ELEE 4230: Sensors and Transducers
Course Project – Spring 2025
SmartBite – Food Scale with App Tracking
Emerson Hall

*Figure 1: Food Scale*

# Introduction and Motivation

Maintaining awareness of food intake and nutrition is essential, especially during lifestyle changes. This project focuses on developing a smart food scale shown in Figure 1 designed to help users track their meals more effectively. The scale will not only measure food weight using a load cell but also connect to an app to log food data and estimate calorie content. This innovation stems from the increasing need for convenient and precise dietary monitoring, particularly for individuals adjusting their eating habits after changes in physical activity. The motivation for this project comes from the recognition that dietary awareness becomes more important when transitioning away from structured athletic training.

A major goal of this project is to accurately measure the weight of food and integrate that measurement into a digital platform for easy tracking. The challenge is to provide a precise, user-friendly system that measures food weight with minimal error while ensuring the system responds intuitively to user input. To solve this, the scale must address several key measurement and operational issues, including loading errors such as eccentric loading, which can distort readings if weight is not evenly distributed on the sensor. Additionally, it must account for sensor accuracy, including factors like hysteresis, temperature drift, and signal noise, which could affect long-term reliability. Another challenge is providing an interactive interface for users, which requires the capacitive touch sensor and proximity sensor to function seamlessly.

The Proximity Sensor (APDS-9930) uses an infrared (IR) LED to detect reflected IR light from nearby objects, operating based on the Photoelectric Effect, where photons irradiate a material and cause the ejection of electrons, enabling the scale to automatically activate when something is placed near it. The Capacitive Touch Sensor (TTP223B) detects touch by sensing changes in capacitance when a conductive object, such as a finger, approaches. It works based on the Dielectric Effect, where the permittivity of the material changes in response to exposure to the measurand, providing a touchless, intuitive interface. The Load Cell Sensor (5kg Load Cell Weight Sensor) measures force or weight by detecting mechanical deformation and converting it into an electrical signal. It utilizes the Piezoresistive Effect, where the resistivity of the material changes when a mechanical force is applied, allowing for accurate weight measurement.

The project also aims to ensure that the system is capable of reliable calibration and data filtering to maintain precision, even in varying environmental conditions. Implementing real-time data processing and connectivity with an app will help users seamlessly log food information, track their intake, and monitor calories more efficiently.

This project applies sensor technology, wireless connectivity, and data analysis to create a modern, user-friendly food scale. By combining real-time weight measurement with an interactive app, the system will provide an efficient solution for users seeking to track their nutrition with ease and accuracy.

# Physical Environment

The smart food scale is designed for use in kitchen and dining environments, where temperature changes, humidity, and nearby vibrations could affect sensor performance. Calibration techniques and signal filtering are employed to improve accuracy and reliability, modeling key factors such as weight distribution on the load cell, temperature variations, electrical noise, and sensor response time.

However, certain aspects of operation, such as user handling errors (e.g., improper weight placement), long-term wear on the load cell, and external environmental interference (e.g., electromagnetic fields or excessive moisture), remain unmodeled. To address these, the system integrates periodic calibration routines and software-based compensation techniques, ensuring better robustness in varied conditions.

For further details on safety precautions and operational best practices, please refer to the general safety list provided in the Appendix A).

## Sensor Dynamics

The system integrates multiple sensors to achieve accurate weight measurement and a user-friendly interface. The load cell shown in Figure 2 measures applied force and converts it into an electrical signal based on the Piezoresistive Effect. This sensor requires signal conditioning through an instrumentation amplifier to enhance its output for processing.

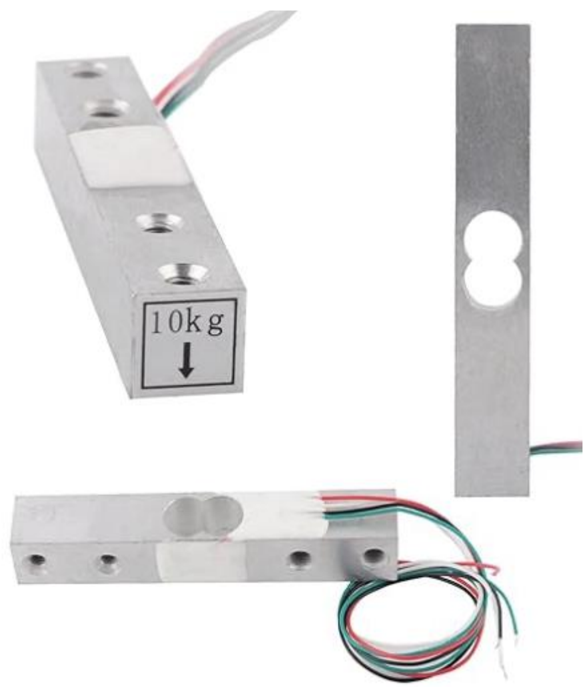



*Figure 2: Load Cell*

The mathematical model governing the load cell's behavior can be expressed as $Vout = G * S * F$, where G is the gain of the instrumentation amplifier, S is the sensitivity of the load cell (typically given in mV/V per unit force), and F represents the applied force in Newtons. Since the raw signal from the load cell is small, amplification is necessary to bring the signal within the input range of an analog-to-digital converter (ADC). The INA126 instrumentation amplifier is used to achieve this, with a gain set by the external resistor Rg. The conditioned signal is then digitized by a successive approximation register (SAR) ADC to obtain precise weight readings.

Several factors can affect the accuracy of the load cell measurement. Hysteresis can cause small errors if the load cell does not return to zero after unloading. Temperature drift can introduce variations in resistance, affecting sensor output, while mechanical creep may result in slow changes in the measured weight when force is applied over time. To mitigate these errors, periodic calibration is necessary to ensure consistent performance. Additionally, digital filtering techniques such as a Kalman filter or low pass filtering help remove noise and improve measurement stability.

Beyond the load cell, additional sensors will enhance the system's functionality. A capacitive touch sensor shown in Figure 3 will provide a responsive, button-free interface, allowing users to interact with the scale through touch-based controls. This feature will enable actions such as activating the tare function and switching between measurement units. Additionally, an RGB/proximity sensor shown in Figure 4 will detect user presence and adjust the display accordingly. The RGB capability may also be used to provide visual feedback, such as indicating stable measurements or errors through color changes.



*Figure 3: Capacitive Touch Sensor* *Figure 4: RBG/Proximity Sensor*

The amplified and digitized load cell signal is processed by a Raspberry Pi Pico 2W shown in Figure 5, which applies compensation algorithms and transmits weight data to a connected application. The system will also support real-time data logging, enabling users to track weight measurements over time. The next steps involve implementing real-time data logging, refining the filtering process, and optimizing the user interface with additional sensor functionalities to enhance the food scale's usability.


*Figure 5: Raspberry Pi Pico 2W*

# Complete Signal Processing

The signal processing system of the smart food scale is designed to provide precise and stable weight readings while minimizing noise and interference from environmental factors. The system is powered by a regulated 5V power supply to ensure stable operation across all components. This stable voltage helps maintain consistent performance for the instrumentation amplifier, filtering stages, and the analog-to-digital conversion process.

The analog signal from the load cell is first processed through an INA126 instrumentation amplifier, which is responsible for amplifying the small differential signal generated by the load cell. The gain of the INA126 is determined based on the expected output voltage range from the load cell, ensuring that the amplified signal is suitable for further processing by the ADC. The gain is set using the following equation:

$$G = 5 + (80k\Omega/Rg)$$

where G is the gain, and Rg is the external resistor used to set the gain. To achieve an appropriate gain, a target value of 100 was chosen, which resulted in the equation:

$$100 = 5 + (80k\Omega/Rg)$$

Solving for Rg:

$$Rg = \ 80k\Omega/(100 - 5) = 80k\Omega/95 \approx 842.1\Omega$$

However, the gain did not suffice. A standard resistor value of 220Ω was selected instead to amplify the signal more. Using the 220Ω resistor results in a higher gain of approximately:

$$G \approx 5 + \left(\frac{80k\Omega}{220\Omega}\right) = 364.5$$

This gain ensures that the signal is amplified sufficiently to fall within the input range of the ADC without saturating the signal, maintaining the integrity of the weight measurements.

After amplification, the signal passes through a low-pass filter to reduce high-frequency noise. The filter is implemented using a 10kΩ resistor and a 1µF capacitor. This configuration shown in Figure 6 helps attenuate unwanted high-frequency components from the signal, ensuring that only the relevant low-frequency components (corresponding to the weight measurements) are passed through for digitization. For a more detailed view of the circuit configuration, see Appendix B) for the Multisim simulation diagram.

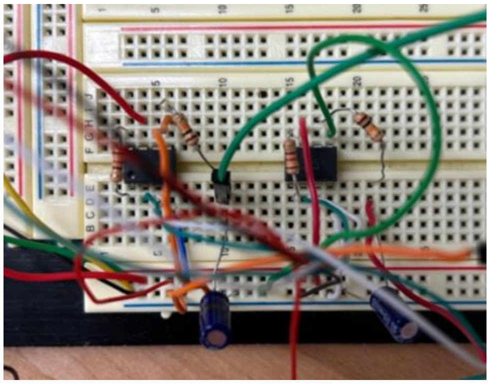


*Figure 6: Amplifier and Filter Circuit*

The filtered signal is then sent directly to the Raspberry Pi Pico microcontroller, which processes the analog voltage to determine the corresponding weight value. The microcontroller is equipped to handle the analog input, utilizing its internal analog-to-digital conversion capabilities or an external method for voltage measurement. Once the signal is captured, it is processed for further use, such as displaying the weight or transmitting the data to an app.

Once the signal has been digitized or captured, a Kalman filter is applied to minimize noise and fluctuations in the weight data. The Kalman filter is an optimal recursive filter that estimates the true value of the weight by considering both the system's dynamic model and the noise in the measurements. The application of the Kalman filter significantly improves the stability and accuracy of the weight readings, as demonstrated by a comparison of raw and filtered data, which shows a marked reduction in noise.

In summary, the signal processing system effectively amplifies, filters, and processes the raw sensor data from the load cells, ensuring accurate and stable weight measurements. The INA126 instrumentation amplifier, low-pass filter, and microcontroller (with voltage measurement capabilities) work together to prepare the data for further processing, while the Kalman filter further improves the accuracy of the final weight reading. This system setup ensures reliable performance, even in the presence of environmental noise and other potential interferences.

# Digital Logic Implementation

The Raspberry Pi Pico is chosen for this project due to its low power consumption, adequate ADC resolution, and compatibility with the Arduino IDE, making it a suitable microcontroller for processing sensor data. The microcontroller uses I2C and SPI protocols for communication with the sensors, enabling efficient data transfer. The system is programmed to read raw sensor data, apply a Kalman filter to reduce noise, and then transmit the filtered data to an IoT server for remote monitoring and real-time food tracking.

To optimize the estimation of weight measurements, the Kalman filter is applied to the raw sensor data. The filter operates in two main steps: prediction and correction. In the prediction step, the previous state and control input are used to estimate the next state of the system. The correction step then adjusts the estimate by incorporating the difference between the predicted state and the actual sensor measurement. The formula for the Kalman filter is as follows:

$$X_k = K_k * Z_k + (1 - K_k) * X_{k-1}$$

where $X_k$ is the current estimation, $K_k$ is the Kalman gain, $Z_k$ is the actual sensor measurement and $X_{k-1}$is the previous estimation. The Kalman filter is particularly advantageous over traditional filters, such as low-pass filters, because it dynamically adapts to varying levels of noise, providing more accurate and optimal estimates. However, it does require careful tuning of parameters like the process noise and measurement noise covariance. Additionally, the Kalman filter assumes Gaussian noise, which may not always apply in real-world scenarios. The raw data and the Kalman filter are shown in Figure 8 and more data is shown in Appendix D).

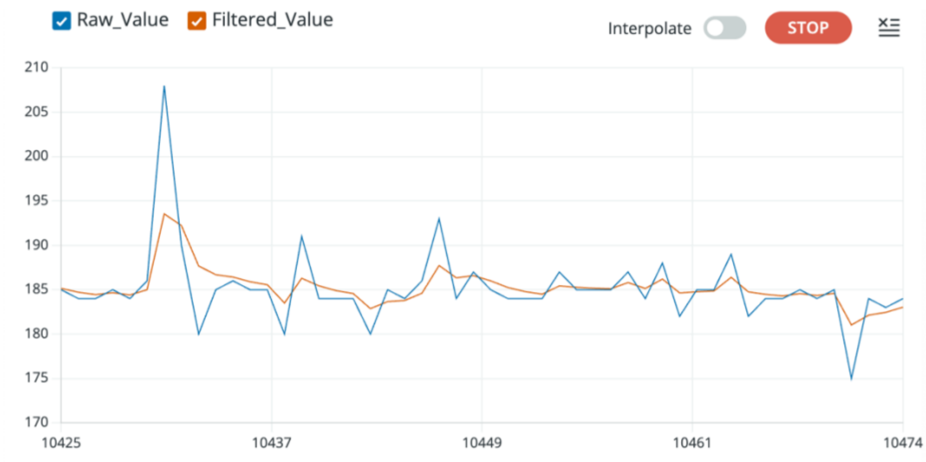



*Figure 7: Raw Data and Kalman Filter*

Incorporating IoT capabilities, the system uploads the processed weight data to a cloud server, allowing users to monitor their food intake and calorie estimates through an app. This IoT functionality enhances the convenience and accessibility of the system, enabling real-time tracking of dietary information and offering valuable insights into user consumption patterns.

# Final Design and Experimental Results

The current implementation of the smart food scale focuses on integrating the raw sensor stage, where the load cells are connected with signal conditioning and noise reduction techniques. The load cell outputs a small voltage signal, which is amplified by the INA126 instrumentation amplifier to ensure it can be accurately detected and processed. To further clean the signal, a low-pass filter consisting of a 10kΩ resistor and a 1µF capacitor is used, effectively reducing high-frequency noise before digitization.

To improve the accuracy of the weight measurements, the processed signal undergoes Kalman filtering. The Kalman filter significantly reduces fluctuations and noise, providing more stable and reliable weight readings compared to the raw sensor output. A direct comparison between the raw and filtered data shows that the Kalman filter smooths out transient variations, ensuring the true weight measurement is accurately captured while minimizing noise.

Currently, only the load cell system has been fully implemented and tested. The touch and proximity sensors, ADC integration, and wireless connectivity are planned for subsequent stages. Once these components are added, additional testing will be conducted to evaluate the full system's performance under real-world conditions. Future improvements will focus on refining the filtering algorithms, enhancing calibration procedures, and optimizing data transmission to ensure the system is both reliable and easy to use.

The experimental results show that the Kalman filter has greatly enhanced the reliability and precision of the weight readings from the load cells. The comparison between the raw and filtered data demonstrates the Kalman filter's ability to stabilize readings, even in the presence of environmental noise such as interference from nearby appliances. The INA126 instrumentation amplifier also plays a key role in the system's accuracy by ensuring the small signals from the load cells are sufficiently amplified before processing.

The low-pass filter proves effective at reducing high-frequency noise, although further optimization may be needed to improve the system's resistance to other types of interference. Full system testing, including the wireless connectivity and additional sensors, will provide further insight into the robustness of the scale in various real-world environments, particularly with changing factors like temperature and humidity.

For the structural setup, a 3D printed plate shown in Figure 8 has been designed to securely attach the load cells. Using Fusion 360, the plate was printed on a Bambu Labs printer to ensure proper alignment and stability. See Appendix C) for the Fusion version of the plate. The material chosen for the print is durable, offering long-term reliability. The load cells are connected to the plate using M4 bolts, nuts, washers, and spacers, providing a secure and stable attachment. The print quality has been satisfactory, and the plate fits seamlessly into the overall scale design.

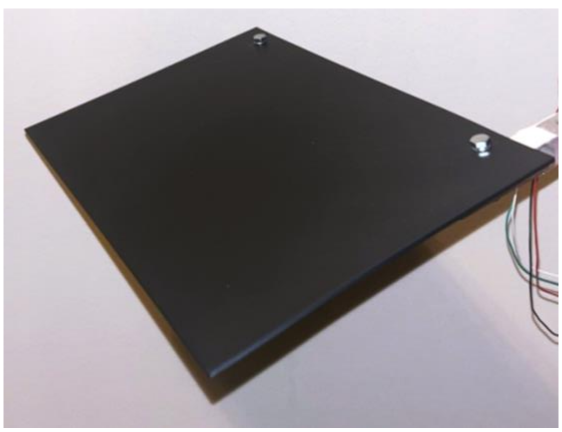


*Figure 8: 3D Printed Plate*

A video demonstration of the smart food scale will be included in the final submission, showcasing the system's performance and the effectiveness of the Kalman filter. The video will highlight the scale's accuracy in providing stable weight readings and demonstrate the signal processing steps in action.

The signal processing steps, including amplification by the INA126 and noise reduction via the low-pass filter, have been successfully implemented and tested. These intermediate steps ensure that the load cell output is accurately amplified and the signal is filtered before being processed by the Kalman filter. These processes are crucial for achieving accurate and reliable weight measurements.

# Appendix

A) General Safety Checklist:

| **General Safety Checklist Adapted from the Sensors Technology Handbook** | | | | |
|---|---|---|---|---|
| Project | SmartBite - Food Scale | Role | Engineer | |
| Rev | 1 | Date | 2/27/25 | |
| Customer | Public | Engineer Responsible | Emerson Hall | |
| Comments | Using 5kg load cell sensor for weight measurement, RGB ambient light sensor, and capacitive touch sensor for user interaction. | | | |
| | | | | |
| **Category** | **Name** | **Part Number** | **Vendor** | **Quantity and Cost** |
| Sensor | 5kg Load Cell Sensor | FZ1878X2 | Wishiot | 2 for $11.99 |
| | Capacitive Touch Sensor | TTP223B | WWZMDiB | 6 for $6.99 |
| | RGB and Proximity Sensor | 3-01-1574-US | HiLetgo | 3 for $6.99 |
| Cables | Signal and Power Cables | | | |
| Power supply | 5V Power Supply | | | |
| Amplifier | | | | |
| DAQ | Raspberry Pi Pico | RP2040 | Wonrabai | $16.31 |
| Other | | | | |
| | | | *Total* | $42.28 |

| **Additional Info** | **Comments** |
|---|---|
| Installation | Components will be mounted on a 3D-printed base with M4 bolts, nuts, washers, and spacers. The load cell will be fixed at one end, while the other end remains free for force measurement. |
| Have these components been used before? | No, these are newly sourced components for this project. Testing and calibration are required. |

| | | | | | |
|---|---|---|---|---|---|
| Datasheet on file | | Yes, datasheets for the YZC-133 Load Cell, RGB Ambient Light Sensor, and Capacitive Touch Sensor are available. | | | |
| **Sensor** (and the environment) | | | | | |
| **Area** | **Check** | **Pass/Fail** | **Environment Range** | **Sensor Range** | **Comments** |
| Environment * | Temperature Range | Pass | 0°C - 70°C | Load Cell operates in this range | |
| | Max shock and vibration | Pass | | | Ensure proper mounting to minimize shock |
| | Humidity | Pass | 0% to 90% non-condensing | Capacitive Touch sensor works well in these conditions | |
| | Pressure | Pass | 1 atm | | No effect on sensors. |
| | Acoustic Level | N/A | | | Not applicable for these sensors. |
| | Corrosive Gases | Pass | | | Suitable for non-corrosive environments |
| | Magnetic and RF Fields | Pass | Low | | Sensors are not sensitive to RF interference |
| | Nuclear Radiation | N/A | | | Not applicable for these sensors. |
| | Salt Spray | N/A | | | Not applicable for these sensors. |
| | Transient Temperatures | Pass | | | Ensure proper calibration in extreme temperatures |
| | Strain in the Mounting Surface | Pass | | | Proper mounting ensures no strain |

| *Overall accuracy is MOST affected by sensors characteristics such as environmental effects and dynamic characteristics. | | | | | |
|---|---|---|---|---|---|
| **Area** | **Check** | **Pass/Fail** | **Environment Range** | **Cable Range** | **Comments** |
| Sensor Cable* | Temperature Range | Pass | -10°C to 80°C | -10°C to 80°C | Suitable for the sensor cables. |
| | Humidity Conditions | Pass | 0% to 90% non-condensing | 0% to 90% non-condensing | Works in typical environmental conditions |
| | Noise levels | Pass | Low | Low | Cables are shielded to prevent noise. |
| | Size and weight | Pass | | Small, light | No issues with weight or size for the setup |
| | Flexibility | Pass | | Flexible | Cables are flexible for easy routing |
| | Is a sealed connection req? | Pass | | Sealed connection needed | For load cell, it's important to avoid moisture interference. |
| *often the weakest link in a measurement system chain | | | | | |

| **Sensor** (is this the correct sensor?) | | | | |
|---|---|---|---|---|
| **Area** | **Characteristics** | **Datasheet Value** | **At what temp/condition?** | **Comments** |
| Sensor* | Sensitivity | 1.0 ± 0.15mV/V | -10°C to 50°C | Standard sensitivity for this type of load cell |
| | Frequency Response | N/A | N/A | Not specified in the datasheet. |
| | Resonance Frequency | N/A | N/A | Not specified in the datasheet. |
| | Minor Resonances | N/A | N/A | Not specified in the datasheet. |

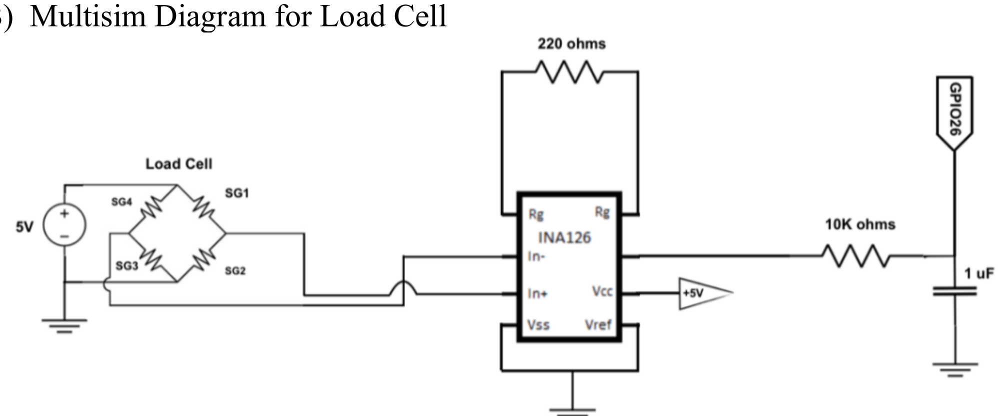
| | | | | |
|---|---|---|---|---|
| | Internal Capacitance | N/A | N/A | Not specified in the datasheet. |
| | Transverse Sensitivity | N/A | N/A | Not specified in the datasheet. |
| | Amplitude and Linearity | 0.0005 | Room Temperature (25°C) | Excellent linearity performance. |
| | Hysteresis | 0.0003 | Room Temperature (25°C) | Very low hysteresis, ensuring repeatability. |
| | Temperature Deviations | 0.003%RO/°C | Over full range | Minimal temperature deviation. |
| | Weight | 30g | | Confirmed from datasheet. |
| | Size | 12.7 mm*12.7mm*80mm | | Compact size for integration. |
| | Internal Ω at max Temp | 1066±20Ω | -20°C to 65°C | Stable resistance values within range. |
| | Calibration Accuracy | ±0.1%RO | Room Temperature (25°C) | Factory-calibrated accuracy |
| | Strain Sensitivity | 0.001 | Room Temperature (25°C) | Small long-term drift. |
| | Damping at Temp extremes | 0.02RO/°C | Over full range | Good thermal stability. |
| | Zero Measurand Output | ±0.1%RO | Room Temperature (25°C) | Low offset when unloaded |
| | Thermal Transient Response | N/A | | Not specified in the datasheet. |

*The most important element in a measurement system is the sensor. If the data is distorted or corrupted by the sensor, there is often little that can be done to correct it.

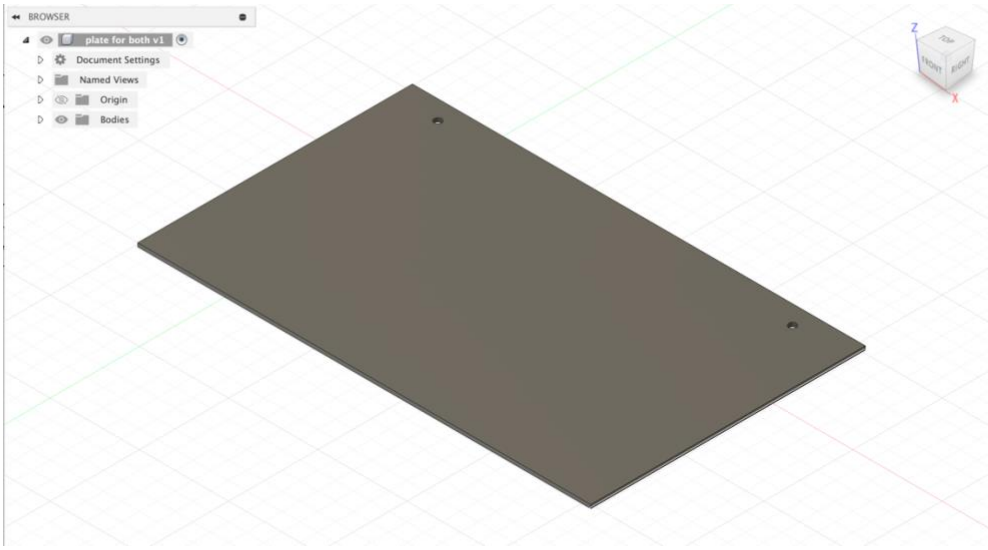
**Sensor Questions**

| Questions | Y/N | Comments/Description |
|---|---|---|
| Describe the mounting setup. Is the proper mounting being implemented? | Y | 3D printed plate with M4 bolts, nuts, washers, and spacers for load cell mounting. |
| Are insulating studs used? Needed? | N | Not required for this setup. |
| Do grounds Loops exist? | N | No ground loops identified in the setup. |
| Has a  sensor calibration been performed? | Pending | Needs calibration to ensure accuracy. |
| Is adhesive mounting required? | N | Mechanically fastened with M4 hardware. |
| If threads are used list all hardware required to mount sensor. | Y | M4 bolts, nuts, washers, and spacers. |
| Is extra adhesive (i.e. Blue Loctite) used? | N | Not necessary with current setup. |
| Is there additional testing needed? | Y | Calibration and load validation required. |

B) Multisim Diagram for Load Cell




C) Fusion Plate




D) The Raw Data and the Filtered Value for one Load Cell

```
02:04.555 ->        Raw_Value:185    Filtered_Value:186.61
02:05.049 ->        Raw_Value:225    Filtered_Value:200.88
02:05.577 ->        Raw_Value:399    Filtered_Value:274.54
02:06.072 ->        Raw_Value:445    Filtered_Value:337.91
02:06.567 ->        Raw_Value:461    Filtered_Value:383.67
02:07.063 ->        Raw_Value:586    Filtered_Value:458.89
02:07.559 ->        Raw_Value:590    Filtered_Value:507.63
02:08.051 ->        Raw_Value:572    Filtered_Value:531.56
02:08.579 ->        Raw_Value:556    Filtered_Value:540.65
02:09.074 ->        Raw_Value:478    Filtered_Value:517.36
02:09.570 ->        Raw_Value:186    Filtered_Value:394.17
02:10.062 ->        Raw_Value:185    Filtered_Value:316.41
02:10.557 ->        Raw_Value:185    Filtered_Value:267.55
02:11.052 ->        Raw_Value:183    Filtered_Value:236.12
02:11.578 ->        Raw_Value:189    Filtered_Value:218.60
02:12.073 ->        Raw_Value:184    Filtered_Value:205.74
02:12.568 ->        Raw_Value:185    Filtered_Value:198.03
02:13.064 ->        Raw_Value:185    Filtered_Value:193.18
02:13.558 ->        Raw_Value:185    Filtered_Value:190.14
02:14.051 ->        Raw_Value:184    Filtered_Value:187.86
02:14.576 ->        Raw_Value:185    Filtered_Value:186.80
```