Pumped – Breastmilk Weighing, Labelling, and Tracking Device

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***Abstract* — Mothers of newborns and infants can opt to pump breastmilk for later feeding to fit their schedule better. This tends to happen late at night or early in the morning, where the mother may struggle to clearly label the bag. This project aims to assist mothers in that process by weighing the bag, creating a label for it, and uploading the bag into an online inventory that can be accessed via an accompanying mobile app.**

***Index Terms* — Inventory management, labeling, printing, weight measurements, wireless application protocol**

I. Introduction

Our sponsors, Victoria Rodriguez and Matthew Aberman, are parents who proposed the idea of a device that would assist breastfeeding mothers in organizing and tracking stored breastmilk. The process of pumping breastmilk into bags for later use requires weighing the amount pumped, labelling the bag, and storing it in a freezer. Currently, there are no products on the market that combine the three processes into a single user experience.

Pumped aims to remedy this by creating a portable device utilizing a scale and a printer to weigh the bag of breastmilk and print out the contents on a sticky label that can be attached to the bag. A touchscreen on the device will provide a user interface that will allow caregivers to adjust the measurement units, add allergen warnings onto the label, and confirm the print of the label. Buttons on the enclosure will provide the ability to put the device into sleep mode and to tare the scale reading on the screen. These hardware components will be integrated together by an MCU board inside the enclosure, as well as voltage regulators that will provide the proper power to each subsystem.

Along with the physical device, a mobile app will communicate with the MCU via Wi-Fi to upload the gathered data onto a database, allowing users to view, manage, and edit their existing inventory of breastmilk. The app will also give users notifications informing them of when to use milk in the inventory before its expiration date.

II. System Components

This section will break down the subsystems of the Pumped design to provide a more in-depth understanding of how each component works within the project.

A. Microcontroller

The ESP32-WROOM-32 microcontroller was selected for its exceptional suitability in portable, battery-powered embedded systems. This module features a dual-core Tensilica LX6 processor running at up to 240 MHz, offering ample computational power for real-time sensor processing and wireless communication tasks. It integrates built-in Wi-Fi and Bluetooth v4.2, enabling seamless wireless data transmission and mobile app connectivity. The module also supports ultra-low power consumption modes, ideal for extending battery life in mobile applications. With 520 KB of SRAM, 4 MB flash memory, and a wide range of digital interfaces (such as I^2C, SPI, UART, ADC, and PWM), the ESP32-WROOM-32 supports integration with peripheral components like load cell amplifiers, touch displays, and label printers.

B. Touchscreen

The ILI9488 TFT Display, a 3.5-inch LCD touchscreen, was selected as the primary input and output interface for the device due to its balance of cost-effectiveness, high resolution, and excellent visibility. Its generous screen size and intuitive touch interface are particularly important for ensuring a user-friendly experience. Operating at a supply voltage of 3.3V–5V, the ILI9488 is electrically compatible with the ESP32, and its SPI interface ensures reliable and efficient communication for responsive performance. This combination of size, functionality, and ease of integration makes it an ideal choice for our system.

C. Weight Sensor

For the scale's fundamental operation, a strain gauge-based load cell is employed as the weight sensor. This type of load cell converts the applied physical force into an electrical signal, which is then processed to determine the precise weight of the breastmilk. It forms the core of our digital weighing system.

For our scale, we utilized the SparkFun SEN-13329 load cell, selected for its compact form factor, lightweight construction, and high measurement precision. With a maximum load capacity of 5 kg, this load cell is well-suited for small-scale, high-sensitivity tasks such as monitoring fluid quantities in neonatal care. Its 5 V excitation voltage is fully compatible with our system's power architecture, facilitating seamless electrical integration.

D. Load Cell Amplifier

The HX711 Load Cell Amplifier was selected due to its affordability, ease of use, and built-in features, which significantly simplify its integration with the ESP32 microcontroller. This amplifier is critical for accurately reading the minute voltage changes from the strain gauge load cell and converting them into a digital signal without requiring an external Analog-to-Digital Converter (ADC). Its gain adjustability further optimizes accuracy by allowing compatibility with various load cell sensitivities.

E. Printer

For the label printing functionality, the Primuz Micro Thermal Printer was selected due to its compatibility with embedded systems and its native support for label-format media. During the component selection process, a key challenge was identifying a thermal printer that could be directly integrated with our microcontroller while also supporting label printing, rather than standard receipt-style output. Many available thermal printers were either incompatible with the desired label size or required the use of proprietary user interfaces, which would have necessitated hardware deconstruction or limited direct software control.

The Primuz Micro Thermal Printer addresses these challenges by offering a simple and flexible hardware interface. It features a dedicated power supply input, a serial UART interface, and full compatibility with the ESP32-WROOM-32 microcontroller. This enabled seamless integration into our system for automated label generation, allowing us to print weight, timestamp, and feeding-related data without the need for external drivers or complex workarounds. Its compact size and embedded control support make it well-suited for our application.

F. Voltage Regulator

The LM2576 buck converter was chosen as the primary voltage regulation component due to its high efficiency and reliability in stepping down input voltage for battery-powered systems. It plays a critical role in providing a stable 3.3 V output for key components such as the ESP32 microcontroller and the ILI9488 touchscreen display, ensuring consistent performance and system stability. Additionally, its ability to supply a regulated 5 V output supports peripherals like the HX711 load cell amplifier, making it a versatile solution for multi-voltage requirements. The LM2576's compact design, integrated thermal shutdown, and high current capability further enhance its suitability for compact embedded applications with mixed-voltage demands.

G. Power Supply

The system is powered by a TalentCell Rechargeable Lithium-ion Battery Pack, which serves as the primary external power source for all components. This portable power bank provides dual regulated outputs: 12V at 6000mAh and 5V at 12000mAh (via USB), offering flexible voltage rails suitable for embedded systems and peripheral devices. The TalentCell battery pack includes built-in overcharge, over-discharge, and short-circuit protection, ensuring safe operation under portable and continuous-use conditions. It comes with a 12.6V charger for convenient recharging and supports plug-and-play connectivity with standard barrel-jack DC outputs. This external battery was selected for its high capacity, reliability, and portability, making it an ideal fit for mobile embedded applications like ours. Its long battery life supports extended on-the-go usage, while its compact form factor contributes to the overall portability of the device.

III. System Concept

The "Pumped" project is designed to seamlessly integrate hardware and software to create an intuitive and efficient breastmilk management platform. Utilizing the ESP32-WROOM-32 as the source of connection between the HX711, printer and touchscreen. All components are powered by a rechargeable 12V battery pack, which includes a 5V DC/DC buck converter for the HX711 and a 3.3V DC/DC buck converter for other digital components. This is all showcased in Fig. 1, which gives a detailed visual of how each component is integrated into the system and the communication utilized between them. The touchscreen facilitates user input and real-time data display, while the load cell and its amplifier provide precise weight measurements. Wi-Fi enabled through the ESP32-WROOM-32 enables seamless data transfer to a companion mobile application for comprehensive inventory management and tracking.

The ESP32-WROOM-32 will serve as the main source of communication between the load cell amplifier, touchscreen, and printer leveraging its GPIO pins. The touchscreen display will communicate with the MCU via SPI. The touchscreen serves as the interface that allows the user to weigh in their preferred units and accurately record the contents of the breastmilk. The load cell sensor sends the raw data to the load cell amplifier, which then converts it to the selected unit of measurement using the calibration factor. The HX711 amplifier then transmits the data to the ESP32. The printer communicates with the MCU via

UART using RX and TX communication lines. Once the user has confirmed the information they would like on the label, the information is then transmitted to the printer through its respective GPIO pin.

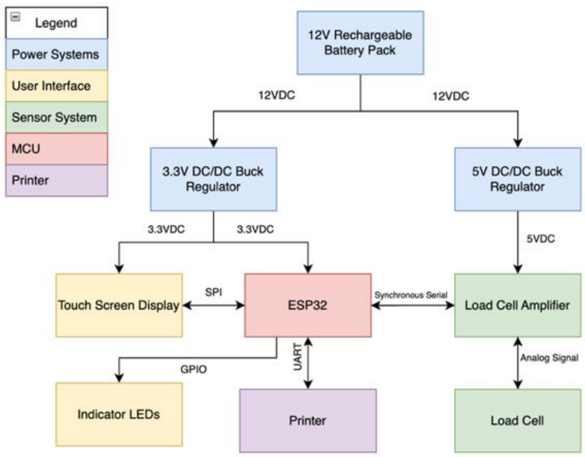

Fig. 1. Hardware Block Diagram

IV. Hardware Detail

A. Touchscreen

The system uses a 3.5-inch ILI9488 TFT LCD touchscreen as both the primary input and output interface. It is directly connected to the ESP32-WROOM-32 microcontroller via the SPI interface, allowing real-time display of weight readings, timestamps, and user-defined inputs such as dietary restrictions. The touchscreen is powered by the 3.3V DC-DC buck converter, which ensures stable operation while maintaining compatibility with the ESP32's voltage levels. Its user-friendly graphical interface enhances the overall usability of the system, especially in low-light or time-sensitive situations. Its intuitive interface is especially beneficial for busy mothers, helping to reduce cognitive load and streamline the milk labeling process.

B. Weight Sensor

The system uses the SparkFun SEN-13329 single-point load cell as the core weight measurement component. This strain-gauge sensor converts applied force into a small analog voltage signal. With a maximum capacity of 5 kg, it is ideal for accurately measuring breastmilk quantities. The load cell requires a 5V excitation voltage, which is supplied via the system's 5V DC-DC converter, ensuring proper and consistent performance during weight detection.

C. Load Cell Amplifier

To process the weak signal output from the load cell, the system employs the HX711 load cell amplifier module. This component amplifies and digitizes the analog signal from the load cell and transmits it to the ESP32 via dedicated GPIO pins (DT and SCK). The amplifier is powered by the 5V rail, which ensures sufficient operating headroom for accurate signal amplification. The integration between the amplifier and microcontroller allows for high-resolution weight readings, which are then processed, displayed, and used for label printing.

D. Printer

The thermal printer serves as the final output stage of the hardware system, generating physical labels that document each breastmilk pumping session. After the user places a filled milk bag on the scale, the load cell detects the weight and sends the data to the ESP32 microcontroller via the load cell amplifier. The touchscreen interface allows the user to review the recorded weight, add optional dietary notes, and confirm the labeling process. Once the user initiates printing through the touchscreen, the ESP32 formats the information and sends it to the printer via serial communication.

The printer is powered directly from the 12V output of the portable battery pack, operating independently from the lower-voltage components in the system. Its role is entirely event-driven, it remains idle until triggered by the microcontroller. When activated, it receives the formatted label data and immediately prints it onto thermal label stock, completing the user interaction cycle. This process ensures quick turnaround between weighing and labeling, minimizing manual steps for the user and streamlining milk storage organization.

E. LEDs / Buttons

The system incorporates a set of status LEDs to provide users with immediate visual feedback on device operation. Each LED is controlled by the ESP32 microcontroller via dedicated GPIO pins and reflects a specific subsystem's state. A power LED indicates when the device is actively receiving power from the external battery pack. Separate LEDs are used to signal active Wi-Fi and Bluetooth connections, turning on once the respective wireless modules are initialized and paired. An error LED is also included to alert the user when the microcontroller detects an issue with the load cell readings—such as a disconnected or faulty sensor—allowing for quick identification and resolution of hardware faults. These LEDs serve as a simple yet effective interface for users to monitor device status without interacting directly with the software.

Two physical buttons are integrated into the system to provide direct user control over essential functionality. One button is used to place the device into a low-power sleep mode, signaling the ESP32 to shut down non-critical components in order to conserve energy during periods of inactivity. The second button serves as a manual tare function for the scale. When pressed, it prompts the microcontroller to zero the current weight reading from the load cell, ensuring that only the net weight of the milk is captured. These buttons operate through digital input pins on the ESP32 and are debounced in software to ensure reliable performance. Their inclusion allows for quick physical interaction with the system.

F. *Voltage Regulator*

The system incorporates multiple voltage regulation components, with the LM2576 buck converter playing a key role in delivering stable power to the system. A 12V input from the main power source is stepped down independently to both 5V and 3.3V using separate buck converters. The 5V output is used exclusively to power the HX711 load cell amplifier, while the 3.3V output supplies power to the ESP32 microcontroller, power LED indicator, buttons, and the ILI9488 touchscreen display.

G. *Power Supply*

The entire system is designed for portable operation and is powered by an external portable battery charger that provides a regulated 12V output. This 12V supply is routed directly to the thermal label printer and also serves as the input for two DC-DC buck converters. These converters step the voltage down to 5V and 3.3V, which power the load cell amplifier, ESP32 microcontroller, and touchscreen display, respectively. This setup simplifies the power architecture while ensuring stable and efficient energy delivery to all subsystems. The use of a standard portable charger supports ease of use and reliable on-the-go operation without the need for internal batteries or charging circuitry.

V. SOFTWARE DETAIL

The PUMPED system utilizes both embedded software for device control and an accompanying mobile application for easy breastmilk storage management. The architecture of the software is designed with accessibility and maintainability in mind by ensuring real-time data flow, user control, and long-term inventory tracking.

A. *Embedded Software*

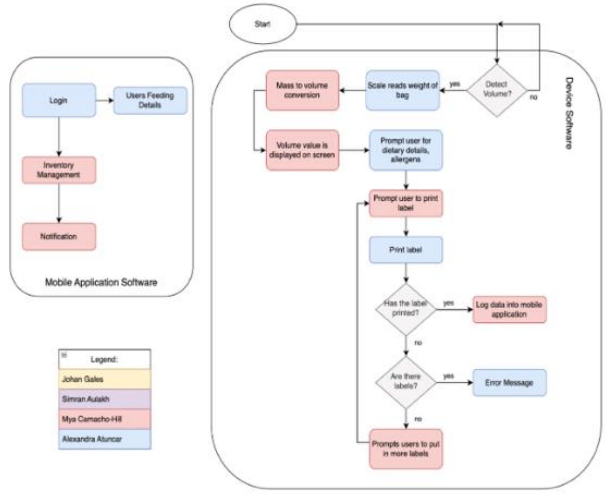

Fig. 2. Activity State Diagram

The device's embedded firmware, running on the ESP32-WROOM-32 microcontroller, utilizes a loop-based execution model enhanced by event flags and state monitoring to deliver responsive user interaction and reliable hardware control. It manages essential functions such as weight measurement, touchscreen interface handling, label printing, and Bluetooth data transmission to the mobile application. The load cell subsystem features an HX711 amplifier, which converts analog weight signals into digital data for the ESP32 via serial communication and includes overload detection to ensure safe operation. Visual system feedback is provided through the LED subsystem, which uses GPIO pins and global status variables to indicate power status, sleep mode, Wi-Fi and Bluetooth connectivity, and any detected errors. Two dedicated buttons are included to allow users to easily access tare and sleep functions.

A key component of the device is its graphical user interface (GUI), which serves as the primary point of interaction between the user and the system. The GUI walks users through the process of weighing and labeling breastmilk, ensuring that data is accurately prepared for upload to the mobile database. The home screen offers streamlined access to the scale's main functions through five buttons: Mode, Sleep, Restart, Settings, and Print. The Mode screen allows users to customize measurement units and choose whether they are weighing breastmilk or water. The Sleep function puts the device into a low-power deep sleep state to conserve resources when not in use. The Settings menu provides additional customization options, including date and time configuration and Bluetooth pairing. The Restart button reinitializes the device and re-tares the scale, providing users with a quick way to reset the system. The Print screen guides users through the label creation process by displaying a preview of the label and allowing entry of allergen information to ensure an accurate upload to the mobile application.

The firmware also implements a touchscreen flowchart that defines the logical sequence for a labeling session, guiding the user through each step—from dietary input to final print confirmation—with multiple layers of validation to prevent user error. Touch input is restricted to well-defined regions of the screen to minimize accidental selections and ensure precise interaction.

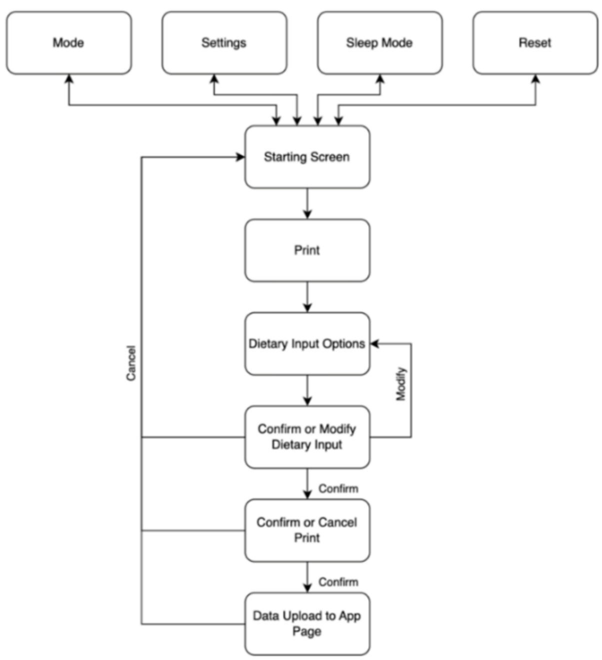

Fig. 3 Touchscreen GUI

B. *Application Software*

The Pumped mobile application serves as the central user interface for managing breastmilk inventory, reviewing past logs, and configuring device and user preferences. Upon launching the app, users are greeted with the login screen, where they can enter their email and password credentials to access their account. For new users, a registration link is provided, directing them to a sign-up page that collects their first name, last name, email, password, and password confirmation. All credentials are securely handled using Firebase Authentication, and each user is assigned a unique identifier (UID), which is used to associate user-specific milk logs and child information within the Firebase Realtime Database. A "Forgot Password" option is also available, which initiates a secure password reset process via email.

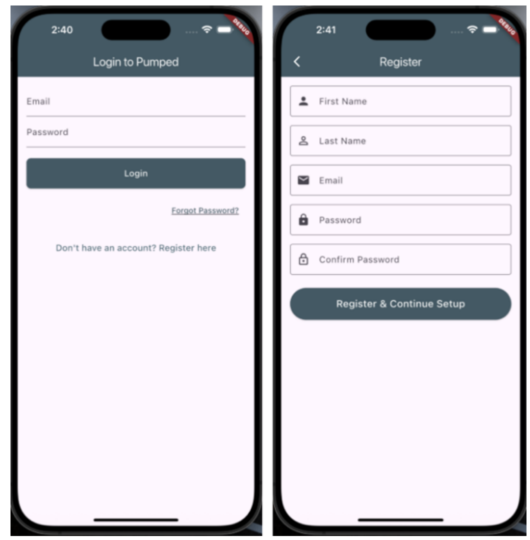

Fig. 4. Login & Register page

After successful registration, first-time users are guided through a setup flow. The first step collects child-specific information, including name, age and weight. The user is then prompted to select a preferred language, currently supporting English and Spanish. Following this, a notification preferences page allows the user to enable alerts for milk expiration, feeding reminders, or low storage capacity warnings. Upon completing setup, users are prompted to link their Pumped device via Bluetooth.

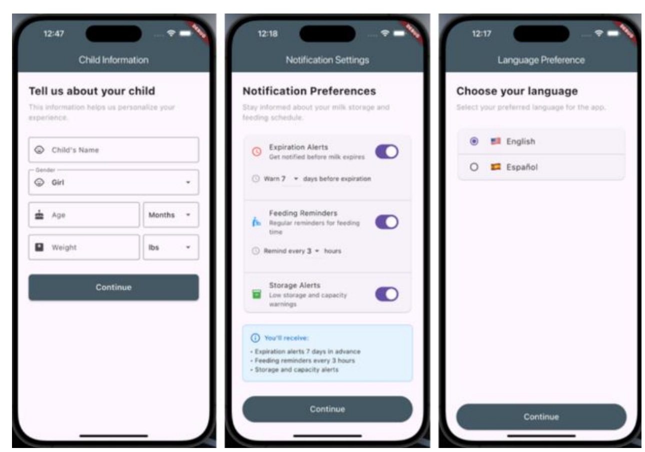

Fig. 5. Login flow

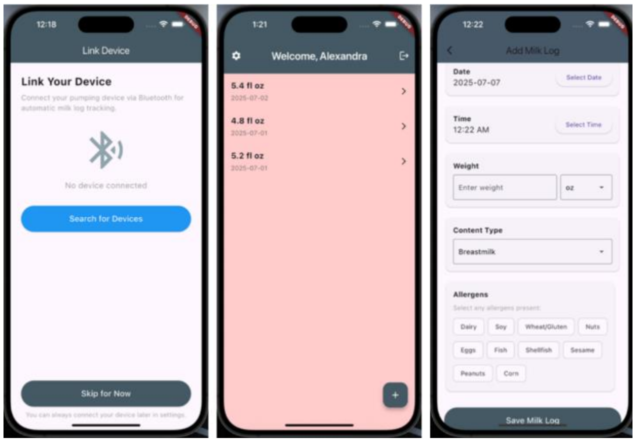

Fig. 6. Login flow & Homepage

The application then transitions to the home screen, which displays a personalized greeting and a list of all recorded milk logs. Each log entry includes the volume, date, time, content type, and any allergen tags selected by the user. Tapping an entry allows the user to view, edit, or delete the log. A floating action button located at the bottom right of the screen allows users to add a new log, which opens a form for entering relevant information. Upon submission, the new log is uploaded to Firebase and displayed on the home screen in real time.

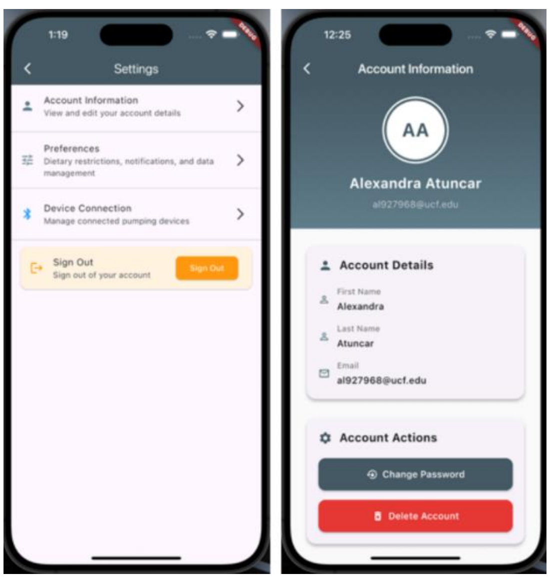

Fig. 7. Settings & Account Information Page

From the home screen, users can access the Settings menu by selecting the icon in the top-left corner. This page provides access to account information, general preferences, notification controls, and linked device management. To log out, users can select the sign-out button in the top right corner, which redirects them securely back to the login screen.

The Pumped mobile app is developed using the Flutter framework for cross-platform support and integrates Firebase for backend services including authentication, database management, and cloud storage. All milk inventory data is structured under /milk_inventory/{uid}/{logId} in the Realtime Database to ensure reliable and individualized access across devices.

VI. PCB Design

A. MCU PCB

The central control unit of the system is built around the ESP32-WROOM-32 microcontroller, which manages communication, user interaction, and data processing. Key peripherals are interfaced through clearly labeled headers, including connections for the touchscreen, thermal printer, power supply, and user interface components such as LEDs and buttons. Dedicated lines for RESET and BOOT enable firmware updates and debugging, while onboard voltage regulation ensures stable power delivery throughout the system. Peripheral grouping and trace routing have been optimized to minimize interference and simplify hardware integration. The spacing on the board reflects the locations that the corresponding hardware components will be situated within the 3D printed enclosure; towards the right of the board, the headers for the touchscreen and the LEDs/buttons daughterboard sit close to the front face of the enclosure. On the left, the printer communication headers rest directly underneath the cutout where the printer will be. The wide space towards the left half of the PCB allows the boards for the 3.3V and 5V regulators to sit and be directly connected to the according header pins.

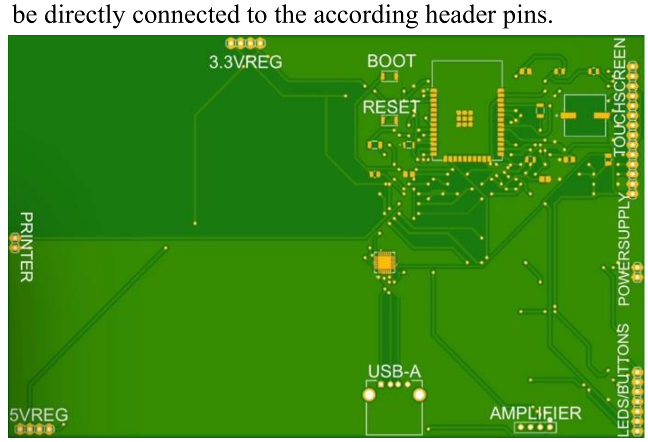

Fig. 8. MCU PCB design

B. Load Cell Amplifier PCB

The load cell interface is designed around the HX711 precision 24-bit analog-to-digital converter [1], which provides signal amplification and digitization of the weight sensor's output. The layout incorporates filtering capacitors and supporting passives to stabilize the analog front-end and ensure clean signal acquisition. A clearly labeled dual-header interface simplifies integration with both the MCU board and the load cell itself, preserving signal integrity across interconnections. Compact routing and decoupling help minimize noise and maintain precision during measurements. This modular amplifier board enables accurate weight detection while maintaining mechanical and electrical isolation from the core system.

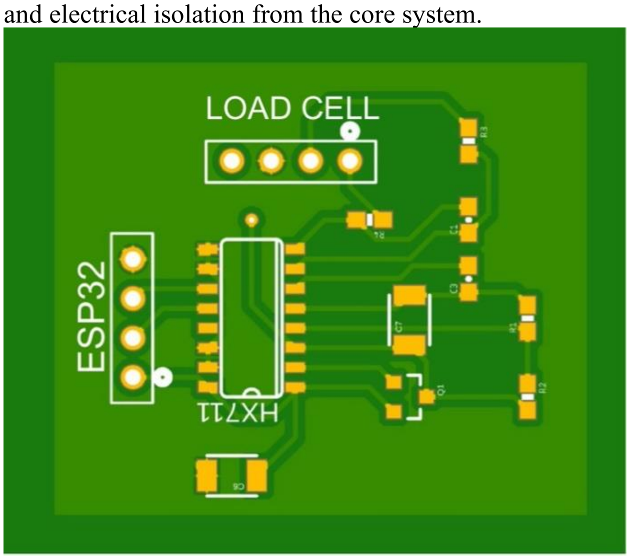

Fig. 9. Load cell amplifier PCB design

C. *3.3V / 5V Regulator PCB*

As previously referenced in Fig. 1, there are two power rails required by the system components; 3.3V for the ESP32 and touchscreen, and 5V for the load cell amplifier. Since both rails will be supplied from the same 12V battery pack, the board design is shared between them, utilizing the same buck regulator schematic with different resistor values. The primary difference between the two is that the 3.3V regulator uses the LM2576T-3.3/NOPB Buck regulator, specific to 3.3V, while the 5V regulator uses the LM2576T-ADJ which can be used to step down an output voltage between 1.23V - 37V depending on the values of the resistors and capacitor in the feedback network.

To select the resistors for our 5V regulator, we used (1) provided in the LM2576 datasheet. These resistors were soldered to the output pin of the regulator to set the desired output voltage by adjusting the feedback voltage divider. This approach allowed us to reuse the same PCB layout as our 3.3V regulator, simplifying the design and maintaining consistency across both voltage regulation circuits.

$$R2 = R1\left(\frac{VOUT}{VREF} - 1\right)$$

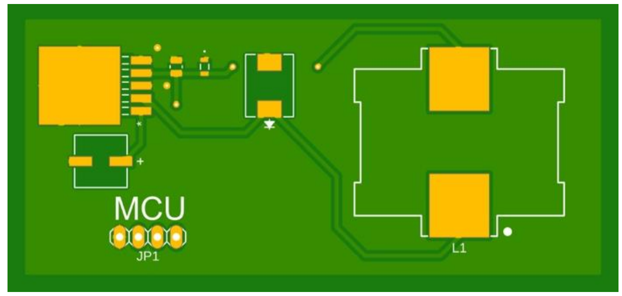

Fig. 10. 3.3V / 5V Regulator PCB design

D. *LED / Buttons PCB*

While the previous boards house components that will be contained within the enclosure, the daughterboard described in this section will hold the pin connections for the LEDs and buttons of our device, allowing greater flexibility for extending these peripherals out to the face of the enclosure. Like the MCU PCB, the layout of this daughterboard reflects the general location that the components will sit on the face of the device with the lights in a column along the left side and the buttons in a row along the bottom.

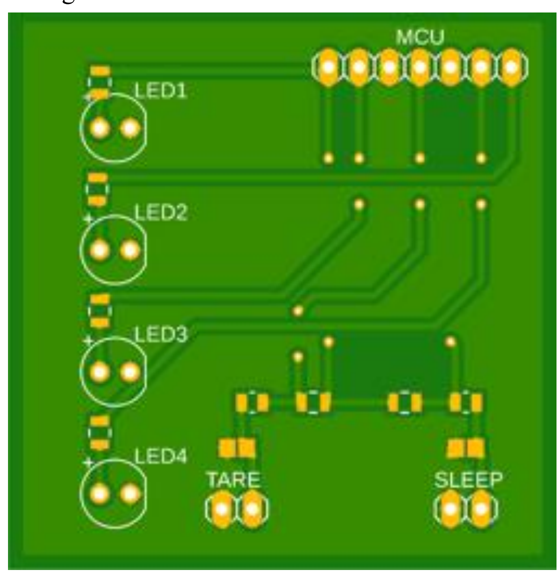

Fig. 11. LEDs/Buttons PCB design

VII. Physical Design

The physical enclosure of the project will be 3D printed from a CAD designed from Onshape. It features a cutout for the load cell with a raised perimeter to stabilize the bag of breastmilk and minimize potential spillage. The printer will be situated behind the scale where the surface will be flush with the enclosure, allowing users to easily access the paper tray to refill labels when needed. At the front of the enclosure, the LCD touchscreen will sit at an ergonomic ~60° angle, ideal for both standing and sitting use. On the same face as the touchscreen, there are also cutouts for the three status LEDs (Power, Sleep, and Error) as well as the two buttons (Sleep and Tare). Internally, a dual-level chamber will house the 12V battery pack as well as provide a place for the PCB boards to sit.

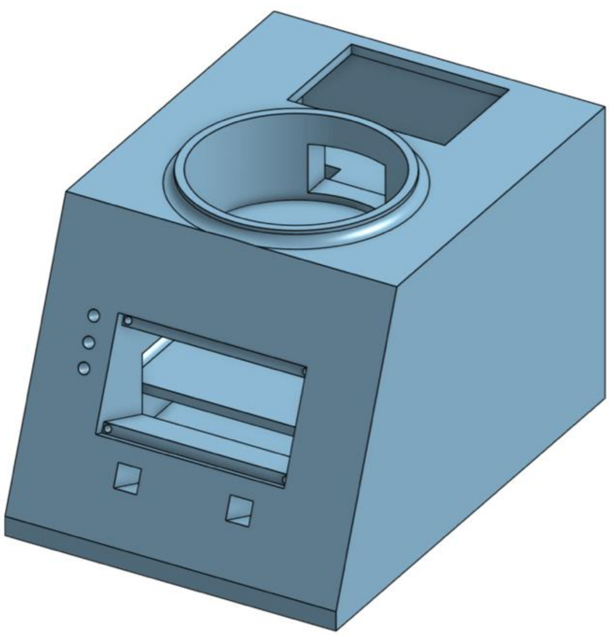

Fig. 12. Enclosure design

VIII. Conclusion

This work presents the development of a portable digital weighing system with an integrated label printing interface, designed for accuracy, portability, and ease of use. The system combines custom electronics with a touchscreen-based interface and label output to support a wide range of daily weighing tasks. While the hardware is compact and optimized for real-time measurement and tare functionality, the software is central to enhancing the user experience, particularly for mothers. The interface allows users to track weight history, manage inventory, and receive notifications for restocking or feeding reminders, helping to reduce the mental load of daily caregiving tasks. This design provides practical value in home environments, especially for tracking infant growth and preparing accurate formula servings. With its intuitive workflow, portable form factor, and intelligent tracking features, the system is well-suited to support the needs of busy parents and caregivers.

Acknowledgments

The authors would like to acknowledge Victoria Rodriguez and Matthew Aberman for initiating the project concept and providing early-stage direction that helped shape the scope of the Pumped system.

The team also thanks Suboh Suboh, Dr. Nazanin Rahnavard, and Mark Lundstrom for serving as project reviewers and providing valuable feedback during final testing.

Additionally, the authors recognize Dr. Chan and Dr. Weeks for their continued support throughout the entire duration of the project. Their technical insight and availability during both the design and implementation phases were instrumental to the success of the Pumped system.

The Engineers

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Alexandra Atuncar is a 21-year-old graduating Computer Engineering student with interests in embedded systems and hardware-software integration.

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[1] SparkFun Electronics. (n.d.). *HX711 24-bit A/D converter for weigh scales* [Datasheet]. Retrieved 7, March 2025, from https://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/hx711_english.pdf