VIETNAM NATIONAL UNIVERSITY OF HOCHIMINH CITY
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SMART SCALE: AN INTELLIGENT SYSTEM FOR MONITORING FOOD CONSUMPTION

By
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Smart Scale: An Intelligent System For Monitoring Food Consumption

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Abstract

This paper discusses the process of designing, developing, and implementing Smart Scale, an intelligent hardware system for monitoring food consumption in today's society. Incorporating different hardware components with optimal algorithms based on the Wheatstone Bridge Principle, the research aims to develop a set of electronic balances with the capability to record and return the most accurate changes in weight, utilizing the processing speed of the Arduino UNO R3 for fast recording and data collecting, as the result of low-fidelity, mid-fidelity, and high-fidelity prototypes development. The research studies two experiments that involve the hardware application: Weight Position Test and User Study On The Impact of Flavor and Their Overall Judgment. The findings proved that the hardware system has good longevity and precision in weighing subjects regardless of their positioning and time left without extra calibration. Furthermore, the research found different patterns in how people judge food with their vision, smell, and taste and how nutrient intake can affect their overall emotional and mental states. The research scope and sample size can be extended with the purpose of gaining more insights into food intake patterns and different aspects impacting the habits of people nowadays.

Chapter 1: Introduction

1.1. Background

Analyzing food consumption habits in today's society has been one of the most crucial aspects of medical and market research. For medical, it is about accessing and researching unhealthy dietary patterns and their impact on chronic diseases. According to UNICEF, for dietary recommendations for adults, fats should be around 30-35% of total energy consumption, along with at least 400 grams (or five servings) per day for a healthy and balanced meal [1].

However, many consumers today do not follow that diet. Research has shown that in 2017, 11 million (95% uncertainty intervals [UI] 10-12) fatalities and 255 million disability-adjusted life-years (DALYs) were the results of unhealthy dietary choices, taking into account factors like high sodium consumption, low ingestion of whole grain, and low intake of fruits. [2] Studying the change in nutritional habits is how researchers in the medical field, especially nutritional experts, can access and understand the current trends and, from there, provide solutions for the better.

Acknowledging society's food intake habits can also be an essential element of market analysis for businesses and industries. Plant-based diets and vegan food production are two examples. Studies have shown that compared to nearly 4 million estimated vegans in the US in 2014, there was a drastic increase to 19.6 million in 2017, marking a 500% increment. [3]

In Vietnam, a survey conducted by Rakuten Insight has shown that as of February 2024, among younger respondents between the ages of 25 and 34, 49% reported they had plant-based foods many times per week. [4] A survey published in April 2022 also revealed that nearly 47.7% of participants were willing to replace meat with vegan alternatives in their daily diets. [5] This change in food consumption habits has impacted the plant-sourced food production industry, with a report showing that in 2023, this market in Vietnam was estimated to be worth $250 million and is projected to have grown at 10.8% compound annual growth rate (CAGR) by 2032.

In monitoring and researching the food consumption habits of consumers, many tests were carried out for participants with different types of hardware and devices, and electronic weighing scales were one of them. These scales are designed to have high sensitivity, which can detect the most minor change in weight based on the user's eating pace and display the output up to three decimal places. [7] Researchers have discovered new findings regarding dietary patterns by measuring with these scales, with studies from the US [8] or the Netherlands [9], which will be discussed further in this research paper.

With the application of electronic weighing scales, this thesis focuses on developing a smart scale system to monitor and assist researchers in analyzing the food consumption habits of ordinary Vietnamese family meals.

1.2. Problem Statement

Although there have been experiments and research about meal patterns in Vietnam, reports about applying electronic weighing scales are uncommon. To assist the Vietnamese medical field in analyzing and assessing nutritional trends for better pharmaceutical evaluation, but also aiming at providing testing hardware devices with high efficiency and economical, this thesis focuses on the development of the Smart Scale sensor system, which can be integrated with software to experiment and monitor dietary choices of users or medical participants, providing the results with the highest precision possible.

Focusing initially on Vietnamese research fields, this study intends to explore the eating habits of Vietnamese families and gain insight into different aspects that can impact their change, such as the amount of several nutrients or the types of dishes in a regular family meal. The research results can inform practical data for nutritional experts to study and provide better health assessments for businesses and industries for their market research.

1.3. Scope and Objectives

There are two main parts to this study's focus. The first part is the development of the hardware:

- A set of four scales will be included to represent four dishes in a normal family meal, connecting to one microcontroller board to compile and provide the data to the user,
- A functional hardware code to fit the hardware's requirements, including returning necessary results such as time stamps recorded in real-time and the weight output from the scales.

Based on the low-fidelity prototype, this work aims for the most practical hardware with the highest efficiency, considering user-friendliness and user expectations.

The second part of the study is the experiments that evaluate the efficiency of the scales, testing their accuracy in recording and sending weight output by any subject positioning and their precision when being used for any practical experiment, specifically the user study on flavor judgment and effects on emotions during and after food intake.

- In the first experiment, it should prove that the scales' design and build are fit for the objective of weighing any object accurately regardless of their positions on the weighing disk, ensuring convenience and easy usage during experimenting and researching processes involving the hardware system.
- In the second experiment, the hardware system was used for data collecting and analyzing for the Flavor Judgment test. By being utilized in a practical experiment, the objective was to accurately send the weight output from the test subject in real time for the purpose of data analysis.

By combining the development of the hardware system with experiments on weight positioning and application in a user study, this research provides important insights into the design of the scales system and different patterns of flavor judgment of distinct types of people while proving the efficiency of the hardware's development and implementation processes.

1.4. Assumption and Solution

This research is based on some assumptions to understand user behavior better.

First, in-depth data analysis and user feedback are believed to set a foundation for continuous hardware improvement. Second, it is essential to emphasize that the study remains impartial regarding whether the change in dietary consumption is based on the preferred nutrients of a usual family meal or the condition of food used in the experiment. The objective is to oversee a research study exploring different aspects and factors affecting how normal people eat or choose to digest food.

Through different phases of user studies, including user experience and feedback, the long-term objective is continuously improving the hardware to return the most accurate results with the highest precision while providing the most user-centered experience possible.

1.5. Structure of Thesis

This chapter, *Chapter 1: Introduction*, introducing the background, problems, and objectives, will be followed by:

- *Chapter 2: Related Work* - Reviews existing studies and technologies in context to dietary behaviors in today's society,
- *Chapter 3: Methodology* - Describes the system design, hardware development, and data analysis methods,
- *Chapter 4: Implementation and Result* - Details the development processes of the hardware system,
- *Chapter 5: Evaluation and Discussion* - Evaluate the system's performance, including practical experiments for system insights.
- *Chapter 6: Conclusion and Future Work* - Summarizes the research and lists proposals for future development.

Chapter 2: Related Works

2.1. Investigation Of Food Consumption Habits and Their Changes in Recent Years

2.1.1. Factors that Impact Nutrient Intake

Research about dietary preferences has accessed different age groups over recent years, showing distinct eating patterns among them. Noha M. Almoraie *et al.* (2024) [10] studied approximately 235 million university students about their preferred food and dietary patterns. They found common patterns such as partiality for fast food over fruits and vegetables, having breakfast as the most skipped meal of the day, or high ingestion of energy-dense food. These behaviors are primarily attributed to the demanding schedules and high-stress levels common among university students. Furthermore, limited access to healthy foods and unhealthy eating habits can also play a role in student's poor eating practices, leading to adverse long-term effects on their health and well-being.

On the other hand, Monica Serano-Gonzalez *et al.* (2021) [11] conducted an experiment involving 139 participants aged 8 to 23 in 2021 to study their preference for low—and high-calorie foods. Their research showed that while low-calorie foods were generally more preferred, older participants showed more fondness for high-calorie ones and scored them higher overall than younger participants. This raises a suggestion of how the lifestyles of different individuals regarding their age groups can change and the importance of increased independence in dietary preferences. Potential causes of these variations include media exposure, social influences, and individual freedom in choosing nutrient products.

Global pandemics, such as COVID-19, also contributed to the shifting food intake habits in today's society. Delfin Rodriguez-Leyva and Grant N. Pierce (2021) [16] reported an increase in unhealthy food consumption, evidenced by the 30% increase in the intake of sugary snacks in some populations and the approximated 20-30% decrease in fruit and vegetable intake in some regions. The factors for these statistical changes are increasing stress, disorder in the food supply chain, and lifestyle alteration due to lockdowns and remote working conditions.

However, the impact of COVID-19 can also be proven positive, as evidenced by the change in healthy food choices during and after this pandemic. A survey of 368 consumers who often bought groceries both offline and online in Hanoi, Vietnam, reported by Anh N.T.M. *et al.* (2021) [17], found that fear of COVID-19 was one of the factors that encouraged them to buy healthy foods from different suppliers.

The results of these studies show that nutrient intake is affected by complicated relations between individual habits, age-related preferences, global events, and socioeconomic factors. This requires versatile strategies, including nutritional education for various age groups, policy interventions to improve accessibility to healthy nutrient products, and extra exertion to reduce the negative influences of stress and lifestyle disarray on food consumption habits.

2.1.2. Statistical Change in Food Consumption Among Society

In recent years, there have been studies about different increases and decreases in nutrients consumed by today's society. A survey carried out by Sanghui Kweon (2021) [12] in Korea, using the 24-hour recall method and calculated the annual percent change (APC) in the food groups and nutrient intake by using SAS and Joinpoint software pointed out that between 1998 and 2018, the intake of grains (APC = -0.4, $p - value < 0.05$) and vegetables (APC = -0.8, $p < 0.05$) decreased, while there was a considerable rise in the proportion of energy consumption from fat (APC = 1.1, $p < 0.05$), opposite from the energy intake from carbohydrates (APC = -0.3, $p < 0.05$). These findings show a significant shift towards a more Westernized diet, with the attributes of higher fat intake and a reduction in dependence on traditional staples.

In Vietnam, Tuyet Thi Nguyen and Maurizio Trevisan (2020) [15] studied some significant alterations in the traditional Vietnamese diet. They discovered that the mean meat and poultry intake rose from 11g per capita per day in 1985 to 84g in 2020, while oil and fat intake considerably boosted 500% in the same period. Meanwhile, vegetable ingestion decreased from 214g per capita per day to 190g. This dietary change reflects wider economic development and urbanization trends in Vietnam, where the income growth has provided access to animal proteins but may have unwittingly caused a reduction in plant-based food intake.

Other global trends reflect similar topics, as proven by more notable findings. In the United States, Lee *et al.* (2022) [13] studied the increase in processed and ultra-processed food, showing the rise from < 5 to $> 60\%$ of these types of products from 1800 to 2018, contrasting with the decreasing amount of home-cooked food during the same period. Meanwhile, Lara-Castor *et al.* (2023) [14] researched the increasing trend in sugar-sweetened beverage intakes among grown-ups between 1990 and 2018 in 185 countries, with the results showing the largest increase in Sub-Saharan Africa compared to other continents.

The important point to be noted from these researches and studies is that these numerical changes in nutrient intake are not equivalent for all populations, with significant dissimilarities in socioeconomic status, age, and geographic locations. For instance, low-income communities often face limitations in accessing fresh food, resulting in increasing dependence on inexpensive, calorie-dense options. Age groups are also a crucial factor, as younger generations often prefer diets based on globalization and media exposure, leading to alteration in traditional nutrient intake patterns.

2.1.3. Impact of the Change in Food Consumption Habits

One of the most highlighted changes in nutrient intake is unhealthy food consumption, specifically fast food or meals with high amounts of oil and fat. Chronic diseases are the most common consequence of this harmful habit. Research from Mai T. M. T. *et al.* (2023) [18] showed that in a study involving 221 children between the ages of 9 and 11 in Ho Chi Minh City, Vietnam, the overall obesity was 31.7%. This resulted from a discretionary diet (snacks and sweetened beverages) and an industrialized diet (fast food and processed meats), heightening the challenges for public health in urban environments.

In contrast with unhealthy food consumption habits, healthy nutrient intake usually leads to better health. Deborah R. Wahl *et al.* (2017) [19] studied 1,200 patients with chronic diseases who followed two different dietary patterns: the Healthy Diet Pattern (high intake of fruits, vegetables, whole grains, fish, and lean meats) and the Western Diet Pattern (WDP) (High intake of processed products, red meat, sweets, and high-fat dairy food). Their research found that patients following the former pattern reported positive physical and mental health changes compared to those with the Western Diet, including lower Body Mass Index (BMI), diminished inflammation markers, and improved mental states, in contrast with patients following WDP, confirmed by substandard health outcomes. This proves that not only do good nutrient intake habits result in better physiological well-being, but they can also lead to improved cognitive wellness.

Global events such as COVID-19 have also raised the benefits of healthy dietary patterns. Chinyanga *et al.* (2024) [20] studied that during the peak of the pandemic, food venue, demographics, and the increased concerns about the virus had raised the apprehension about diets and consumption, leading to the shift to fresh fruit and vegetable intake, along with home-cooked meals preference. Research by Anh *et al.* (2021) [17] also shows that some households have experienced positive shifts to more nutrient-rich foods for greater immunity after the pandemic.

These dietary changes have widespread social impacts, such as rises in healthcare costs in conjunction with diet-related diseases. Policy interventions like tax increases for sugary beverages and endowment for fresh food have been proposed to address these problems. Nutritional education, especially at schools and local areas for children and adolescents, has been promoted and concentrated for the future generations' better life standards, which has shown promising results in altering unhealthy life trends.

2.2. Using hardware devices to monitor food consumption habits

2.2.1. Application of IoT Devices

Along with the usual statistical research, many studies on food intake using different hardware devices have been conducted using emerging technology trends such as IoT. Suganyadevi *et al.* (2021) [21] developed an IoT-based diet-monitoring healthcare system for women, which tracked their food assessment using Wi-Fi-powered sensors and a smartphone application. This system provides valuable insights into daily diet and nutrient intake, assisting its users in making healthy dietary choices.

On the other hand, Park *et al.* (2024) [22] developed a machine-learning neckband for monitoring food consumption. The device is intended to help people with dietary control by accurately recording eating events during daily activities.

Other noteworthy achievements from the hardware development and IoT fields in implementing devices for health and dietary monitoring include wearable textile sensors for continuous glucose monitoring, as reported by Sunstrum *et al.* (2015) [23], and eco-designed cooking appliances based on diets in EU countries, studied by Favi *et al.* (2020) [24].

These innovations demonstrate the potential of IoT devices in monitoring and analyzing data on nutrient intake patterns, with the objective of improving diets for a healthier lifestyle. Furthermore, data tracked by these devices can be valuable in pharmacy research for the medical field or market research for related businesses and industries.

2.2.2. Using Weighing Scales to Monitor Food Consumption Habits

Weighing scales are another methodology that can provide insights into monitoring nutrient patterns. Moursi *et al.* (2023) [8] studied youth participants who were monitored in food intake and BMI by applying weighing scales to measure their nutrient patterns accurately. Hiraguchi *et al.* (2023) [9] also conducted a similar experiment by applying wireless pocket-sized kitchen scales connected to an application tracking real-time food consumption.

Similar to applying weighing scales, Harry R. Kissileff (2022) [25] described the Universal Eating Monitor (UEM), a device that tracks food intake in real-time in laboratory settings. Using an electronic balance covered by a cloth, researchers can evaluate the eating rate and overall consumption of solid and liquid foods, which would provide precise data on nutrient patterns and, as a result, an understanding of food consumption habits and obesity research.

Some studies have used weighing scales in Vietnam for similar purposes, but these are common. P. H. Nguyen *et al.* (2022) [26] evaluated the validity of the Food Recognition Assistance and Nudging Insights (FRANI) smartphone application for dietary assessment among Vietnamese adolescent girls. The application included applying the Tanita KD160 scales to weigh and record all the meals and beverages consumed by participants over a predetermined period.

On the other hand, T. M. T. Mai *et al.* (2022) [27] set the objective of developing and validating a dietary questionnaire for evaluating nutrient intakes of urban-area children. Using 24-hour recall sessions, this study applied weighing scales to measure their food consumption, which provided essential data for their validation process.

Their results showed that employing weighing scales in dietary research in Vietnam is feasible and that this approach could accurately estimate nutrient intake compared to weighed records.

Chapter 3: Methodology

3.1. User Requirement Analysis

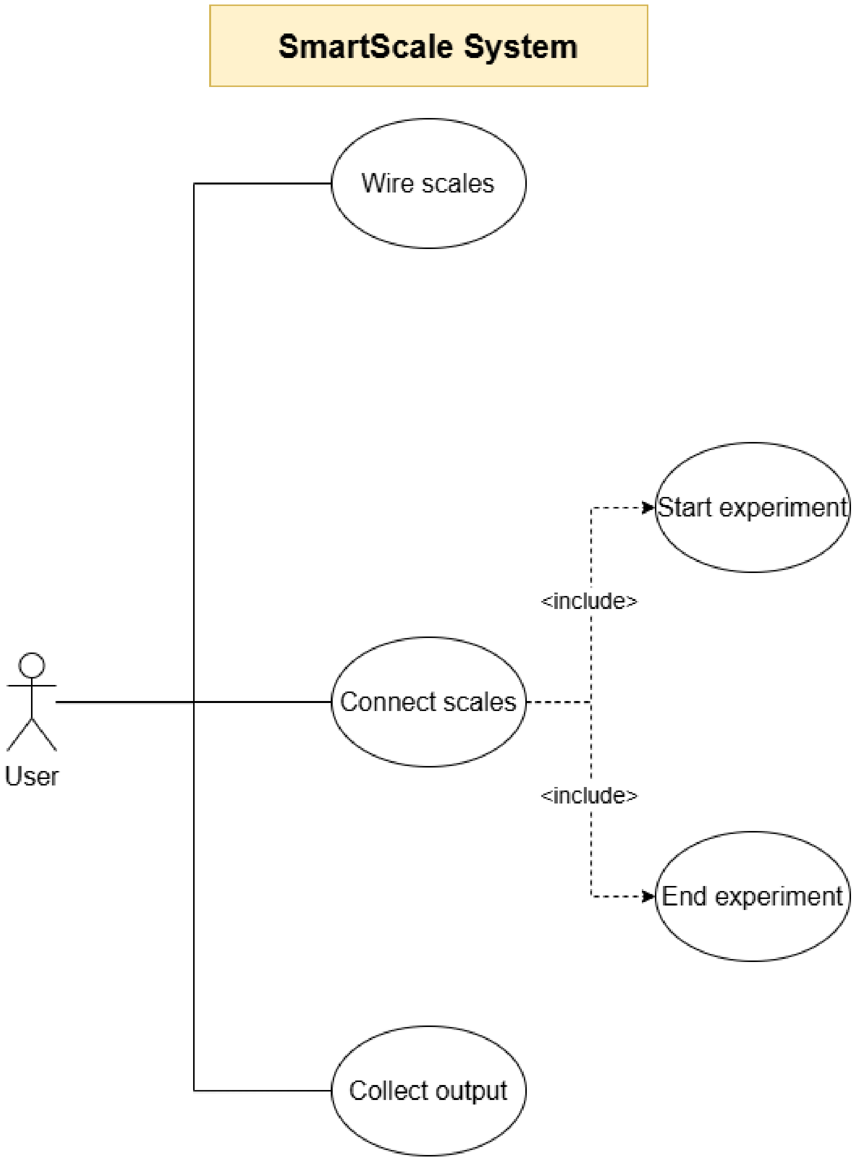

Figure 3.1: Use case diagram

The designed hardware system takes into account one actor: the user. They are required to wire several scales necessary for the experiment and connect them to any PC or laptop via a USB port. This includes starting and ending the monitoring process. The final output from the progress can then be collected.

User's use cases:

- **Wire scales:** Users can wire a specific number of scales based on the requirement of the experiment, with each scale being connected to two data pins of the microcontroller. Based on the limitation of the Arduino, a maximum number of four can be connected simultaneously.
- **Connect scales:** When all the scales are connected, users can connect the microcontroller to their PC or laptop via a USB port. This includes the process of starting or ending the experiment.
- **Collect output:** At the end of the monitoring process, the final output will be returned, which users can collect for several purposes.

3.2. Design Approach

3.2.1. User Experience Design

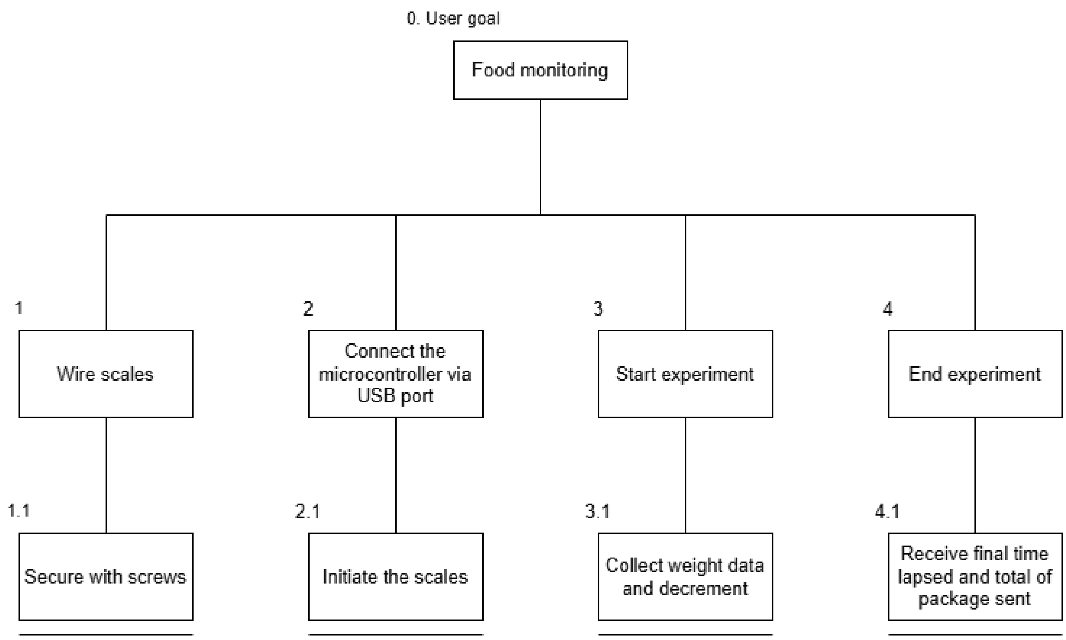

Figure 3.2: Scenario - Testing process

- **Scenario:** Food monitoring process
  - Task 1: Wire scales.
  - Task 2: Connect the microcontroller via USB port.
  - Task 3: Start experiment.
  - Task 4: End experiment.

3.2.1.1. Prototyping Stages

This is the process of visualizing and testing various designs to determine the optimal one at the end of the design process.

1. **Low-fidelity Prototype**

   Low-fidelity prototypes are simple hardware designs. They are quick to design and have the basic platform to construct the hardware without applying too many technical skills or complexity. For example, this is a prototype for the scale based on the description.

   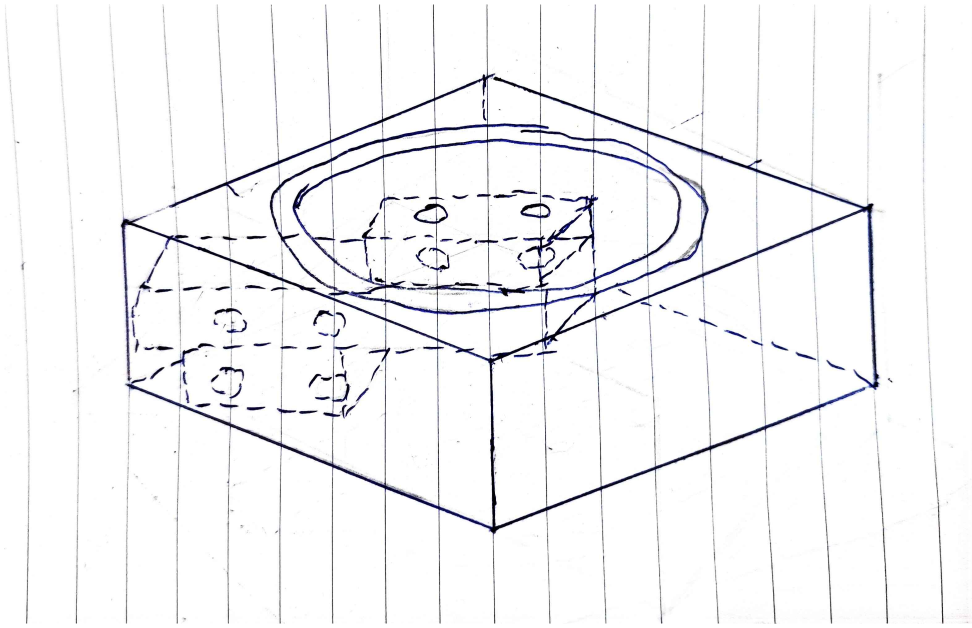

   Figure 3.3: Low-fidelity prototypes: Simple scale with 5-kg load cell

   A simple circuit for the hardware is sketched and tested using simulation software. This can help visualize how it would work in practice and how much material to prepare without going overboard in the preparation state.

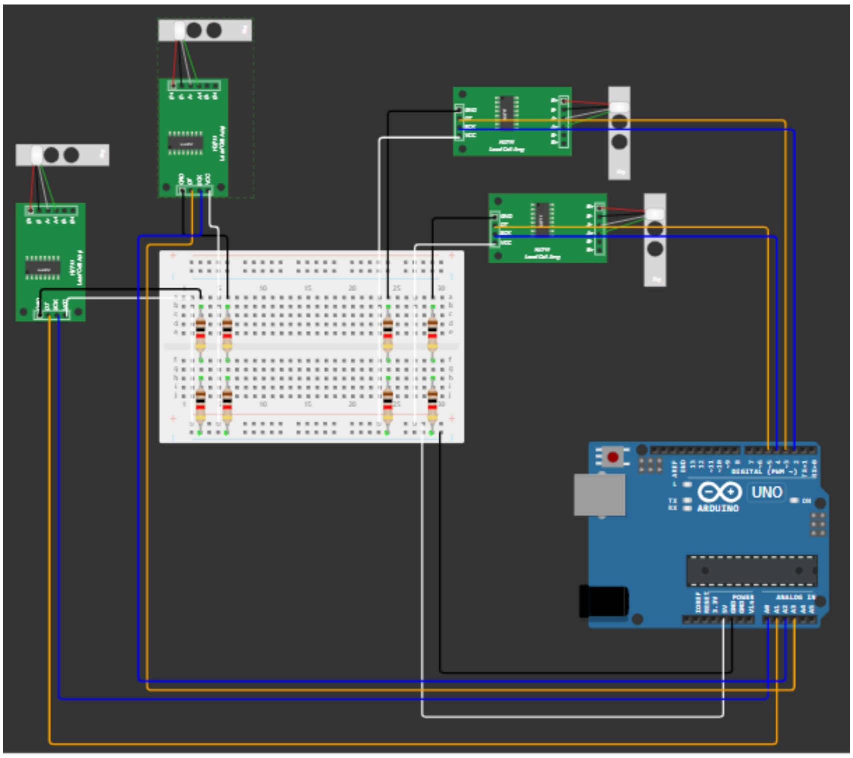

Figure 3.4: Low-fidelity prototypes: Circuit diagram

2. **Physics Principle**

   It is necessary to apply physics principles to hardware heavily based on measurement.

   The Wheatstone Bridge is used in strain gauge scales to measure minute variations in resistance brought on by mechanical deformation or strain when a load or any weight is applied. The bridge consists of strain gauges, which are resistive sensors. When the applied weight changes, this leads to a change in the resistance of the strain gauges, which results in an imbalance of the bridge.

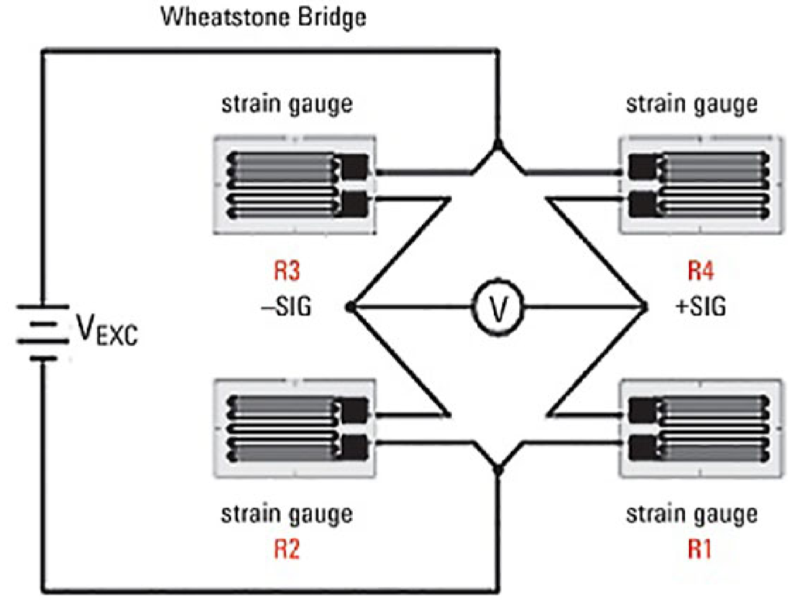

Figure 3.5: Wheatstone Bridge Principle

3. **Mid-fidelity Prototype**

   Mid-fidelity prototypes are simple hardware devices that are designed and built in practice. They are quick to implement while applying the physics principle discussed above. Additionally, the design of the mid-fidelity prototype can be used and improved for the high-fidelity model, which is more complex and modified for more functions to meet the requirements.

   Figure 3.6 shows the mid-fidelity prototype from the designing and implementation phases.

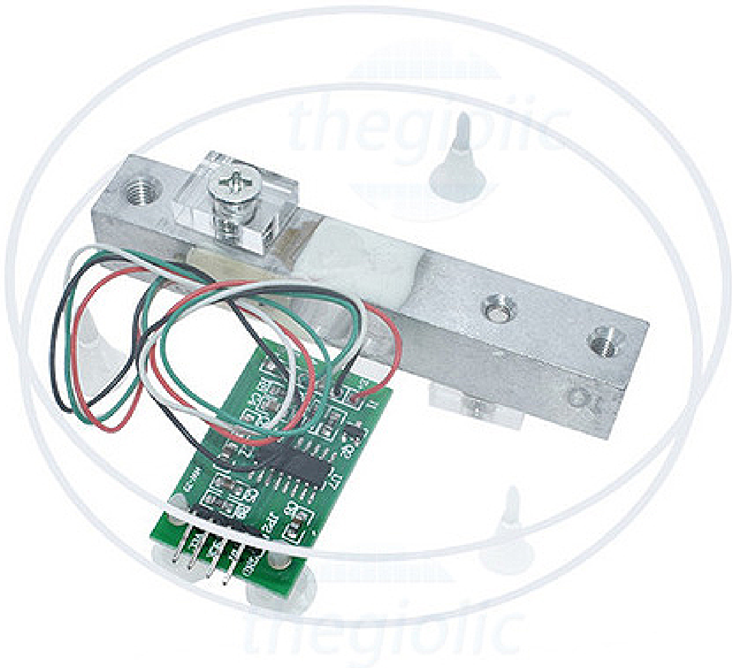

Figure 3.6: Mid-fidelity prototypes: Simple scale with 5-kg load cell

4. **High-fidelity Prototype**

   High-fidelity prototypes can be designed and built based on research and knowledge from the prototyping stages. These prototypes require more technical skills but have more practical uses and are more user-friendly. These are necessary for better gaining from experiments and gathering feedback from users. Figure 3.7 shows the photograph of the high-fidelity prototype.

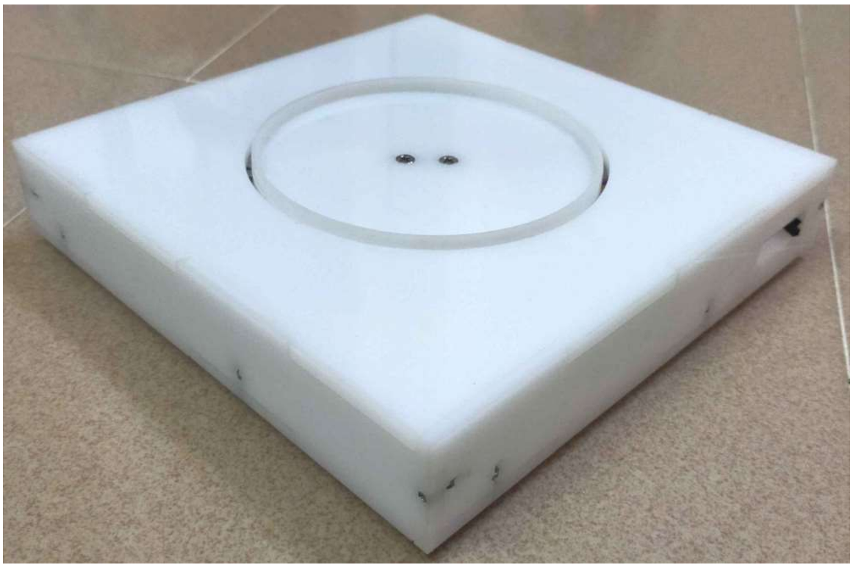

Figure 3.7: High-fidelity prototype: Practical scale from the side

3.2.2. System Design

System designs visualize the interaction between the user and hardware system based on different scenarios, focusing on the flow of operations and interactivities between the scales' components. For instance, Figure 3.8 illustrates the scenario of testing or experimenting envisioned in a sequence diagram.

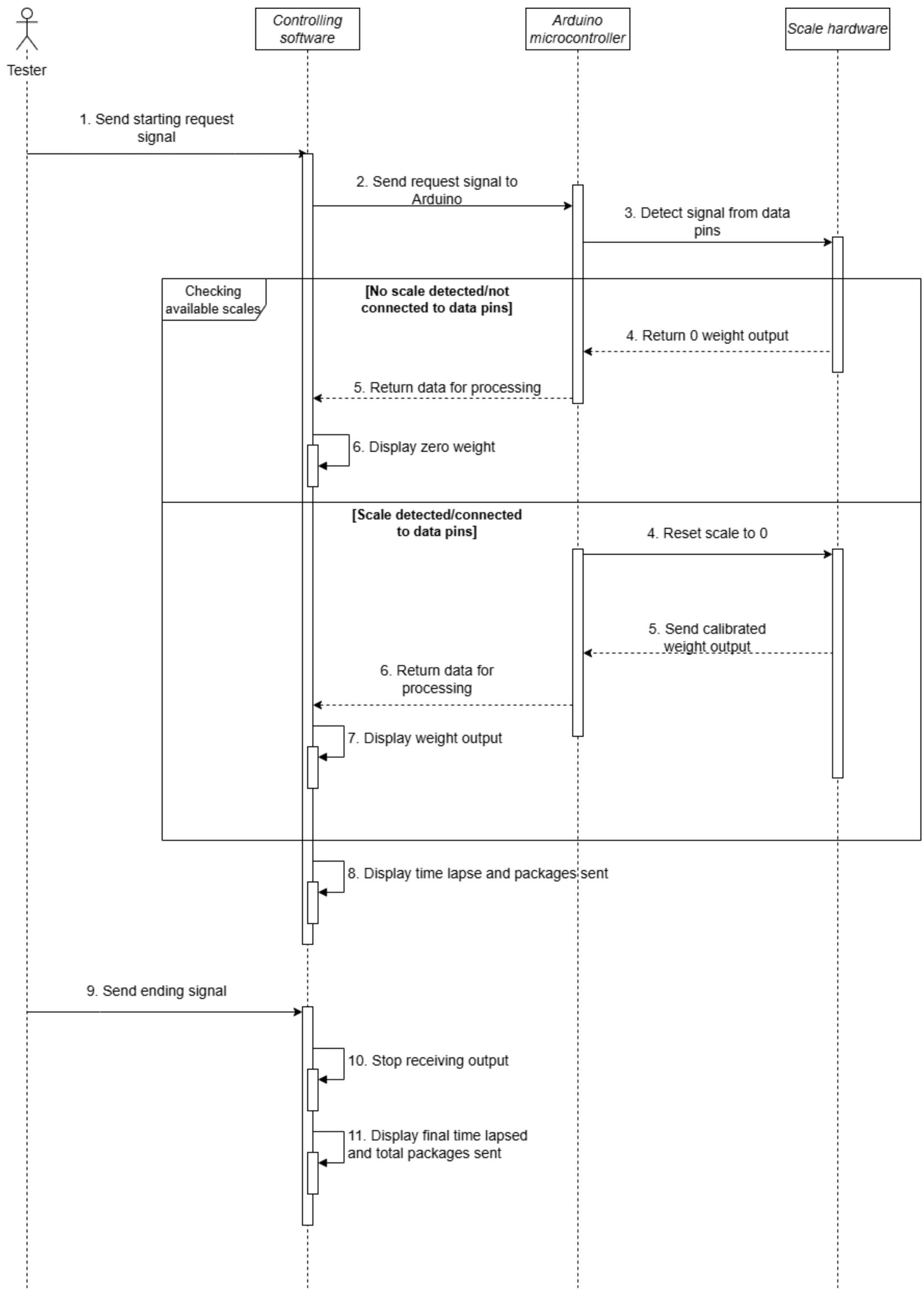

Figure 3.8: Sequence diagram - Testing

When the user sends the starting signal to the integrated software, the controlling IDE transfers it to the Arduino microcontroller. The Arduino then detects the signal from its data pins, which the wires from the scales are connected to. A validation process is executed to detect the number of scales connected, and if there is at least one unconnected sensor, the output returned will be zero. During the experiment, the IDE keeps returning the time lapsed and the amount of packages sent until the user stops the process.

3.3. Tools and Techniques Applied

3.3.1. Software Integration

Development Environment: Arduino IDE is primarily used as the integrated development environment for developing the code inside the Arduino. It is an open-source software that provides an efficient coding environment and a simple way to integrate code into the microcontroller [28].

Programming Language: C++ language is used in the development process. It is the essential programming language when building any hardware system that involves Arduino or other microcontroller boards, providing optimal code for simpler but more efficient practical uses. C code also offers a wide range of Arduino libraries, which add better control to any hardware project [29].

Library Applied: HX711 library is the foremost library when developing the hardware. Providing a wide range of functions, it is the most optimal when building a system that involves strain gauge load cells, with better precision and accuracy in measurement.

Software Environment: The hardware system is integrated with controlling software developed by the SenseXP research team. When the connecting port is detected, the software sends the signal to the microcontroller inside the scales, allowing the hardware to record and send the output results back for data collection and analysis.

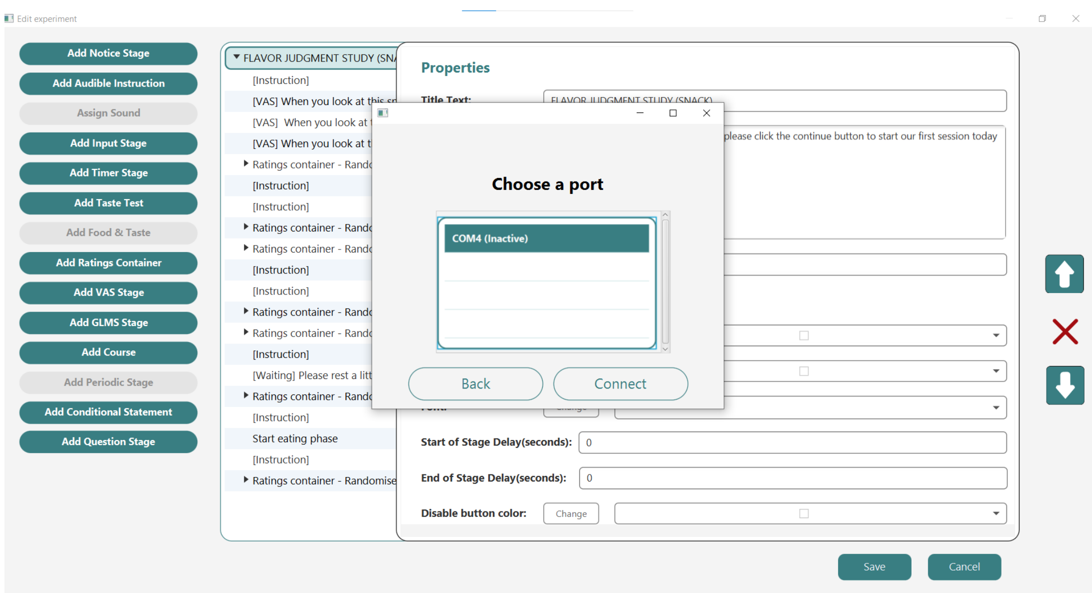

Figure 3.9: Controlling Software

3.3.2. Hardware Components

Microcontroller Board: Arduino UNO R3 is the main microcontroller board for the hardware development process, which controls and receives the data from the scale. A

USB Type-B cable is also required to connect the Arduino to the computer, which sends data for the software to process [30].

Figure 3.10: Arduino UNO R3 microcontroller board

Main component: 5-kg load cell is a strain gauge load cell to build and measure the weights placed on the scale, which works based on the Wheatstone Bridge Principle [31]. Based on the requirements of the monitoring process, the 5-kg type was chosen as the most optimal and viable scale [32].

Figure 3.11: Main component: 5-kg load cell

Other Hardware Components:

- **HX711 module:** This module receives the scale's data, converts it into readable output, and sends it to the Arduino [33].

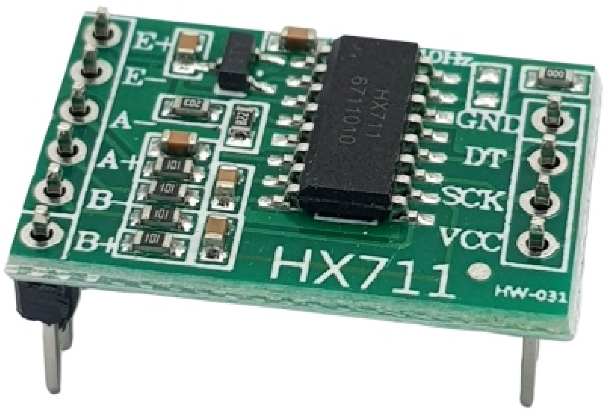

Figure 3.12: Other hardware component: HX711 module

Chapter 4: Implementation & Results

4.1. Hardware Design

The first part of any hardware system is the hardware design. Both the exterior and interior aspects are crucial. Not only do they have to be user-friendly, but they must also provide high functionality, maintain good stability, and be compatible with operative components. During the design process, these requirements must be considered along with high cost-efficiency.

4.1.1. Exterior Design

During the development stages, a rectangular box 20 x 20 x 3.5 centimeters in size was chosen for the exterior of the hardware. This design is the most optimal for the scales, as it is sizeable and easy to build or transfer if necessary, and it is also wide enough to contain the hardware components for the interior. Figure 4.1 shows the technical sketch of the upper part and one of the scale's sides, applying the size requirement in millimeter units.

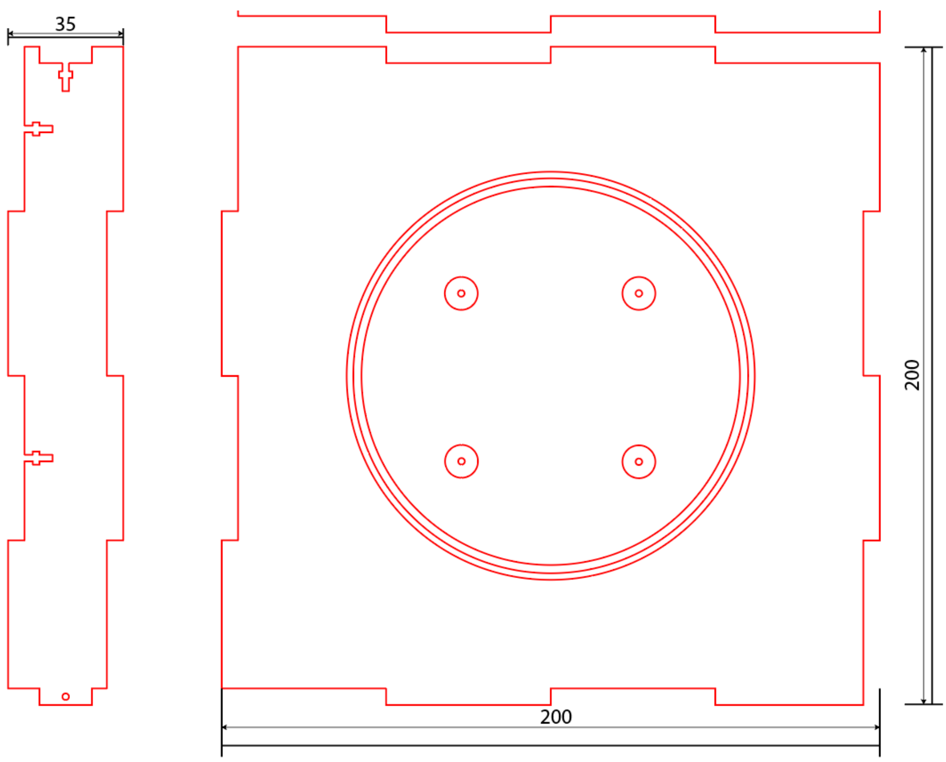

Figure 4.1: Exterior Design: The upper part and side's technical sketch

The most crucial part of designing the hardware's exterior is deciding the disk's size for the scale. Based on the general base size of dinnerware in Vietnam, a 12-centimeter-diameter disk with a 0.5-centimeter wide border is designed.

During monitoring or experiments, the dinnerware must stay and apply its mass to the disk. If any part of the dinnerware comes into contact with the scale's upper cover, even with the slightest contact, its gravitational force will also apply to the cover, resulting in "sharing" the weight. Hence, the output will be inaccurate. Therefore, the disk border is crucial since it prevents the situation discussed above from happening, keeping all its mass on the scale.

Figure 4.2 illustrates the technical drawing of the disk in millimeter units.

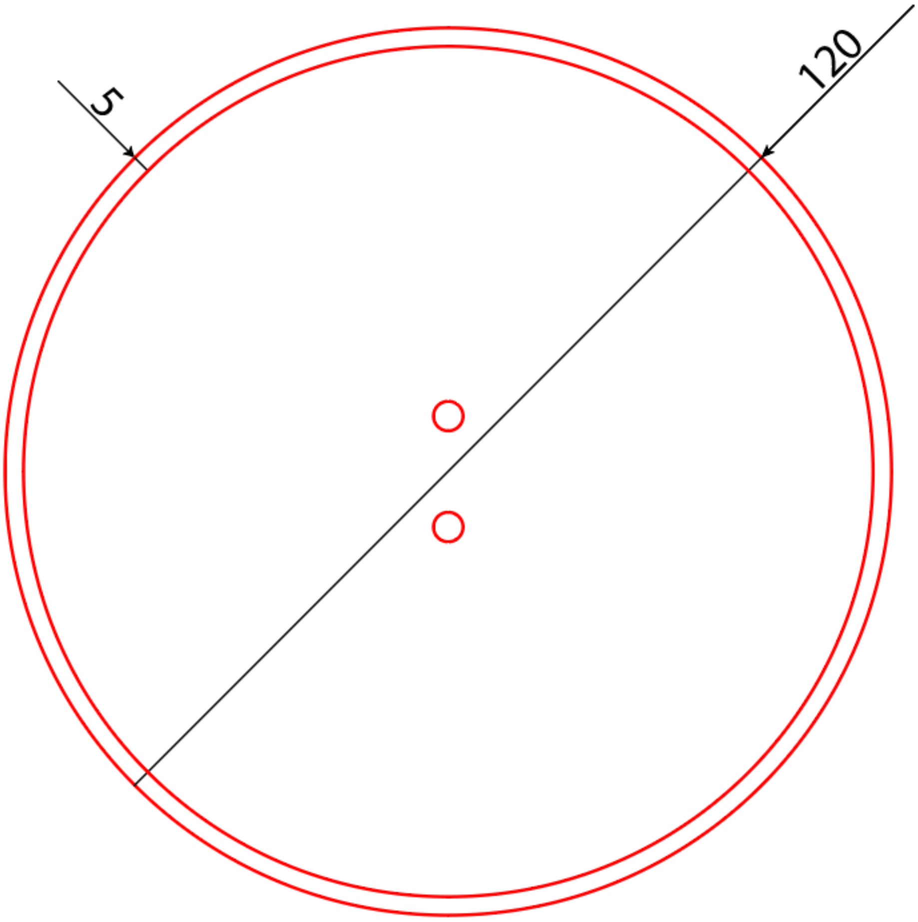

Figure 4.2: Exterior Design: The disk's technical sketch

4.1.2. Interior Design

The interior design process involves wiring and connecting the hardware components to the microcontroller board. Following the circuit design of the low-fidelity prototype and the circuit sketch in Figure 3.4, the wiring process is similar, with just a few adjustments to be simple and user-friendly, in which users with minimal technical skills can easily connect them.

All four load cells are connected to the Arduino board via HX711 modules. This is the maximum number of scales that can be controlled by one board in practice, with minimal latency and the ability to provide enough power to initiate the scales.

4.2. Microcontroller Programming

After the wiring and connection process, the final step is to program the microcontroller according to the requirements. This includes outputting the timestamp that the result is received in real-time, the sent package's number, and the weight output from four different scales.

4.2.1. Initial Setup

```
#include <HX711.h>

HX711 scale;
HX711 scale2;
HX711 scale3;
HX711 scale4;

float calibration_factor = 418375;
float calibration_factor2 = 438320;
float calibration_factor3 = 445630;
float calibration_factor4 = 431530;

unsigned long startTime; // Variable to store the start time
unsigned long elapsedTime; // Total time lapsed
bool sendingScaleData = false; // When receiving signal from Java -> start sending data

unsigned long previous = 0;
const long interval = 100;

long packageNo = 0;

// Pin definitions
const int scale1_DT = 3;
const int scale1_SCK = 2;
const int scale2_DT = 5;
const int scale2_SCK = 4;
const int scale3_DT = 7;
const int scale3_SCK = 6;
const int scale4_DT = 9;
const int scale4_SCK = 8;
```

Figure 4.3: Initial setup: Define library and objects

This figure uses the HX711 library to set up, control, and calibrate each scale.

Calibration factors are also one of the most essential objects in the programming process. Initially, the data sent from the scales is usually called raw data output since they are inconsistent and unreadable when there is a weight change. To receive the correct data with the requisite measurement, a calibration factor is required to calibrate the scales and obtain the precise output, following the formula [34]:

$$calibration\ factor = \frac{output\ signal}{known\ weight} \tag{4.1}$$

Some other objects, such as *startTime* and *elapsedTime* for calculating time lapsed, a Boolean object as a signal to start sending packages, *packageNo*, and the pins for connection are also defined.

```
scale.begin(3, 2); // (DT, SCK)
scale.set_scale();
scale.tare(); // Reset value to 0

scale2.begin(5, 4); // (DT, SCK)
scale2.set_scale();
scale2.tare(); // Reset value to 0

scale3.begin(7, 6); // (DT, SCK)
scale3.set_scale();
scale3.tare(); // Reset value to 0

scale4.begin(9, 8); // (DT, SCK)
scale4.set_scale();
scale4.tare(); // Reset value to 0
```

Figure 4.4: Initial setup: Initialize connection with respective pins

According to Figure 4.4, the program sets the scales according to the Arduino pins to which DT and SCK from the module are connected (i.e., Analog pins A1 for DT and A0 for SCK). The importance of the *tare()* function is also worth noting since it resets the weight to zero and avoids any potential inaccuracy during the testing process.

4.2.2. Output Loop

```
scale.set_scale(calibration_factor); // Adjust the scale based on calibration factor
scale2.set_scale(calibration_factor2);
scale3.set_scale(calibration_factor3);
scale4.set_scale(calibration_factor4);
```

Figure 4.5: Output loop: Setting scales

As can be seen in Figure 4.5, at the beginning of the output loop, the scales are set with the calibration factor calculated by the user. This should ensure that the weight output received will be readable, consistent, and precise.

According to the requirements, when the microcontroller board is connected, if no issue or error is encountered, it will wait for the signal to send the output from the user. Applying this condition, a listener is implemented, as shown in Figure 4.6.

```
// Listener
if(Serial.available())
{
  char temp = Serial.read();
  if (temp == 's') {
    startTime = millis();
    sendingScaleData = true;
    Serial.println("Begin sending data!");
  } else if (temp == 'e') {
    sendingScaleData = false;
    elapsedTime = millis() - startTime;
    Serial.println("Stop sending data!");
    Serial.print("Elapsed Time: ");
    Serial.print(elapsedTime / 1000);  // Print time in seconds
    Serial.println(" seconds");
    Serial.print("Total packages sent: ");
    Serial.println(packageNo);
    packageNo = 0;
  }

}
```

Figure 4.6: Output loop: Microcontroller's listener

When the correct input is sent to the serial monitor, the boolean object *sendingScaleData* will be set to true, thus acting as the signal to initiate the sending process, with the output implemented in Figure 4.7 and 4.8. Each value is separated by a semicolon for easier distinguishing, with the order of time lapsed, the package's number, and the weight output from the four scales.

```
if (sendingScaleData) {
  unsigned long currentMillis = millis();

  if (currentMillis - previous >= interval) {
    previous = currentMillis;

    unsigned long totalSeconds = currentMillis / 1000;
    unsigned long hours = totalSeconds / 3600;
    unsigned long minutes = (totalSeconds % 3600) / 60;
    unsigned long seconds = totalSeconds % 60;
    unsigned long milliseconds = currentMillis % 1000;

    packageNo++;

    if (hours < 10) Serial.print("0");
    Serial.print(hours);
    Serial.print(":");
    if (minutes < 10) Serial.print("0");
    Serial.print(minutes);
    Serial.print(":");
    if (seconds < 10) Serial.print("0");
    Serial.print(seconds);
    Serial.print(".");
    if (milliseconds < 100) Serial.print("0");
    if (milliseconds < 10) Serial.print("0");
    Serial.print(milliseconds);

    Serial.print(";");

    Serial.print(packageNo);
    Serial.print(";");
```

Figure 4.7: Output loop: Time-lapse and number of packages sent

```
float reading = scale.get_units();
Serial.print(reading, 3);
Serial.print(";");

float reading2 = scale2.get_units();
Serial.print(reading2, 3);
Serial.print(";");

float reading3 = scale3.get_units();
Serial.print(reading3, 3);
Serial.print(";");

float reading4 = scale4.get_units();
Serial.print(reading4, 3);

Serial.println();
```

Figure 4.8: Output loop: Weight output

Chapter 5: Evaluation & Discussion

5.1. Evaluation

5.1.1. Experiment 1: Weight Position Test

This test evaluates the scale's sensitivity. During the experiments, the assessors must be placed in any position on the weighing disk. High precision and accuracy are the main objectives in the scales' development and design phases, and the weight change during the test must be correct.

5.1.1.1. Design

In this evaluation, various selections of weights were placed on two positions of the disk, which were center and side (close to the border). Each position is separated into two phases. The weight was placed before and after calibrated scales, with its average weight output checked 10 times. After that, the test was repeated after 1 and 3 days.

5.1.1.2. Procedure

The experiment procedure can be outlined as follows:

- **Choice of Weight:** Multiple known weights were chosen for the test, with minimum error, to provide the most precise result possible.
- **Disk Positioning:** Center and side of the weighing plate. These choices aimed to check for possible errors when placing the test subject on different areas of the scale.
- **Test Duration:** The experiment was separated into three phases: Before and after calibration, after 1 day, and after 3 days. The primary purpose was to check the scales' consistency, as proven by the days without extra work or modification during the delays.
- **Data Analysis and Reporting:** The collected data was analyzed for insights. The expectation was the test results (weight outputs) had to be the same as the exact weight placed on the disk (up to three decimals).

5.1.1.3. Result

1. **Center - Collected data:**

   A 0.912-kg weight was first placed on the disk's center in this test phase, as shown in Figure 5.1.

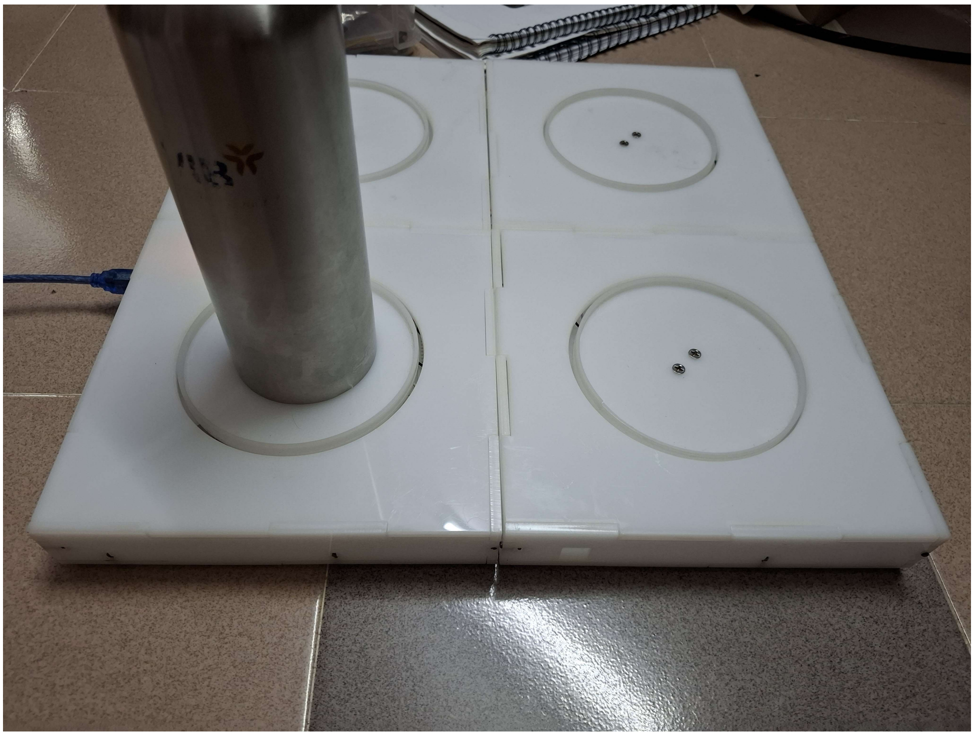

Figure 5.1: Weight Position Test - Center

Figure 5.2: Testing Weight: 0.912kg

Table 5.1 shows the average weight output when evaluated after 10 times. The results presented are known as raw digital output, or signal output, showing its inconsistency and errors during the test. The line chart in Figure 5.3 shows how the average results change after each time.

Times	*S1*	*S2*	*S3*	*S4*
1	382161.125	400290.875	407971.375	392295.812
2	382203.000	400326.687	407939.812	392216.000
3	382111.687	400296.187	407924.125	392328.812
4	382175.125	400333.000	408015.625	392226.812
5	382165.375	400392.500	408001.500	392241.312
6	382207.687	400382.187	407894.187	392274.000
7	382200.187	400404.312	407970.812	392342.312
8	382246.312	400323.625	407936.687	392244.406
9	382192.625	400365.500	407881.000	392383.093
10	382213.187	400373.375	407922.187	392261.000

Table 5.1: Before Calibration - Center

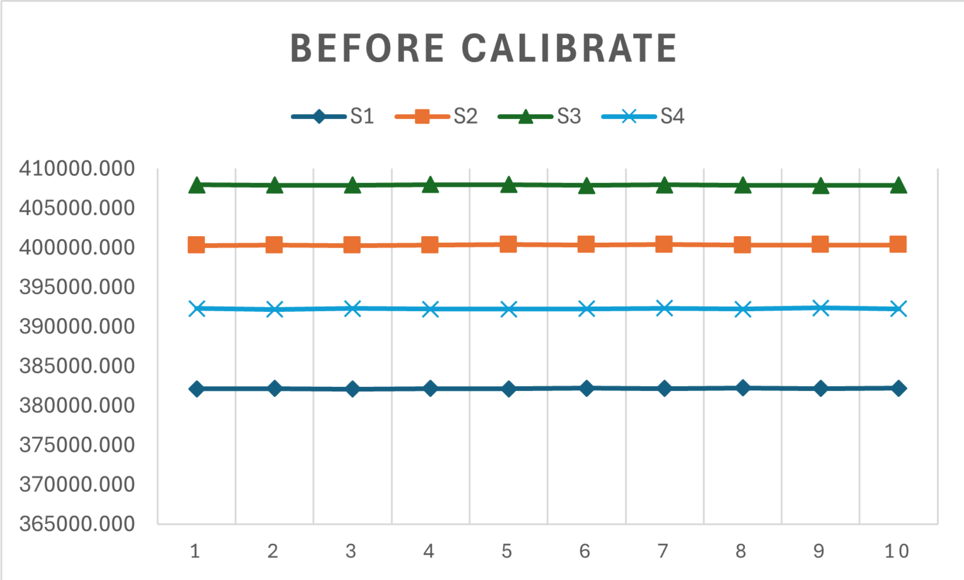

Figure 5.3: Before Calibration Line chart (Center)

Applying the calibration factor formula discussed in Chapter 4, the initial weight was tested again 10 times. In this experiment, as shown in Table 5.2, the average results were more accurate and precise, with minimum error returned.

Times	*S1*	*S2*	*S3*	*S4*
1	0.915	0.913	0.912	0.913
2	0.915	0.913	0.912	0.913
3	0.915	0.913	0.912	0.913
4	0.915	0.913	0.912	0.913
5	0.915	0.913	0.912	0.913
6	0.915	0.913	0.912	0.913
7	0.916	0.913	0.912	0.913
8	0.915	0.913	0.912	0.913
9	0.916	0.913	0.912	0.913
10	0.916	0.913	0.912	0.913

Table 5.2: After Calibration - Center

Figure 5.4's line chart displays the results after testing. As can be seen in the chart, the lines are more linear, showing the scales' consistency after being calibrated. However, during the 7th, 9th and 10th tests, the recorded weight from Scale 1 rose to 0.916kg.

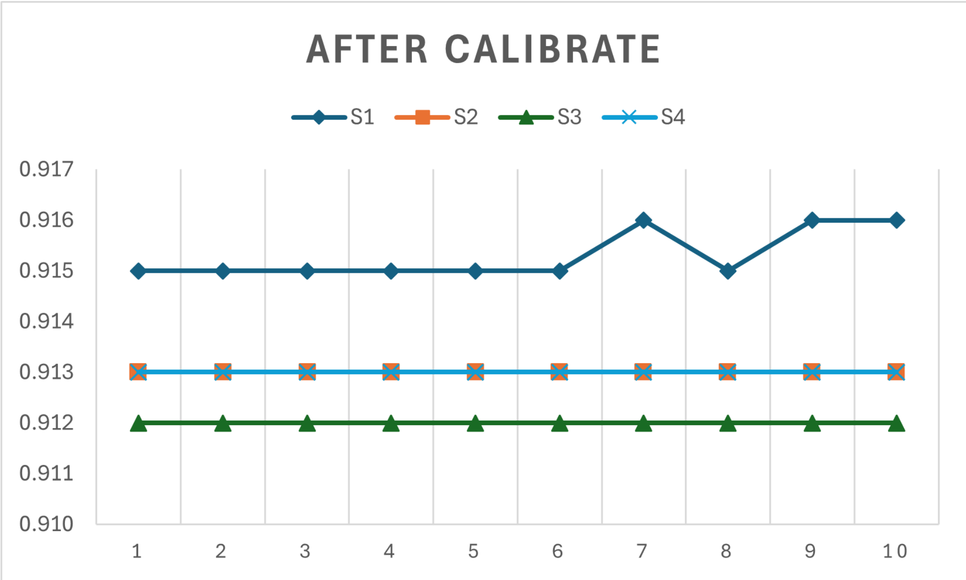

Figure 5.4: After Calibration Line chart (Center)

After 1 day, the evaluation restarted another 10 times, keeping the scales calibrated and using a different weight of 0.910kg.

Figure 5.5: Testing Weight: 0.910kg

In this test, the results were more linear for each scale. However, there were some notable error, including 0.004, 0.002, and 0.001 differences, each from Scale 1, Scale 2, and both Scale 3 and 4.

Table 5.3 shows the test results after 1 day, and Figure 5.6 shows the results illustrated by lines for four scales.

Times	*S1*	*S2*	*S3*	*S4*
1	0.914	0.912	0.911	0.911
2	0.914	0.912	0.911	0.911
3	0.914	0.912	0.911	0.911
4	0.914	0.912	0.911	0.911
5	0.914	0.912	0.911	0.911
6	0.914	0.912	0.911	0.911
7	0.914	0.912	0.911	0.911
8	0.914	0.912	0.911	0.911
9	0.914	0.912	0.911	0.911
10	0.914	0.912	0.911	0.911

Table 5.3: After Calibration - Center (after 1 day)

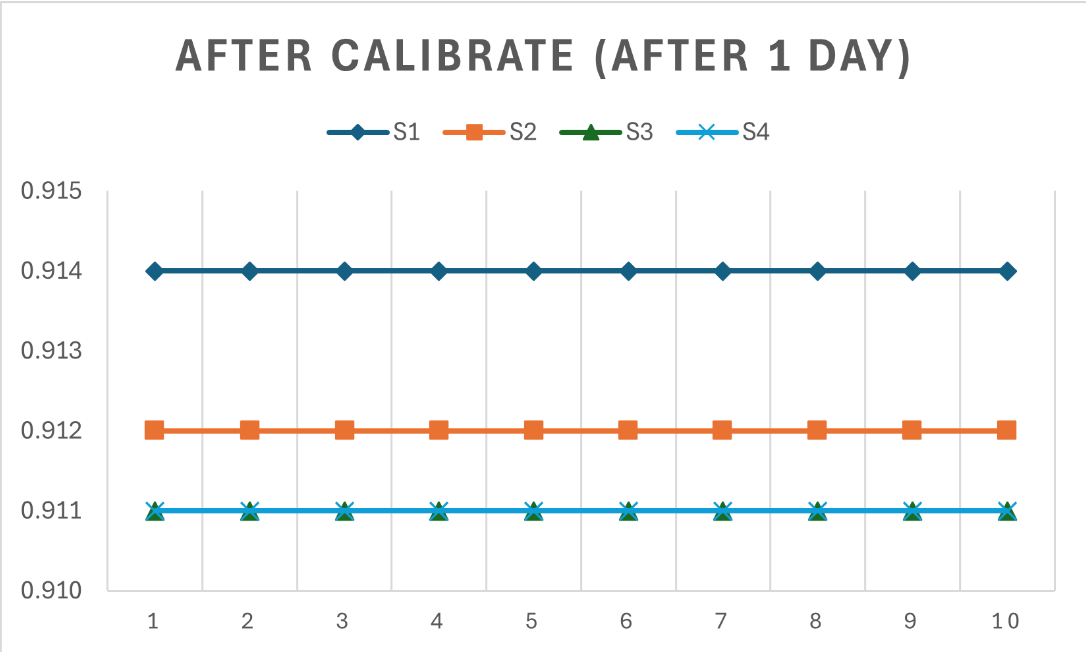

Figure 5.6: After Calibration (after 1 day) Line chart (Center)

The experiment restarted with the same steps three days after the first test, using a 0.915-kg testing weight.

Figure 5.7: Testing Weight: 0.915kg

According to the test results, only Scale 3 recorded the correct weight output. Meanwhile, Scale 1 had a 0.003 error, and both Scale 2 and 4 got a 0.001 difference compared to the actual weight.

Table 5.4 displays the experiment results, showing high accuracy and precision were achieved as the main objectives.

Times	*S1*	*S2*	*S3*	*S4*
1	0.918	0.916	0.915	0.916
2	0.918	0.916	0.915	0.916
3	0.918	0.916	0.915	0.916
4	0.918	0.916	0.915	0.916
5	0.918	0.916	0.915	0.916
6	0.918	0.916	0.915	0.916
7	0.918	0.916	0.915	0.916
8	0.918	0.916	0.915	0.916
9	0.918	0.916	0.915	0.916
10	0.918	0.916	0.915	0.916

Table 5.4: After Calibration - Center (after 3 days)

Figure 5.8 shows the test results after 10 times, illustrated by lines for each scale. As shown in the graph, the lines are more linear than the results prior.

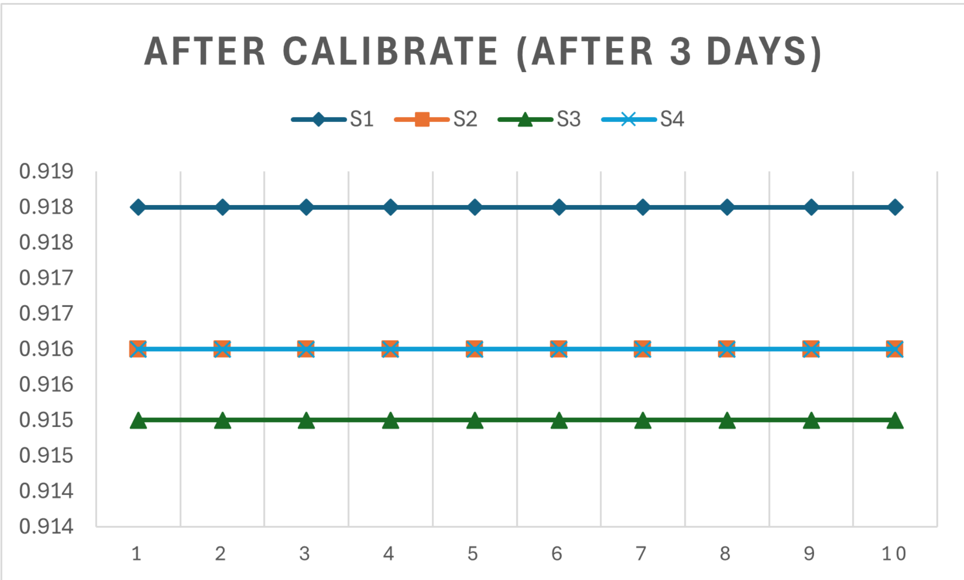

Figure 5.8: After Calibration (after 3 days) Line chart - Center

2. **Side - Collected data:**

   For this test phase, the initial weight was placed on the disk's side, being as close to the border as possible, as shown in Figure 5.9.

Figure 5.9: Weight Position Test - Side

The same as the first position assessment, the weight of 0.912kg was tested before the scales were calibrated. The results were inaccurate and not precise since they only returned the signal output from the microcontroller. Table 5.5 presents the results after evaluating and taking the average results after 10 times.

Times	*S1*	*S2*	*S3*	*S4*
1	382221.875	400334.500	407901.000	392255.187
2	382148.000	400273.625	407896.125	392168.312
3	382199.500	400236.312	407829.312	392257.093
4	382189.375	400275.187	407859.500	392144.500
5	382166.687	400360.375	407885.812	392250.687
6	382196.125	400345.812	407762.500	392319.000
7	382216.125	400389.687	407730.000	392295.000
8	382220.375	400276.687	407783.500	392391.500
9	382151.500	400399.312	407878.625	392306.093
10	382109.312	400205.687	408015.687	392267.812

Table 5.5: Before Calibration - Side

Figure 5.10 illustrates the results in a line graph, further showing its inconsistency and inaccuracy.

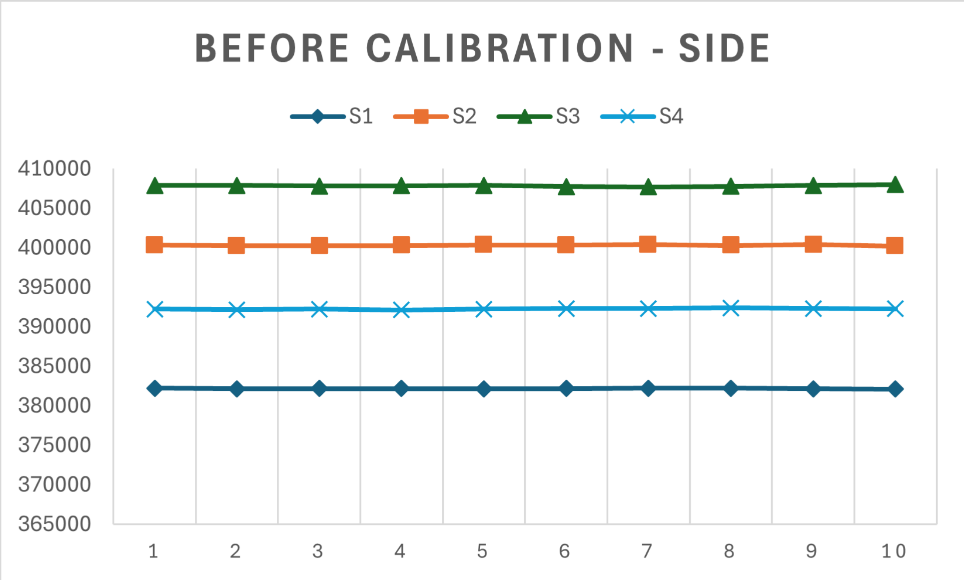

Figure 5.10: Before Calibration Line chart (Side)

The initial weight was retested ten times after using the calibration factor formula. There were some notable error, including 0.004, 0.001 from Scale 1 and both Scale 2 and 4. During the 3rd, 4th, and 8th tests, the weight recorded from Scale 2 also increased to 0.914kg, as indicated in Table 5.6.

Times	*S1*	*S2*	*S3*	*S4*
1	0.916	0.913	0.912	0.913
2	0.916	0.913	0.912	0.913
3	0.916	0.914	0.912	0.913
4	0.916	0.914	0.912	0.913
5	0.916	0.913	0.912	0.913
6	0.916	0.913	0.912	0.913
7	0.916	0.913	0.912	0.913
8	0.916	0.914	0.912	0.913
9	0.916	0.913	0.912	0.913
10	0.916	0.913	0.912	0.913

Table 5.6: After Calibration - Side

The post-test findings are shown in the line chart in Figure 5.11. The diagram illustrates the uniformity of the scales after Calibration by displaying more linear lines.

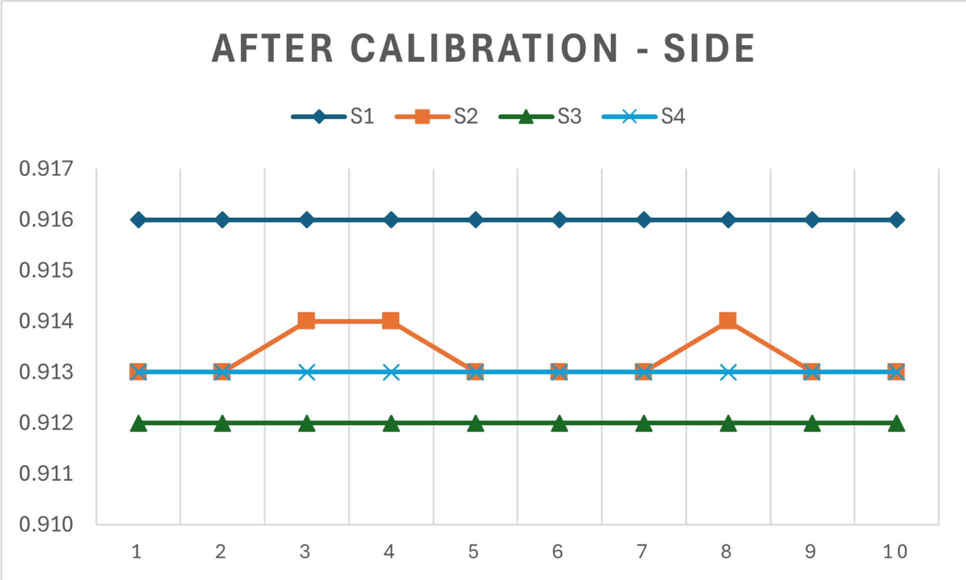

Figure 5.11: After Calibration Line chart (Side)

The experiment restarted 10 times while keeping the scales calibrated after 1 day, applying the 0.910-kg weight. In this experiment, there were some differences in weight, including 0.004, 0.002, 0.001 errors each from Scale 1, 2 and both Scale 3 and 4, as shown in Table 5.7. From the table, it is also shown that during the last three tests, the weight output from Scale 2 rose to 0.913kg.

Times	*S1*	*S2*	*S3*	*S4*
1	0.914	0.912	0.911	0.911
2	0.914	0.912	0.911	0.911
3	0.914	0.912	0.911	0.911
4	0.914	0.912	0.911	0.911
5	0.914	0.912	0.911	0.911
6	0.914	0.912	0.911	0.911
7	0.914	0.912	0.911	0.911
8	0.914	0.913	0.911	0.911
9	0.914	0.913	0.911	0.911
10	0.914	0.913	0.911	0.911

Table 5.7: After Calibration - Side (After 1 day)

Figure 5.12 displays the findings in a line chart, showing the linear lines for four scales after the assessment.

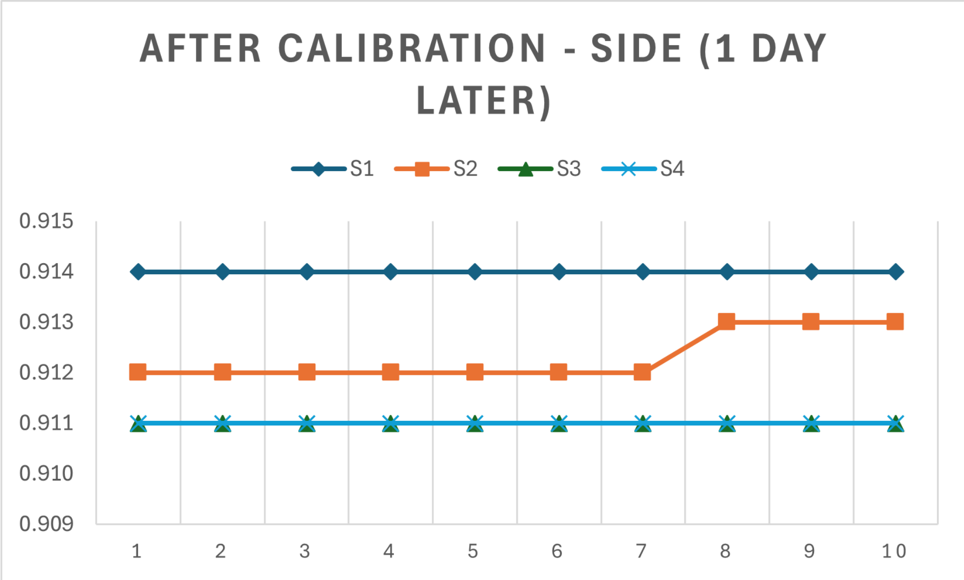

Figure 5.12: After Calibration Line chart (Side - 1 day later)

The test was conducted again using identical procedures three days after the initial phase, testing the weight of 0.915kg. With the same weight output across all testing periods, the line trends for all four scales are more linear. However, there were still some errors, including a 0.003 difference from Scale 1 and 0.001 errors from both Scale 2 and 4, compared to the actual weight. The average results are shown in Table 5.8.

Times	*S1*	*S2*	*S3*	*S4*
1	0.918	0.916	0.915	0.916
2	0.918	0.916	0.915	0.916
3	0.918	0.916	0.915	0.916
4	0.918	0.916	0.915	0.916
5	0.918	0.916	0.915	0.916
6	0.918	0.916	0.915	0.916
7	0.918	0.916	0.915	0.916
8	0.918	0.916	0.915	0.916
9	0.918	0.916	0.915	0.916
10	0.918	0.916	0.915	0.916

Table 5.8: After Calibration - Side (After 3 days)

The assessment findings after ten runs are displayed in Figure 5.13, with lines for each scale. The graph indicates that the lines are more linear than the first ones.

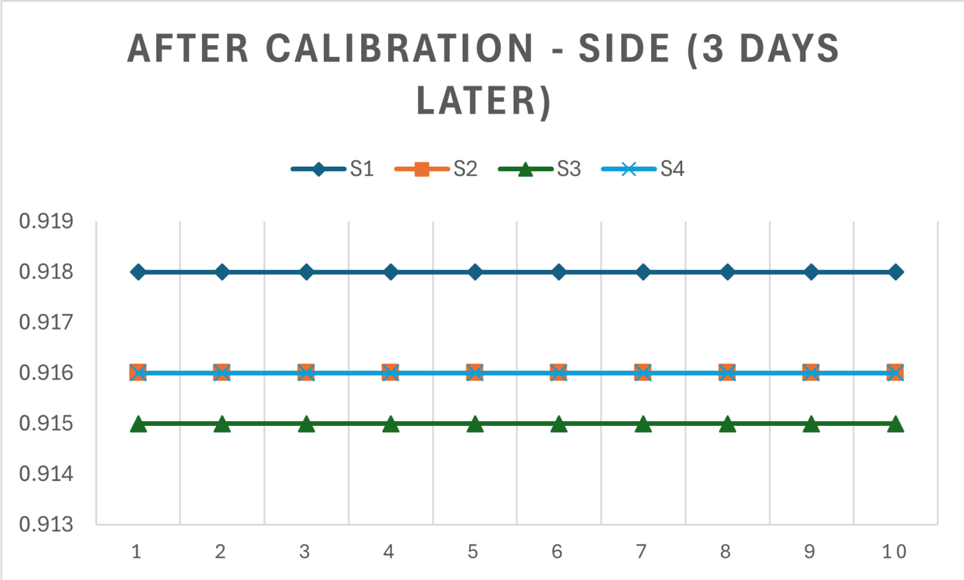

Figure 5.13: After Calibration Line chart (Side - 3 days later)

5.1.2. Experiment 2: User Study On The Impact of Flavor and Their Overall Judgment

This experiment aims to investigate the impact of food flavor, precisely the taste and smell of the snack, on the participants by integrating the Smart Scale hardware system. This experiment was carried out after the Sweet-liking Phenotypes Test [35] of the SenseXP research group, with the purpose of exploring the sensory awareness of three types of participants: Extreme sweet likers (ESL), Moderate sweet likers (MSL), and Sweet dislikes (SD).

5.1.2.1. Design and Procedure

The experiment *Flavor Judgment Test* was carried out with 5 participants based on the 5-user rule [36] for user testing. Each participant was required to join in three sessions on one test day. Their meetings were booked beforehand via Google Forms, in which they had to fill out their personal information, such as occupation and age.

Since this experiment required tasting and smelling, the participants must also note their personal health information. This included aspects such as smoking habits, test stimuli allergies, or any illness when they filled out the forms.

During Session 1, the participants would be given an Information Sheet - providing them with general information about the experiment - and the Consent Form to sign in. After signing the form, participants would perform the procedure required, which included observing the snack on the weighing scale and answering **Session 1 Visual Analogue Scale (VAS) [37] and Generalized Labeled Magnitude Scale (gLMS) [38] Questionnaires**, consisting of questions of their experiment on their experience.

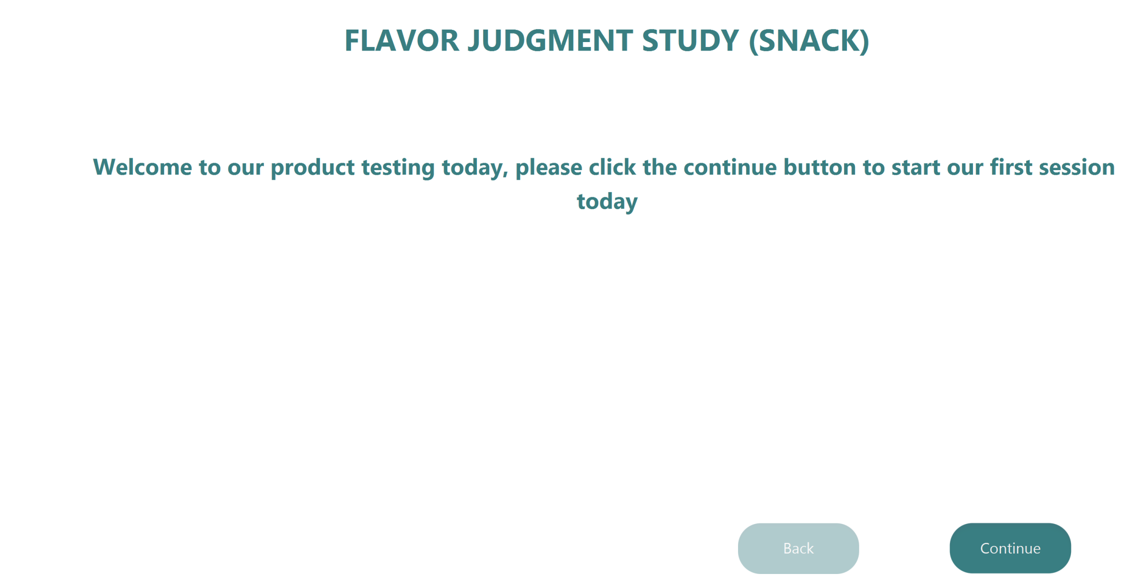

Figure 5.14: Experiment 2: Session 1 introduction

During Session 2, participants were required to smell and taste the snack and answer another set of **Session 2 Questionnaire**, which also contained questions regarding their experience during the smelling process. The testing and questionnaire-filling processes were carried out simultaneously during this session, and the participants had to follow the instructions displayed on the software provided by the research group. In the middle of the experiment session, participants were also given a set amount of time to rest before following through with the rest of the procedure.

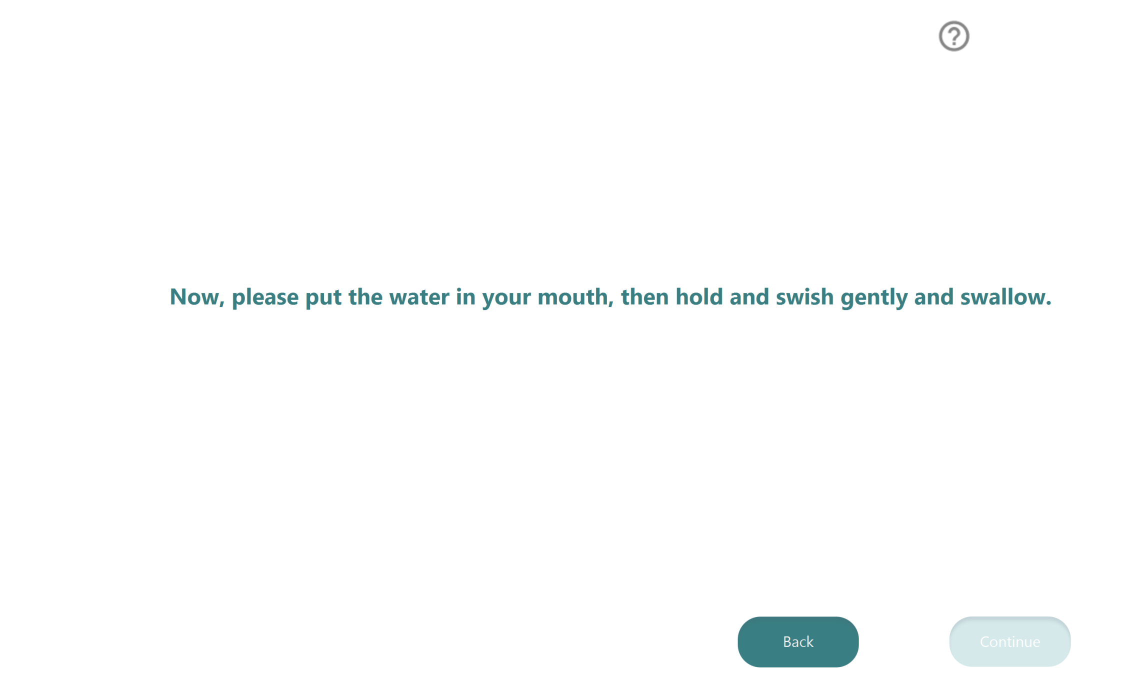

Figure 5.15: Experiment 2: Session 2 instruction

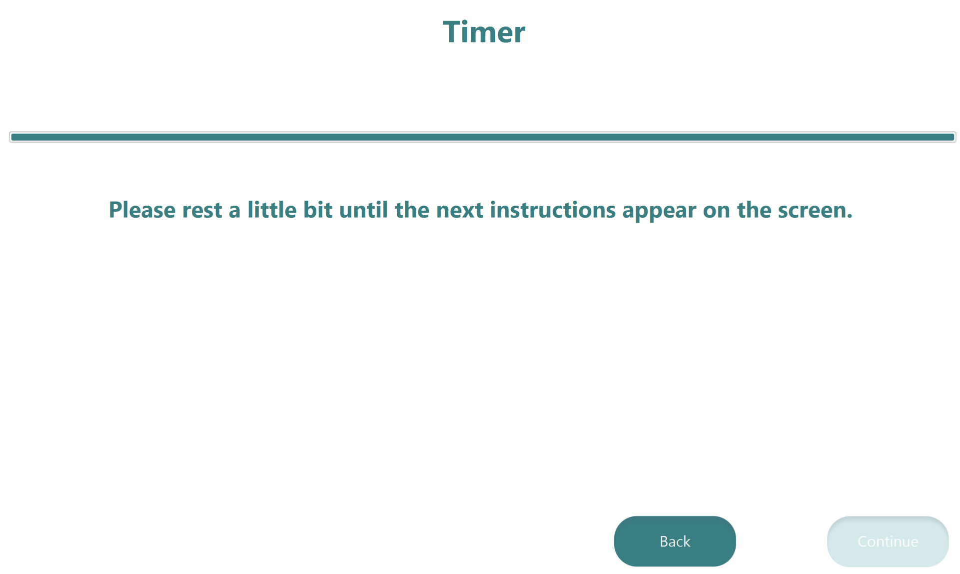

Figure 5.16: Experiment 2: Session 2 rest time

During Session 3, participants had to fill out a **Mood and Affect Assessment Questionnaire (MAAQ)** after smelling and tasting the snack. This questionnaire evaluates their emotional and physical states post-experiment and consists of VAS questions regarding their overall experience and judgment. After filling out the MAAQ, they would be given gratitude from the research team for participating in the study.

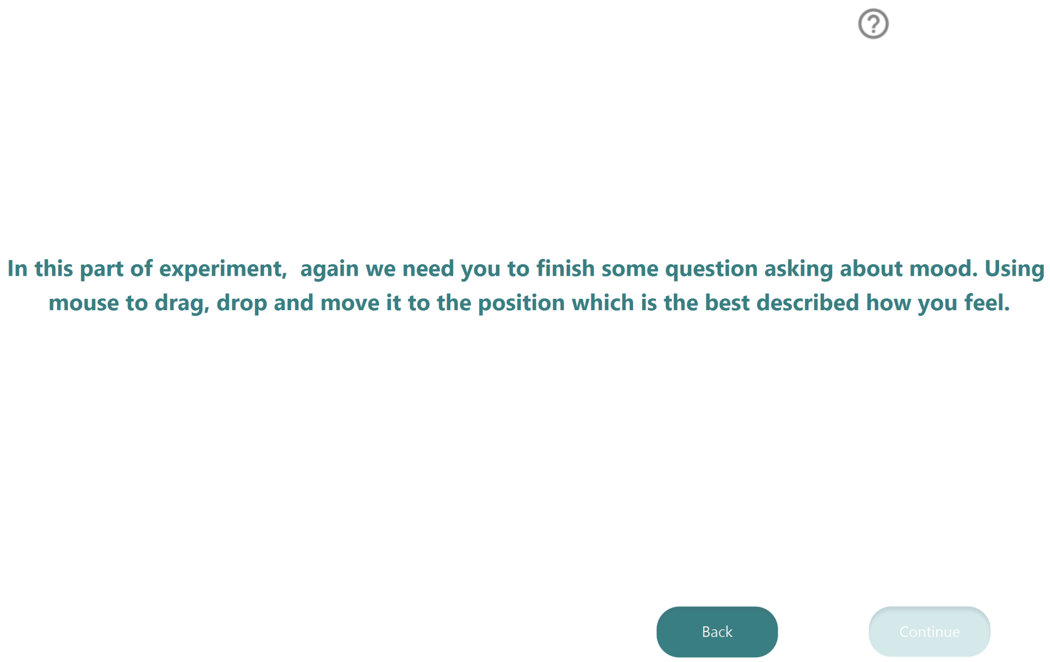

Figure 5.17: Experiment 2: Session 3 instruction

The explanation for the sheets and forms mentioned above in detail are:

- **Information Sheet:** The document provides necessary information about the experiment the participants were about to join. This includes:

  - Study Title and Invitation Paragraph,
  - The study purpose,
  - Restrictions before each session,
  - Potential risks and benefits of taking part,
  - Confidentiality of this research to the provided information,
  - Participants' right to have the result of the experiment,
  - Contact Information.

- **Consent Form:** A list of requirements for the participants to acknowledge their participation in this experiment and ask for their full consent.

- **Session 1 Questionnaire:** This questionnaire is displayed by the software during Session 1 of the experiment after the snack observation from the participant. This includes:

  - ***Part 1: Snack Preference:*** using a continuous scale, ranging from one extreme (i.e., "Extremely like") to the other (i.e., "Not at all like"), this part asks for the participant's experience on:
    * How much they like it,
    * How much they like to eat it,
    * How full they will feel after eating this snack.

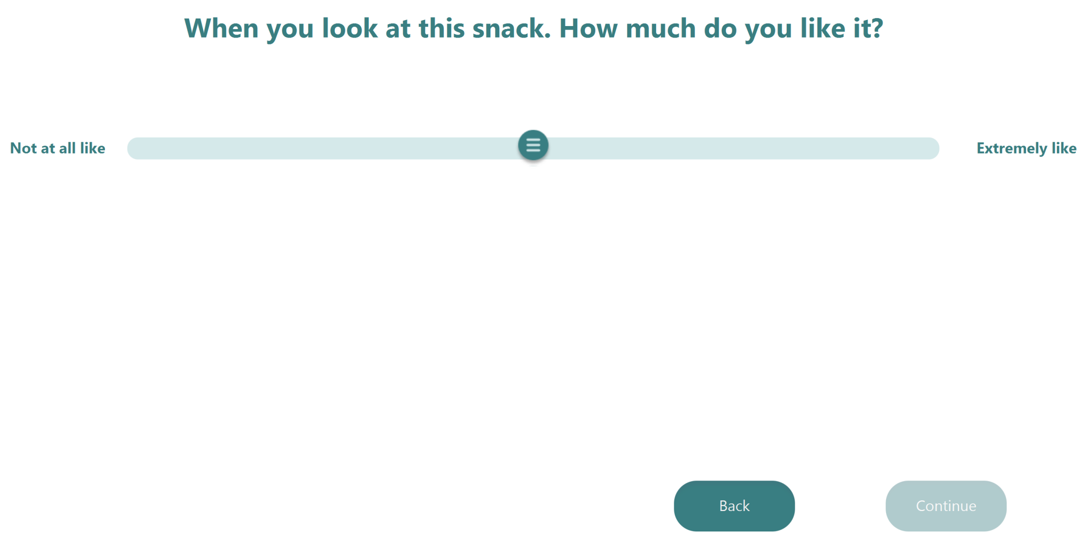

Figure 5.18: Experiment 2: Session 1 VAS question

  - ***Part 2: Snack Flavor Imagery:*** using GLMS, ranging from No Sensation to Strongest Imaginable, this part asks for the participant's perceived intensity of the snack taste by imagining eating the snack, regarding the sensory attributes of:
    * How bitter they think it will be,

  * How sweet they think it will be,
  * How sour they think it will be,
  * How salty they think it will be.

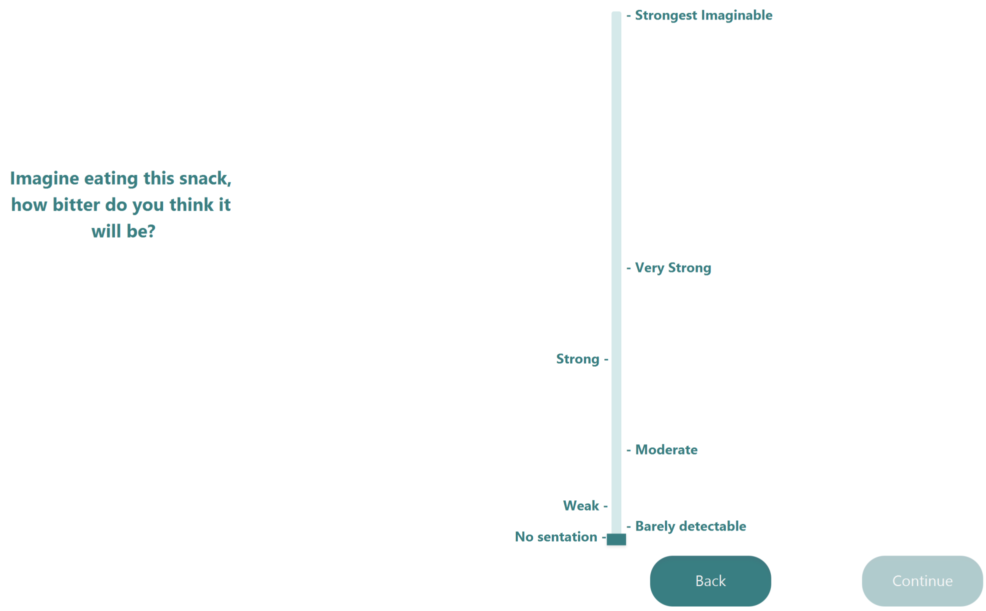

Figure 5.19: Experiment 2: Session 1 GLMS question

- Thank you note.

- **Session 2 Questionnaire:** This questionnaire is displayed by the software during Session 2 of the experiment, in which the participant had to answer each question displayed after each step of the procedure, including smelling and tasting the snack. This includes:
  - ***Part 1: Sensory and Fullness Perception:*** using a set of VAS questions, ranging from one extreme to the other, this part asks the participant their feedback on:
    * How much they like it,
    * How much they like it after smelling the snack,
    * How full they will feel after eating the snack when looking at it.

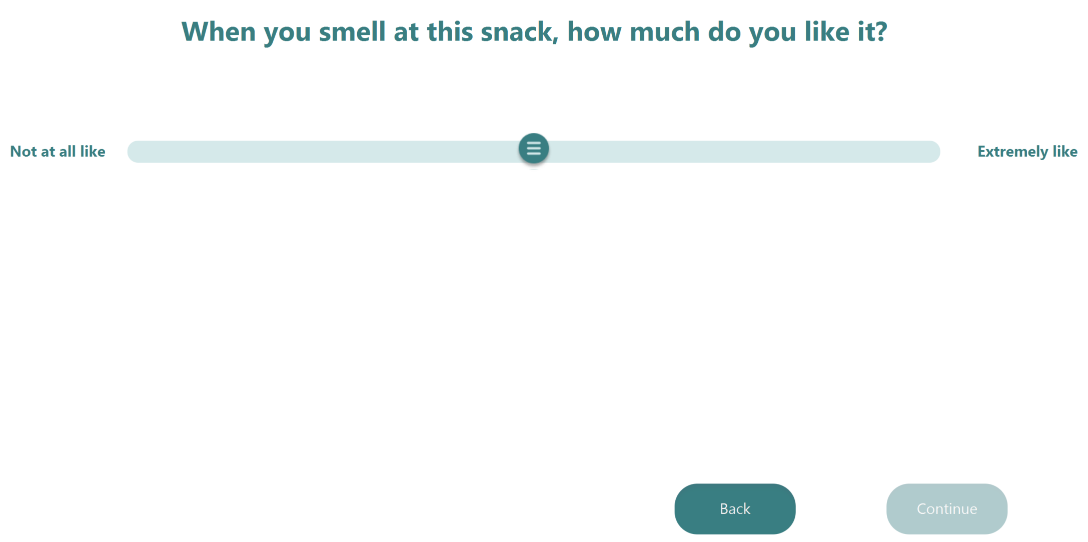

Figure 5.20: Experiment 2: Session 2 VAS question

- ***Part 2: Snack Flavor Imagery:*** using GLMS, ranging from No Sensation to Strongest Imaginable, this part asks for the participant's perceived intensity of the snack taste by imagining eating the snack, regarding the sensory attributes of:
  - How bitter they think it will be,
  - How sweet they think it will be,
  - How sour they think it will be,
  - How salty they think it will be.
- ***Part 3: Snack Flavor Assessment:*** using a set of VAS questions, ranging from one extreme to the other, and GLMS questions, this part asks the participant their feedback after eating two pieces of snack:
  - *VAS questions:*
    - How much do they like it?
    - How much do they like to eat this?
    - How full do they feel after eating this snack?
  - *GLMS questions:*
    - How bitter does it taste?
    - How sweet does it taste?
    - How sour does it taste?
    - How salty does it taste?
- ***Part 4: Emotional and Mental States Assessment:*** This part takes the feedback from the participant regarding their overall experience after eating the snack, assessing their emotions ranging from one extreme to the other:
  - Exhaustion,
  - Happiness,

    * Hunger,
    * Thirst,
    * Nervousness,
    * Satisfaction.

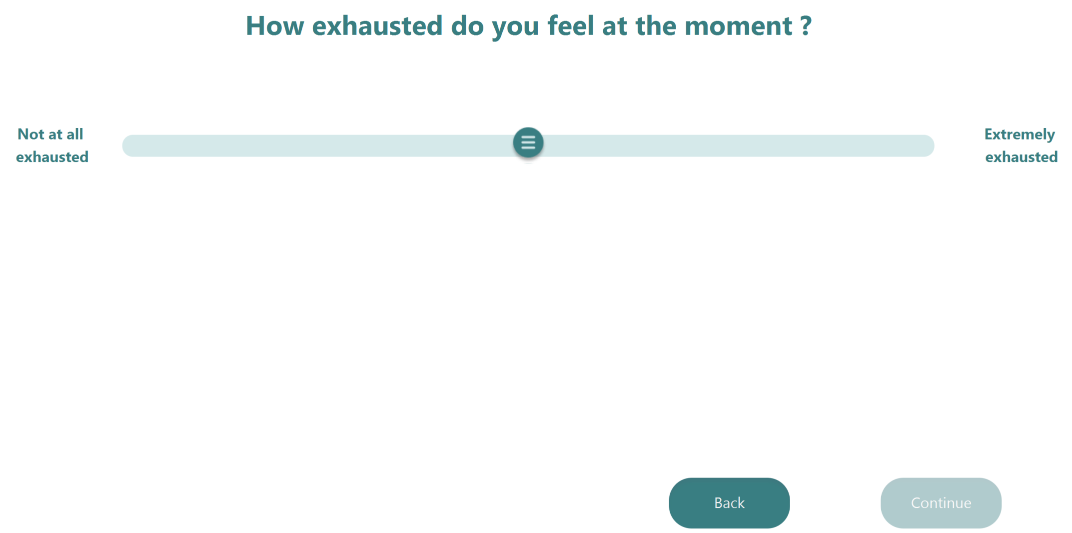

Figure 5.21: Experiment 2: Session 2 VAS question - Emotion Assessment

  - Thank you note.

- ***Session 3 MAAQ:*** The software displays this questionnaire during Session 3 of the experiment after the participant has finished smelling and tasting the snack from the previous session. This includes:
  - ***Emotional and Mental States Assessment:*** This part takes the feedback from the participant regarding their overall experience after the last two sessions, assessing their emotions after finishing the sessions, ranging from one extreme to the other:
    * Exhaustion,
    * Happiness,
    * Hunger,
    * Thirst,
    * Nervousness,
    * Satisfaction.
  - Thank you note.

5.1.2.2. Result

The results show data collected from five participants: demographic information, responses to scenario-based questions, and weight changes recorded by the hardware system during the experiment.

- **Demographic Information:** Before the user study, participants were asked about their profiles and backgrounds, focusing on age, gender, and occupation.
  - ***Age Distribution:*** Three participants were under 25 years old, while only one belonged to the 25-34 years group, and the other was in the 55-64 years.
  - ***Gender:*** 60% of participants were male and 40% were female.
  - ***Occupation:*** 60% of participants were university students, while 40% were university lecturers.
- **Question Responses:**
  - ***Session 1:***
    * *Part 1: Snack preference*

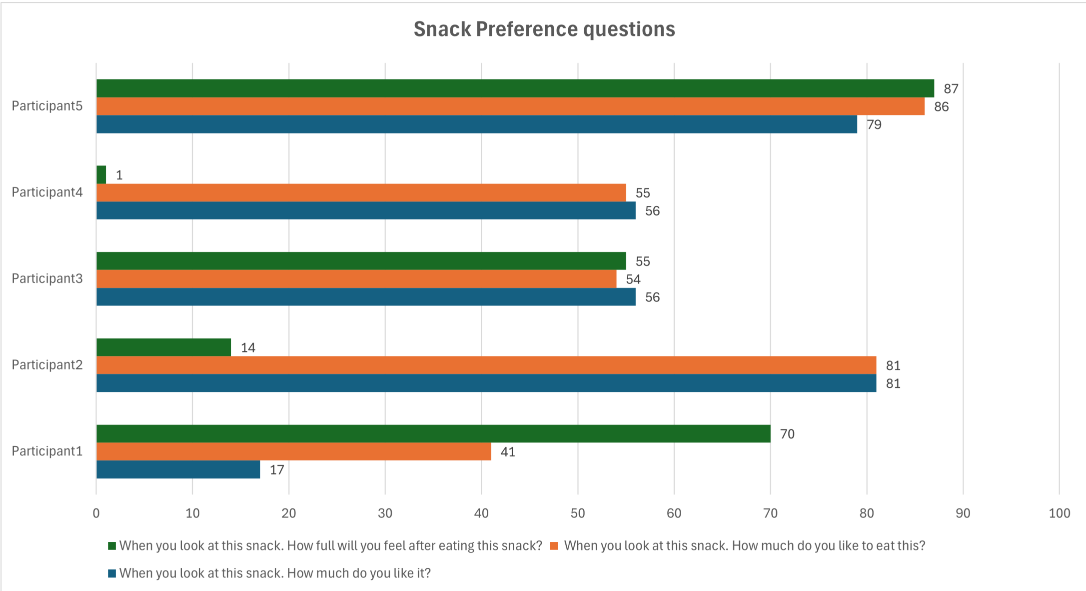

Figure 5.22: Study Result - Snack Preference (Session 1)

In Figure 5.22, when asked about snack preference, from "Not at all" (0) to "Extremely" (100), only one participant answered they almost did not like the snack at all, while the others were either neutral or preferred it. Almost all participants would like to eat the snack, and only two participants would not feel full after eating it.

    * *Part 2: Snack flavor imagery*

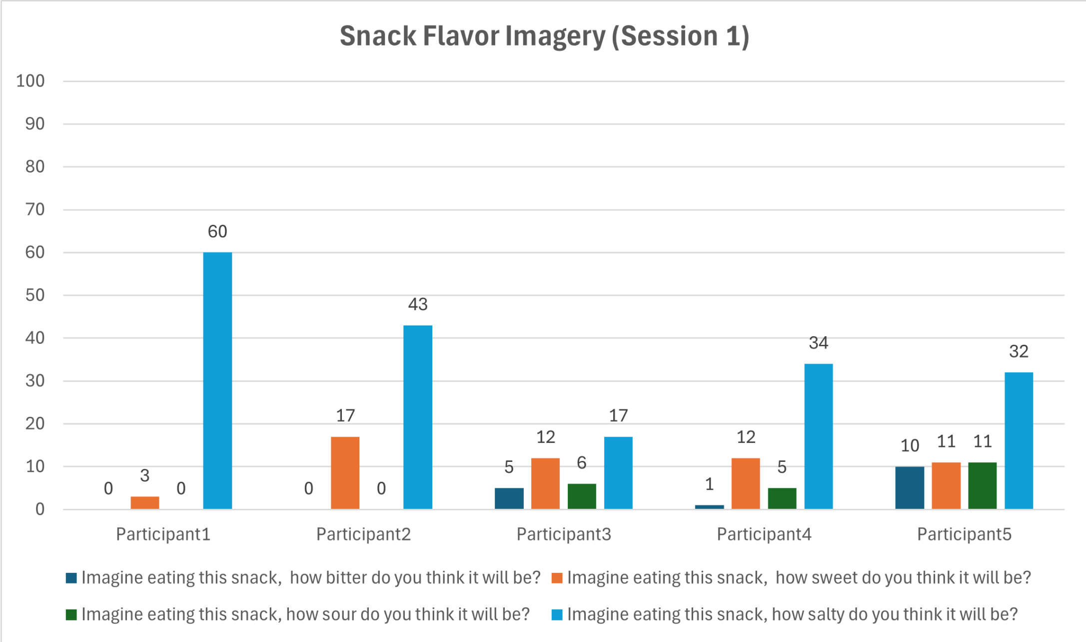

Figure 5.23: Study Result - Snack Flavor Imagery (Session 1)

In Figure 5.23, when asked about snack flavor, ranging from "No Sensation" (0) to "Strongest Imaginable" (100), almost all participants thought that it would most likely be salty, with one of them more confident in that opinion.

- *Session 2:*
  * *Part 1: Sensory and Fullness Perception*

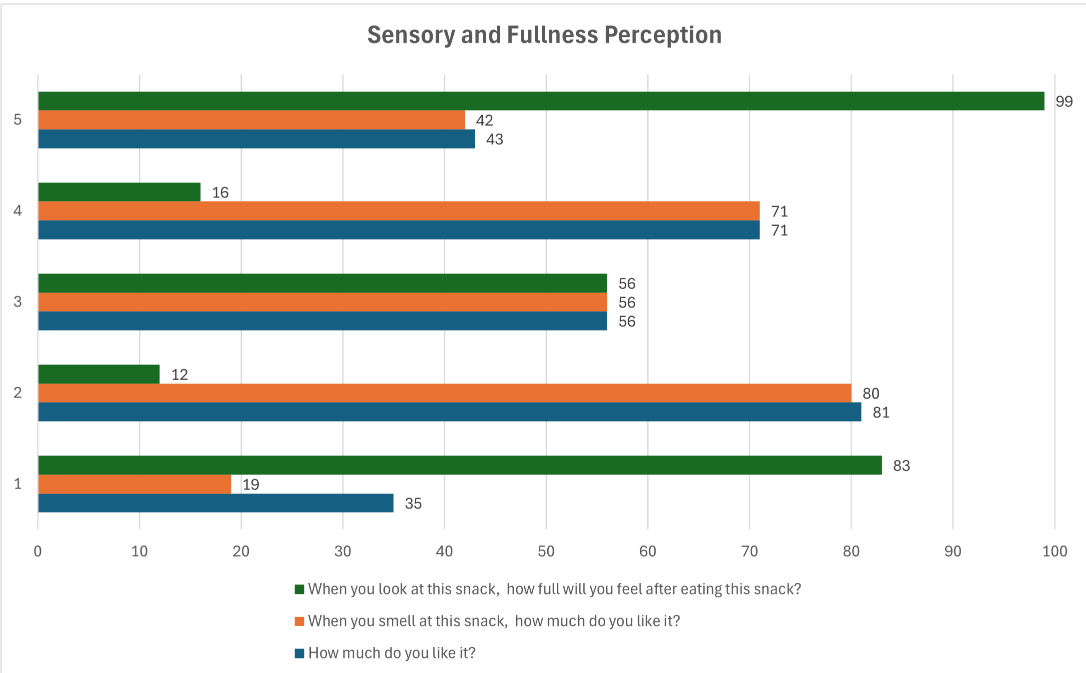

Figure 5.24: Study Result - Sensory and Fullness Perception

In Figure 5.24, more than half of the participants liked the snack before and after smelling it. 60% of them would also feel full after looking at the snack.

∗ *Part 2: Snack Flavor Imagery*

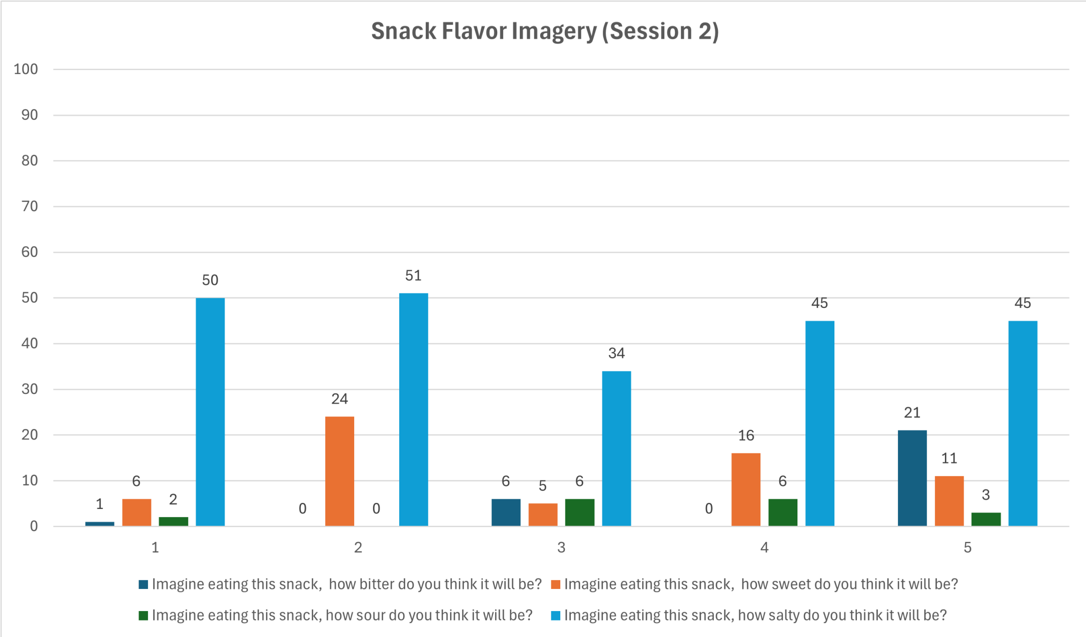

Figure 5.25: Study Result - Snack Flavor Imagery (Session 2)

In Figure 5.25, all the participants thought the snack was salty, while the second-most imagined flavor was sweetness.

∗ *Part 3: Snack Flavor Assessment*

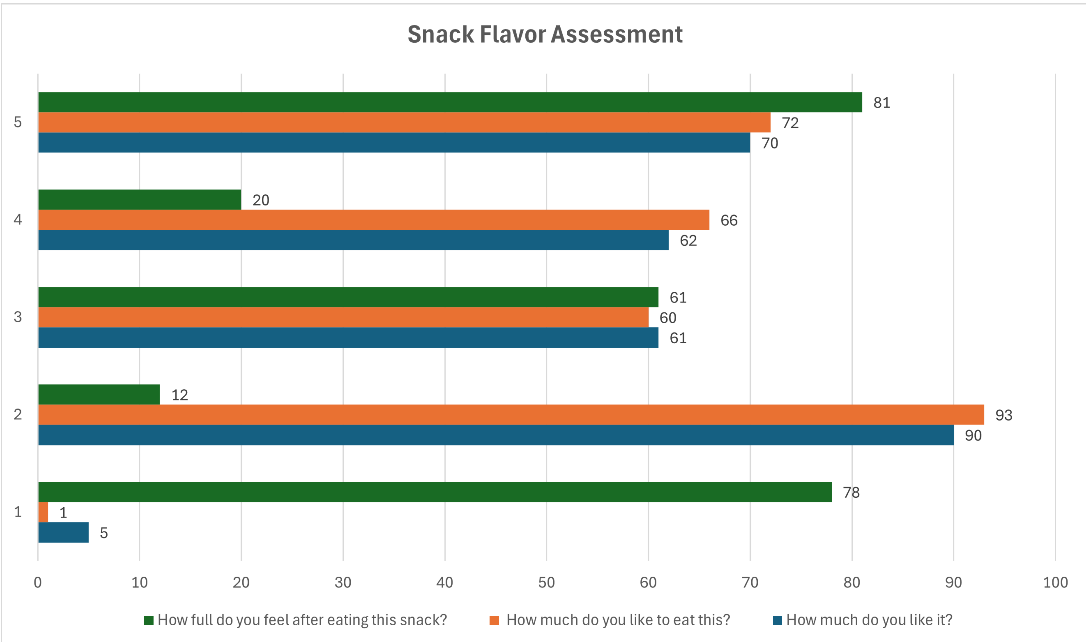

Figure 5.26: Study Result - Snack Flavor Assessment (VAS)

According to Figure 5.26, after eating the snack, only one participant did not like it and did not like eating it. 60% of the participants felt full after eating the snack.

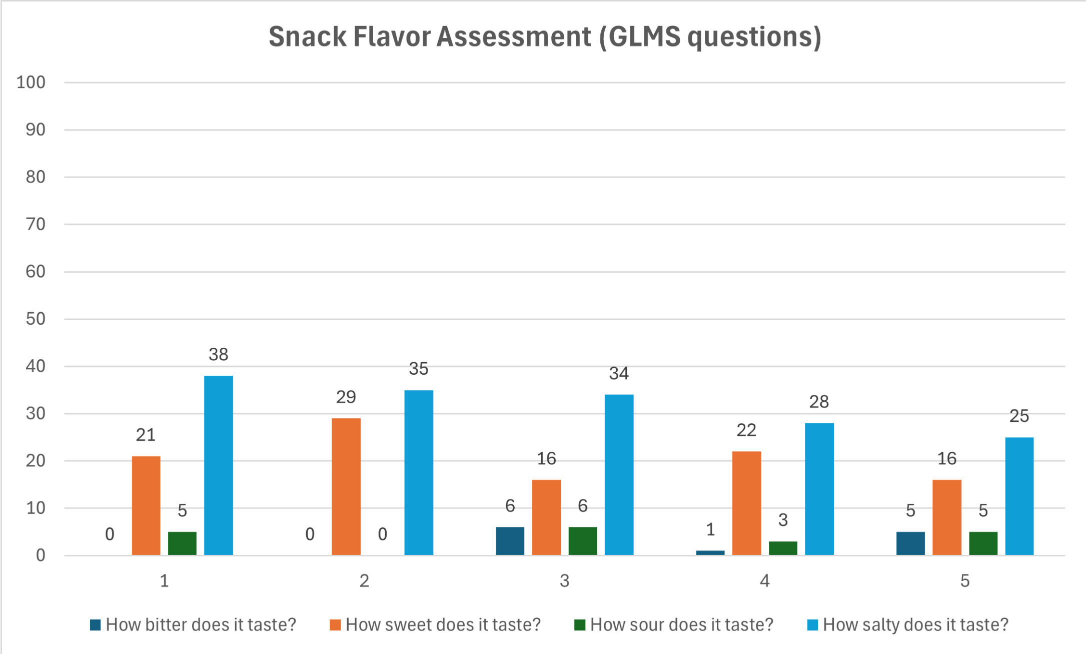

Figure 5.27: Study Result - Snack Flavor Assessment (GLMS)

Based on Figure 5.27, after eating the snack and when being asked about its flavor, the general opinion about it was sweet and salty.

∗ *Part 4: Emotional and Mental States Assessment*

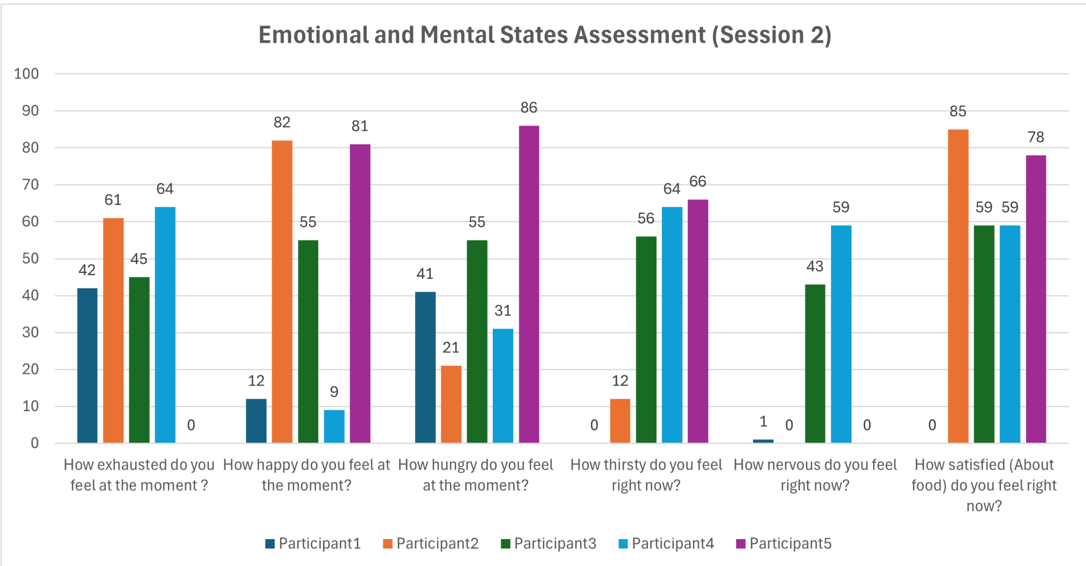

Figure 5.28: Study Result - Emotional and Mental States Assessment (Session 2)

After a short break in the experiment and asked about the participants' current emotional and mental states, according to Figure 5.28, the general feelings were happiness, hunger, and satisfaction. Only two of them felt nervous after the experiment session.

– ***Session 3:***

∗ *Emotional and Mental States Assessment*

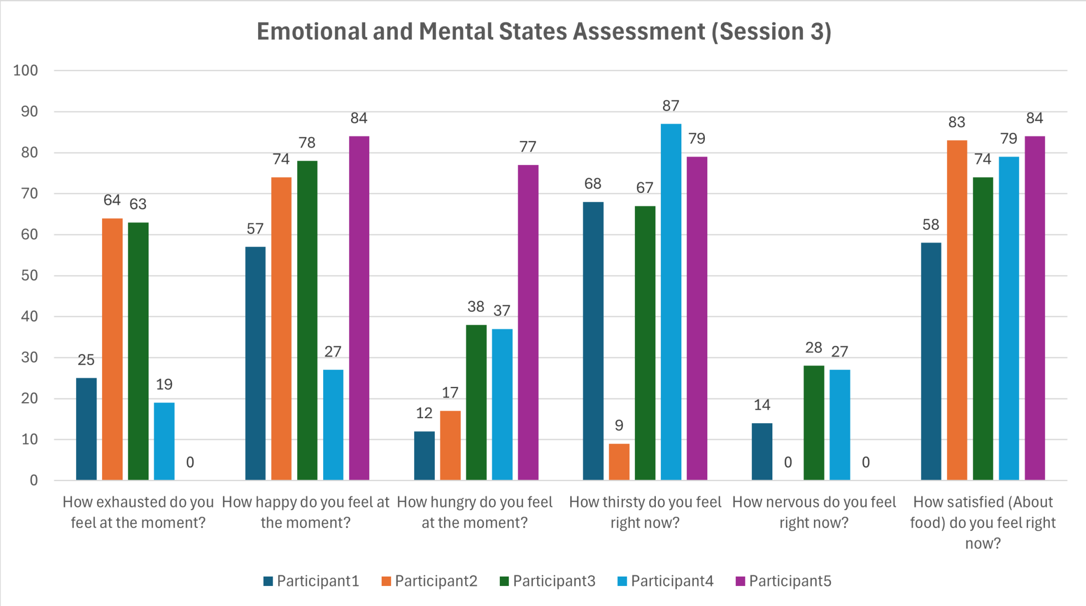

Figure 5.29: Study Result - Emotional and Mental States Assessment (Session 3)

When assessing the participants' moods in this session, Figure 5.29 shows that the majority of them felt happy, thirsty, and satisfied. More than half of the participants also were a little nervous after the experiment.

– **Weighing scale performance:**

During the experiment, the Smart Scale system continuously measured and recorded the weight output until the end. Considering the requirement of returning ten packages in one second for the most accuracy, more than 1000 packages were sent to the software throughout the study for data collection and analysis. While the amount of snacks eaten by the participants was the same for all, the changing patterns recorded by the scale were different:

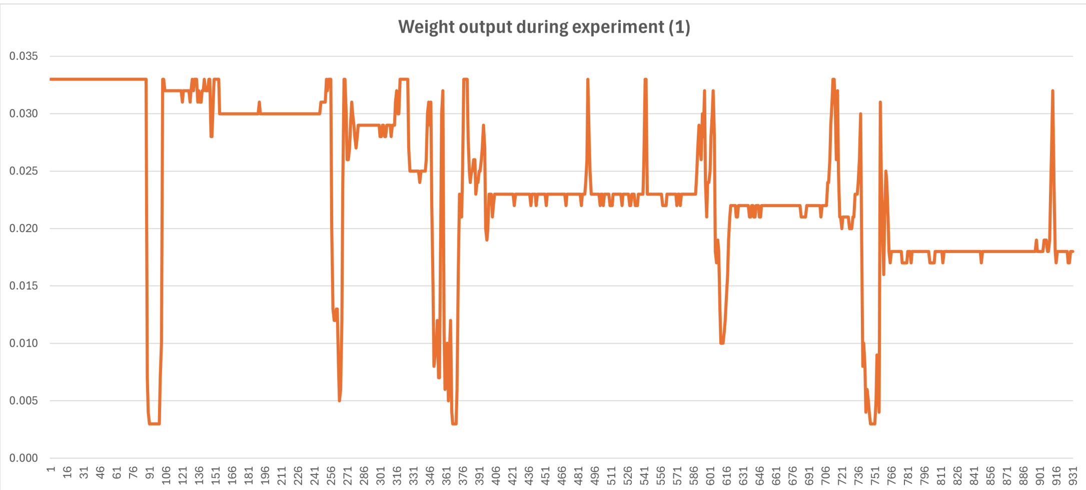

Figure 5.30: Study Result - Weight output pattern 1

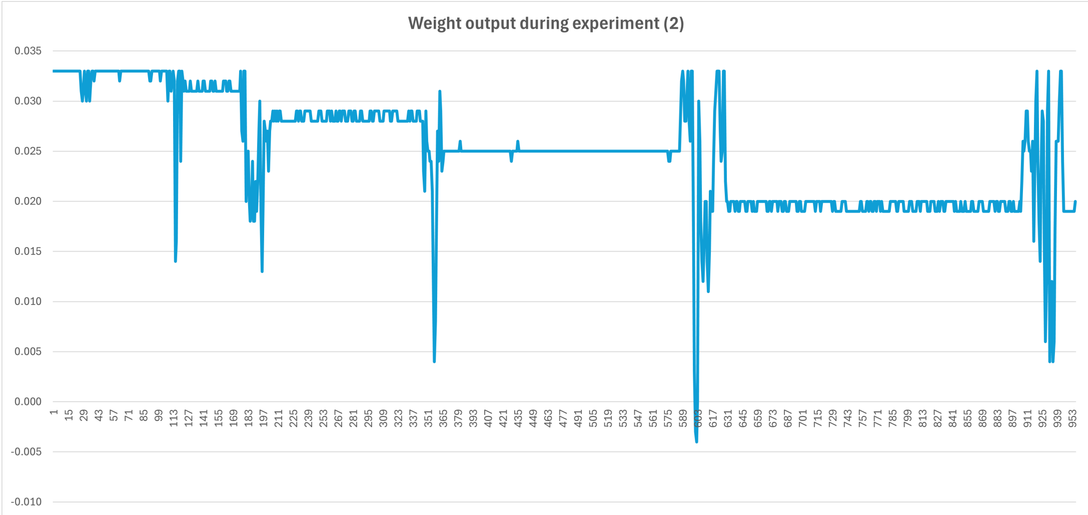

Figure 5.31: Study Result - Weight output pattern 2

However, as can be seen in Figure 5.30 and Figure 5.31, when rounding the results to three decimal places, the line trends both ended at around 0.018-0.019 kg, from the initial weight of 0.033 kg of the snack.

5.2. Discussion

Both experiments explored the efficiency and accuracy of the Smart Scale system when put into practice. While the study on the placement of a specific weight on different positions of the weighing disk proves its precision and longevity over time, the assistance from the hardware system in the second experiment helped explore the users' behaviors with different flavors and their emotional states after consuming.

In the first experiment, the test studies the efficiency of the weighing scales when testing with a known weight and positioning on the least centered place possible of the weighing disk. First of all, the experiment proves that the scale can return more accurate and consistent results with minimum error, rounding to three decimal places because of calibration beforehand. Secondly, the study confirms that with the same calibration factor, the scales can prolong great longevity and endurance over time, judging by the stable and precise results even after three days of testing.

In the second experiment, the study explores the participants' tastes and feelings, with the weight output being recorded by the hardware system. Firstly, the test shows different preferences and flavor predictions from the participants when judging the snack using their vision, smell, and taste. Secondly, the experiment discovered different emotions in the participants during and after the testing sessions. Based on the results, the primary emotions were happiness, hunger, and satisfaction, while only a few were nervous or exhausted.

These feelings can be factors when evaluating and analyzing food consumption in today's society, with aspects to consider, such as the urge to consume more or stop eating or the preference to have something more based on the flavor or personal liking.

During the second experiment, the importance of the hardware system was proven. The constant recording pace of the system, with the ability to output multiple packages in one second, helped the research team take note of not only the continuous changes in weight until the end of the study for each participant but also their eating pace during the experiment phases. Although the changing trends were different for each turn of the experiment, since the experiment durations and executions were not consistent, it is essential to take into account that in various sessions of the test, the weight output recorded when the snack was placed on the weighing scale were nearly identical down to the final weight output with only a few minor errors.

However, it is critical to recognize the limitations. In the first experiment, although being applied with the same weight for each period, the recorded data from each scale were different, especially Scale 1, which had the largest error. Furthermore, based on the line graphs of the data collected from the studies, some unstable parts of the trends show the slight instability of the weighing scales when used for a more extended period in a day. Some potential issues can be pointed out, such as the complexity of wiring the scale or the influence of outside factors, such as hardware placement, subtle impact of sound, or vibration. The hardware system also had some difficulties in weighing heavier objects, evident by the inconsistency of each scale, even though the test results were mostly linear. This requires feedback from the future users of the systems, specifically other researchers or experiment designers, to objectively discover the drawbacks of the hardware.

It is also crucial to note that despite applying the 5-user test, the sample size was small and insufficient to cover the broader aspects of the problem. There are still more aspects that the experiment did not cover, requiring more studies with a larger scale and bigger sample size, especially when dealing with a greater variety of participants of different age groups and preferences. With more improvement for future studies, this can help explore a more thorough understanding of a wider range of aspects that impact people's food consumption habits today.

In summary, the research proves the efficiency of the Smart Scale system, based on its design and implementation, which assists in studying, collecting, and analyzing data from other experiments. Based on the snack provided, the experiment explores different user preferences and taste patterns and how varied emotions can affect their food intake. While there are limitations, this can only leave more space for further improvements and experiences for future studies and analysis.

Chapter 6: Conclusion & Future work

6.1. Conclusion

The study used a set of electrical balances combined with supervisory software to demonstrate the creation of an intelligent system for tracking nutrient intake. Furthermore, the research studies the efficiency of scale sensitivity in recording changes in food weight in connection with the participants' food consumption habits. The finding reveals the contrasting conception of how people judge food based on their vision, smell, and taste. The study also explores how nutrient intake of a specific flavor can affect their emotional and mental states. Furthermore, the studies prove the efficiency of the scales in data collecting and analysis, taking into account their precision and accuracy.

6.2. Future Work

Further improvements and enhancements can be developed and implemented for the hardware by designing and developing more features to boost user experience. Some miscellaneous features are taken into consideration:

- **Stop-and-go light signal:** A light signal system indicates whenever the scales are successfully connected to the hardware and sending the data to process and whenever the scales have stopped sending the results per users' request.
- **LED screens for the scales:** Similar to normal electronic balances, each scale is implemented with an LED screen displaying necessary information such as the scale's name or the dinnerware's weight placed on the disk.
- **Buttons to control the scales:** Multiple buttons can be implemented for the scales for functions such as begin, end the experiment, or reset the weight to zero if the users only count the meal's weight.

Along with providing the hardware with the best quality, users' reviews and feedback are also important for further upgrades or maintenance. Some key areas that have to be taken into account:

- **Clients' reviews and feedback:** Users' reviews and feedback help note which features are the most efficient or which aspects must be improved further. This can help in market research, increase customers' trust, and build a good reputation for product promotion.
- **High accessibility:** For the medical field, the product should be able to be used by people with impairments.

- **Online purchasing methods:** Offering various safe online payment options provides customers with a more convenient buying experience, especially for the target customers in Vietnam. Some methods, such as pay-later options, digital wallets, and payment gateway integration, can be considered.

One of the future upgrades being considered is changing the microcontroller board for the hardware. The main drawbacks of the Arduino UNO R3 are its slow processor speed compared to the other latest controllers and its lack of wireless connection, which is the reason for the complexity of wiring the scales. On the other hand, the NodeMCU ESP-32 microcontroller board can significantly improve the Arduino, with higher processor and clock speed and the ability to control wirelessly with the implication of an I2C connection [39].

Figure 6.1: NodeMCU ESP-32 microcontroller board

Utilizing the ESP-NOW communication protocol [40], each scale would be implemented with an ESP-32 board as a "slave," which would constantly communicate with a master board and send data for it to process, as illustrated as a sample in figure 6.2.

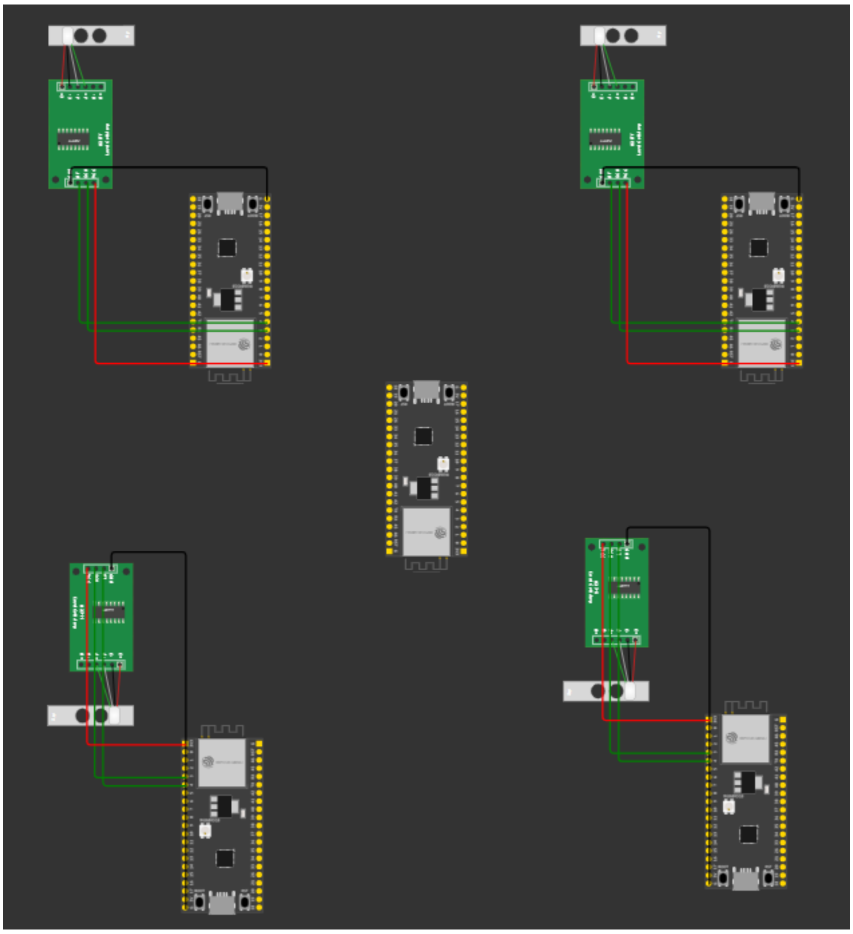

Figure 6.2: Hardware circuit diagram (Using NodeMCU ESP-32)

There are some benefits from this new implementation:

- **Wireless connection:** Since the boards would be communicating by detecting their MAC addresses, the requirement of wiring the scales into one board is no longer necessary.
- **Faster processing speed:** As discussed above, the ESP-32 board has a faster processor speed than the Arduino UNO R3. This would improve its data processing pace and provide better accuracy when tracking the continuous weight change.
- **More cost-efficiency:** ESP-32's market price is lower than the Arduino UNO R3. This can help reduce the manufacturing budget and, as a result, reduce the product price for the customers.
- **Higher number of implementable scales:** The Arduino UNO R3 can only provide enough power to control a maximum of four scales simultaneously. With the implementation of the I2C connection, potentially more than four scales could be controlled and communicated simultaneously.

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