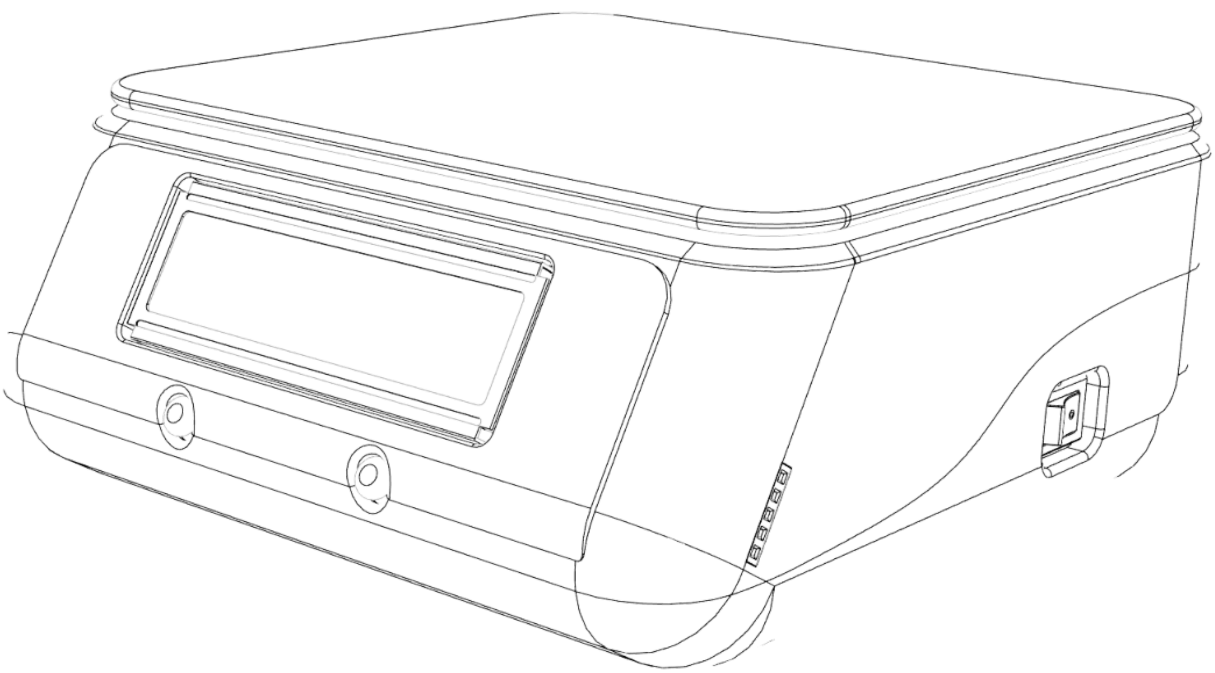
MMT Scale Development Division
Internal Memo

TO: RU Custom Inc.
Author: W.E Chase Quijano
DATE: 12-17-2024

Development of a Custom Digital Scale

Technical Report for Manufacturing and Measurement Techniques



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Executive Summary

This report presents the design, development, and evaluation of a custom digital scale prototype, developed as part of RU Custom Inc.'s new product line. The scale is designed to weigh objects in the range of 0–3 kg with ±1% accuracy. Emphasizing customization, the scale integrates standard components within a uniquely designed enclosure tailored to customer preferences. Key challenges included achieving design precision, manufacturing efficiency, and ensuring robust functionality. The report details the problem definition, objectives, methodologies, and project outcomes.

Objective

The primary objective of this project was to design and develop a functional digital scale prototype that demonstrates the seamless integration of standard components within a custom enclosure. This prototype serves as a proof of concept for marketing customizable weighing appliances.

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Scale Specifications

1. **Measurement Range:** The scale must measure within the 0–3 kg range.
2. **Accuracy:** The scale must achieve ±1% accuracy when reporting values in grams.
3. **Display:** The scale must include an LCD showing weight, and units, and incorporating button functionality.
4. **Tare Functionality:** The scale must include a TARE function.
5. **Units of Measure:** The scale must toggle between at least two units—kg/g and lbs.
6. **Significant Figures:** Displayed values must use appropriate significant digits.
7. **Component Mounting:** Internal components (microprocessor, buttons, etc.) must be rigidly mounted to prevent rattling when the scale is gently shaken.
8. **Power Source:** The scale must be powered by two AA batteries.
9. **Power Switch:** The scale must have an externally accessible power switch (on/off).
10. **Shroud Protection:** The scale shall include an IP31-rated shroud to protect internal electronics. This solids rating must remain intact during battery replacement.
11. **Standard Components:** The scale shall be designed using the standard internal components provided.
12. **Enclosure Size:** The scale enclosure (excluding the weighing tray) shall fit within a cuboid of 75 in^3 total volume.
13. **Shroud Infill:** The scale shroud must be printed with 20% infill or less.
14. **Accessibility:** The scale's internals must remain accessible through engineered fastening solutions; do not glue the enclosure shut. Consider how to change the batteries.

Code Specifications

1. **Platform:** The code shall be written in the Arduino IDE.
2. **Header Documentation:** The code shall include a commented header containing the engineer's name, section number, and a brief description of its functionality.
3. **Line-by-Line Comments:** The code shall be fully documented, including comments for each line to ensure clarity and maintainability.

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Objective Evaluation

The project's success was assessed through a set of criteria to ensure that technical requirements and user considerations were met. The criteria included:

1. Functional Testing: Each prototype underwent testing to ensure that the scale measured weight accurately within the specified 0-3 kg range while maintaining a ±1% margin of error. Calibration tests involve the comparison of measured values against known standardized weights.
2. Aesthetic and Ergonomic Assessment: The enclosure design was evaluated by presenting the prototype to colleagues and professors to receive constructive feedback. Individuals assessed the scale's enclosure's visual appeal, shape, and overall surface finish. Feedback on the ergonomics of the UI, such as button placement and readability of the LCD, as well as ease of accessing the battery compartment, was taken into account.
3. User Experience (UX) Testing: The user experience was tested multiple times throughout the prototyping process. Colleagues would take a look at the scale and test out the multiple features such as toggling between units and utilizing the TARE function. This feedback was taken into account as well for the final design.

The utilization of these evaluation methods ensured that the scale would meet its technical specifications, with the addition of addressing user expectations such as aesthetics, usability, and long-term reliability.

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Enclosure Design

A 3D model was created in Fusion 360, a cloud-based CAD software. Throughout the design process, a multitude of features and aspects of the design requirements were taken into consideration. The approach was to have a sleek and organic design with rounded edges. The enclosure also features a clamshell design with an offset lip that fits the two halves of the shroud together, ensuring resistance to dust and other particles entering the scale. In addition to the clamshell design, brass heat-set inserts were utilized for fastening the entirety of the enclosure together, as well as the PCB and battery compartment cover. This form of fastening ensures structural integrity throughout the enclosure, as well as modularity for potential improvements in the future.

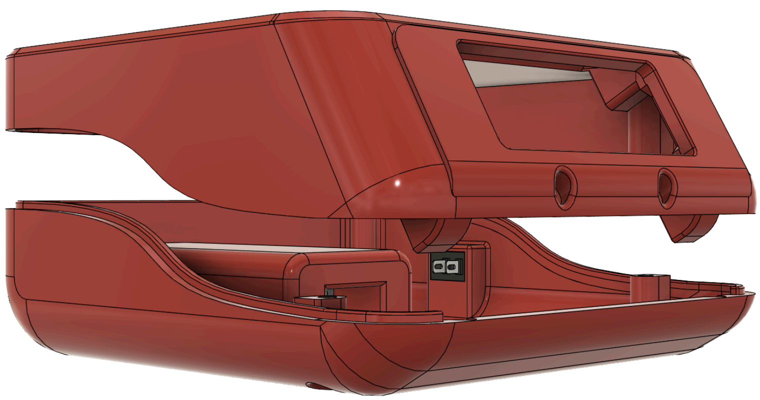

Figure 1.

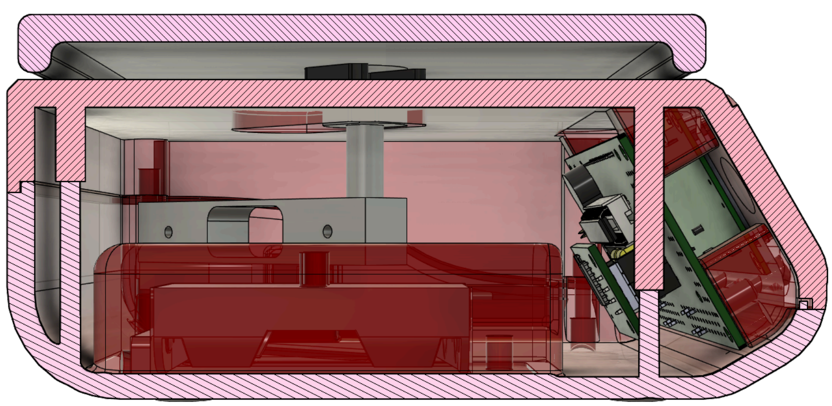

Figure 2.

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Component Integration

Internal components included:

1. PCB
2. Custom load cell
3. Strain Gauge
4. 16 x 2 character LCD Display
5. On/Off Rocker Switch
6. AA Battery Pack Holder
7. Sheet metal Baseplate
8. Load Tray Mount
9. General Block Spacer
10. Load tray

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When considering how all necessary components would be integrated into the final design, all CAD models were created or derived from manufacturer sites and imported into Fusion 360. From there they were arranged into the ideal configuration that would allow for a scale to be designed about the component placement. The PCB interfaces with the LCD directly, allowing pushbuttons to be directly below allowing for an intuitive user experience. With the usage of heat-set inserts, the PCB and Display were designed to be tilted at a 60-degree angle backward and mounted directly to the shroud, with cutouts for the display as well as push buttons.

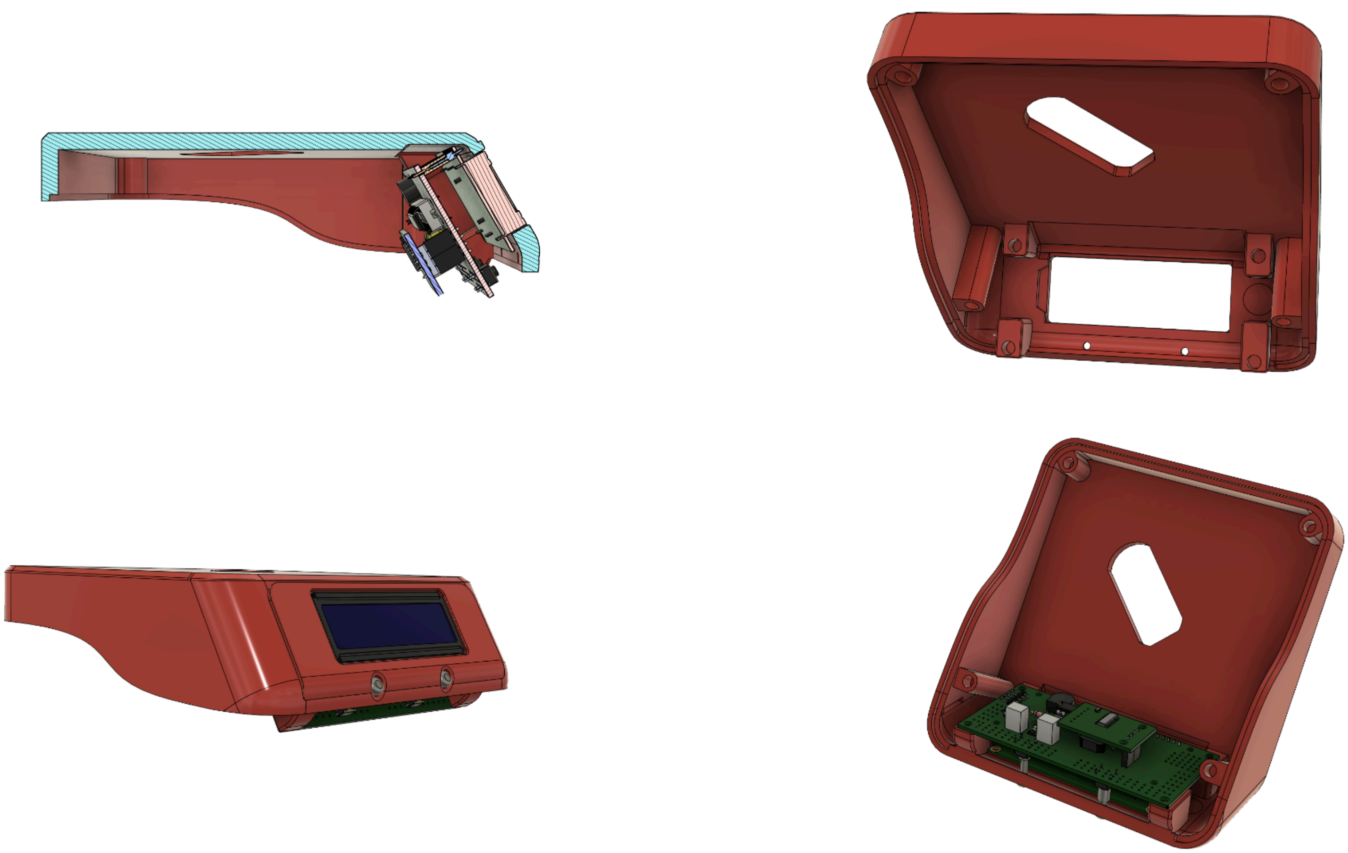

Figure 3.

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The assembly for the entire load cell which includes the sheet metal baseplate, load tray mount, general block spacer, and load tray was designed to have the point of measurement in the center point of the scale. To reach this end goal, the assembly was rotated at a 45-degree angle within the scale whilst keeping the center point fixed. By doing so it allows for the shroud to stay within the dimensional constraints, and prevents the load cell assembly from interfering with other components.

Figure 4.

The On/Off rocker switch was placed flush with the side portion of the shroud to retain an ergonomic design. By doing so it prevents the scale from accidentally being powered on or off when bumped against any objects.

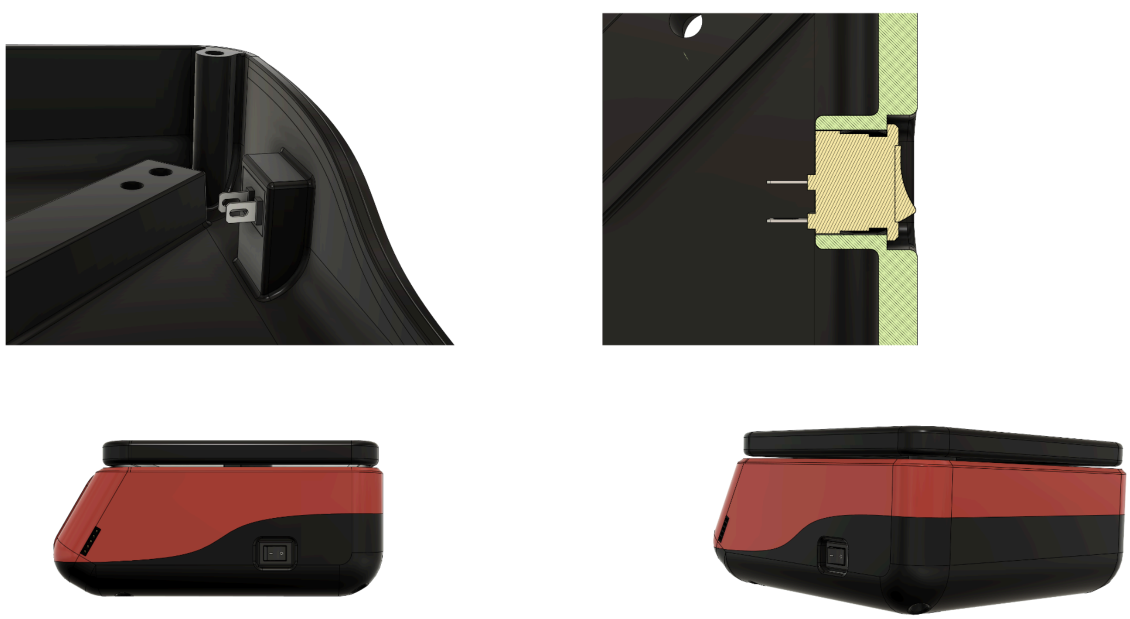

Figure 5.

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The AA battery pack holder placement was seen as detrimental to the user experience during the design process. If it was placed in an inconvenient spot, or with improper fastening it could lead to corrosion of connectors due to being exposed to the elements, or a sensitive power connection leading to unreliability of the overall design. With these aspects in mind, I placed the battery compartment on the bottom of the scale, with a battery cover that fastens into the shroud with the usage of heat-set inserts and neodymium magnets. This allows for the battery pack holder to be securely fastened in the shroud and resilient to any potential drops or vibrations, as well as dust or moisture entering the enclosure.

Figure 6.

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Load Cell Design and Fabrication

The custom load cell, a critical component responsible for translating mechanical force into measurable electrical signals, was machined from 6010 aluminum. This aluminum alloy was chosen for its favorable strength-to-weight ratio, corrosion resistance, and ease of machining. The fabrication process involved CNC milling to achieve precision geometry and consistent dimensional tolerances.

Before machining, a series of Solidworks static stress simulations were performed. These simulations allowed the design team to iterate through various geometries and thicknesses, ensuring the load cell could reliably support loads in the 0–3 kg range while maintaining minimal deflection. By analyzing stress distribution, identifying high-stress regions, and adjusting the design accordingly, an optimal load cell shape was achieved.

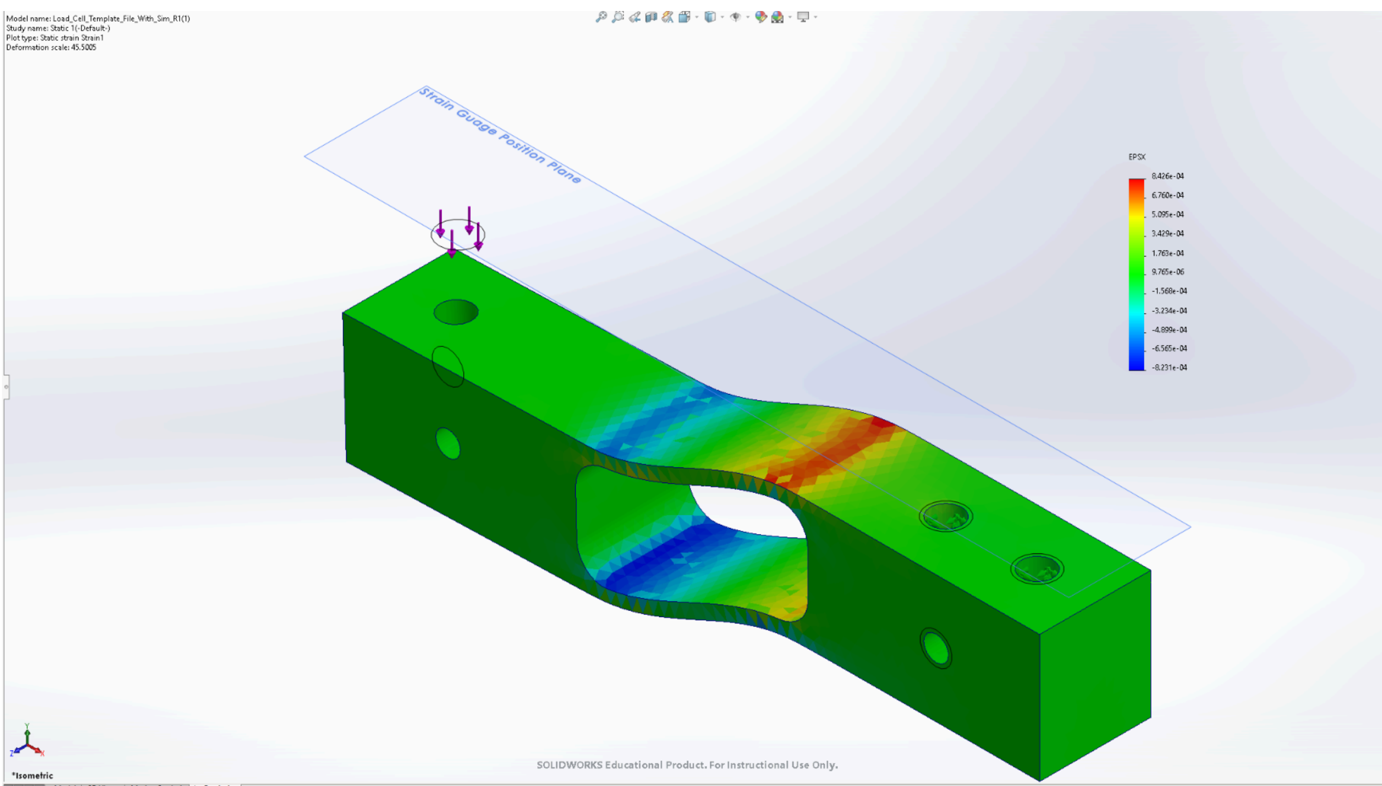

Figure 7.

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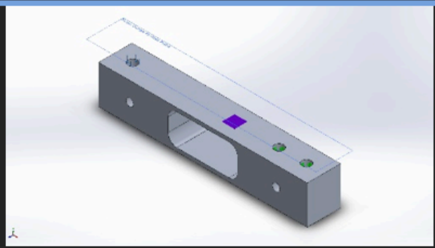
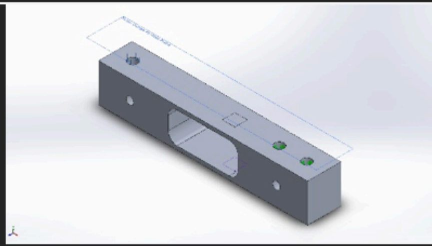
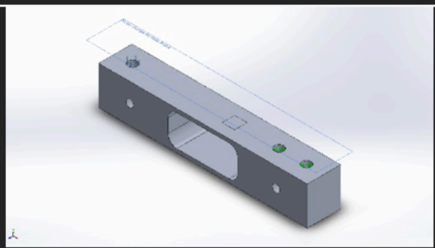
Sensor name	Location	Sensor Details
Top Strain Gauge		Value : 4.443e-04 Entities :1 face(s) Result :Strain Component :EPSX: X Normal Strain Criterion :Average of Selected Entities Step Criterion : Across all Steps Step No.:1 Alert Value: NA
Bottom Strain Gauge		Value : -4.487e-04 Entities :1 face(s) Result :Strain Component :EPSX: X Normal Strain Criterion :Average of Selected Entities Step Criterion : Across all Steps Step No.:1 Alert Value: NA
Minimum Factor of Safety1		Value : 3.840e+00 Entities : Result :Factor of Safety Component :Automatic Criterion :Model Min Step Criterion : Across all Steps Step No.:1 Alert Value: is less than 3

Figure 8.

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During the machining process, a manual bridgeport mill was utilized. First, a technical diagram was drawn up and printed out to establish an order of operations. First, a facing operation was done on either side to have a flat surface to reference from. An edge-finding tool was utilized to find the center point of the stock aluminum material, after that the necessary holes were located and drilled through the usage of the digital readout of the X and Y axes. The holes were threaded carefully with a hand crank threading tool. The part was then placed onto a custom jig that allowed for mounting via the previously drilled holes. From that point on the center pocket was milled utilizing a ¼” end mill, and the exterior dimensions were milled down utilizing the same tool.

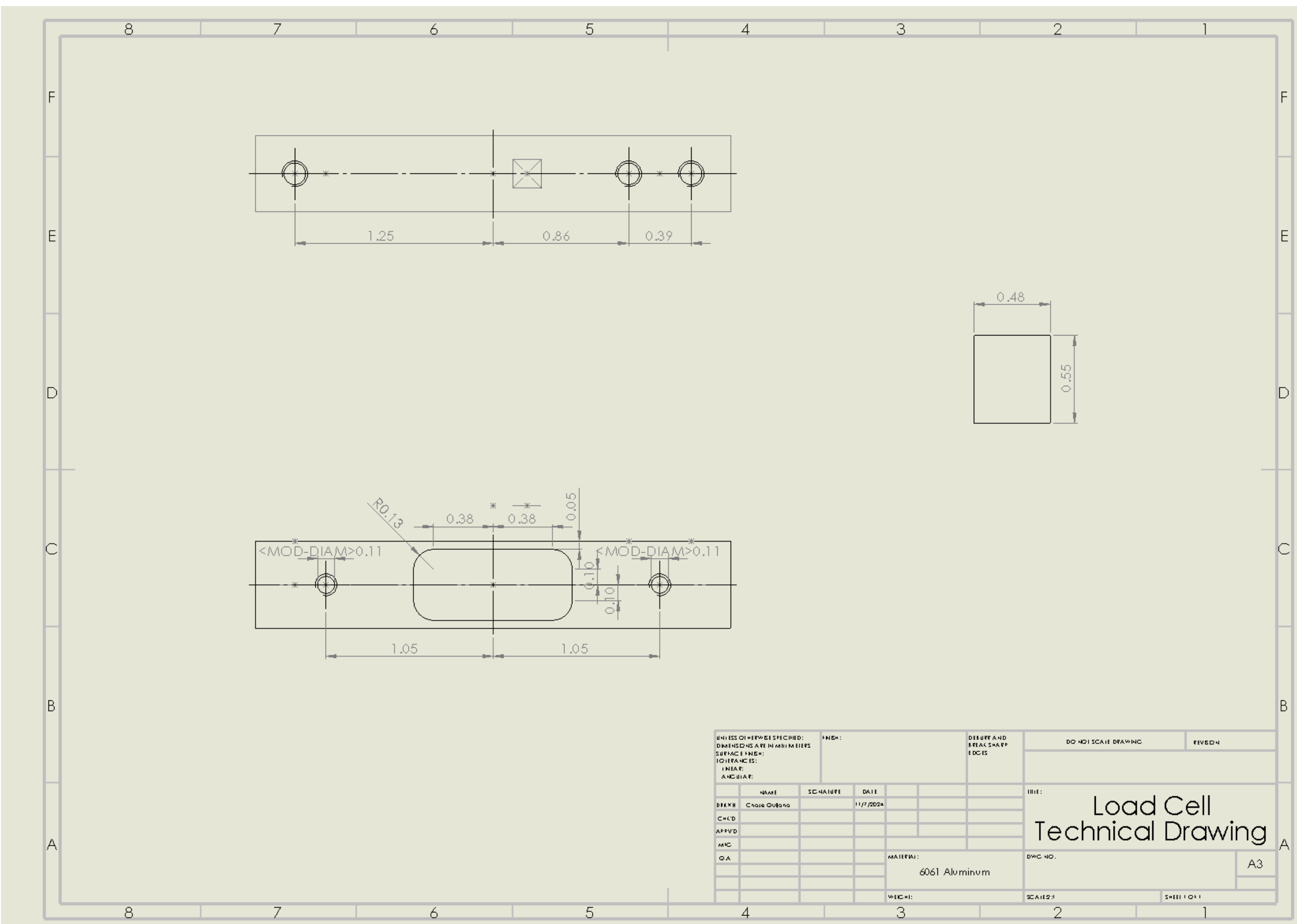

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Figure 10.

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Similar machining processes were done for the standard spacer block and load tray mount. The standard spacer block was done entirely on the Bridgeport mill and then tested with a smoothness gauge in order to ensure it fell within the desired tolerances.

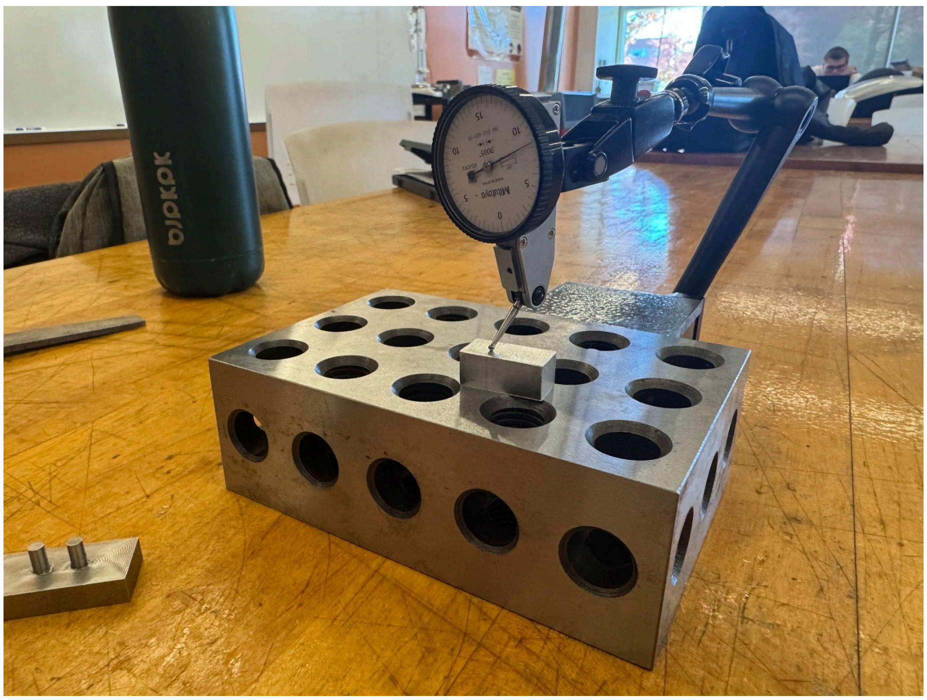

Figure 11.

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The load tray mount however had more complexity regarding the order of operations. Initially, a piece of aluminum stock was turned down to the appropriate dimensions on a manual lathe. In the next step, the part was then transferred to a custom holding jig on the manual Bridgeport mill, where an end mill would mill down the side faces of the load tray mount according to the required tolerances.

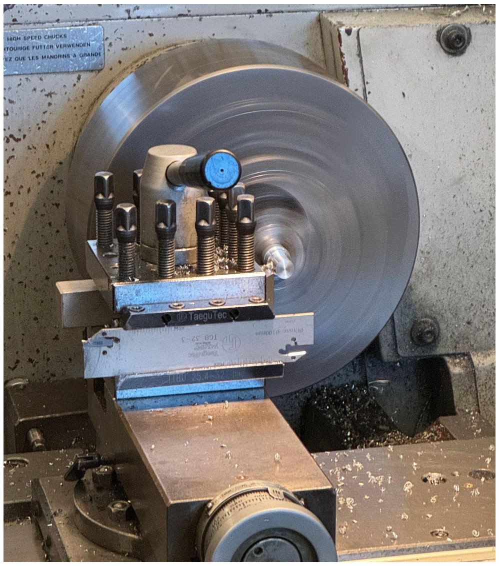

Figure 12.

Figure 13.

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After being machined, the load cell was prepared for strain gauge installation. Surfaces were carefully cleaned, and the strain gauge was sprayed with a glue accelerant. After the application of the CA glue, the strain gauges were carefully placed on the optimal point of stress found during static stress simulations. After installation, the strain gauges were wired into the strain gauge amplifier pcb which amplifies and sends readable values to the microcontroller.

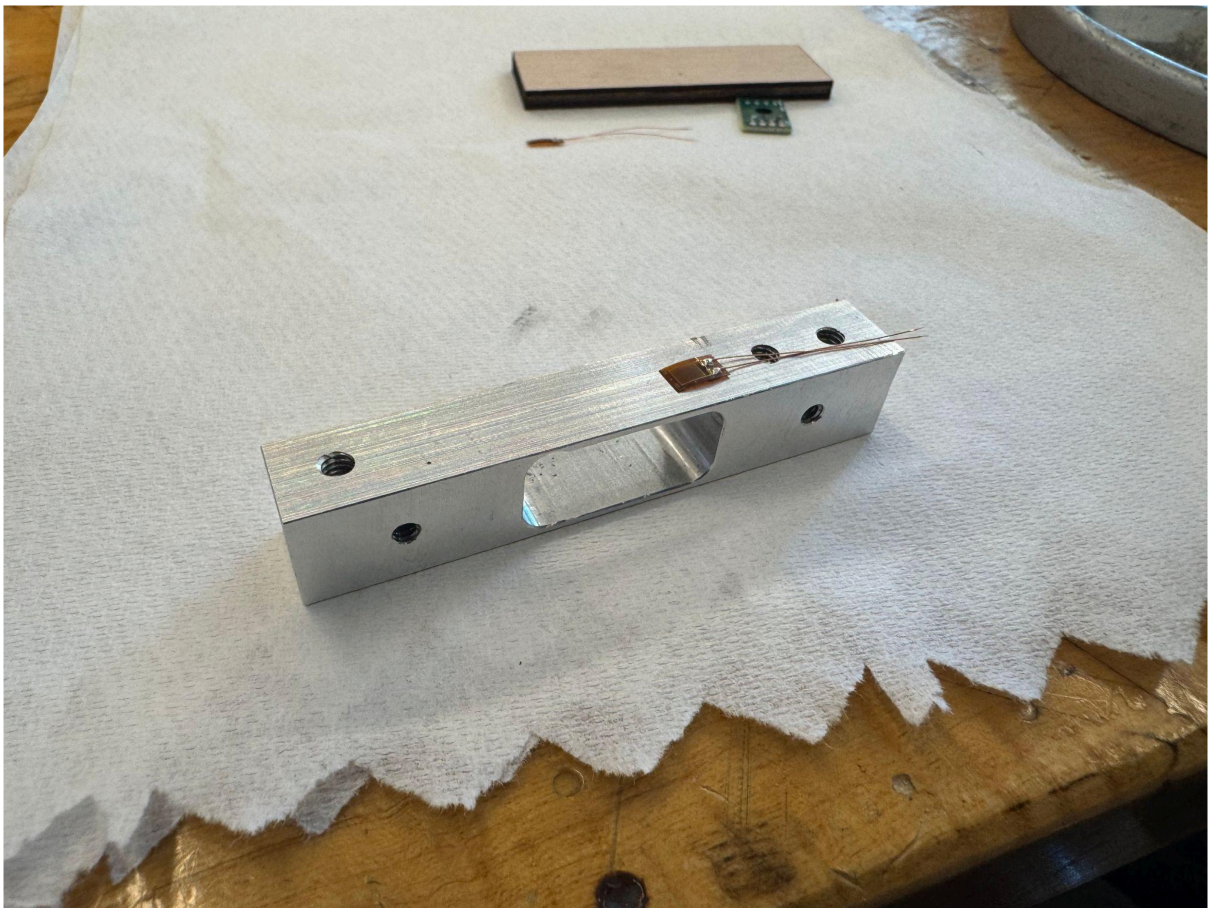

Figure 14.

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Manufacturing Overview

Prototyping:

All prototypes were made using FDM (Fused Deposition Modeling) 3D printing. This rapid prototyping technique allowed for quick refinements in the enclosure geometry and component mounts.

Material Selection:

High-impact ABS Plastic was selected for the enclosure due to its durability as well as resilience to UV Light in a potential scenario involving outdoor usage. The majority of 3D printing was via a Bambu Lab P1S printer, with 10% grid pattern infill. TPU Material was utilized for feet on the bottom of the enclosure as well, this helped prevent vibrations and any slippage that could potentially interfere with the accuracy of readings.

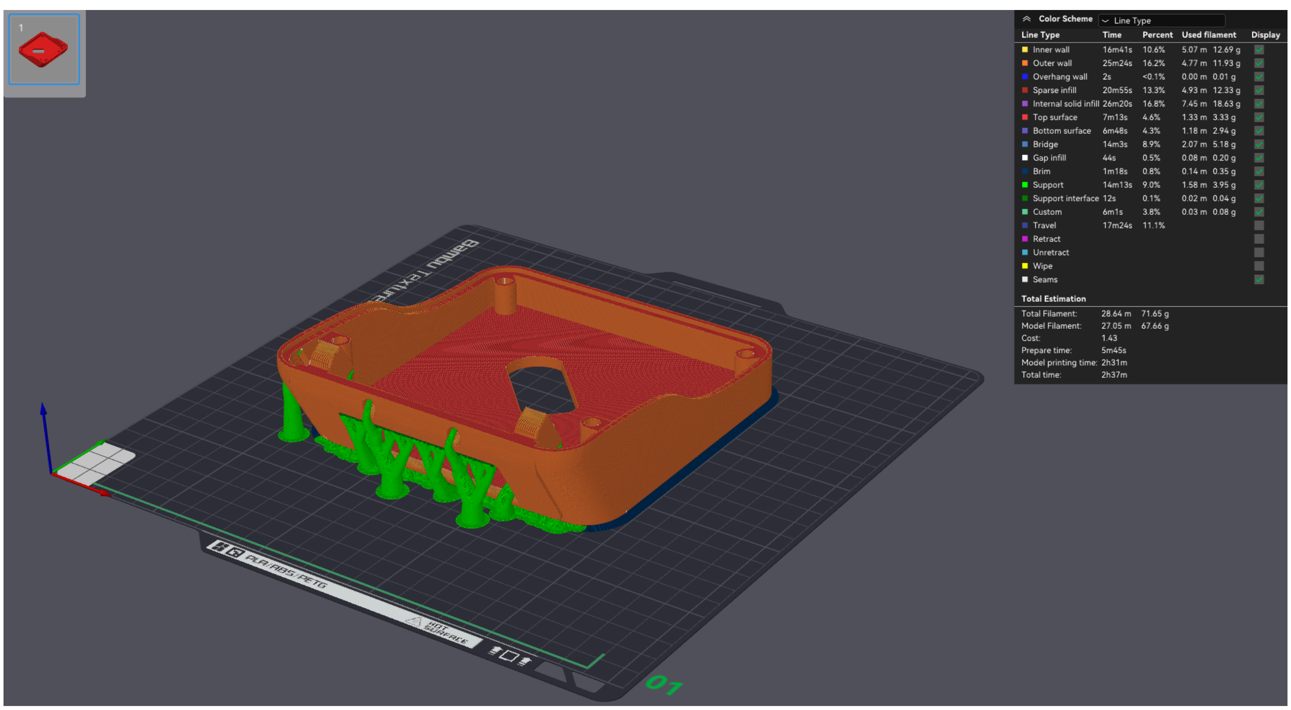

Figure 16.

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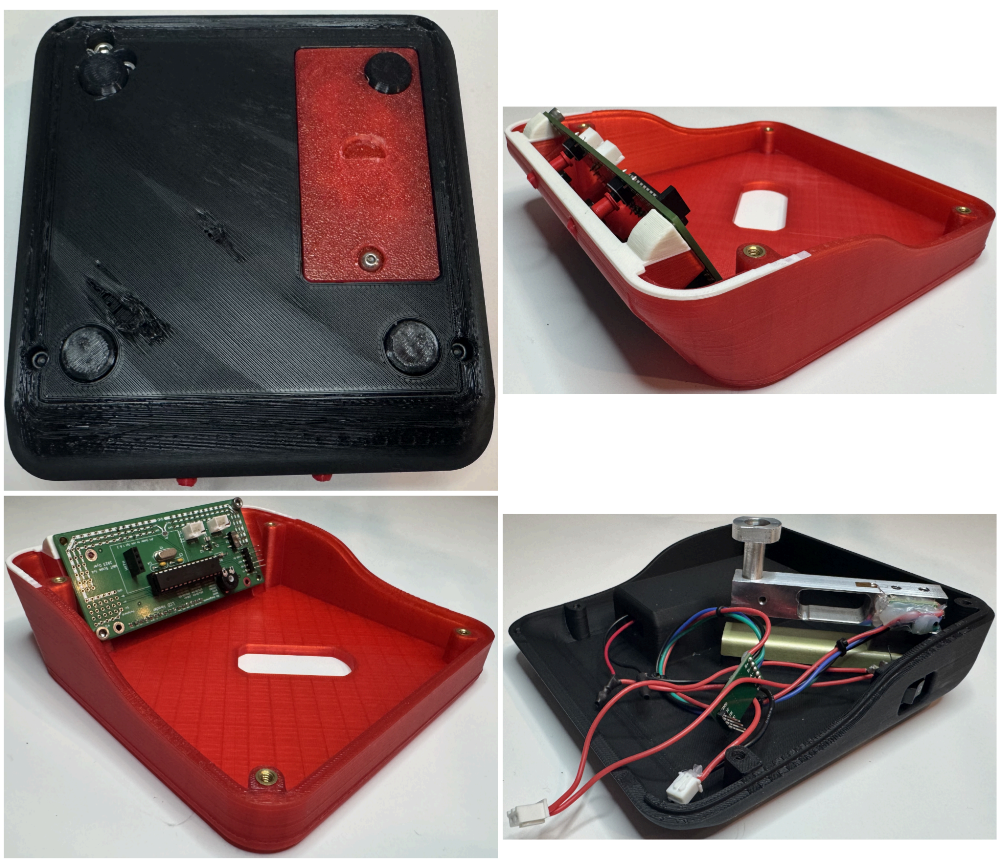
Assembly Process:

After the final 3D printed components were removed from the printer's build plate, support material was carefully removed with pliers and some light sanding. Brass heat set inserts were then inserted into the designated holes in the shroud with a soldering iron jig that goes down in a controlled manner. The PCB was soldered with all necessary components and tested for continuity with a multimeter. The AA Battery holder and power switch required a way to interface with the PCB, so JST connectors were crimped onto both components to allow for easy disassembly. After that, the components were pressed fit into place, and the PCB was fastened down with #6-32 screws into the enclosure with buttons in between that allow for mode selection. The entire load cell assembly was bolted from the bottom up into the threaded portion of the load cell with the utilization of two #8-32 screws. TPU feet were glued into place on the bottom of the shroud, and then the two halves of the shroud could be fastened together with 4 #6-32 screws.



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Code Development and Integration

The control logic for the digital scale was implemented in Arduino IDE. Libraries for the LCD and load cell amplifier (HX711) were utilized. The code was written into distinct steps - initialization, calibration, measurement, user interaction, and display updating. It was vital to ensure the overall load cell was properly calibrated with a standardized weight. A 200g weight was utilized for this calibration process, and the scale was able to achieve readings within a 1% margin of error.

Initialization and Setup:

The code begins by including the necessary libraries, defining pin connections for the load cell and LCD, as well as setting parameters such as the calibration factor. Global variables store the tare value as well as which unit of measurement has been selected by the user.

```
#include <LiquidCrystal.h> // LCD Library
#include "HX711.h"         // Load cell library

#define DOUT 5  // Arduino Pin connection data
#define CLK 4   // Arduino Pin connection data
#define SW2 2   // Right switch (unit swap)
#define SW1 3   // Left switch (tare)

HX711 loadCell;
long tareValue = 0;
double calibrationFactor = 0.0019963; // [grams/ADC value]
...
```

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During the setup, the LCD and load cell are initialized. The scale is tared to reach a baseline zero reading. Having interrupts for the unit switch and tare buttons ensures a fast response time. The code prints out "Initializing…" to the LCD, this is a way of providing real-time feedback to the user while the system is being prepared for usage.

```
void setup() {
  pinMode(SW1, INPUT_PULLUP);
  pinMode(SW2, INPUT_PULLUP);

  attachInterrupt(digitalPinToInterrupt(SW2), sw2ISR, FALLING);
  attachInterrupt(digitalPinToInterrupt(SW1), sw1ISR, FALLING);

  lcd.begin(16, 2);
  lcd.setCursor(0, 0);
  lcd.print("Initializing...");
  delay(2000);

  Serial.begin(9600);
  loadCell.begin(DOUT, CLK);
  tare();

  lcd.clear();
  lcd.print("Ready!");
  delay(1000);
}
```

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This section of the code revolves around the tare functionality. To achieve accurate measurement the system needs to zero out any pre-existing offsets. In Figure 20, the tare() function takes multiple samples to find a precise zero baseline. Through averaging the readings, fluctuations in readings and noise are minimized, ensuring overall accuracy of readings.

```
void tare() {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Taring...");

  long total = 0;
  for (int i = 0; i < NUM_SAMPLES; i++) {
    total += loadCell.read();
    delay(10);
  }
  tareValue = total / NUM_SAMPLES;

  lcd.setCursor(0, 1);
  lcd.print("Tare complete!");
  delay(1000);
  lcd.clear();
}
```

Figure 21.

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As previously mentioned, interrupts were integrated into the code to assist with fast response time to enhance the overall user experience.

```
void sw2ISR() {
  sw2Pressed = true;
}

void sw1ISR() {
  sw1Pressed = true;
}
```

Figure 22.

To have the feature of switching between multiple units in real-time, the main loop reads the load cell values averages them, and subtracts the tare offset. The code takes the raw readings and converts them into units (grams, kilograms, pounds, or ounces) based on user preference. The calibration factors and unit conversions are applied to ensure that all readings are correct.

```
long rawValue = getAverageReading() - tareValue;

switch (selectedUnit) {
  case 1: weight = rawValue * calibrationFactor; break;   // Grams
  case 2: weight = rawValue * calibrationFactor / 1000.0; break; // Kilograms
  case 3: weight = rawValue * calibrationFactor * 0.00220462; break; // Pounds
  case 4: weight = rawValue * calibrationFactor * 0.035274; break;  // Ounces
}
```

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This section of the code addresses the display update function. This allows the LCD to show the current measured weight, the chosen unit, and indicators for TARE and UNITS. This simple and intuitive UI allows the user to easily read and understand the data being displayed.

```
void displayWeight(double weight, const char *unit) {
  lcd.setCursor(0, 0);
  if (weight > MAX_WEIGHT) {
    lcd.print("Exceeds max!");
  } else {
    lcd.print(weight, 2);
  }

  lcd.setCursor(0, 1);
  lcd.print("TARE");

  lcd.setCursor(11, 0);
  lcd.print("     ");
  lcd.setCursor(11, 0);
  lcd.print(unit);

  lcd.setCursor(11, 1);
  lcd.print("Units");
}
```

Figure 24.

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Results and Discussion

The fully assembled digital scale prototype met the objectives of accurate measurement, user-friendly operation, and robust design. Functional testing confirmed that the device could measure weight within a ±1% margin of error across the specified range and effectively switch between multiple units of measurement (grams, kilograms, pounds, and ounces). The TARE feature performed consistently, allowing users to zero out the baseline for various containers or objects without recalibration.

The shroud, manufactured from ABS plastic, displayed durability and weather resistance, ensuring reliable operation under everyday conditions. Prototyping with ABS was deemed difficult as it required a heated build chamber and produced toxic fumes, however after adjustments with slicer settings there were consistent 3D prints made. Its sleek, curved enclosure not only protected the internal components but also provided a user-friendly form factor. The clamshell enclosure design, equipped with multiple fastening points, strengthened the structure against moisture and debris while allowing easy maintenance and component access. The modular scale plate assembly allowed for rapid swaps to accommodate different weighing configurations, increasing the product's adaptability.

The machining process for all aluminum components was deemed a substantial learning curve at the beginning. The necessary feeds and speeds for all machines required memorization, in addition to the proper cutting methods and tools. Manufacturing of the load cell carried the most complexity out of all machining processes, milling of the inner pocket was an extremely high-stakes process as the slightest miscalculation in movement could ruin the entire part. After lots and lots of practice, however, these processes started becoming second nature and made the machining process significantly more efficient and enjoyable.

User interface elements—including a responsive LCD and clearly labeled mode-selecting buttons—supported intuitive operation. The battery holder, combined with a protective cover, made battery replacement easier without compromising water resistance. Feedback from colleagues and faculty members showed value in the design and highlighted the organic form factor. Adjustments for injection molding and further streamlining of assembly processes would make the product commercially viable.

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Future Work

While it may be unlikely that there will be continued development on this project, there are multiple improvements and features that have been considered. Machining a much higher accuracy load cell could also substantially improve the quality of readings given. Having a piezo speaker would allow for custom sounds in response to different mode selections on the scale. In addition to this, multiple indicator LEDs could illuminate based on similar modes. These features would overall substantially improve the user experience as it would clarify what modes are activated through auditory and visual aspects. An additional feature while being potentially time-consuming to implement, would be Bluetooth connectivity. A phone app could link to a Bluetooth module integrated into the scale and get a live readout of the data being read, this could allow the user to save the information and log it into an Excel spreadsheet or another software for their personal use.

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Conclusion

The digital scale prototype successfully integrated precision load cell technology, rugged materials, and thoughtful ergonomic design into a final product. It met or exceeded all established objectives, from accuracy and functionality to ease of use and maintainability. With refinements, this design could potentially transition from a proof-of-concept prototype to a consumer product.

Figure 25.