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Design Document

Summary

1. Needs Assessment
2. Analysis
3. Costs
4. Risks
5. Testing and Validation

Needs Assessment

As described by UNEP FI, “Many regions, including the emerging economies, could potentially be at the forefront suffering from a lack of comprehensive and reliable climate data (UNEP FI, 2023c). This could be primarily due to differences in resource availability and priorities. (UNEP FI, 2024)” [1]

In particular, our project aims to assist with providing sufficient local weather data to a community that’s long been at the short end of the stick in regards to adequate funding and data scarcity within Canada, the Inuit.

Customer Base: Inuit

Attributes

Geographic: Often referred to as *Inuit Nunangat*, the Inuit occupy the northern regions of Canada comprising Inuvialuit (Northwest Territories and Yukon), Nunavik (Northern Quebec), Nunatsiavut (Labrador), and Nunavut. [4]

Economic: Traditional Inuit economies are primarily based on subsistence production. This primarily involves hunting fish, land and sea mammals, and other wildlife from their environment. Upon this, they also diversify into arts and tourism. [5]

Demographic: As of the 2021 Census of Population, there are approximately 70,000 Inuit in Canada. On average, Inuit women have 2.7 children and the median age is just 23, reflecting both their high birth-rates and community social issues. [4]

Client Challenges

As the Inuit often lack the resources to provide or access localized weather data [3], they are left disproportionately vulnerable to the disastrous implications of climate change.

[2] Living in arctic geographic areas where climate change is most rapid, the Inuit experience:

- Melting ice thickness, making for dangerous travel, hunting, and infrastructure conditions.
- Altered wildlife migration patterns, affecting hunting for both food and cultural purposes.
- Rapid land changes isolate Inuit from activities that connect them with both the land and others.
- Rising prices of essentials

As countless communities such as the Inuit lack the resources and options, distribution of our low cost sensor weather balloon can be the future of ensuring that climate data is sufficiently collected regardless of socioeconomic condition.

Our weather balloon provides a viable option in regards to both cost and reliability. Using it, we can fill in weather data gaps surrounding Inuit land and territory. This will lead to more accurate climate models and hence better climate predictions that allow both the Inuit and Canadian Government to better adapt and mitigate [3]. (Reinforcing infrastructure, sustaining traditional practices, sustaining agriculture and wildlife populations, sustaining sufficient water sources, etc.)

Competitive Landscape

While existing systems address our customer problem, each system possesses their own respective shortcomings. Examples include:

1. **Satellite-Based Weather Data:** Both polar orbiting and geostationary satellites are applied to environment monitoring and climate prediction through the measure of similar things such as atmospheric humidity and temperature. Certain initiatives, such as NASA's SERVIR initiative employ this to assist developing countries such as Africa in similar issues regarding food scarcity, land change, and climate disasters. [6]

   Shortcomings: satellites cost tens to hundreds of millions of dollars to launch and operate as opposed to our material cost of approximately $300. Pairing this with the limited lifespan of satellites, our product is more financially viable even in the long term by a factor of millions. [7]

2. **Community-Based Weather Data:** Local community initiatives such as CBFEWS often employ volunteers to conduct numerous small-scale weather monitoring and testing in particular environments (through rain gauges, thermometers, anemometers, barometers, etc). Hence, localized weather data can be collected in real-time by the same local community that needs it. [8]

   Shortcomings: While financially viable, volunteers often lack the professional competence or expertise needed to accurately collect data without human error and inconsistencies. The precision and quality of such low-cost and basic equipment can also be brought into question. Moreover, even in a local context, limitations in regards to both network size and technology can mean insufficient scalability.

3. **Portable Weather Stations**: Portable weather stations are small compact meteorological weather monitoring devices. Rapidly deployable and installed in various locations, they consist of similar sensors to also measure things such as temperature, humidity, and atmospheric pressure to provide affordable localized weather data. [10]

   Shortcomings: While similar to our weather balloon in regards to sensors and data collection, it lacks the range due to it being stationary on the ground. Measuring the atmosphere at higher altitudes where many weather systems form will provide more accurate data. Ground activities can also interfere with accurate data collection. Many portable weather stations also rely on wifi or bluetooth, whereas ours don't. [10]

Requirement Specifications

Can accurately depict:

Temperature: the degree of heat present in the atmosphere

- Measured from two sensors
- Operating range and accuracy ; -40 to 80 C, ±0.5 C [10]
- Operating Range : -40 to 85 C [11]

Humidity: the amount of water vapor present in the air

- Operating range and accuracy ; 0-100% RH; ±2% RH [12]

Atmospheric pressure: the force exerted by the weight of the atmosphere on the Earth's surface (this value is also used to calculate the altitude)

- Operating range and accuracy ; 300 - 1100 hPa; ~ ±1 hPa [13]

Geographical Location: physical location where the balloon is situated, calculated through a GPS module

- Operating position accuracy and tracking sensitivity; 2M and better with multiple good satellite signals, -161 dBm [14]

Technical

We need to determine:

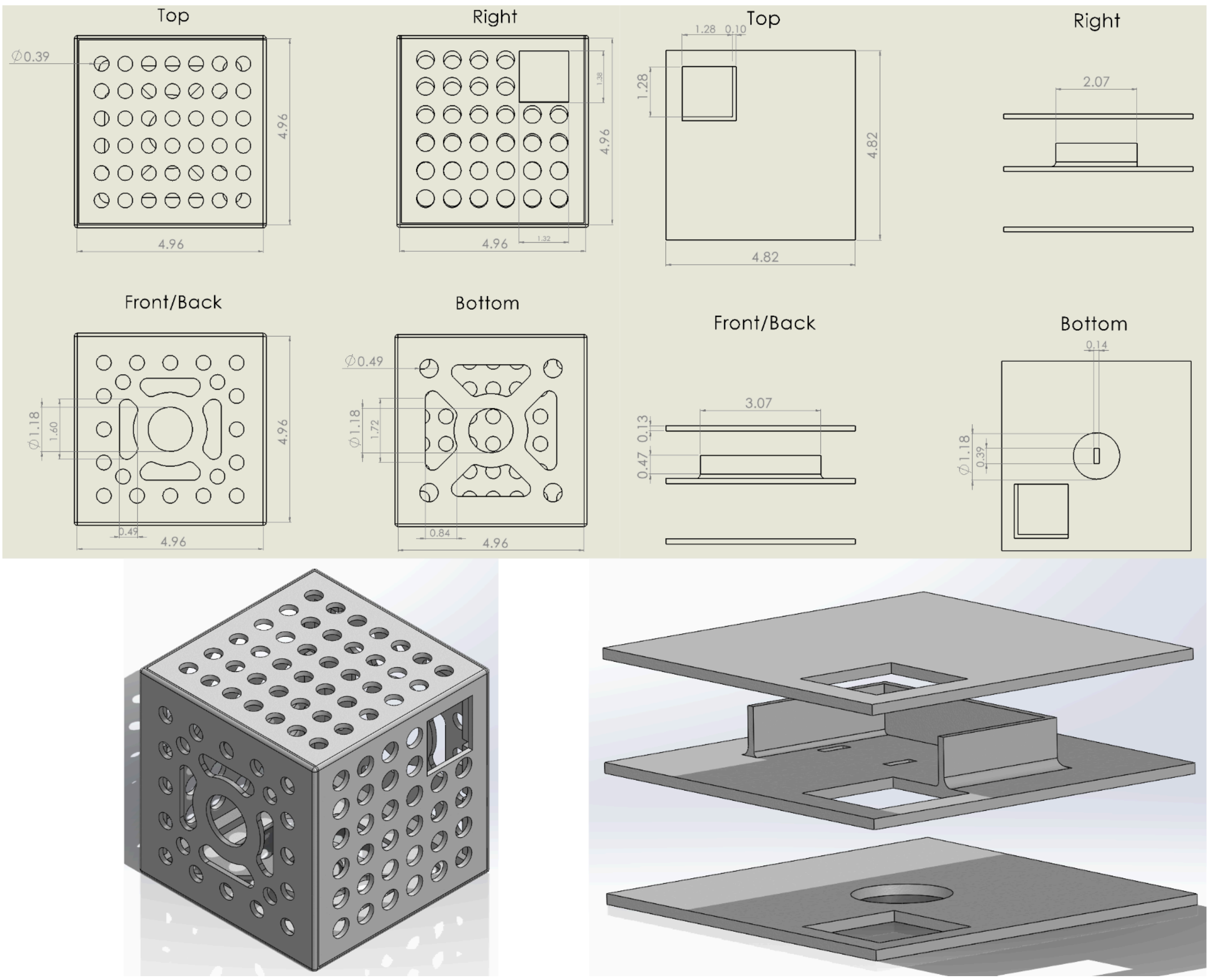
- The range of the operative altitude. For high altitude weather balloons, they can typically go up to 40km. [13]
- The LoRa connective range of the weather balloon. Most LoRa's support 10 km of wireless communication which can go up to 15 km with clear line of sight. [14]
- We need to ensure that the balloon's altitude:
    - Is within the LoRa connective range.
    - Is high enough to gather precise temperature, humidity, and atmospheric pressure data.
- The maximum weight of the payload supported by our weather balloon is estimated to be around 3kg.
- The balloon must be able to carry the weight of the sensors and payload housing to be able to measure the data we require. Quantified in citation. [15]

Safety

- Compliance with Canadian aviation regulations: maximum unregulated launch altitude of 60,000 feet. [11]
- Structurally rigid housing for balloon/overall durability to withstand weather conditions and altitude + payload safety.

Analysis

Design (Outer housing and inner PCB layers)



All units are in inches

The grid of holes act as ventilation and exposure for the sensors, allowing for internal conditions to mirror the external environment. Discrepancies between inner and outer conditions might otherwise arise due to humidity build up, heat build up from the electrical components, or pressure differences. Reducing the build material through this pattern also allows us to minimize weight without compromising structural integrity of the frame.

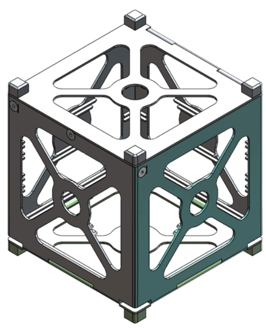
The design is also modular. Inside the housing, sensors and modules are organized and pre-assembled upon three layers of PCB's that can be slid in. In regards to mechanical optimization, this arrangement allows both space efficiency and ease of maintenance. Setting up is easier with simpler assembly, and ease of disassembly allows better troubleshooting, interchangeability, or upgradeability as PCB's are just slid either in or out. Lastly, customers can flexibly purchase, configure, and utilize only select modules for data that is relevant to them.

More information regarding assembly can be found under our assembly section.

Requirements:

All sensors are compatible and capable of the requirements. The housing is rigid and can safely host all electrons and weigh far under the maximum payload (315g).

Alternatives:



Technical reasoning: Designed primarily to reduce weight and material costs, a very minimal frame to host the components was designed as an alternative choice. This alternative weighs only 50g as opposed to the one we've ultimately chosen (315g). However, we deemed that reducing the weight when it's already so far below our expected maximum payload would not be necessary. If anything, a lighter weight to that degree would struggle more to withstand harsh weather conditions. Paired with much larger openings, the components within the housing would also be damaged by any exterior factors. Because the frame is thin, it has less rotational inertia to resist weather conditions such as harsh wind [20]. Stiffness and rigidity also scales with thickness. Hence, this alternative is more prone to deformation under stress. [21]

Technical Analysis

Sensor Integration and Data Acquisition (Scientific and Mathematical Principal #1)

Sensor Integration and Data Acquisition

In designing our project, we focused on integrating various sensors directly without relying on Arduino libraries, in compliance with the project guidelines. Below, we outline how we will implement each sensor and module using low-level programming on the STM32 Nucleo platform.

MPU6050 Accelerometer and Gyroscope:

- **Principle:** The MPU6050 measures acceleration and rotational motion using MEMS technology. This principle is appropriate for our case as it helps determine the speed of our weather balloon from which wind speed can be reasonably derived. [12]
- **Implementation:** we interfaced with the MPU6050 sensor using the I2C protocol by directly accessing its registers. To initialize the sensor, we will write to its configuration registers as specified in the datasheet. Calibration involved reading raw accelerometer and gyroscope data to calculate offsets manually, correcting for sensor biases. In the main loop, we continuously read data registers to obtain raw values and then computed the X and Y angles using a Complementary Filter for sensor fusion, which combines accelerometer and gyroscope data to provide accurate orientation. [14]

BMP280 Pressure and Temperature Sensor:

- **Principle:** The BMP280 utilizes piezoresistive technology to measure atmospheric pressure and temperature. This principle is appropriate for our case as it gives us an accurate measure of temperature and pressure which can also be used to derive altitude in appropriate units and defined range of accuracy. [13]
- **Implementation:** we will communicate with the BMP280 sensor over I2C by directly writing to and reading from its registers. Initialization involved setting up the control and measurement registers according to the required sampling rates and filter settings. We will read the raw temperature and pressure data and apply the compensation formulas provided in the BMP280 datasheet to convert these readings into calibrated temperature and pressure values. To determine altitude, we will use the barometric formula, factoring in the standard sea-level pressure. [14]

DHT11 Humidity and Temperature Sensor:

- **Principle:** The DHT11 measures humidity using a capacitive sensor and temperature via a thermistor. This principle is appropriate for our case as it gives us an accurate measure of temperature and humidity in appropriate units and defined range of accuracy. [15]
- **Implementation:** Since the DHT11 uses a proprietary single-wire protocol, we will implement this communication by manipulating a GPIO pin on the microcontroller. We will send the start signal by pulling the pin low and then high, adhering to the timing requirements specified in the datasheet. We then read the incoming data bits by measuring the durations of high and low signals, reconstructing the 40-bit data stream to extract the temperature and humidity values.

GPS Module:

- **Principle:** The GPS module determines geographic location by receiving signals from GPS satellites. This principle is appropriate for our case as it gives us an accurate geographical location of our weather balloon in appropriate units. [16]
- **Implementation:** We will interface with the GPS module using UART communication without relying on external libraries. We will configure the STM32's UART peripheral to match the GPS module's baud rate. By reading the incoming NMEA sentences, we will manually parse the data to extract latitude and longitude information. We will focus on the GPRMC and GPGGA sentences, tokenizing the data fields based on commas and converting the received strings into usable numerical values for latitude and longitude. [17]

Data Logging with SD Card:

- **Principle:** Data is stored persistently on an SD card using the FAT32 file system. This principle is appropriate for our case as it gives us an alternate medium of storage as it is good practice to have redundancies. [18]
- **Implementation:** We will use the SPI protocol to communicate with the SD card, handling the low-level initialization and command sequences as per the SD card specification. Instead of implementing the full FAT32 file system, We opted to store data in a raw format by writing blocks of data directly to the SD card. This approach simplified the implementation while still allowing for data persistence. We managed block addresses manually to ensure data was written sequentially.

Wireless Communication using LoRa:

- **Principle:** LoRa enables long-range, low-power wireless communication using spread-spectrum modulation. This principle is appropriate for our case as it gives us a wireless medium of communication over long ranges. [19]
- **Implementation:** We will communicate with the SX1278 LoRa module over SPI by directly accessing its registers. We will initialize the module by setting the frequency, spreading factor, bandwidth, and coding rate according to the requirements of my application. For data transmission, we will write the sensor data to the module's FIFO buffer and control the transmission process through register settings. On the receiver side, we will configure the module to receive mode and read incoming data from the FIFO buffer upon receiving a payload.

Timing Control:

- **Principle:** Non-blocking timing allows for performing actions at regular intervals without halting program execution.
- **Implementation:** We will utilize the STM32's hardware timers to keep track of elapsed time. We will configure a timer to generate an interrupt every one second, triggering the data acquisition and transmission processes. This approach ensured that the main loop remained responsive to other tasks, such as handling incoming data or managing sensor states.

Application of Principles in Design

By directly interfacing with each sensor and module at the hardware level, We ensured compliance with the project guidelines prohibiting the use of Arduino libraries. This approach required a deep understanding of communication protocols such as I2C, SPI, and UART.

- **Modular Sensor Integration:** We will initialize and configure each sensor by directly manipulating the microcontroller's registers and the sensors' registers. This method will allow us to tailor the configuration of each sensor to the specific needs of the project.
- **Efficient Data Handling:** By implementing non-blocking timing mechanisms using hardware timers, we will be able to read and process sensor data at precise intervals without affecting the responsiveness of the system.

- **Robust Communication Strategy:** Directly configuring the LoRa module will enable us to establish a secure and efficient long-range communication link between the weather balloon and the ground station STM32 Nucleo board.
- **Data Persistence:** Storing data directly to the SD card in a raw format ensured data redundancy and reliability. Although we will not implement the full FAT32 file system, the method allows for persistent storage critical for post-flight data analysis.

Power Distribution System (Scientific and Mathematical Principal #2)

Principle:
The **LM317T** is an adjustable three-terminal positive voltage regulator capable of supplying more than **1.5 A** over an output voltage range of **1.25 V to 37 V**. It operates by maintaining a constant voltage difference between its output and adjustment terminals, allowing for precise control of the output voltage using external resistors.

Implementation:

- **Setting Output Voltage:**
  The output voltage (**V_OUT**) is set using two resistors (**R1** and **R2**) connected in a voltage divider configuration:

$$V_{OUT} = V_{REF} \times (1 + R2 / R1) + I_{ADJ} \times R2$$

- **V_REF** is typically **1.25 V**.
- **I_ADJ** is the adjustment pin current, usually negligible (~50 µA).

Designing for Specific Voltages:

- **For 5 V Output:**
  Choosing **R1 = 240 Ω**:

  $$V_{OUT} = 1.25\ V \times (1 + R2 / 240\ \Omega)$$

Solving for **R2** when **V_OUT = 5 V**:

$$5\ V = 1.25\ V \times (1 + R2 / 240\ \Omega)$$

$$(R2 / 240\ \Omega) = (5\ V / 1.25\ V) - 1 = 3$$

$$R2 = 3 \times 240\ \Omega = 720\ \Omega$$

Therefore resistors used will be **R1 = 240 Ω** and **R2 = 720 Ω**

- **For 3.3 V Output:**

  $V\_OUT = 1.25\ V \times (1 + R2 / 240\ \Omega)$

Solving for **R2** when **V_OUT = 3.3 V:**

  $(R2 / 240\ \Omega) = (3.3\ V / 1.25\ V) - 1 \risingdotseq 1.64$

  $R2 \risingdotseq 1.64 \times 240\ \Omega \risingdotseq 393.6\ \Omega$

- Use a standard resistor value of **390 Ω** or **400 Ω.**

Therefore resistors used will be **R1 = 240 Ω** and **R2 = 390 Ω**

Input Voltage Considerations:

The LM317T requires an input voltage at least **2 V** higher than the desired output voltage (dropout voltage). With an input of **9 V,** it can comfortably supply **5 V** and **3.3 V** outputs.

2. Parallel Connection of Batteries

- Principle:
  Connecting batteries in parallel keeps the voltage the same while increasing the total capacity (ampere-hours). This extends the system's operational time without altering the voltage levels required by the regulators.
- Implementation:
  - Total Voltage: Remains at **9 V**.
  - Total Capacity: Sum of individual battery capacities. If each **9 V** battery has a capacity of **500 mAh**, the total capacity becomes **1,500 mAh**.

Application of Principles in Design

- Efficient Voltage Regulation:
  - The **LM317T**s are configured to provide the necessary voltages for different components:
    - **3.3 V** for low-voltage digital ICs or sensors.
    - **5 V** for higher voltage sensors
    - **9 V** (unregulated) for components that require the full battery voltage which in our case would be the STM32 Nucleo Voltage In

Component Selection:

- Capacitors:
  Input and output capacitors are added to improve stability and transient response:
  - Input Capacitor (C_IN): Typically **0.1 µF** ceramic capacitor placed close to the regulator's input pin.
  - Output Capacitor (C_OUT): Typically **1 µF** tantalum or **10 µF** electrolytic capacitor.

Protection Features:

- The **LM317T** includes built-in protection against overcurrent and overheating, enhancing the reliability of the power distribution system.

LoRa (Scientific and Mathematical Principal #3)

- Principle:

  LoRa (Long Range) is a modulation technique based on Chirp Spread Spectrum (CSS) that enables long-range communication with low power consumption. The mathematical principle lies in spreading the transmitted signal across a wider bandwidth using chirps, which are frequency-swept signals. The key parameters that define LoRa's communication capabilities are Spreading Factor (SF), Bandwidth (BW), and Coding Rate (CR). These parameters ensure the signal can be detected even at very low power levels (down to -148 dBm sensitivity).

  The connection between the SX1278 LoRa module (transmitter) in the balloon and the ground receiver relies on calculating key properties such as data rate (R), transmission power, and link budget, which determines the maximum communication range.

  The data rate (R) can be computed using:

  R=BW×SF2SF×CRR = BW \times \frac{SF}{2^{SF}} \times CRR=BW×2SFSF×CR

  Where:

  - R is the data rate (in bits per second)
  - BW is the bandwidth (typically 125 kHz, 250 kHz, or 500 kHz)
  - SF is the spreading factor (range: 7 to 12, higher values = more range, less data rate)
  - CR is the coding rate (range: 4/5 to 4/8, improves reliability but reduces data rate)

Additionally, the link budget (which defines the total range) is given by:

Link Budget=PT−PL+GT+GR\text{Link Budget} = P_T - P_L + G_T + G_RLink Budget=PT−PL+GT+GR

Where:

- P_T is the transmission power of the SX1278 (up to 20 dBm)
- P_L is the path loss (dependent on distance, frequency, and environmental factors)
- G_T is the gain of the transmitting antenna
- G_R is the gain of the receiving antenna

The signal's range can be increased by adjusting the SF and reducing the data rate, ensuring that the SX1278 module maintains connection even as the weather balloon ascends to higher altitudes.

- Implementation:

  In your weather balloon, the SX1278 LoRa module will be configured with the following parameters:

  - Bandwidth (BW): 125 kHz
  - Spreading Factor (SF): 12 (for maximum range)
  - Coding Rate (CR): 4/5 (to balance reliability and speed)
  - Transmission Power (P_T): 17 dBm (to comply with local regulations)

  These settings will allow the SX1278 module to transmit environmental data (e.g., temperature, pressure, GPS location) over long distances to a ground receiver. The ground receiver antenna will have a gain (G_R) of 5 dBi, improving signal reception.

  Given the low data rate with SF=12, you can expect the range to exceed 10-15 km under ideal line-of-sight conditions, and even further at higher altitudes with minimal interference. The LoRa’s ability to combat interference and noise ensures that your balloon's telemetry data will reliably reach the ground station throughout the flight, despite the challenges posed by distance and atmospheric conditions [9].

Costs

Bill of Materials

Product	Quantity	Manufacturer + Homepage Hyperlink	Distributor + Product Hyperlink	Location of Manufacturer	Unit cost (CAD)	Total cost (CAD)
Weather Balloon	1	Gadpiparty	Amazon	Shenzhen, China	50.89	50.89
Helium Tank	1	AiRise	Canadian Tire	Singapore	64.99	64.99
SX1278 Lora	2	ElectronicNova	Amazon	California, US	16.26	32.52
2-Pack 433Mhz Antenna	1 (2)	CENXIFJUDZ	Amazon	Wuzhou, China	6.07	12.14
ECE 198 Kit	1	UW Store	UW Store	Waterloo, CA	46.50	46.50
DHT22	1	Aideepen	Amazon	Shenzhen, China	16.99	16.99
5-Pack BMP280	1 (5)	DUTTY	Amazon	Montréal, Quebec	2.20	9.99
10-Pack LM317T	1	HUABAN	Amazon	Hangzhou, China	0.90	8.99
GY_NEO6MV2	1	Phoncoo	Amazon	Shenzhen, China	17.86	17.86
12-Pack Prototype Board	1	Eiechip	Amazon	Hangzhou, China	0.99	11.99
2-Pack 9V Batteries	2 (2)	Duracell	Amazon	Connecticut, US	5.48	21.92
Male to Male/Female Jumpers	1 (120)	Cangfort	Amazon	Shenzhen, China	0.09	10.68
10-Pack 9V Connectors	1 (10)	LampVPath	Amazon	Wuzhou, China	0.90	8.99
Cable Ties	1	SUREERLOK	Amazon	New Jersey, US	0.01	0.60
					Total Costs	**303.06**

Installation Manual / User Guide

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1. Ground Station:

- Connect the **ground station module** to your computer with a **USB**.

- Run the provided executable.
    - Ensure **STM32CubeIDE** and **Excel** are running.

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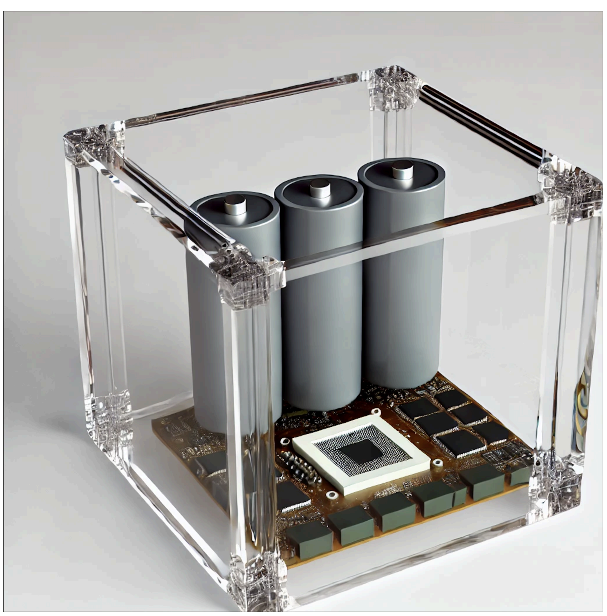
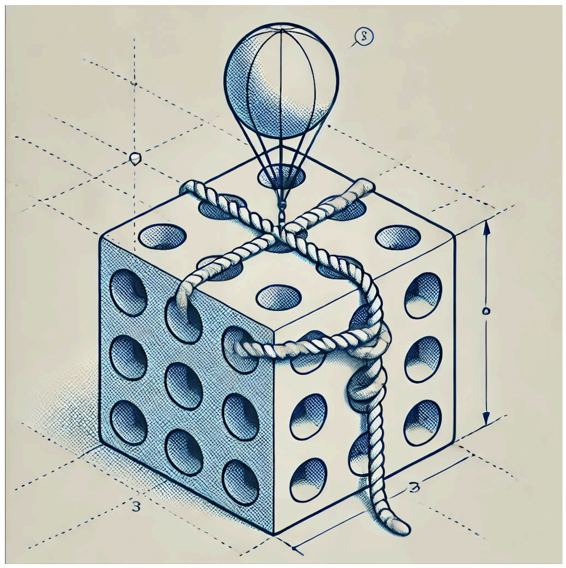
2. Housing Unit:

- Insert:
    a. Three **9V batteries** into the middle layer.
    b. A **prototype board** into the bottom layer.



3. Weather Balloon:

- Attach the deflated weather balloon to:
    a. The housing unit.
        - To ensure that the housing unit is tightly secured to the balloon, tie three knots around the holes of the balloon, as demonstrated below:



    b. The ground.
- Run the code provided from the executable on the **STM32CubeIDE.**
    a. Ensure the sensors are transmitting data to the ground station.
- Inflate the weather balloon with 3,500 L of helium.
- Deploy the balloon by untying it from the ground.

Risks

Energy Analysis

Energy Calculations and Analysis

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1. Reference Standard Indicating Baseline Power Levels

The baseline power levels are based on standard **9V alkaline batteries** with an average capacity of **500 mAh**. This standard is commonly used for portable electronic devices and provides a suitable compatible voltage for the project's components.

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2. Evidence for Appropriateness of Reference Standard for the Design

Using 9V batteries is appropriate because:

- **Voltage Compatibility:** The components (STM32 Nucleo board, sensors, and communication modules) operate within voltage levels that can be derived from 9V using voltage regulators.
- **Energy Requirements:** The battery capacity aligns with the calculated energy consumption for both the weather balloon and ground station over the operational period.
- **Availability:** 9V batteries are readily available and easy to replace or source.

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3. Analysis of Design Components for Significant Energy Storage

Weather Balloon System (6 hours operation):

- **Components and Current Consumption:**
  - STM32 Nucleo: **50 mA**
  - DHT22 Sensor: **1.5 mA**
  - BMP280 Sensor: **<1 mA**
  - SX1278 LoRa Module (TX mode): **93 mA**
  - GPS Module: **67 mA**
- **Total Current Consumption:** Approximately **212.5 mA**
- **Total Energy Consumption:** 212.5mA×6h=**1,275mAh**

Ground Station System (6 hours operation):

- **Components and Current Consumption:**
  - STM32 Nucleo: **50 mA**
  - SX1278 LoRa Module (RX mode): **12.15 mA**
- **Total Current Consumption:** Approximately **62.15 mA**
- **Total Energy Consumption:** 62.15mA×6h=**372.9mAh**

Significant Energy Storage Assessment:

- **Electrical Energy:** Stored chemically in the batteries; no large capacitors or inductors that could store significant electrical energy.
- **Chemical Energy:** Limited to the capacity of the batteries used.
- **Mechanical Energy:** No components (like springs or flywheels) store mechanical energy.
- **Conclusion:** No significant energy storage beyond the chemical energy in the batteries.

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4. Quantification of Maximum Total Energy Stored and Used

Weather Balloon System:

- **Number of 9V Batteries Required:**
  - (1,275mAh)/(500mAh per battery) = 2.55 ⇒ **3 batteries** (rounded up)
- **Total Energy per Battery:**
  - 9V×500mAh=4.5Wh9V×500mAh=**4.5Wh**
- **Total Energy Stored:**
  - 4.5Wh per battery×3 batteries=**13.5Wh**
  - Convert to joules: 13.5Wh×3,600J/Wh=**48,600J**

Ground Station System:

- **Number of 9V Batteries Required:**
  - (372.9mAh)/(500mAh per battery)=0.75 ⇒ **1 battery** (rounded up)
- **Total Energy Stored:**
  - 9V×500mAh=**4.5Wh**
  - Convert to joules: 4.5Wh×3,600J/Wh= **16,200**

5. Project limitations for Energy

- **Maximum Power Consumption of Weather Balloon Module:**
  - 9V×0.2125A = **1.9125W** (Which is less than the project limitation of 50W)
- **Maximum Power Consumption of Ground Station Module:**
  - 9V×0.06215A = **0.55935W** (Which is less than the project limitation of 50W)

Risk Analysis

Potential consequences to safety or the environment from operating the balloon as intended:

- The disruption of nearby birds' migration patterns.

- The carbon footprint of the sensors (inconsequential, but still considerable).

Potential consequences to safety or the environment from operating the balloon incorrectly:

- Deploying the weather balloon when the sensor's battery levels are insufficient.
- Inflating the balloon with an insufficient quantity of helium, reducing its airtime and stopping it from reaching the altitude necessary to gather accurate data.

Potential consequences to safety or the environment from operating the balloon not as intended:

- The balloon falling, due to deploying it somewhere unsafe,
  - Onto a nearby body of water and polluting it (assuming it's never recovered).
  - Onto a nearby object, incurring costs in damages.
  - Onto someone, putting their lives at risk.
- Adding extra payload to the balloon,

Potential ways the design could malfunction:

- Sensors on the weather balloon malfunctioning due to:
  - Low battery
  - Extreme weather conditions (hailstorm, heavy fog)
- The balloon popping before it reaches its maximum altitude due to extreme weather conditions.

Potential consequences to safety or the environment for each of the failure mechanisms specified:

- Sensor malfunctions due to low battery:
  - Incomplete or inaccurate data collection, leading to flawed weather predictions.
  - Missed critical data that could warn of severe weather events, potentially endangering people or infrastructure.
- Sensor malfunctions due to extreme weather (hailstorm, heavy fog):
  - The sensors may provide faulty readings, impacting forecast reliability and potentially causing inaccurate emergency responses.
  - If damage occurs mid-flight, recovery attempts may be dangerous in severe conditions.
- The balloon popping before reaching maximum altitude due to extreme weather conditions:
  - The balloon could fall unpredictably, creating risks for people, wildlife, or infrastructure below.

- If the balloon falls into a sensitive area (e.g., a wildlife reserve or water source), it may cause pollution or disrupt ecosystems.

- Balloon inflates with insufficient helium, cutting its airtime short:
  - The mission may fail to gather sufficient or accurate data, leading to wasted resources.
  - The balloon could descend in unpredictable locations, posing risks to people, animals, or structures on the ground.
- Balloon falls into a body of water and is not recovered:
  - Potential contamination from non-biodegradable materials (e.g., sensors or balloon components) in aquatic ecosystems.
  - Could harm marine life through entanglement or ingestion of debris.
- Balloon falls onto infrastructure or private property:
  - Damage to structures, which could incur financial liabilities or legal consequences.
  - Could interrupt essential services if it falls onto critical infrastructure (e.g., power lines or communication towers).
- Balloon falls onto a person:
  - Risk of injury to individuals struck by the falling equipment.

Testing and Validation

Test 1: Flight test

Test setup:

- Full housing + modules + sensors, as included with our product.
- 10 balloons

Environmental Parameters:

- Open outdoor space
- Unobstructed airspace

Test Inputs:

- Height

- Stability

Quantifiable Measurement Standard:

- Measurements of height will be in feet.

Pass/Fail Criteria:

- The full product must be able to fly 10 feet stably, with an intuitively sufficient lift speed that would indicate it can continue flying to pass.

Test 2: Temperature Sensor Accuracy

Test setup:

  - Temperature sensor within the housing, as included with our product.
  - Accurate thermometer for reference
  - Data logging system for temperature data collection

Environmental Parameters:

  - Medium sized indoor environment with controlled temperatures (AC).
  - Minimum airflow disturbance

Test Inputs:

- Temperature and reference temperature

Quantifiable Measurement Standard:

- Measurements of both the reference thermometer and our weather balloon sensor will be in degrees Celsius.

Pass/Fail Criteria:

- Sensor readings must be within a **±0.5°C** error margin of the reference thermometer's readings to pass.

Test 3: Humidity sensor accuracy

Test setup:

- Humidity sensor within the housing, as included with our product.
- Accurate Hygrometer
- Data logging system for humidity data collection

Environmental Parameters:

- Medium-sized indoor environment with controlled humidity (humidifier + diffuser).

Test Inputs:

- Humidity and reference humidity

Quantifiable Measurement Standard:

- Measurements of both the reference humidity and our weather balloon sensor will be in relative humidity (RH).

Pass/Fail Criteria:

- Sensor readings must be within a **±1% RH** error margin of the reference thermometer's readings to pass.

Test 4: Geographical Location

Test setup:

- GPS within the housing, as included with our product
- A circle of 5m radius around 3 different test sites are plotted

Environmental Parameters:

- Stationary and known geographical location

Test Inputs:

- Time
- Location/radius

Quantifiable Measurement Standard:

- Time will be measured within seconds and milliseconds

- Radius will be measured within meters

Pass/Fail Criteria:

- The GPS must output a location that's plotted within the circle to pass.
- Response time must be less than 5 seconds to pass

Test 5: Weather Resistance Test

Test setup:

    - Full housing + modules + sensors, as included with our product.
    - Tools to artificially mimic various weather conditions (leaf blowers, hoses, etc).
    - All other tests are reconducted, now under more intense conditions

Environmental Parameters:

    - Unobstructed, medium-large space outdoors

Test Inputs:

- Humidity, Temperature, Height, Location, Time

Quantifiable Measurement Standard:

- Measurements remain the same as the other tests

Pass/Fail Criteria:

- Criteria remain the same as in other tests to pass, only now under replicated weather conditions.

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