Project Deliverable F:

Prototype I and Customer Feedback

Group 16: The Sample Snatchers

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March 2, 2025

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Abstract

This report details the development and evaluation of the first set of prototypes for measuring sample collection. The goal is to meet the requirement of collecting 30 to 80 mg of sample by utilizing the selected concept of a pneumatically deployable sample device.

Following client feedback, the team prioritized achieving the specified sample amount while ensuring full functionality. Therefore, the first test evaluates the measurement efficiency of the load cell via three prototypes. The details of these tests have been analysed and recorded through the initially developed test plan, providing additional points as guidance for future development. Additional feedback has been considered through a design review complete with our peers, which has been considered as we progress through prototyping and testing.

As the first testing phase has been analyzed, the team has reviewed the detailed design, target specifications, and the Bill of Materials (BOM) and updated content where applicable. The presented detailed test plan for the second set of prototypes will test the assumption that a sample can be collected by testing whether the chosen methodology can remove material from the pressure tube interior. Additionally, the team task plan has been developed to implement necessary sub-tasks to complete the second prototype based on the results provided from the first prototype with structural details defining, timing, and responsibility.

The document concludes with preparations for the upcoming client meeting. At this meeting, design refinements and future design testing strategies will be discussed to obtain all possible feedback for further improvement.

1.0 Introduction

This report details the first three initially developed prototypes, focusing on obtaining the required 30 mg to 80 mg of sample. Additionally, the team has devised a thorough test plan for the second prototypes and testing phase.

This document highlights critical feedback from the client based on the chosen detailed design of the *Pneumatically Deployable Inflatable Tube.* Based on the targeted objectives displayed through the first test plan, the team has developed three focused prototypes ranging in fidelity levels to evaluate the performance measurement of the collected sample size. Further documentation will outline the analysis and results of these prototypes. Through a design review, the team has obtained feedback from peers regarding the prototypes, test plans, and Bill of Materials (BOM). The necessary adjustments to the target specifications, detailed design, and BOM have been made as the testing has been completed and comprehensively analyzed.

For further preparation, the team has outlined a prototyping test plan to build and test the second round of prototypes focused on the performance of the sampling method. This plan emphasizes obtaining feedback for ideas, verifying feasibility, and analyzing critical subsystems to reduce risk and uncertainty while defining clear stopping criteria to end the test. The team's Trello board and Gantt Chart display additional updates to the task plan schedule.

As the team approaches the third client meeting, we have provided a simple outline of the presentation to encourage additional feedback and further questions. This presentation explains the updated detailed design, the first prototype(s), and their test results.

2.0 Feedback

2.1 Client

The client expressed concerns about the complexity of many of our concepts. This coincided with our statement about pursuing the “Pneumatically Deployable Inflatable Tube” design, with the wheel-propelled design as a backup plan, as our other concepts had significant mechanical complexity. The client also mentioned that he would be satisfied with the design if it reaches the sample site and returns with a 30-80 mg sample.

A later announcement on Brightspace mentioned that the client wanted to see more thought from every group put into the whole process, including how the user brings the device to the vault and handles the sample. Our consideration for this process has not yet been detailed; however, we have begun considering how the sample will be removed from the device and how the device will be moved in and out of the vault space.

To conclude, these notes were taken:

- Not interested in excessive mechanical work
- Like the wide variety of ideations
- Found the clarity of sketches very helpful
- Prefers fewer components
- Later in the announcement, it mentioned considering the whole operation

2.2 Classmates

The classmates' feedback suggested including visual or auditory indicators, such as LED lights, small piezo speakers, or a small display, to allow operators to monitor the measurement status and receive error alerts. We already have wireless functionality that sends data and the device's state to an external monitor. We are using an ESP32 for this function, but including lights on the device could be a good secondary option.

3.0 Prototyping Test Plan and Results

3.1 Prototype Test Plan

With this prototype, our objective is to build a device that accurately measures the collected sample so that we can later verify the effectiveness of our sampling tool. This device will also trigger the condition for returning the tool head to the user.

Load cells or strain gauges are how most digital scales work. Leads are attached to a metal bar and as a mass is applied to one end of the bar, the material stress changes the component's resistance. A calibration factor can be achieved using a verifiable mass. This calibration factor determines the accuracy of the measurement, however, different strain gauges can have different tolerances and precision. We are testing the load cells to calibrate as accurately as we can, and reduce the effects of other environmental factors, so that we can accurately determine the success of our sampling tool in the next prototype.

Updated prototype test and task plans will be appended at the end of the document for improved clarity, and consistency.

3.2 Prototype Test and Results

Prototype 1-1 was a LoFi-focused 5kg load cell prototype. It was connected to the HX-711 Analog-to-Digital Converter, which was wired to an Arduino. This prototype allowed us to test the initial code, learn how to calibrate, implement the tare command, and see how the measured mass might fluctuate due to interferences such as mechanical creep, thermal variance, and electromagnetic interference.

Figure 3.2-1: Prototype 1-1 (5kg Load Cell - LoFi Focused)

During the test, functions to average the data over multiple samples had to be implemented to bring the data within an acceptable range. Even with the rolling average function, the variation was still far too high to be adequate for the device (over 100mg of change). The test below was done with a sample that was roughly 106.1g.

```
17:49:40.622 -> one reading:    -106.0  | average:      -106.10910
17:49:46.556 -> one reading:    -106.3  | average:      -106.11896
17:49:52.527 -> one reading:    -106.2  | average:      -106.20032
17:49:58.414 -> one reading:    -106.2  | average:      -106.23237
17:50:04.376 -> one reading:    -106.3  | average:      -106.24716
17:50:10.274 -> one reading:    -106.2  | average:      -106.27429
17:50:16.209 -> one reading:    -106.2  | average:      -106.25703
17:50:22.135 -> one reading:    -106.2  | average:      -106.24963
17:50:28.101 -> one reading:    -106.2  | average:      -106.20771
17:50:34.027 -> one reading:    -106.1  | average:      -106.20278
17:50:39.920 -> one reading:    -106.2  | average:      -106.20771
17:50:45.854 -> one reading:    -106.1  | average:      -106.17566
17:50:51.812 -> one reading:    -106.2  | average:      -106.14855
17:50:57.735 -> one reading:    -106.2  | average:      -106.19292
17:51:03.678 -> one reading:    -106.2  | average:      -106.14608
17:51:09.603 -> one reading:    -106.2  | average:
```

Figure 3.2-2: Prototype 1-1 Data Set 1

A filtering function was implemented to account for mechanical creep and thermal variances, which smoothed the values a fair bit, but a lot of inconsistency was still found (±0.05g). To further reduce this, we chose to try a 100g load cell instead.

```
18:04:07.828 -> Raw Weight: -41.97378 | Filtered Weight: -6.41231
18:04:13.409 -> Raw Weight: -41.97132 | Filtered Weight: -10.60944
18:04:18.954 -> Raw Weight: -42.02803 | Filtered Weight: -14.81225
18:04:24.517 -> Raw Weight: -42.03049 | Filtered Weight: -19.01530
18:04:30.072 -> Raw Weight: -42.03049 | Filtered Weight: -23.21834
18:04:35.601 -> Raw Weight: -42.05268 | Filtered Weight: -27.42361
18:04:41.179 -> Raw Weight: -42.09213 | Filtered Weight: -31.63282
18:04:46.717 -> Raw Weight: -42.09706 | Filtered Weight: -35.84253
18:04:52.282 -> Raw Weight: -42.07487 | Filtered Weight: -40.04484
18:04:57.853 -> Raw Weight: -42.12417 | Filtered Weight: -42.04750
```

Figure 3.2-3: Prototype 1-1 Data Set 2

Prototypes 1-2 were used as an intermediate step to visualize how the load cell may fit into the sample tube. This prototype serves only as a visual guide for the device's scale rather than relying purely on CAD analysis. Several models were made to test fit and create a standard form for future parts to fit inside. This will make it easier for the group to collaborate on future components.

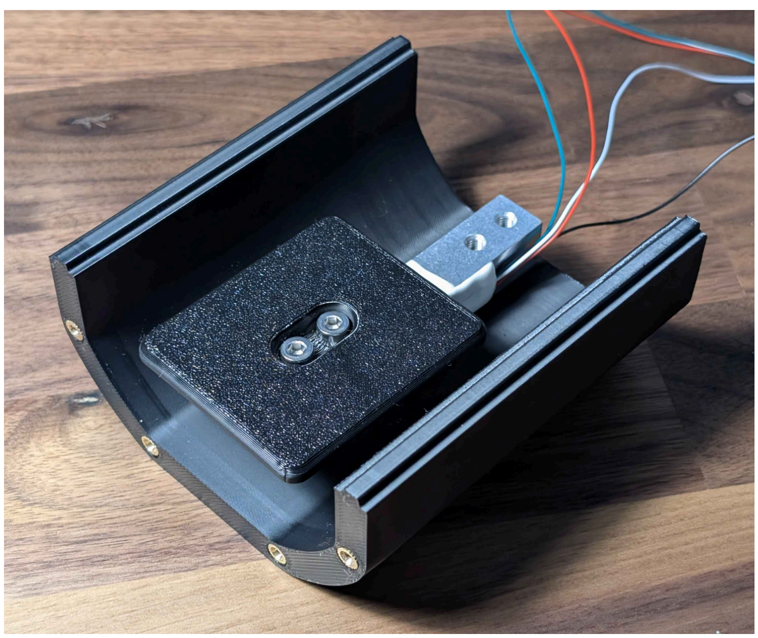

Figure 3.2-4: Prototype 1-2 (HiFi Focused)

Figure 3.2-5: Prototype 1-2 Variations (HiFi Focused)

Prototype 1-3 utilized the 100g load cell with the same HX-711 ADC chip. The wires were twisted in pairs to reduce the electromagnetic interference, and the device implemented all the previous functions mentioned.

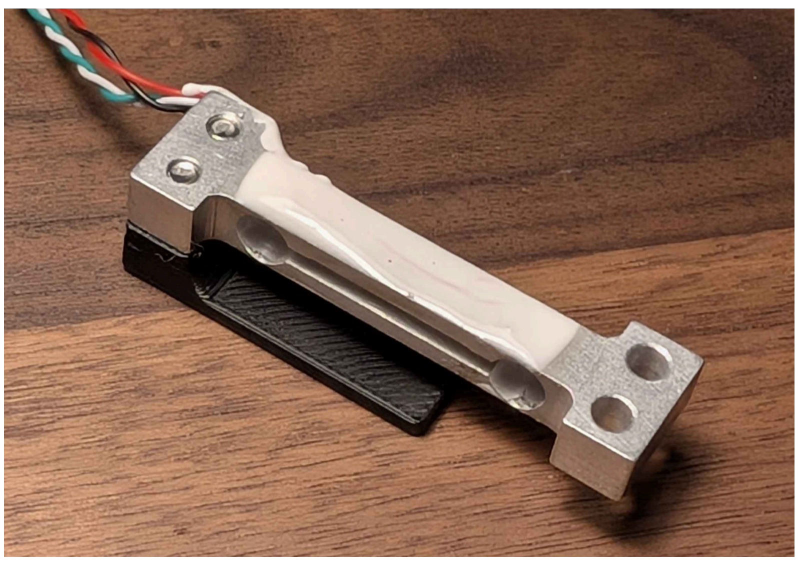

Figure 3.2-6: Prototype 1-3 100g Load Cell (LoFi Focused)

The new prototype produced the resulting data. The variance is now reduced to ±9.5mg, which the team believes is acceptable accuracy as the sample collected needs to be within the 30-80 mg range. However, getting the device to measure more accurately than this would require expenses outside the project budget. If the device were to be built, a higher-resolution analog-to-digital converter could be implemented, alongside better grounding and shielding for the load cell connections. This prototype has not yet been implemented into the chassis, as the group is exploring a method by which the load cell will disconnect from the sample container.

```
18:49:56.868 -> Weight: 3090 mg
18:50:06.717 -> Weight: 3104 mg
18:50:16.474 -> Weight: 3108 mg
18:50:26.320 -> Weight: 3109 mg
18:50:36.105 -> Weight: 3108 mg
18:50:45.891 -> Weight: 3103 mg
18:50:55.706 -> Weight: 3105 mg
18:51:05.503 -> Weight: 3091 mg
```

Figure 3.2-7: Prototype 1-3 Data Output

4.0 Updates to Specifications and Design

4.1 BOM

Below is the updated BOM. Yellow indicates components that have been sourced but not verifiably implemented, and green indicates those that have been implemented into the design.

Table 4.1: Updated Bill of Materials

Sample Snatchers - Bill of Materials						
Item #	**Part**	**Vendor**	**Description**	**Qty**	**Cost**	**Link to Purchase**
1	ESP32-WROOM-C3	Elegoo	Controller w/ Wifi + BT	1	9.99	Link
2	PLA - ~0.5 KG	Bambu	Filament for chassis	1	9.99	Link
3	HX711 Sensor	Aliexpress	Strain gauge for mass analysis	1	1.80	Link
4	608 ZZ 608RS	Aliexpress	Ball bearings	1	2.40	Link
5	M3 Female Threaded Insert	Aliexpress	Heat set threaded inserts for chassis	1	0.80	Link
6	LM2596	Aliexpress	Step down buck converter, 36V/24V/12V/5V/3V	1	2.35	Link
7	M3/M4 Machine Screws	Aliexpress	Various length M3 Machine Screws	1	2.40	Generic
8	XT60 Connectors	Aliexpress	Connectors for battery pack	1	1.60	Link
9	22 awg Wire	Amazon	Wires for connecting components to the circuit	1	2.00	Link
10	H-Bridge Motor Driver BTS7960	Aliexpress	Driving 12V motor for scraping	1	7.41	Link
11	Resistor set	Aliexpress	Various resistors	1	4.30	Link
12	Power button	Aliexpress	Push button for power	1	1.85	Link
13	GB37-520 7rpm 12v Motor	Aliexpress	For moving the armature with the lathe bit	1	11.28	Link
14	100g Load Cell	Aliexpress	Strain gauge to measure mass	1	5.93	Link
15	16 awg Wire	Amazon	Wires for 12v components	1	2.00	Generic
16	P42A Molicel Battery 21700	18650 Battery	For battery pack assembly	3	15.00	Link
17	3S Battery Management System	Aliexpress	For safety	1	2.94	Link
Total				**13**	**84.04**	

4.2 Changes to Design

After considering how the load cell unit would be implemented into the chassis, we found many issues regarding how to close the container and measure the mass without structural conflict affecting the load cell's function. As a solution, the removable container will also contain the load cell. This way the structure will not conflict with the load cell operation, and the load cell frame of reference can be from within the container system.

At this time, our design specifications are unchanged.

Table 4.2-1: EDS - Functional Requirements

	Design Specifications	Relation (=, < or >)	Value	Units	Verification Method
	Functional Requirements				
1	Collect a metal sample from the tube wall	=	30-80	mg	Test
2	Completely Removable	=	Yes	N/A	Test
3	Enclosed Sample	=	Yes	N/A	Test
4	Stage Reporting	=	Yes	N/A	Test
5	Visual for process	=	Yes	in, dpi	Test
6	Device speed	<	7	min	Test
7	Power source included	=	Yes	N/A	Analysis

Table 4.2-2: EDS - Constraints

	Design Specifications	Relation (=, < or >)	Value	Units	Verification Method
	Constraints				
1	Weight	<		kg	Analysis
2	Size (Diameter)	<	4	in	Analysis
3	Size (Length)	<	4	ft	Analysis
4	Sample Exposure	<	Yes	N/A	Test
5	Sample Collection	=	30 - 80	mg	Test

Table 4.2-3: EDS - Non-Functional Requirements

Design Specifications		Relation (=, < or >)	Value	Units	Verification Method
	Non-Functional Requirements				
1	Aesthetics	=	Yes	N/A	Survey
2	Safety	=	Yes	N/A	Analysis
3	Corrosion Resistant	=	Yes	N/A	Analysis
4	Operation Time	<	10	mins	Test
5	Creative Solution	=	Yes	N/A	Analysis

5.0 Plan - Prototype 2

The team has begun developing the second prototype. This LoFi - Physical prototype will test the performance measurement of the collected sample.

5.1 Prototype 2 Test Plan

Using the developed "Prototyping Test Plan" template in the lecture, the team has detailed our prototyping test plan for the second prototype. This plan organizes the procedure for the analysis of the sequences of tests to validate the prototype. The critical components consider the critical issues, the test objectives, descriptions of the test, method of analysis, measurables, metrics, fidelity levels, prototype type, with additional notes for feedback and results as the test meets the defined stopping criteria. Applying this devised plan provides consistent methodology while meeting the necessary criteria for completing a successful test to verify feasibility and critical analysis features while reducing risk and uncertainty.

In the current progress, the tooling and motor mounts have been modeled in OnShape and will be used to assemble the second prototype sampling armature.

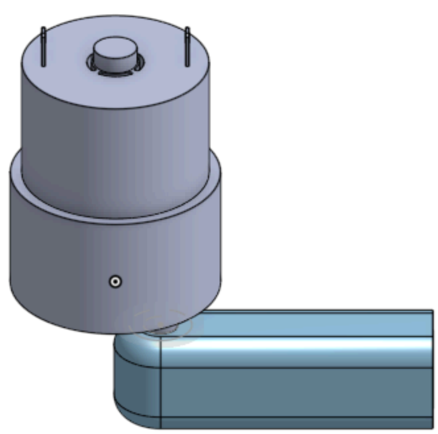

Figure 5.2-1: Scraper Bit Holder Attached To GB37-520 Motor (Back View)

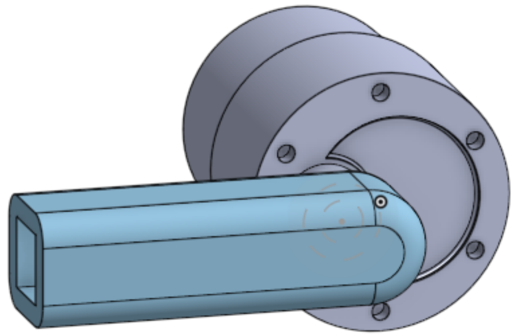

Figure 5.2-2: Scraper Bit Holder Attached To GB37-520 Motor (Bottom View)

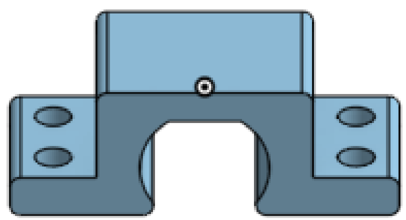

Figure 5.2-3: N20 Motor Mount (Top View)

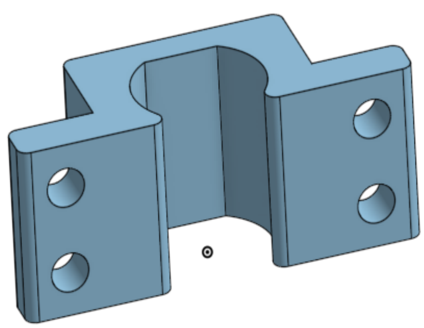

Figure 5.2-4: N20 Motor Mount (Bottom View)

5.2 Prototype 2 Task Plan

Based on the analysis of the first prototypes, a detailed task plan has been updated to organize the necessary sub-tasks to achieve a fully developed second prototype testing the sample collection. This plan includes tasks with descriptions to be completed (i.e. CAD models), an estimated time duration, and delegated responsibility. Further considerations discuss potential risks and contingency plans to eliminate risk while providing alternative applications. As the team continues to complete tasks for this prototype, the necessary changes have been implemented with ease following the generated plan.

Updated prototype test and task plans will be appended at the end of the document for improved clarity, and consistency.

6.0 Client Meeting 3 Preparation

6.1 Presentation Outline

Content in red is subject to change.

Content to Include:

- Slide 1 (30 seconds): Introduce team
    - State group name + hook
    - Brief sentence regarding problem statement

- Slide 2 (1 min): Mention chosen design: inflatable tube design
    - Mention why it was chosen
    - Show sketch of current design choice
    - Briefly describe the different elements of the design: inflatable tube, scraper, container, load cell, etc.
    - How it works: subsystems

- Slide 3 (1 min): Show prototypes
    - Images of different components
        - new load cell, shell component, battery pack, motor
        - Possibly add old prototypes
            - Discuss the trial and error faced
    - Briefly describe each of the prototypes
        - Function of that element in the design

- Slide 4 (30 seconds): possible design change (back up)
    - Include sketch of design with wheels
        - Describe the elements of the design
        - Mention the main differences between this design and the other design
            - Pros and cons

- Slide 5:
    - Closing and questions
        - Does the device need to be able to operate both vertically and horizontally in the tube?

General Content:

1. Problem statement - helps client understand our approach to the problem
2. Present design choice - showcase chosen design and describe how design would work and the individual components of the design
3. Prototype elements - show the current prototype elements being worked on, describe the elements made and how they would work
4. Second design option - show a possible second option for the design, describe the pros and cons between the two designs, and a backup in case the first design fails

Consideration of Images (to include):

- Sample snatchers logo
- Sketch of current design approach
- Prototype images
    - Image of load cell (new)
    - Battery component
    - motor
    - Outer shell component with load cell
    - Possibly include testing
- Sketch of backup design
- CAD Images

7.0 Conclusion

7.1 Completed Objectives

This document details the groups developed prototypes thus far, which were aimed at measuring a 30- 80 mg sample. As a result, the test concluded with a variance of ± 9.5 mg based on the three iterative prototypes performed. Therefore, we have determined to use the 100g load cell as a critical component in our design to meet the sample size requirement specified in the target specifications. In addition, the document provides a test plan for the second prototype testing phase. The document also notes the critical feedback the client gave on the design of the *Pneumatically Deployable Inflatable Tube.* The document further expands and updates the team's BOM, prototype test plan, and task plan. Finally, a preliminary outline of the group's presentation for the third client meeting has been included.

7.2 Trello: Task Plan Update

The team’s task board in Trello has been updated to include changes in task duration, missing tasks, task responsibilities, and other details necessary for effective project management. Additionally, a GANTT chart of the timeline of the group tasks has been attached to the submission.

Appendices

Appendix A: Code in Arduino IDE (C) for Load Cell and Bluetooth Logging

```
#include "HX711.h"
#include "BluetoothSerial.h"

#define DT 3  // hx711 data pin
#define SCK 2 // hx711 clock pin
#define TARE_BTN 4  // tare button pin

BluetoothSerial SerialBT;  // create bluetooth serial object
HX711 scale;
bool newDataset = true;

// creep correction variables
float previousWeight = 0;
unsigned long lastCreepTime = 0;
const float creepThreshold = 10.0;  // change this if creep correction is
too sensitive
const unsigned long creepInterval = 30000;  // time interval for creep
correction (30 seconds)

void setup() {
    Serial.begin(9600);
    pinMode(TARE_BTN, INPUT_PULLUP);

    // start bluetooth with a pin
    SerialBT.begin("ESP32_BT_Logger", true);  // enable secure pairing
    SerialBT.setPin("1234");  // set bluetooth pin

    scale.begin(DT, SCK);
    scale.set_scale(17896.738281); // set calibration factor
    scale.tare(); // reset scale to zero

    Serial.println("Time(ms),Weight(mg)"); // print csv header
    SerialBT.println("START");  // tell bluetooth that the connection is
active
}

// function to adjust for creep (small drifts in weight over time)
```

```
long correctCreep(long weight_mg) {
    unsigned long currentTime = millis();

    // check if it's time to adjust for creep
    if (currentTime - lastCreepTime >= creepInterval) {
        float creepOffset = weight_mg - previousWeight;

        // if weight change is very small, reset the scale to correct
drift
        if (abs(creepOffset) < creepThreshold) {
            scale.tare();
            Serial.println("creep correction applied");
            SerialBT.println("creep correction applied");
            previousWeight = 0;
            return 0;
        }
        previousWeight = weight_mg;
        lastCreepTime = currentTime;
    }
    return weight_mg;
}

void loop() {
    static bool buttonPressed = false;

    // check if the tare button is pressed
    if (digitalRead(TARE_BTN) == LOW) {
        if (!buttonPressed) {
            scale.tare();
            Serial.println("\nnew dataset");
            SerialBT.println("\nnew dataset");
            newDataset = true;
            buttonPressed = true;
            delay(300); // simple debounce delay
        }
    } else {
        buttonPressed = false;
    }

    // get weight from the scale
```

```
    float weight_g = scale.get_units(100); // average 100 readings for
stability
    long weight_mg = weight_g * 1000; // convert to mg

    // apply creep correction
    weight_mg = correctCreep(weight_mg);

    // print data to serial monitor
    Serial.print(millis());  // timestamp
    Serial.print(",");
    Serial.println(weight_mg);

    // send data over bluetooth
    SerialBT.print("DATA,");
    SerialBT.print(millis());
    SerialBT.print(",");
    SerialBT.println(weight_mg);

    delay(500);
}
```

Appendix B: Python Script to Log Incoming Serial Data and Categorize into Data Sets

```
import serial
import time

COM_PORT = "COM9"  # Make sure this matches your ESP32's COM port
BAUD_RATE = 9600
RETRY_DELAY = 2  # Seconds before retrying connection
TIMEOUT = 5  # Increased timeout

# Try connecting to the ESP32 until successful
while True:
    try:
        print(f"Trying to connect to {COM_PORT}...")
        ser = serial.Serial(COM_PORT, BAUD_RATE, timeout=TIMEOUT)
        print(f"✅ Connected to {COM_PORT}")
        break
    except serial.SerialException:
```

```python
        print(f"⚠️ ERROR: Cannot open {COM_PORT}. Make sure ESP32 is connected and running a program.")
        time.sleep(RETRY_DELAY)

filename = "scale_data.csv"

# Open the file and start logging
with open(filename, "w") as file:
    file.write("Time(ms),Weight(mg)\n")  # CSV header
    print("✅ Logging started. Press Ctrl+C to stop.")

    try:
        while True:
            try:
                line = ser.readline()  # Read raw bytes from Serial

                # Decode safely, ignoring bad bytes
                decoded_line = line.decode("utf-8", errors="ignore").strip()

                # Ensure we only log valid sensor data
                if decoded_line.startswith("DATA"):
                    print(decoded_line)  # Show data in terminal
                    file.write(decoded_line.replace("DATA,", "") + "\n")  # Save to CSV
                elif decoded_line == "START":
                    print("🔄 ESP32 Data Stream Started...")
                elif decoded_line:
                    print(f"⚠️ Ignored Unrecognized Data: {decoded_line}")

            except Exception as e:
                print(f"⚠️ Serial Read Error: {e}")
                time.sleep(1)

    except KeyboardInterrupt:
        print("\n🛑 Logging stopped.")
        ser.close()

# Keep script open after stopping
print("\nLogging has stopped.")
```

```
input("Press Enter to exit...")
```

Appendix C: Test Plan & Test Plans

On the following pages, the test plan for the second prototype, the task plan for developing the second prototype, and the Gantt Chart displaying the teams' progression have been shown sequentially.