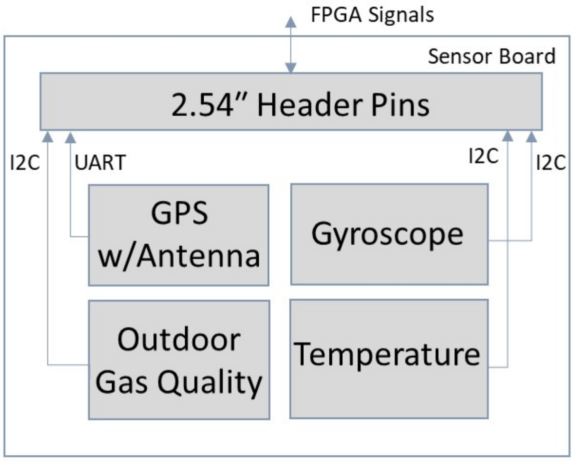

Figure 6. Sensor Board

3.4 RF Transceiver Board

The RF transceiver module in the CubeSat, depicted in Figure 7, is designed to handle wireless communication with ground stations. The module's power is managed by an AP7333 voltage regulator, which provides a stable 3.3V supply to the RF transceiver unit. This transceiver unit facilitates both transmission (TX) and reception (RX) of signals, ensuring reliable data exchange. An RFIO interface connects the transceiver to a U-FL connector, which serves as the antenna connection point, enabling the CubeSat to communicate effectively in space. This streamlined design supports continuous and stable RF communication, crucial for maintaining contact and data transmission with the ground station throughout the mission.

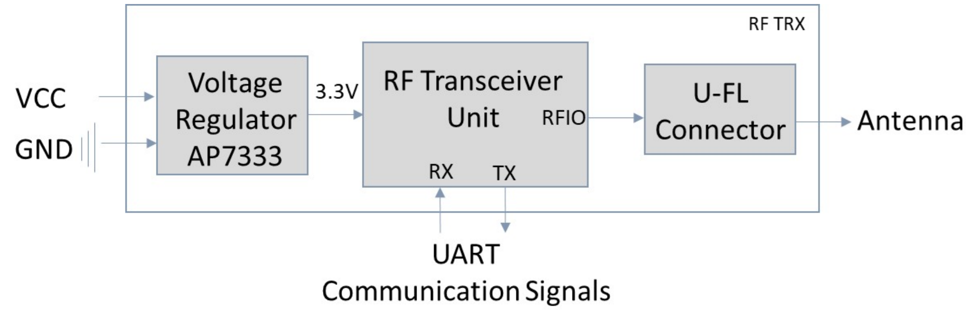

Figure 7. RF Transceiver Board

3.4 Mission Computer Design

The mission computer design for the CubeSat, illustrated in Figure 8, is built around a Xilinx A35T FPGA, which hosts the AvionCPU as the primary processing unit. The system architecture includes an interconnect that facilitates communication between the AvionCPU and various data grabbers responsible for acquiring data from onboard sensors. These data grabbers manage inputs from the temperature sensor, gyroscope, GPS, outdoor gas sensor, and RF transceiver, each dedicated to capturing and processing specific sensor data. Additionally, the design integrates memory for data storage and includes debugging modules—namely, the Integrated Logic Analyzer (ILA) and Virtual Input/Output (VIO) modules—to support real-time monitoring and troubleshooting. This modular structure enables efficient data handling and robust performance, ensuring that all critical information from the CubeSat's sensors is processed and transmitted reliably.

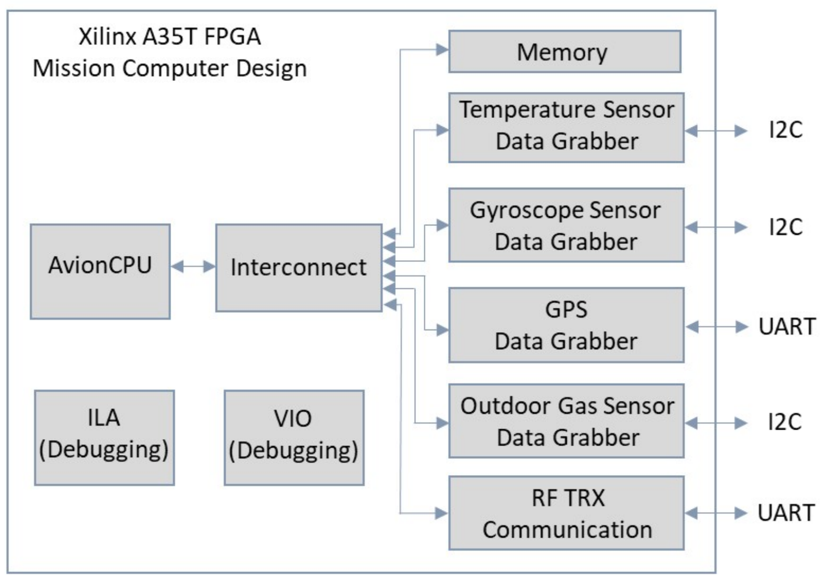

Figure 8. Mission Computer Design

3.5 AvionCPU Development

The AvionCPU architecture integrates three core components essential for the CubeSat's onboard processing: a Processing Unit (ALU) for handling arithmetic and logical operations, a Control Unit for managing instruction flow and coordinating operations, and a Memory & Interface Controller that facilitates data storage and communication with other systems. This structure ensures that the AvionCPU can effectively execute tasks and handle data from various subsystems. The detailed architecture of the AvionCPU is illustrated in Figure 9 below.

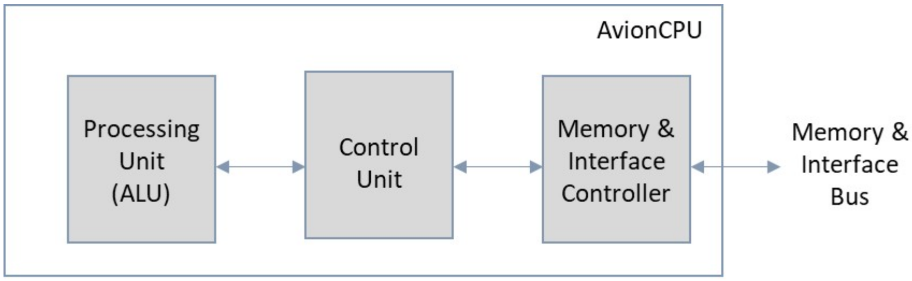

Figure 9. AvionCPU Block Diagram

This processor employs a 5-state finite state machine, as shown in Figure 10 below. It begins in S0 by fetching an instruction, then moves to S1 to decode the instruction and increment the program counter (PC). In S2, the processor checks the opcode: if greater than 6, it completes the operation without additional memory access and returns to S0. For opcodes 6 or less, it transitions to S3 for a memory access before looping back to S0. If the opcode is 9, the processor enters a “dead state” (S4), halting all activity. Figure 10 illustrates this structured state flow, which enables efficient and controlled instruction handling.

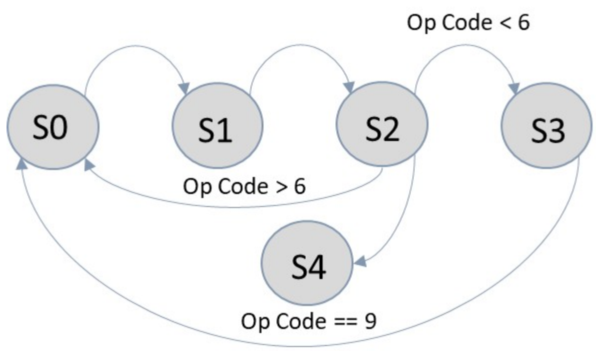

Figure 10. AvionCPU State Machine

3.6 *Sensor Grabber and Communication Modules*

This design showcases the data acquisition and communication modules within the CubeSat’s architecture, each tailored to gather and relay specific types of information essential for mission objectives. The Temperature Sensor Data Grabber continuously monitors the ambient temperature around the CubeSat, crucial for assessing the thermal environment in space. The Gyroscope Sensor Data Grabber provides real-time orientation and stability data, enabling precise attitude control to maintain the CubeSat's orientation. The GPS Data Grabber collects positional data, allowing the CubeSat to determine its location and orbit, which is vital for navigation and tracking. The Outdoor Gas Sensor Data Grabber monitors the chemical composition of the surrounding space environment, useful for research and analysis of space particles or atmospheric elements at specific altitudes. Lastly, the RF TRX Communication module facilitates bi-directional communication with ground stations, handling both the transmission and reception of mission data and commands. These modules, illustrated in Figure 11 below, work together to ensure comprehensive environmental monitoring, positional accuracy, and reliable data exchange, forming a cohesive and efficient subsystem network within the CubeSat.

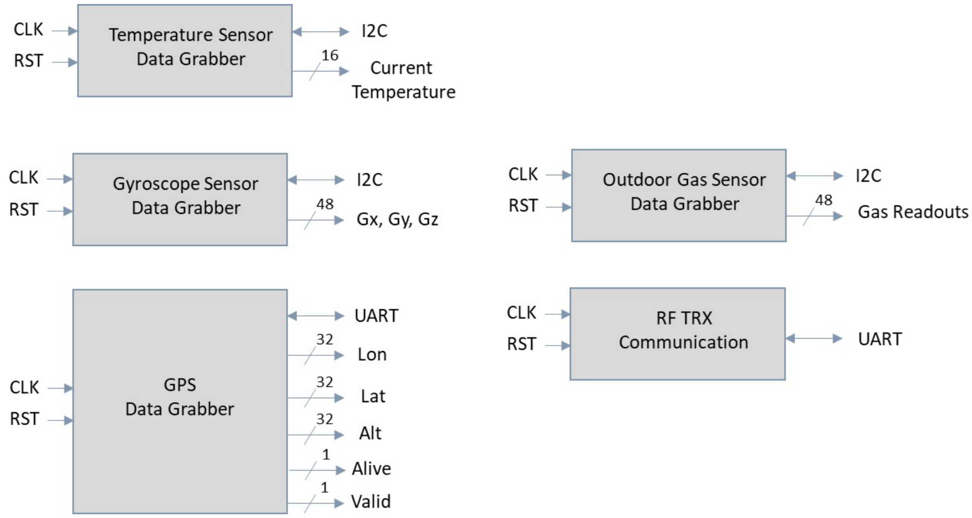

Figure 11. AvionCPU State Machine

3.7 *Receiver Unit Development*

The receiver unit, as depicted in Figure 12, is designed to capture and process incoming data, integrating key components to ensure reliable communication and environmental monitoring. Power is supplied via a USB Type C Connector, providing a 5V input. This voltage is then regulated by the AP2112 Voltage Regulator, which steps down the voltage to 3.3V to support the operation of various 3.3V components within the unit. A CP2102 USB-to-UART bridge chip handles the communication between the USB interface and the RF transceiver, facilitating serial data exchange with the host system. This transceiver communicates with the RF Transceiver Unit, which operates on the RFIO interface for radio communication. Data received or transmitted via this RF transceiver is connected through a U-FL Connector, which serves as the antenna interface.

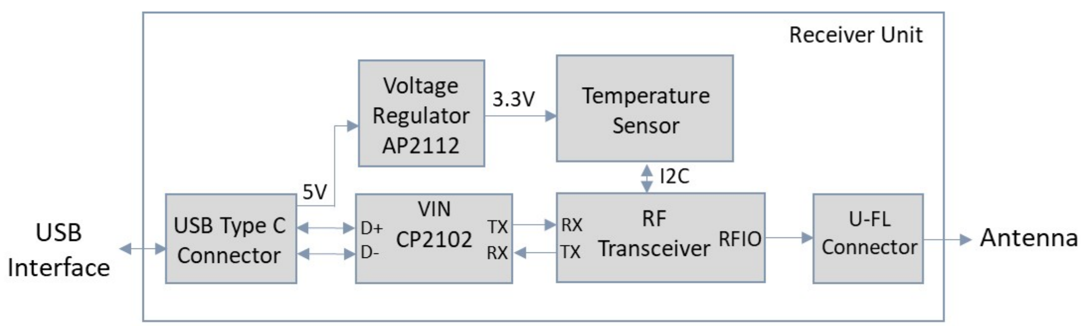

Figure 12. Receiver Unit

3.8 *Groundstation Unit and GUI Application Development*

The ground station system is designed to provide real-time monitoring and control of the CubeSat through a Groundstation Computer and a dedicated GUI Application. Connected via a USB Connector, the system begins by receiving data transmitted from the CubeSat. The UART Listener within the GUI application captures this incoming data stream, ensuring continuous and reliable communication. Once data is received, the Data Parser processes and organizes the raw information, converting it into a readable format. Finally, the GUI Update component refreshes the display on the Monitor, allowing operators to view the CubeSat's status and telemetry data in real time. This setup creates an intuitive and responsive interface, enabling ground station operators to track, analyze, and respond to CubeSat operations efficiently, as illustrated in Figure 13 below.

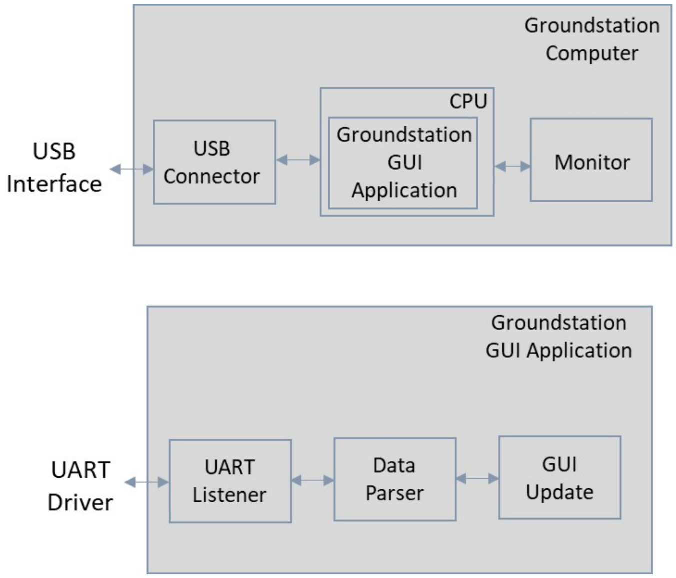

Figure 13. Groundstation Unit and GUI Application Development

The Spacebox Ground Station interface offers a comprehensive, real-time overview of the CubeSat's telemetry and environmental data through a well-organized display. Temperature data is presented with a historical line graph and a current reading gauge, enabling continuous monitoring of thermal conditions. The gyroscope section provides historical data for the X, Y, and Z axes, along with a visual indicator of the CubeSat's orientation, ensuring precise tracking of its stability. GPS information, including latitude, longitude, altitude, and signal status, is shown alongside an interactive map that highlights the CubeSat's current location, enhancing geographic awareness. Additionally, gas sensor readings are displayed on gauges, providing insight into the atmospheric conditions surrounding the CubeSat. This structured interface allows operators to easily monitor critical metrics, supporting efficient and informed control of the mission.

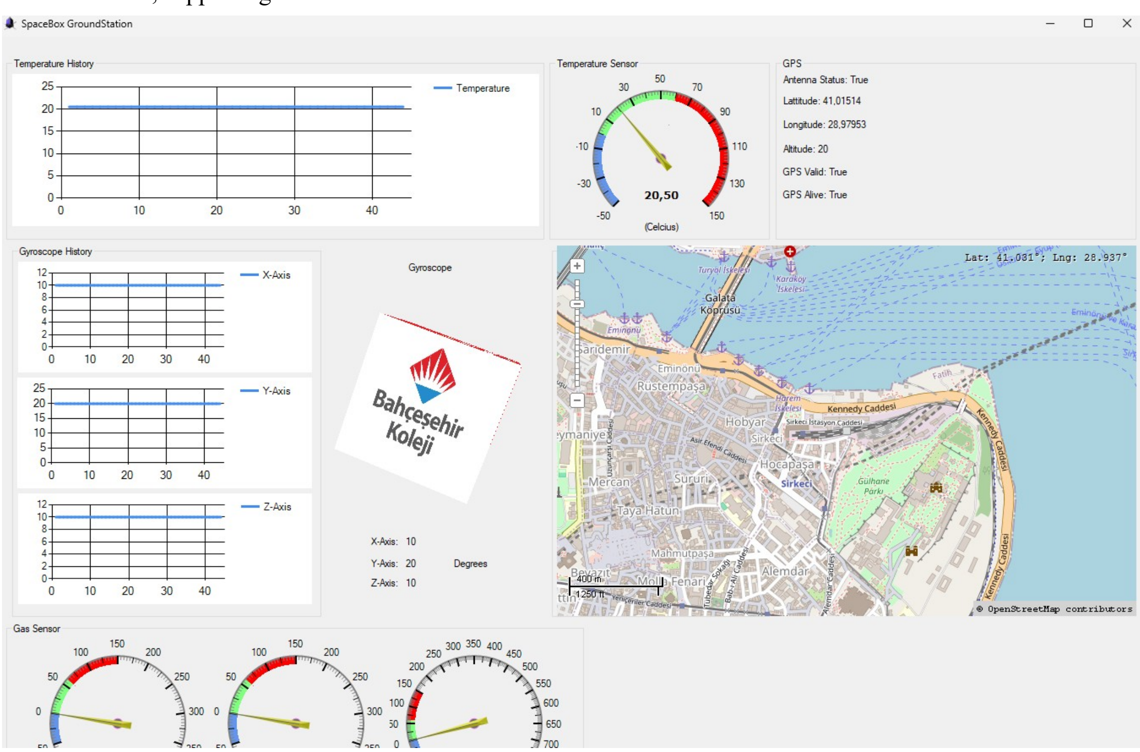

Figure 14. Groundstation GUI Application

4. Balloon Controller Unit

To ensure safe and controlled testing of the CubeSat during altitude experiments, developed a balloon control unit to prevent the CubeSat from drifting randomly or suffering damage due to an uncontrolled descent. Without this system, the CubeSat could easily end up in a random location, potentially resulting in a burst balloon and damaged components, complicating recovery efforts. This unit also enables rapid adjustments and repeated trials, providing a flexible setup for making modifications and running tests as needed, supporting efficient testing and iterative development of the CubeSat's functionalities. The balloon control unit illustrated in The Figure 15 enables controlled altitude adjustments of a CubeSat tethered to a helium-filled meteorological balloon. At the core of this system is a microcontroller unit (MCU) that receives control commands via a serial interface. These commands include parameters such as step motor speed, step count, direction, servo motor speed, and operation mode. The operation mode can be set to either single-cycle or continuous; in single-cycle mode, the command is executed once, while in continuous mode, the system loops the command until a new command is received.

The step motor is driven based on the parameters received from the serial interface, enabling precise control of the rotation of a pulley attached to the motor. This pulley winds or unwinds a fishing line tethered to the CubeSat. As the pulley rotates, it controls the CubeSat's ascent or descent, allowing for controlled altitude adjustments.

A ceramic ring guides the fishing line, minimizing wear and tear on the line during operation. The servo motor is tasked with ensuring even distribution of the line across the pulley. It accomplishes this by oscillating back and forth, adjusting the line position as it is wound onto the pulley, thus ensuring a stable and uniform wrap. This mechanism supports consistent and controlled operations for altitude adjustments, allowing for efficient CubeSat deployment and retrieval.

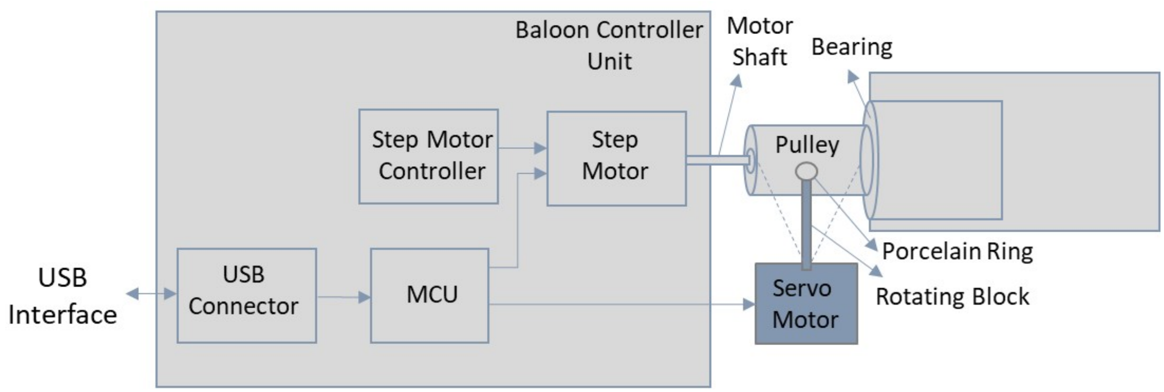

Figure 15. Balloon Controller

The state machine within the MCU software controls command processing and motor actions in a structured sequence. Starting from S0 (idle state), the MCU receives and interprets commands through states S1 to S7, handling parameters like motor speed, step count, and direction. In states S8 to S13, it executes the step and servo motor actions, managing single or continuous operation modes. Upon completing the command, the system returns to S0 to await the next input. This organized state flow enables precise altitude control for the CubeSat. This flow is illustrated in Figure 16 below.

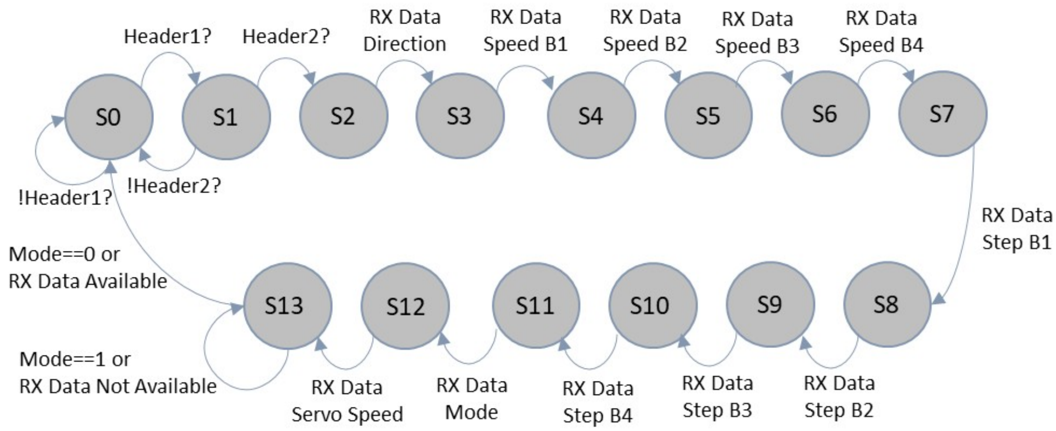

Figure 16. Balloon Controller MCU State Machine

The Balloon Controller GUI Application is designed to facilitate real-time monitoring and control of the CubeSat's altitude adjustments. The application operates in three primary stages: the UART Listener captures incoming data through the serial interface, ensuring continuous communication. The Data Parser then processes this raw data, converting it into a structured format for analysis. Finally, the GUI Update component refreshes the display to present the latest data and system status to the user, enabling efficient interaction and control over the balloon system. This flow is illustrated in Figure 17 below.

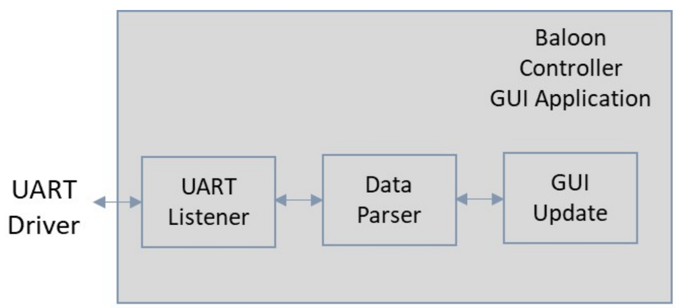

Figure 17. Balloon Controller

The Balloon Controller GUI provides a comprehensive interface for managing CubeSat altitude adjustments, offering both manual and automated control options. In the Manual Operation section, users can configure parameters such as direction, speed, step count, and servo speed, with a continuous mode option allowing commands to loop until manually stopped. The Automatic Operation panel enables predefined control with settings for direction, speed, and target altitude, simplifying recurring tasks. For system calibration and testing, the Test Operations section allows adjustment of parameters like loop count, speed, step count, and delay, ensuring reliable performance under controlled conditions. Additionally, the Stats panel displays real-time feedback on key metrics, such as total ascent and descent, current position, running time, and completed operations, providing a clear view of system status and performance. This well-organized GUI structure enhances operational precision and adaptability, as illustrated in Figure 18 below.

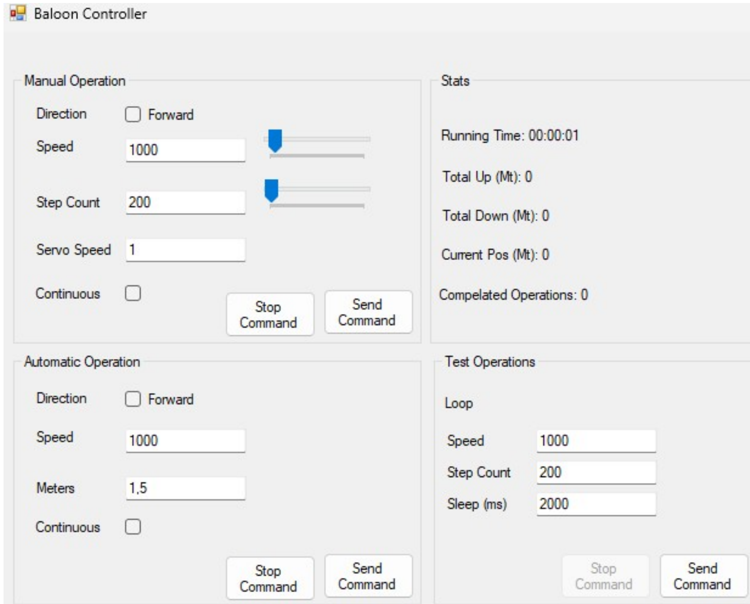

Figure 18. Balloon Controller GUI Design

5. Real-World Field Testing for Controlled CubeSat Deployment

The development and testing of a CubeSat deployment system require meticulous planning and execution to ensure safe and efficient operations, especially when conducted in real-world environments. A weather balloon, as illustrated in Figure 19, is used to elevate the CubeSat to the desired altitude. The CubeSat is equipped with essential components, including a mission computer, sensors, communication units, battery blocks, solar panels, and a robust chassis. Through an RF link wireless connection, data is transmitted in real-time from the CubeSat to a ground station, where it is received and processed. This groundstation setup, complete with a receiver and a ground station interface, enables operators to monitor CubeSat conditions, execute altitude adjustments, and ensure controlled deployment.

The testing infrastructure shown in Figure 19 highlights the integrated approach of using a tethered weather balloon system for altitude control, which aids in preventing unplanned descent or component damage. By allowing repeated tests and modifications, this setup provides a flexible and reliable means for iterative testing, validating both the CubeSat's functionalities and the safety of deployment operations.

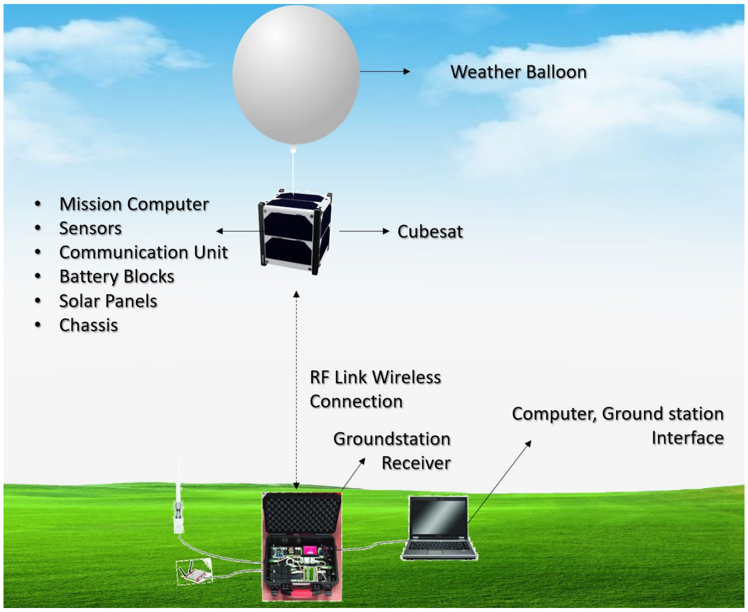

Figure 19. Experiment Setup

The final CubeSat system and its ground station receiver, shown in Figures 20 and 21, demonstrate a multi-layered design with each layer fulfilling a distinct role within the unit's operational architecture. At the top lies the Sensor Layer, responsible for gathering environmental and operational data through various sensors, enabling real-time monitoring of the CubeSat's conditions. Beneath this is the Power Layer, which contains battery packs and power management systems to ensure a steady distribution of power across all components, supporting reliable, uninterrupted functionality. The foundational Mission Computer Layer houses the mission computer, the central processing unit that executes operational commands, processes sensor data, and maintains communication with the ground station. The Ground Station Receiver, equipped with an antenna, facilitates ongoing data transmission between the CubeSat and ground operators, enabling continuous real-time monitoring and control. Through this interface, the ground station can execute commands, analyze performance metrics, and make altitude adjustments as needed, ensuring successful deployment operations.

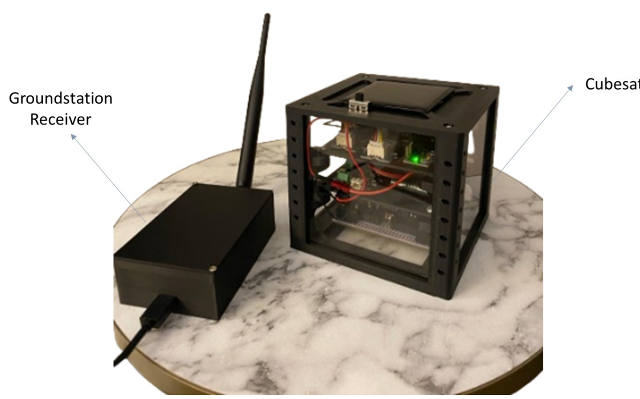

Figure 20. Final Cubesat and Receiver Unit

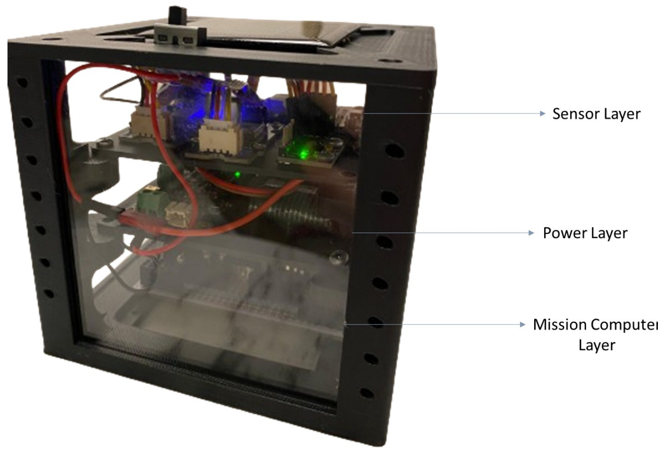

Figure 21. Cubesat Layers

The balloon control unit used in the experiment, shown in Figure 22, is designed to facilitate precise altitude adjustments for the CubeSat tethered to a weather balloon. At the core of this system is a step motor that drives a pulley, which manages the winding and unwinding of a durable fishing line connected to the CubeSat. This configuration allows for controlled ascent and descent, ensuring the CubeSat remains at desired altitudes during testing. A ceramic ring guides the line, reducing friction and wear, while a servo motor aids in the uniform distribution of the line across the pulley by oscillating as it winds, thus preventing tangling and ensuring stability. This setup enables repeated and accurate altitude control, supporting safe, consistent, and flexible testing of the CubeSat system.

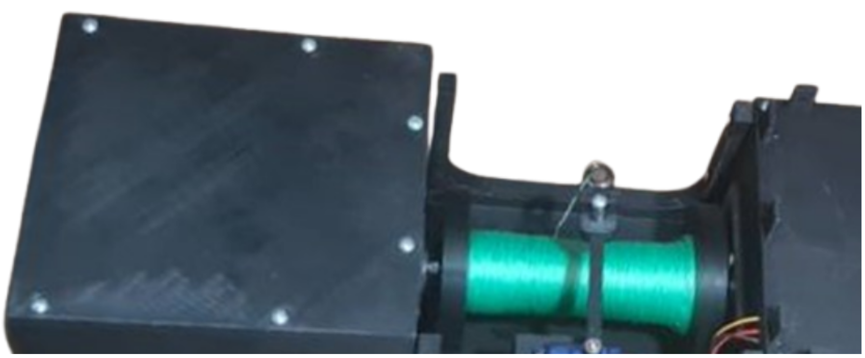

Figure 22. Balloon Controller

The CubeSat altitude testing setup (Figure 23) illustrates the necessary tethering and control arrangement for a safe and effective test of the CubeSat's functionality and communication capabilities.

- Weather Balloon Preparation: At the top, the weather balloon is filled with helium and connected to a strong monofilament line (1 meter, 4 strands) attached to a metal ring. This ring stabilizes the ascent, reducing twisting and ensuring a smooth lift.
- CubeSat Connection: The CubeSat is secured to the tether system with additional metal rings and shorter monofilament lines (30 cm, 4 strands each), maintaining alignment and stability as it ascends, which is crucial for accurate sensor readings and reliable communication.
- Balloon Controller and Tether Management: A 500-meter monofilament line (4 strands) connects the final metal ring to the Balloon Controller at the base. This line is wound on the Balloon Controller, which allows precise control over the CubeSat's altitude by reeling in or out as needed to reach desired testing levels and safely retrieve the CubeSat after testing.

• Communication Quality Check: Before raising the CubeSat, the RF link with the ground station is evaluated. Key indicators such as the Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR) are checked to ensure strong telemetry and communication quality throughout the altitude test.

• Following these steps ensures the CubeSat's systems are tested in a controlled environment, verifying communication stability and operational readiness for future missions.

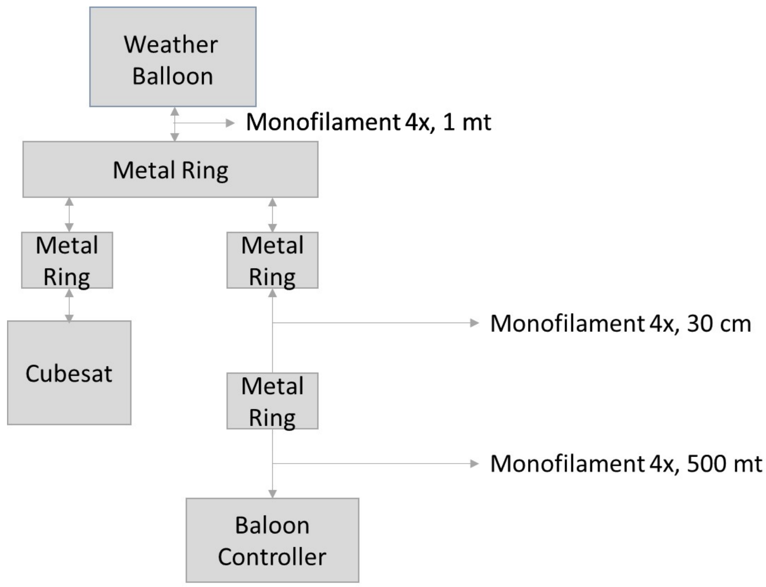

Figure 23. Test Connection Procedure

The field-testing sequence for the CubeSat deployment system is illustrated in Figures 24, 25, and 26. In Figure 24, the weather balloon is seen freshly inflated and tethered to the CubeSat, positioned on the ground, preparing for ascent. This initial stage allows for last-minute system checks and ensures that the balloon and CubeSat are securely connected and operational. Figure 25 shows the balloon at a significant altitude, demonstrating the system's capability to maintain controlled elevation and stability as it ascends. This phase is crucial for observing the real-time response of the CubeSat's components in a high-altitude environment. Finally, Figure 26 displays the live data monitoring interface at the ground station, which receives telemetry from the CubeSat via RF link. This setup provides operators with continuous visual feedback, including environmental data and operational metrics, ensuring informed control over the CubeSat's altitude and functional status during the test.


Figure 24. Pre-Flight Ground Tests


Figure 25. Flight Tests

Figure 26. Groundstation Live Data Capture

6. Results

The resource usage of the Mission Computer on the A35T AMD FPGA is summarized in Table 1, outlining the allocation of various hardware resources for each key functional unit. The Mission Computer Total row presents a holistic view of the FPGA's resource consumption, with 8843 Slice LUTs, 9470 Slice Registers, 3800 Slices, 8330 LUTs, 7.5 Block RAM Tiles, and 1 DSP. Each component, such as the Temperature Sensor Grabber, RF Transceiver, Gyroscope Data Grabber, GPS Data Grabber, Gas Quality Data Grabber, AvionCPU Code, and Program Memory, contributes uniquely to the overall resource distribution. Notably, high-resource functions like the Gyroscope Data Grabber and GPS Data Grabber require significant LUT and Register usage, while lower-resource tasks such as the Temperature Sensor Grabber and RF Transceiver occupy minimal resources.

Table 1. Resource Usage of Mission Computer on A35T AMD FPGA

	Slice LUTs	Slice Registers	Slice	LUT	Block RAM Tile	DSPs
Mission Computer Total	8843	9470	3800	8330	7.5	1
Temperature Sensor Grabber	136	64	51	136	0	0
RF Transceiver	193	112	74	193	0	0
Gyroscope Data Grabber	2796	3265	1274	2548	4	0
GPS Data Grabber	2304	2279	1146	2304	0	0
Gas Quality Data Grabber	2075	2719	922	1834	3	0
AvionCPU Code	225	41	88	225	0	1
Program Memory	7	0	4	7	0.5	0

The Mission Computer operates at a power consumption of 1.155 Watts, allowing for approximately 7 hours of continuous operation in environments without sunlight. This balance between resource efficiency and power usage is crucial for prolonged CubeSat missions, ensuring that all essential components operate effectively within the limited energy budget. These findings demonstrate the feasibility of integrating multiple sensor grabbers and communication interfaces on a compact FPGA platform, achieving an optimal trade-off between functionality and energy efficiency for space-bound applications.

7. Conclusions

This study aimed to inspire high school students by demonstrating that even complex CubeSat technology is within their grasp. By guiding them through the design and development of the CubeSat's mission computer—

the brain of the satellite—we created an immersive learning experience where students could grasp both the theoretical and practical aspects of this advanced technology. Through this approach, students engaged deeply in every phase, from component selection to final integration, experiencing the power of hands-on education. The result was not only a functional and optimized mission computer with low power consumption but also a cohort of students equipped with valuable skills and confidence in their technical abilities.

Key outcomes include:

- High student engagement
- Optimized, low-power mission computer
- Broad skill acquisition
- Empowered self-sufficiency

These achievements underscore the transformative potential of experiential learning. By building a CubeSat from the ground up, students not only gained technical expertise but also cultivated a mindset geared toward problem-solving, innovation, and continuous growth. This project stands as a testament to the capabilities of young learners when they are given the right tools and guidance to tackle ambitious challenges.

In future work, several key enhancements are planned to advance the CubeSat's technical capabilities and expand the educational experience it provides to students. Each enhancement, along with its planned implementation steps and expected impact, is outlined below.

- Daylight Camera Integration: A daylight camera will be integrated to capture real-time visual data. To implement this, a compact, energy-efficient camera will be selected that fits within the CubeSat's size and power constraints. The camera will be positioned to provide a clear field of view, and image processing software will be added to the mission computer to handle data compression and storage. Through this, students will be introduced to Earth observation, basic image processing, and data management within limited space and power resources.

- Aluminum Chassis Development: The CubeSat's existing structure will be replaced with a durable aluminum chassis to improve resistance to environmental stresses. 3D models of the CubeSat frame will be created to ensure precise fit for all components, and various aluminum alloys will be tested to determine the ideal choice for weight, durability, and heat dissipation. Students will gain experience in materials engineering and structural design, which are critical aspects of aerospace engineering.

- Longer-Range RF Transceiver: A more powerful RF transceiver will be installed to extend the CubeSat's communication range. The transceiver will be selected based on its range and energy efficiency, and adjustments to the CubeSat's antenna and signal processing software will be made to ensure compatibility. Communication scenarios will be simulated, and signal stability will be analyzed over various distances. This process will familiarize students with RF systems, antenna design, and data transmission.

- Magnetorquer System for Attitude Control: A magnetorquer system will be integrated to enable precise orientation control using electromagnetic fields. Magnetic coils will be designed and installed to interact with Earth's magnetic field, with various current levels tested to achieve controlled adjustments in alignment. The system will be configured to operate autonomously through the CubeSat's onboard computer. Through this, students will gain an understanding of satellite orientation and control.

- Participation in Competitions: National and international CubeSat competitions will be entered to showcase the CubeSat's advancements. Performance will be refined and presentations prepared to communicate the work effectively. Students will gain experience in technical communication, presentation, and teamwork, receiving valuable feedback from industry experts. This experience is expected to enhance their professional skills and encourage ongoing innovation.

- These enhancements are expected to provide students with hands-on experience in critical areas of satellite design and operation, bridging classroom learning with real-world engineering challenges. Engaging with these projects will allow students to develop a wide range of skills that are foundational for careers in aerospace and engineering.

The Spacebox project website, accessible at bkspacebox.com, serves as an informative hub for all project-related updates. The site allowing visitors to stay informed about upcoming events. This platform engages students and educators promotes awareness of the project's educational impact and technical achievements.

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