CubeSat Size Growing Autonomous System
System Requirements Document (SRD)
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1. Executive Summary

1.1 Project Overview

In partnership with the University of South Florida's Mechanical Engineering team, our project seeks to design and implement an efficient, microprocessor-based system for specimen life support and environmental data collection within a CubeSat. A weather balloon test will be instrumental in evaluating the system's performance in challenging near-space conditions.

1.2 Purpose and Scope of this System Requirements Document

The purpose of this document is to record the essential specifications, functionalities, and constraints for the development of this life support and data collection system. This system is intended to create a controlled environment for plant growth, monitor vital data parameters, and collect valuable information for scientific research on growing edible plants in space.

This document serves as a comprehensive guide for other teams involved in the project and researchers in governmental and scientific organizations interested in growing a food supply outside of Earth. This document will ensure a clear understanding of the project's scope, objectives, and technical requirements.

In scope

This document addresses requirements related to the design of a plant specimen life support and data collection system:

- Design and components of the plant life support system.
- Data collection and transfer method.
- Power distribution and power rationing method.
- Wireless communication protocol.

Out of scope

This document does not address the work of the mechanical engineering teams, which include:

- Design of plant irrigation system.
- Solar panels are deployed to supply power to the CubeSat.
- Construction and dimensions of the CubeSat.
- The launch and flight path of the weather balloon.

1.3 1.3 Definitions, Acronyms, and Abbreviations

ANSYS SDK – A software used to plot the flight path of a satellite.

BIOSat – Botany in Orbit Satellite.

BOM – Bill of Materials.

CONOPS – A Concept of Operations is a high-level document that outlines a system's goals, objectives, and strategies, clearly and concisely describing how it is expected to function and the roles and responsibilities of the components involved.

CubeSat – A nanosatellite under a standard size and form.

DiTL – Day in The Life. A document describing the hour-by-hour operations of the system in a single day.

ISS – International Space Station.

KSAT – Kongsberg Satellite Services.

LEO – Low Earth Orbit.

ML – Machine Learning.

MO – Mission Objectives.

MSC – Mission Success Criteria.

PHMS – Plant Health Monitoring System.

TRL – Technology Readiness Level. A numerical scale is used to assess the maturity and readiness of a technology or project, with higher TRL values indicating more significant development and closer proximity to practical application.

VI – Vegetation Indices. Numerical measures derived from remote sensing data provide information about vegetation's health and condition.

VOC – Volatile Organic Compounds.

1.4 1.4 References

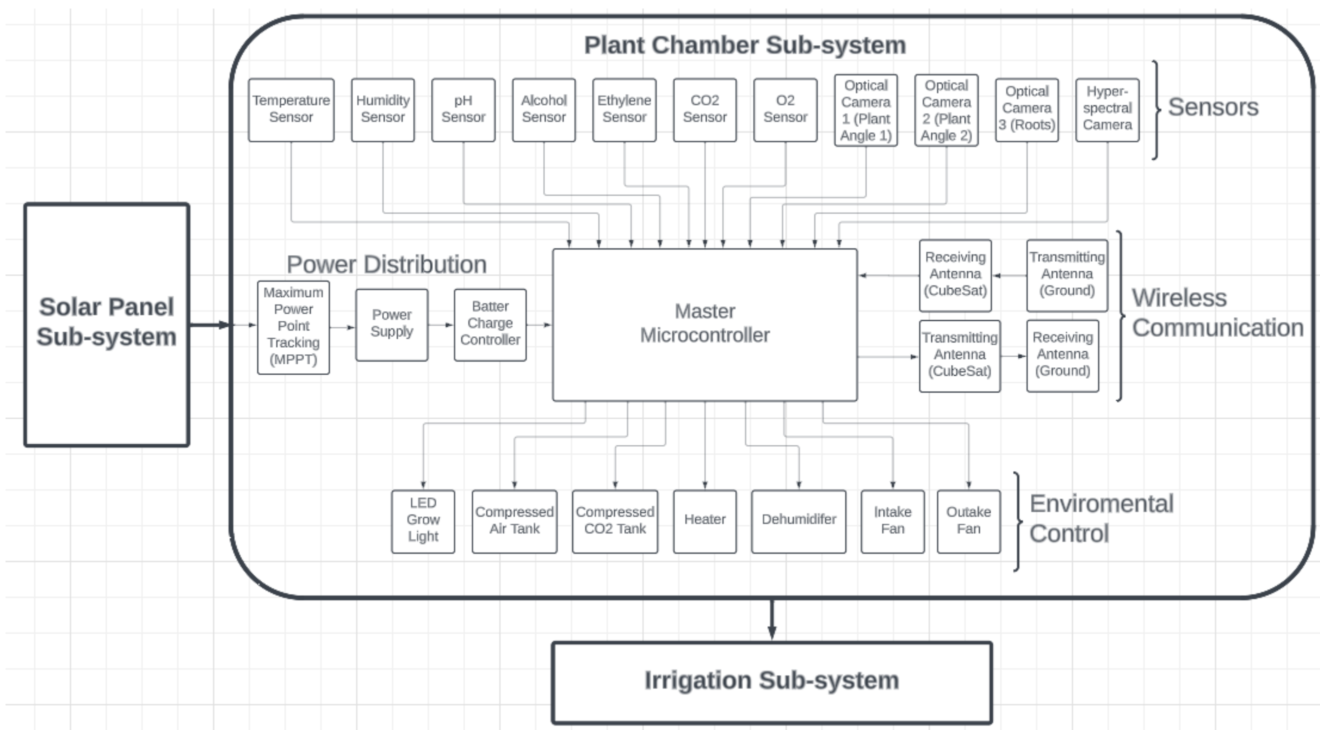
See the Appendix on page 19 for a list of references.

2. Product/Service Description

Throughout our team's discussions, we have determined precise metrics that will be evaluated through the efficiency of the autonomous environmental monitoring systems. Additionally, considering assumptions and constraints is integral to the project's framework, touching on accessibility, security, and ecological nuance. This will inform our project's planning and ensure the success and functionality of the system.

2.1 Product Context

The design of this product is primarily self-contained, as the goal is to create autonomous conditions for the germination and growth of a red cabbage plant. With its power source and microcontroller, this system is self-sufficient and will run mostly without habitual human updates. The communication segment of this system is the only subject that interacts with an exterior interface, which is used to receive the transmitted data.



2.2 Assumptions

1. Modification for CubeSat dimensions is assumed. However, the timeline for when an order with higher detail will be delivered. This may cause a delay with the current timelines.
2. Accessibility to testing in outer orbit conditions is assumed. Other testing methods will become our last resort if access is limited or unavailable.
3. Availability of a ground-based wireless communication infrastructure for data reception is assumed. Without access to an ideal infrastructure, alternative data capturing will be employed.
4. Assumed adherence to budget constraints as specified in the project plan. Any budget changes may necessitate cost-effective modifications to the system.
5. Assumed collaboration with the University of South Florida's Mechanical Engineering team. Any changes in collaboration terms may impact the design and integration of the packaging apparatus.

2.3 Constraints

1. Design constraints related to data management and security require implementing measures to protect sensitive data transmitted from the CubeSat to ground stations and during data analysis.
2. There will be strict design constraints due to the delicate characteristics of environments in outer orbit. The data must be reliable and accurate despite any design constraints.
3. The system will spend most of its time in harsh conditions in a near-space environment, including extreme temperatures, radiation, and vacuum. This places restraints on materials, design, and function.
4. There will be no option to update or alter the system after deployment. Once the system is deployed, any correction is not feasible.
5. Compliance with regulations may cause restriction, permitting, or licensing. Adherence to outer orbit, environmental, and communication regulation will be necessary.
6. The weather balloon and CubeSat both present weight constraints. The selected materials must remain within the limitations that this presents.

2.4 Dependencies

1. The sensors will measure the data and send it to the microcontroller, where the data will be temporarily saved.
2. The microcontroller will send data to the transmitting antenna twice daily to communicate with the ground station.
3. The solar panels implemented by the mechanical engineering team will charge the internal backup battery while supplying power to the sensors, microcontroller, and antenna. This power supply is not continuous for each component but will be supplemental depending on demand.

3. Requirements

3.1.1 User Interface Requirements

- RF communication: We will strictly communicate to our device through radio at a frequency of 433Hz.
- Arduino: The mode of collecting information would be through our Arduino, which will record the measurements taken from our sensors and provide feedback for our control devices.

3.1.2 Performance

Static Numerical Requirements

- Communication Channel: Our CubeSat must support wireless communication via RF at a frequency of 433. Additionally, our CubeSat must be able to transmit and receive signals.
- LED lightning: CubeSat must maintain a steady cycle of lighting (16 hours of LED on, 8 hours of LED off)
- Ventilation: The fan will steadily circulate air throughout the plant chamber at a steady speed
- Camera: The camera will capture a picture every 24 hours, which will then be transmitted.

Dynamic Numerical Requirements

- Temperature and Humidity: CubeSat must be able to accurately measure temperature and humidity through sensors and maintain optimal conditions for both (60 to 80 degrees Fahrenheit and 50-70 percent humid)
- pH Level: The pH Meter will monitor the plant's soil and verify that it is at optimal pH level (6-6.5)
- Gas Analyzer System: Our Gas analyzer system will comprise four sensors (Alcohol, Ethylene, CO_2, O_2). This system will measure the air concentration and ensure the red lettuce is in optimal growing conditions (8ppm for O_2, 800-1000ppm for O_2)

3.1.3 Capacity

- Simultaneous User Support: Define the exact number of simultaneous users the system is engineered to support without performance distortion.

- Maximum User Load: Identify the peak simultaneous user count the system can accommodate while maintaining operational integrity.

- Per-User Memory Distribution: Specify the memory assigned for each active user, ensuring seamless application functionality and user experience.

- Application Throughput: Detail the expected rate at which the system processes requests or data, representing its efficiency and performance under typical and peak loads.

3.1.4 Availability

- The System will need to run continuously to monitor plants' health.
- Downtime will require a halt on data, and estimates can be used from previous data.
- A maximum of one failure per hour will give us sufficient data to make estimates.

3.1.5 Latency

The camera will take pictures at a specific time interval. The data should come back and be read before the proceeding interval occurs. This can be applied to all other sensor readings.

3.1.6 Manageability/Maintainability

3.1.6.1 Monitoring

System Health Monitoring
The system shall continuously monitor the health and status of all critical components, including sensors, power supply, and communication modules. It shall provide real-time updates on the status of each component and overall system health.

Failure Conditions
The system shall define specific failure conditions for each component and subsystem. Any deviation from expected operational parameters or conditions shall be treated as a failure. Failure conditions shall be documented.

Error Detection
The system will include error detection mechanisms for both hardware and software components. Hardware errors such as sensor malfunction or power supply issues trigger alarms. Software errors, including communication protocol failures, shall be logged and reported.

Correction and Mitigation
If failures or errors are detected, the system shall initiate predefined corrective actions. These actions may include restarting the system or adjusting operational parameters. The system shall also attempt to re-establish connections and communication if disruptions occur. If a major system failure occurs, we will try to transfer all valuable data before it is permanently lost.

Logging
The system shall maintain comprehensive logs of all operational events, errors, and exceptions. Logs shall be timestamped and include information such as the nature of the event, its severity, and relevant data values at the time of the event.

3.1.6.2 Maintenance

This system has been purposefully designed to achieve complete autonomy upon the commencement of its 30-day mission. Throughout this mission, physical access to the system will not be available. Hence, the system must exhibit high robustness to operate without requiring maintenance interventions during its mission duration.

3.1.7 Systems Interfaces

A. Sensors
   Each sensor will collect data from the environment and send it to the Arduino control board, which converts the data from analog format to digital format.

B. Environmental Controller
   Digital data from the Arduino controller will determine if specific environmental controllers, such as a heater or dehumidifier, turn on and to what level they are set.

C. Wireless Communications
   Data from sensors, converted in digital format, will be transferred to a storage system to await when the data can be transferred to our ground station via an antenna.

D. Power Systems
   Power generated by solar panels will be stored in a battery. The battery will be fed to the Arduino control board via a power controller that determines if the power provided to the control board comes from the battery or directly from the solar panels if the battery is complete and the solar panels are generating power.

E. Microcontroller
   An Arduino board will process data and send commands to the other subsystems. This will be done using Arduino's software.

3.1.7.1 System and Hardware Interface/Integration

These subsystems will be connected using an Arduino microcontroller, and the Arduino code will be used to collect information from the sensors, process that information, and give orders to the environmental subsystem.

The communication protocol that the connections between the subsystems and the microcontroller will follow the I^2C protocol. This will allow us to connect multiple digital integrated circuits to create our subsystems. The number of ports we will need for our microcontroller is unknown as we are still developing this system's component list.

3.2 System Requirements Matrix

Table 1 Requirements

Req#	Function	Requirement	Comments	Date Reviewed	SME /Faculty Reviewed / Approved
1	ME	The plant chamber shall be capable of fitting within a 3U space	The plant chamber is to fit in CubeSat with electronics and water pump	10/20/24	Arash Takshi
2	ME	Circulate air through the chamber at a velocity of 0.3-0.5 m/s using fans	The fans are the intake and outtake system and will use atmosphere air while in the weather balloon	10/20/24	Arash Takshi
3	EE	The grow light shall be capable of providing an intensity of 200-250 µmol/m2/s with a light wavelength of 400-700 nm for 16-18 hours a day	The light source needs to be powered efficiently to accompany the other sensors	10/20/24	Arash Takshi
4	EE	The microcontroller should have, at the minimum, the same number of I/O pins as sensors with room for expansion boards	Possible expansion boards for RF communication	10/20/24	Arash Takshi
5	EE	The antenna must communicate from the weather balloon to the ground station, a distance of about 25km-35km	Communication between payload and ground station	10/20/24	Arash Takshi
6	EE	Temperature sensor to measure the desired range of 50-80 degrees F	Accuracy: Plus/Minus 1 degree F	10/20/24	Arash Takshi

Req#	Function	Requirement	Comments	Date Reviewed	SME /Faculty Reviewed / Approved
7	EE	Humidity sensor to measure the range of 40%-80% RH	Accuracy: Plus/Minus 5% RH	10/20/24	Arash Takshi
8	EE	CO2 sensor measure range of 400-1500ppm	Accuracy: Plus/Minus 100 ppm	10/20/24	Arash Takshi
9	EE	O2 sensor measure range of 160,000 - 209,000 ppm	Plus/Minus 1000 ppm	10/20/24	Arash Takshi
10	EE	Ethylene sensor measure range of 0-100ppb	Plus/Minus 25 ppb	10/20/24	Arash Takshi
11	EE	The solar panels and battery will generate/store enough power to allow the CubeSat to operate autonomously	Need a specific power budget for each component	10/20/24	Arash Takshi
12	EE	Optical/fisheye camera imaging on root zone and sprout zone	Camera and placement	10/20/24	Arash Takshi
13	EE	Payload shall include hyperspectral camera imaging on the leaf zone	Hyperspectral image	10/20/24	Arash Takshi
14	Software	The acquired payload images and sensor data shall be capable of modeling through MATLAB and machine learning for comprehensive analysis.	Apply filters and enhancement	10/20/24	Arash Takshi
15	Software	Communication between sensors must be SPI, UART, I2C	Bidirectional communication and response to adjustments on both sides	10/20/24	Arash Takshi
16	Software	One programming language will be used for all communication	Consistent language	10/20/24	Arash Takshi

4. User Scenarios/Use Cases

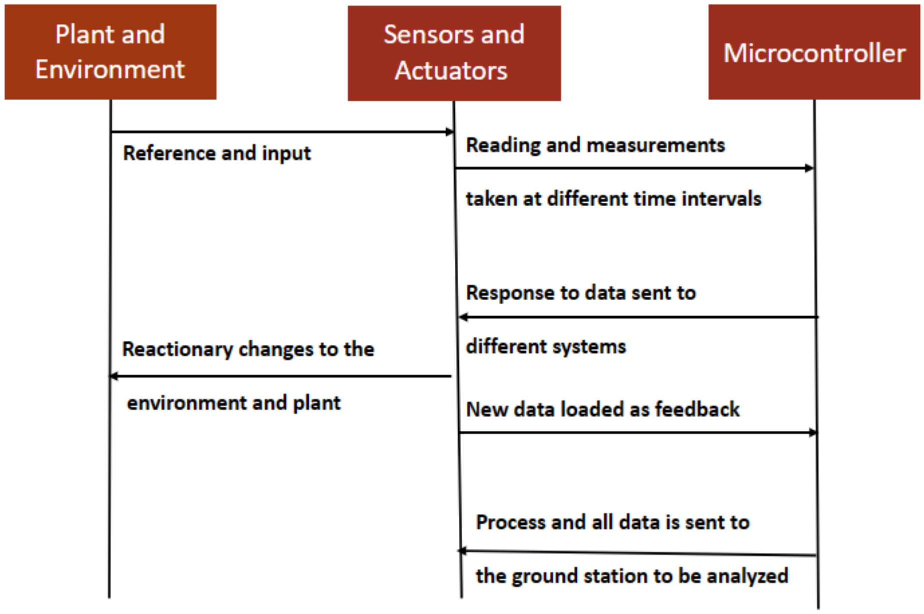
Our project focuses on developing and applying environmental monitoring in the upper atmosphere. This autonomous system is based on NASA's guidelines for research used in their mission to advance plant life in space. Leveraging weather balloon testing to deploy a sub-environment within a CubeSat, we hope to achieve the following:

- Data Collection and Integration
  - Objective: Demonstrate comprehensive readings and measurements.
  - Problem: Connection from the ground station to the weather balloon is not committed. Data is unreadable.
  - Solution: Implement structures that have had success in the past and advance the technology to encompass the desired response.
- Instantaneous Monitoring
  - Objective: Receive real-time information regarding the plant and the surrounding environment.
  - Problem: Failure with a component in the environmental subsystem. Delay in the transmission of the data.
  - Solution: Implementation of a watchdog timer to guarantee measurement communication.
- Reporting and Visualization
  - Objective: Enable stakeholders to retrieve thorough and practical information.
  - Problem: Inaccessible or overly complex data.
  - Solution: Enforce a user-friendly interface and reliable communication.
- Scalability and Customization
  - Objective: The system adapts to stakeholders' satellite or terrestrial use needs.
  - Problem: Subsystems cannot adhere to satellite requirements.
  - Solution: Design customizable options.
- Measurable Success Documentation
  - Germination and Growth Rate: Achieving germination and plant maturation in 30 days.
  - Environmental Data Collection: Accuracy and completeness of environmental data collected.
  - System Reliability: Continuous operation of the system throughout the 30 days.
  - Data Transmission: Reliable data transmission with minimal data loss or corruption.

5. Analysis Models

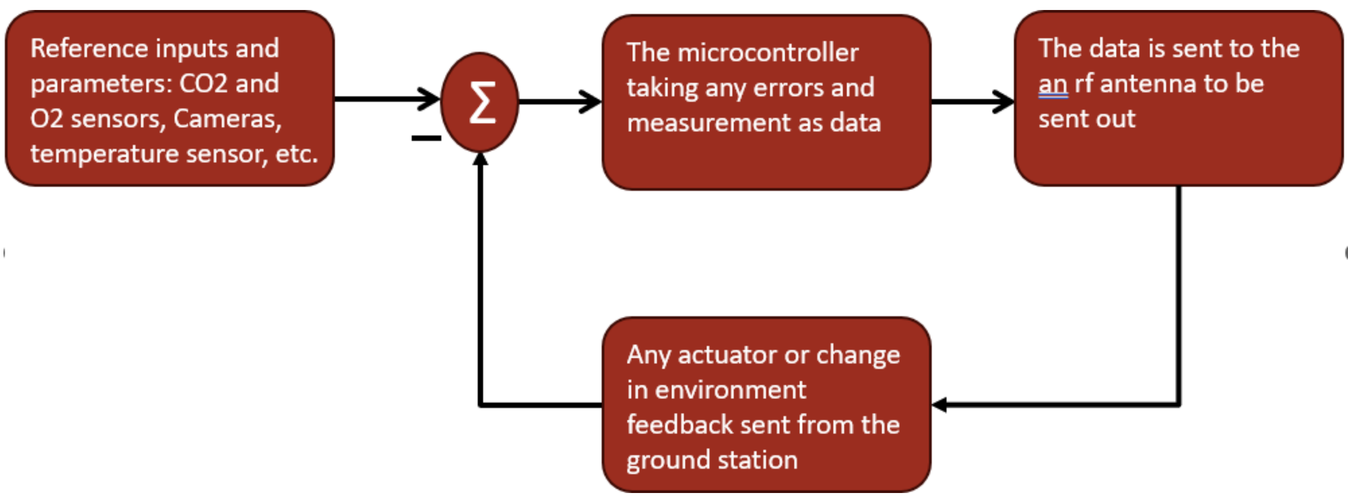
5.1 Sequence Diagrams

This models the sequence of events of our autonomous operation. The plant and environment are the baseline signals to retrieve data. The sensors or any added actuators to the environment must read or receive data from the microcontroller. The ground station is where we will analyze all the data and determine the mission's success.



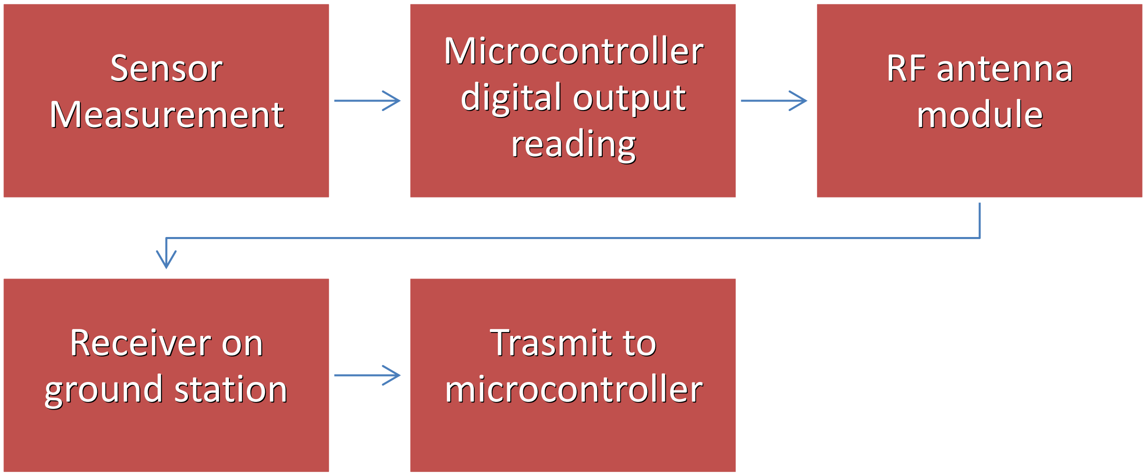
5.2 Data Flow Diagrams

The diagram represents a feedback system in a data flow system. The sigma is the combination of the feedback and inputs and the error. The microcontroller controls any analysis or actuator to correct an error in the appropriate measurement.



5.3 State-Transition Diagrams

The diagram represents the way data flows within our system. The sensor measurement data is collected at the start. The microcontroller reads with the appropriate protocol. It stores the data and sends it to the RF antenna. The protocol is followed to send it to the ground station and if needed, back to the microcontroller.



5.4 SWaP

Please provide Size, weight, and power estimates, and show your estimating methodology.

Component	Voltage	Current	Time Usage	Max expected Current Draw	Size
Solar Panels	10V	2A	N/A	N/A	TBA
Battery	3.7V	6Ah	N/A	N/A	68.072mm*37.08mm*19.05 mm
Temperature, Humid VOC Sensor	3.3V	2m	2 ms	2mA	3.0mm x 3.0mm x 0.93mm.
Oxygen Sensor	3.3V - 5V	6.5mA	1 min	6.5mA	32 mm*2mm
Carbon Dioxide Sensor	3.3V - 5V	4mA	1 min	4mA	32*27*8mm
Alcohol Sensor	3.3V - 5V	10mA	5 mins	10mA	3.0 mm x 3.0 mm x 0.7 mm
Light Sensor	3.3V	2uA - 45uA	24hr	45uA	2.0 mm x 2.0 mm x 0.85mm
Heater	5V	200mA	As needed	200mA	30mmx40mm
LED	3.3V - 5V	16mA (per light)	24hr	16mA	2.0mm x 2.0mm (per LED)
OV2640	2.75V	20mA	Depends	20mA	25.5mm x 24mm
Antenna	TBA	TBA	TBA	TBA	TBA
Antenna Module	TBA	TBA	TBA	TBA	TBA
Total	N/A	N/A	N/A	345.45mA	N/A

5.5 System Performance

Considering the processing power of the microcontroller and the data handling capacity, the system's response time to sensor inputs is expected to be within two milliseconds. Because image processing and data analysis are so extensive, tasks are scheduled to be completed within 5 seconds for each data set, with potential variations based on the complexity of the images and sensor data. The latency for a one-way communication signal from the CubeSat to the ground station is estimated to have a frequency band in LTE, which has around 50 to 100 Mbps. Under average operational conditions, the power system is estimated to sustain all CubeSat functions continuously for up to 15 hours without recharge. Each performing standard is documented in the next section (Requirements Test Matrix).

6. Requirements Test Matrix

Table 2 Test Requirements Matrix

Req#	Function	Requirement	Test Method	Brief Test description	SME /Faculty Reviewed / Approved
1	ME	The plant chamber shall be capable of fitting within a 3U space	Inspection	The plant chamber can be measured using a tape measure or similar tool	AT
2	EE	Circulate air through the chamber at a velocity of 0.3-0.5 m/s using fans	Inspection	Use the fan manual to show the settings and speed of the blades	AT
3	EE	The grow light shall provide an intensity of 200-250 µmol/m2/s with a light wavelength of 400-700 nm for 16-18 hours daily.	Inspection	Can see if the lights are on and switch the different intensities and wavelengths to see if there is a change in sight	AT
4	EE	The microcontroller should have, at the minimum, the same number of I/O pins as sensors with room for expansion boards.	Test	Test I/O by sending or receiving a signal, add an expansion board, and see if data can be sent.	AT
5	EE	The antenna must communicate from the weather balloon to the ground station, a distance of about 25km-35km.	Demonstration	The launch of the weather balloon will be the opportunity to see if communication reaches the required distance.	AT

Req#	Function	Requirement	Test Method	Brief Test description	SME /Faculty Reviewed / Approved
6	EE	Temperature sensor to measure the desired range of 50-80 degrees F	Test	Put the temperature in different ranges using a thermostat to control the environment.	AT
7	EE	Humidity sensor to measure the range of 40%-80% RH	Test	Change the environment using a humidifier and dehumidifier and measure the change.	AT
8	EE	CO_2 sensor measure range of 400-1500ppm	Test	Move sensor to different environments with higher and lower CO_2	AT
9	EE	O_2 sensor measure range of 160,000 - 209,000 ppm	Test	Move the sensor to different environments with higher and lower O_2	AT
10	EE	Ethylene sensor measure range of 0-100ppb	Test	Move the sensor to different environments with higher and lower ethylene levels.	AT
11	EE	The solar panels and battery will generate/store enough power to allow the CubeSat to operate autonomously.	Test	Use datasheets of each component, develop a power budget, and see if the device is powered during operation.	AT
12	EE	Optical/fisheye camera imaging on root zone and sprout zone	Test	Take multiple images in different orientations and positions	AT
13	EE	Payload shall include hyperspectral camera imaging on the leaf zone	Test	Take multiple images in different orientations and positions	AT

Req#	Function	Requirement	Test Method	Brief Test description	SME /Faculty Reviewed / Approved
14	EE	The acquired payload images and sensor data shall be capable of modeling through MATLAB and machine learning for comprehensive analysis.	Test	Run multiple images through the program, checking for errors in MATLAB.	AT
15	EE	Communication between sensors must be SPI, UART, I2C	Test	Send random data or packets between the microcontroller and sensors to see if the protocol works correctly.	AT

7. Project Risk

- Lettuce Seed not germinating
    - The most significant risk in our project is the possibility of our seed not germinating. We plan to avoid this risk by planting multiple seeds, hoping that at least one sprouts. We will also evaluate growing our lettuce in the CubeSat on the ground to allow us to practice and adjust to maximize our chances of successful sprouting.
- All Lettuce seeds germinating
    - In the case that multiple seeds sprout in our CubeSat, we have researched to learn the behavior of plants under extreme resource stress and have come to find out that plants would release hormones that'll kill off surrounding plants as a defense mechanism thus allowing us to guarantee that we will only have to worry about a singular plant. Additionally, we plan only to plant three seeds to control the number of possible plants that could sprout.
- Renewable resources for growing plant
    - The next issue in the case of being successful in plant germination is creating an environment where a plant can grow autonomously, meaning we must be extremely conservative with our resources. We plan to track the utilization of our resources through sensors and control systems to minimize the resources we must use to ensure the plant can grow.
- CubeSat solar panels deployment system
    - Due to our CubeSat being in space, it is essential that the CubeSat has a way of generating renewable energy. We plan to use solar panels and have a deployment system to ensure the solar panels are open to the most optimal position to generate power. We also plan to have a system that will guarantee that the solar panels open correctly.
- Lack of electricity to power CubeSat's systems
    - If our solar panels do not generate enough power for all our systems, we plan to have a program to allocate power towards essential components to keep the plant alive. We can

also track what is being powered through our communication line with CubeSat via satellite comms.

- Establishing communication with CubeSat
    - Establishing communication with our CubeSat is vital to keeping track of our plant systems and locating where our CubeSat is. Regarding this, we plan to use a strong enough antenna that can send and receive signals from space. On the day we send off our CubeSat, we will also have a program that will restart the microcontroller repeatedly until a communication line has been established.

8. Standards

- Radio Frequency (433MHz)
    - https://standards.ieee.org/ieee/C95.2/7284/
- C++ Coding Language (Arduino)
    - https://standards.ieee.org/ieee/716/959/
- Sensor (All sensors listed in the project)
    - https://standards.ieee.org/ieee/2700/6770/
- Energy Storage (Power Supply)
    - https://standards.ieee.org/ieee/1679/7716/
- Solar Cells (Solar Panels)
    - https://standards.ieee.org/ieee/307/504/
- USB 3.0
    - https://standards.ieee.org/standard/802_15_1-2002.html

9. Engineering Ethical Responsibility

If our CubeSat is successful and becomes a product. We plan for it to serve as the pathway towards sustainable living in space. This will significantly impact the world's space excursions as we can now generate a nutritious and autonomous way of making food in space. We plan to achieve this by ethically:

- Reducing Harmful Materials
    - Part of creating a safe and sustainable system must be to minimize using harmful materials in our CubeSat. Our CubeSat was designed to utilize environmentally friendly materials and components that would follow all industry standards and regulations.
- Recyclability and Reusability
    - Due to our mission of creating a sustainable environment for plants to grow, we also planned to include that idea in our CubeSat design. We plan to use as many materials as possible and devices that could be reused or recycled at the end of its life cycle.
- Educational Initiatives
    - In engaging with this project, we also aim to bring awareness towards our responsibility as a species to create a sustainable environment, meaning it is our responsibility to ensure we create and use materials and devices that are capable of being correctly disposable or recycled.
- Long-Term Sustainability

- Our goal for this project is to create a long-term sustainable system to allow plants to grow autonomously. Additionally, we should incorporate that ideology of creating sustainable systems within our lives and future generations by managing our resources in space and on Earth.

10. Change Management Process

The SRD document will be saved on a Microsoft Word document and shared on OneDrive. Any team member can edit the document in real-time. Each team member can edit the document and have an assigned section. The other group members must be alerted when editing someone else's section or an agreed-upon requirement. The revision date of the document will be changed on the front page for any significant changes. The review tab on Microsoft will keep track of any changes and time. In emergency modifications, comments will be used on the document to elaborate on changes.

APPENDIX

References

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