Final Design Report: Weight Wizard

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Executive Summary

Guided by our project partners, Eileen Brodecki and Jennifer Solloway, and our client Bryan at the Shirley Ryan Ability lab, we have designed and prototyped a device that empowers patients to accurately monitor the amount of weight they apply through their lower extremity without the need to constantly glance at the floor to check the weight in pounds. This device is particularly valuable in therapy, where clinicians help patients progress in their weight-bearing journey.

After receiving our project details, we conducted secondary research, including online data collection and reviewing past project reports from DTC. This informed us about existing solutions and potential improvements, shaping our prototype concept. Our primary research involved interviews with our client, Bryan, and Ms. Solloway via Zoom, and two visits to Shirley Ryan AbilityLab. We tested various mockups, ultimately selecting the split scale for its effectiveness. However, due to the complexity of the split scale and constraints in expertise, time, and resources, we shifted to a wireless display scale for our final prototype.

Our design features a standard bathroom weight scale with step-on technology and a wireless display that can be mounted anywhere the user wishes. The scale carries a maximum of 400 lbs. This, according to the average weight supported by weight scales, is enough to qualify our prototype as a commercially valid scale. The display screen along with its frame is 12.5 x 3.3 in. This is important for easy viewing by users due to its large size.

Within the scale, we have rearranged the components and added new ones to the benefit of our prototype. These components and their purpose is stated below in the table

Table 1: Design Components and Purpose

COMPONENT	**PURPOSE**
Arduino microcontroller (with Bluetooth connectivity)	Connects all components of the scale together and enables effective programming of the device
Load cell amplifiers	Converts mechanical force (resistivity) into measurable electrical signals
Display	Shows the output number (weight value)

The device meets the following main requirements:

- Intuitiveness: It is easy to understand for any person who has experience using a weight scale.
- Programmability and Control: The Arduino controller uses a pre-written code that is easy to understand and change to the user's needs. The scale can be switched on and off as well.

Introduction

Recovering from a traumatic lower extremity fracture can be a challenging journey, particularly for patients who must adhere to weight-bearing precautions as part of their rehabilitation process. These precautions dictate the amount of force that can be exerted on the affected limb and vary depending on the type of surgical intervention undergone.

The specific weight-bearing protocols can vary significantly depending on the nature of the surgical intervention, with each patient following a unique trajectory toward their ultimate goal of full recovery and mobility restoration. This entails adhering to a step-by-step progression, typically spanning several weeks or even months, which commences with a mere 10% of weight-bearing (equivalent to 16 pounds) and incrementally advances through stages such as 20% (32 pounds), 30% (48 pounds), 40% (64 pounds), partial weight-bearing at 50% (80 pounds), and culminating in the coveted 100% full weight-bearing status.

Our project partners, Eileen Brodecki and Jennifer Solloway, have given us the opportunity to develop a device that empowers patients to accurately monitor the amount of weight patients apply to their lower extremity fracture without the need to constantly glance at the floor to check the weight in pounds. This device is particularly valuable during Occupational Therapy (OT) and Physical Therapy (PT) sessions in clinical settings, where clinicians help patients progress in their weight-bearing journey.

Existing solutions, like the use of an analog scale, come with several limitations. These include the necessity for constant visual monitoring and the absence of immediate feedback, which is crucial to prevent the over-weighting or under-weighting of the affected limb. Such limitations can significantly hinder effective rehabilitation. In light of these drawbacks, the impetus for our project gained additional momentum. This was particularly influenced by the practical insights and experiences shared by Bryan, a patient currently undergoing treatment at Streeterville DayRehab. Bryan provided valuable user feedback that highlighted the specific challenges and needs faced by individuals in similar situations, guiding our project's direction.

Our device, Weight Wizard, is designed to assist patients recovering from lower extremity injuries, this device offers an easy and precise method for monitoring weight-bearing progress, eliminating the need for continuous floor monitoring. It features a standard bathroom scale with step-on technology and a wireless display, accommodating up to 400 lbs, thereby ensuring its commercial viability and accessibility. The device integrates key elements such as an Arduino microcontroller with Bluetooth, load cell amplifiers, and a large, clear display, all working in sync to deliver accurate weight readings.

The following sections of the report will include the users, requirements, and specifications for this system, as well as an explanation of the design concept and rationale. Finally, we end with suggested future developments for this design.

<u>Users and requirements</u>

<u>Primary User</u>

A patient with a traumatic lower extremity fracture

Our initial primary user, Bryan, was a patient at the Shirley Ryan Ability Lab who had right lower extremity weight-bearing restrictions. His rehabilitation plan required him to incrementally load the injured leg, beginning with static standing to promote healing and progress back to normal activities. The prescribed stress on the limb was to be gradually increased in line with his recovery.

However, during our first user observation, we noted that Bryan had made significant recovery progress, able to walk unaided and nearing full recovery. Consequently, we adjusted our primary user profile to a broader category of patients with lower limb injuries on a similar rehabilitation trajectory.

This shift necessitated our product's design to be adaptable for a wider patient demographic with varied rehabilitation needs, including those with additional challenges such as obesity, color vision deficiency, and hearing loss. The design aim is to ensure our product supports the rehabilitation process effectively for all potential users.

<u>Secondary Users</u>

Physical Therapist (PT)

The physical therapist at Shirley Ryan Ability Lab is Jennifer Solloway. Her task involves working with patients like Bryan to utilize the device to monitor and adjust the weight-bearing load during rehabilitation.

Occupational Therapist (OT)

The occupational therapist at Shirley Ryan Ability Lab is Eileen Brodecki. She will use the scale’s reading to monitor the patients session, and incorporate into her practice to assess the functional weight bearing capacity of patients as they engage in activities of daily living.

Requirements

We identified the following requirements for our design during the course of the quarter (see Appendix A):

Simplicity
The device should possess a simple design and concept, enabling users to operate it with minimal instructions. The scale itself should have at most one switch for determining which side the scale should weigh. The display should have at most one switch to turn it on or off.

Easy Maintenance
It should also have easy-to-open features to facilitate simple fixes and have organized and intuitive wiring for user convenience. Batteries should be easy to replace in both the scale and display. The material used for the scale should be easy to clean, and durable against common cleaning solutions.

Durability
The device should provide a minimum of 2 hours of battery life, ensuring sustained operation without frequent recharging during therapy sessions. Additionally, it should be capable of securely mounting significant weight, guaranteeing robust and stable support for heavy loads. It should also be reasonably durable against impact. It need not be very resistant against water and dust, an IP rating of around 35.

Digital Weight Measurement
Instead of a traditional dial display, the device should incorporate digital technology for measuring weight. This will ensure more precise readings and improve visibility for the user.

No Attachable Weights Required
The design should avoid the need for any additional weights to be attached to the user. This minimizes any extra burden and simplifies the usage process, making it more user-friendly.

Weight Notification
The device should offer visual weight notifications through a multi-color display, where a red light indicates that the weight exceeds the threshold, a yellow light warns of nearing the threshold, and a green light signifies that the weight is below the threshold. Additionally, if possible, we are thinking of considering the inclusion of vibration or sound features. Sound emitted should maintain a non-disturbing volume to avoid inconvenience to the user or their surroundings.

Design Concept and Rationale

Design Concept: Bathroom Scale Modification and Connection to Bluetooth

Overview

The Weight Wizard is a bathroom scale that leverages the ESP32 module's Bluetooth capabilities. This will eventually be used to connect to a wireless display, providing a seamless, real-time data transmission experience. The core of this technology lies in the innovative use of a Wheatstone bridge configuration to integrate the load sensors.

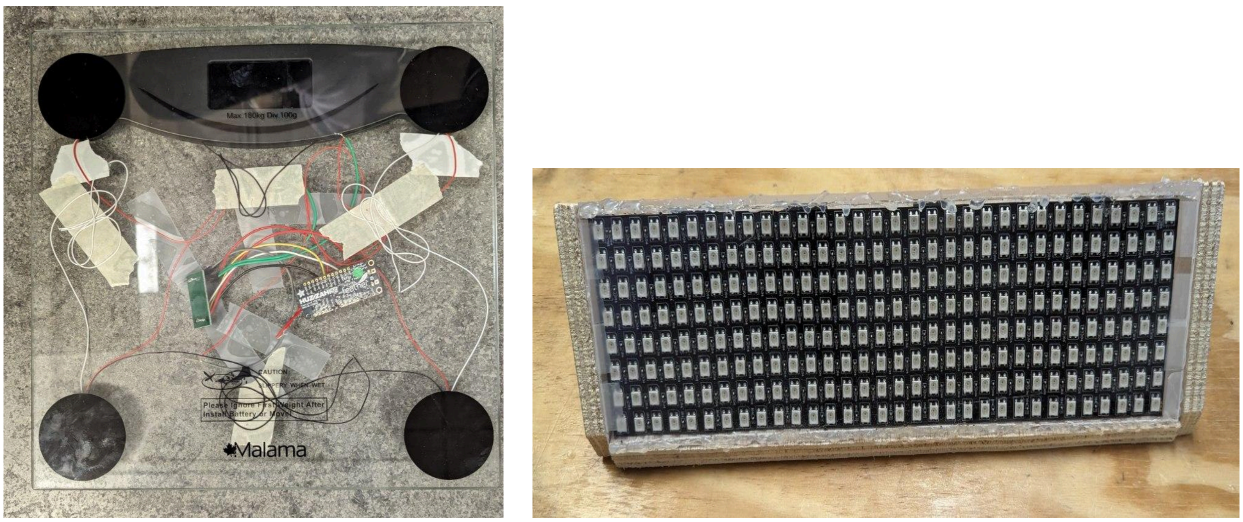

Figure 1: Weight Wizard (scale on the left, display on the right)

Load Sensors Integration

The scale uses four precision load sensors (see Figure 2), one at each corner. These sensors are interconnected in a Wheatstone bridge configuration. The configuration necessitated the use of 4 extraneous wires, into that of a load amplifier, then to an ESP32 bluetooth module.

Figure 2: Load sensor

ESP32 Bluetooth Module

The ESP32 module (see Figure 3) serves as the heart of our wireless communication system. The ESP32 module is capable of sending and receiving data. We utilized bluetooth low energy (BLE) to transmit and receive data, setting up one ESP32 as a server and the other as a client to receive data (see Appendix J and K).

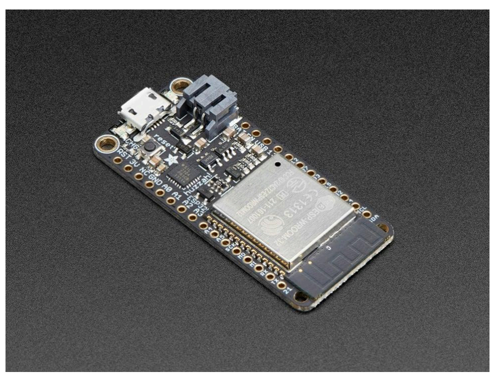

Figure 3: ESP32 featherboard

Data Processing and Transmission

The ESP32 module processes the signals from the Wheatstone bridge, converting them into digital weight readings. These were encoded in bytes, then converted into floating point numbers. These readings are then transmitted via Bluetooth to the wireless display. This process involves real-time data processing and transmission, ensuring immediate feedback to the user (see Appendix H).

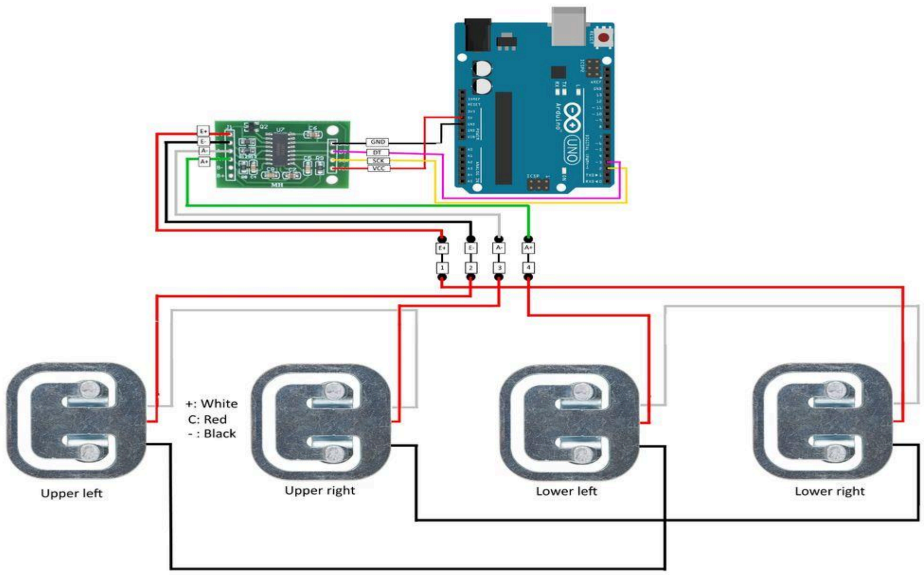

Figure 4: Wheatstone bridge connection map for load sensors

Rationale

Enhanced Accuracy and Reliability

The Wheatstone bridge configuration with four load sensors ensures that weight measurements are accurate and reliable (see Figure 4). This design addresses common issues with single-sensor scales, like inaccuracies due to uneven weight distribution.

User Convenience and Connectivity

The integration of the ESP32 Bluetooth module offers users the convenience of wireless connectivity. It allows users to track their weight measurements on different devices, fostering a more interactive and engaging experience (see Appendix G).

Future-Proof and Scalable

The use of ESP32 makes the scale adaptable for future upgrades, such as integrating Wi-Fi connectivity or connecting to health monitoring apps. This scalability makes it a long-term investment for users.

Eco-Friendly and Energy Efficient

The low power consumption of the ESP32 module contributes to an eco-friendly design, aligning with contemporary concerns about energy efficiency and environmental impact.

Cost-Effectiveness and Open Source Support

One of the compelling aspects of using the ESP32 module is its cost-effectiveness. The ESP32 offers a high-performance-to-cost ratio, making it an affordable choice for advanced features like Bluetooth connectivity. Additionally, the vast array of open-source resources available for the ESP32, including libraries, tools, and community support, significantly lowers development costs and time. This wealth of resources not only makes the development process more efficient but also allows for continuous improvement and customization of the scale, making it an attractive option for both developers and end-users (see Appendix B).

Design Concept: Bluetooth Communication Integration for Scale-to-Display Data Transfer

Overview

This design phase focuses on the advanced implementation of Bluetooth Low Energy (BLE) communication between the smart bathroom scale and the remote display. Unlike traditional Bluetooth, BLE is ideal for IoT applications due to its lower power consumption and better suitability for devices that need to operate with limited energy sources. The ESP32 module plays a pivotal role in facilitating this efficient, wireless data transfer (see Appendix B).

Data Encoding with BLE

The ESP32 module processes and encodes the weight data from the scale into a BLE-compatible format. BLE itself is a transmission protocol, so appropriate libraries in arduino code were installed to encode and send data with the BLE protocol (see Appendix H, J, K).

BLE Server Setup on the Scale

The scale is configured as a BLE server using the ESP32 module. This setup involves initializing the scale as a BLE device, creating a BLE service, and defining characteristics that the client (remote display) can access. This involves the broadcasting of data from the scale in order to make it discoverable to devices nearby via bluetooth (see Figure 5).

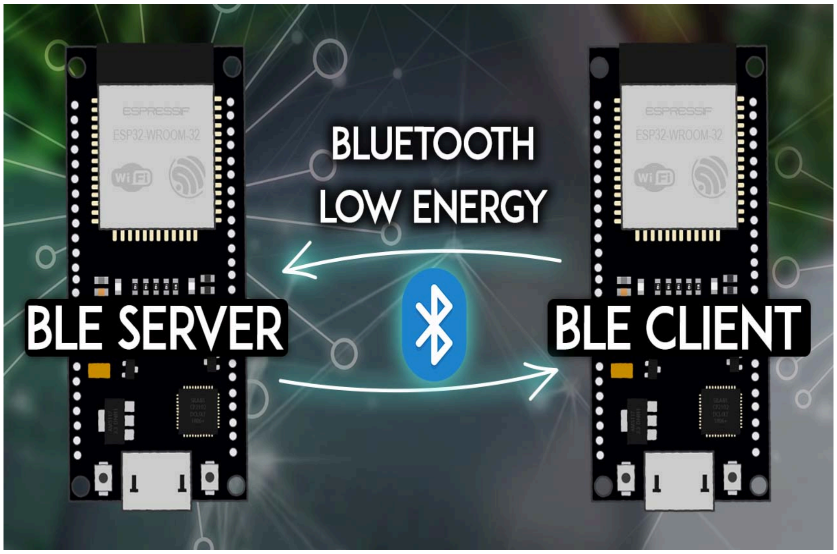

Figure 5: BLE Client-Server Connection

Secure BLE Transmission

The scale, now a BLE server, securely transmits the data over BLE. The BLE protocol provides a secure pairing process, ensuring the connection is exclusive to the scale and the display, thereby preventing interference or accidental connection with other devices like computers.

Client Configuration on the Display

The remote display is configured as a BLE client, designed to scan for, connect to, and interact with the BLE server on the scale. This involves searching for the scale's BLE service and reading the data from its characteristics. The display will constantly search for a service until it will lock onto the server from the BLE server on the scale.

Real-Time Data Synchronization

The data is programmed to be sent real-time, with tenth-second-long intervals between pulling data and data transmission. The client-side (display) is also capable of reading in data at this pace.

Rationale

Uninterrupted and Secure Data Flow

The use of Bluetooth communication ensures an uninterrupted and secure flow of data from the scale to the display. This wireless approach safeguards user data and enhances the overall reliability of the system.

Reduced Latency for Immediate Feedback

By focusing on efficient Bluetooth communication, the design minimizes latency, which is essential for real-time feedback. This immediacy is particularly important for instantaneous readings for weight tracking, which will be performed in real time during OT sessions of the patient (see Appendix F).

Simplified Connectivity

Bluetooth technology simplifies the process of connecting the scale to the display. It eliminates the need for wires or complex setup procedures, making the scale more user-friendly and accessible for healthcare staff.

Energy Efficiency

Bluetooth, especially in its low-energy iterations, is known for its energy efficiency. This aspect is critical in preserving the scale's battery life and maintaining long-term operational efficiency (see Appendix E).

Flexibility and Compatibility

Bluetooth's widespread adoption in various devices ensures that the scale can easily connect with a range of displays, offering flexibility and broader compatibility.

Design Concept: Digital Display

Wooden Base and Sides

The foundation of the display is built using high-quality wood (see Figure 6). This material was chosen for its lightweight yet robust characteristics. The wooden base provides a stable platform for the display, while the wooden sides create a non-transparent enclosure that effectively conceals the wiring, adding to the overall neatness of the design. There exists a small opening on one side used to access the ESP32 during data transfer (see Figure 7).

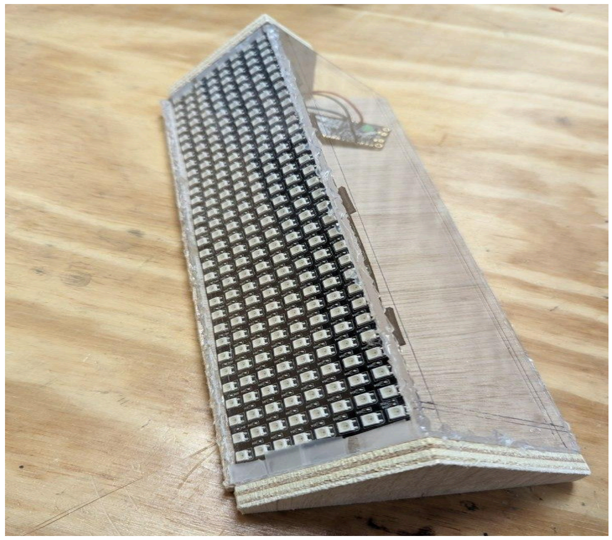

Figure 6: Display with wooden frame

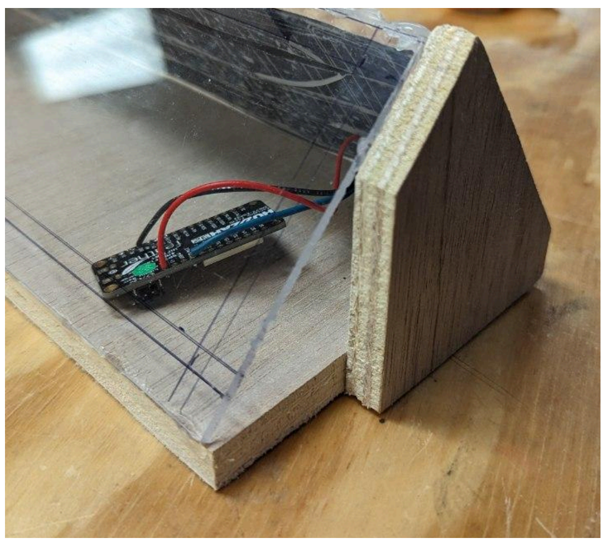

Figure 7: Small opening to access ESP32

Durability and Aesthetics

The wood's natural texture offers an aesthetically pleasing look, blending seamlessly with various interior designs. Additionally, the wooden structure is designed to withstand accidental falls, ensuring the display's longevity and reliability in everyday use.

Neomatrix Display

At the heart of the display is a Neomatrix LED panel. Known for its vibrant colors and clarity, this display type was chosen to provide clear and bright readings from the smart scale. It offers excellent visibility and is capable of displaying complex graphics and texts with ease (see Figure 8).

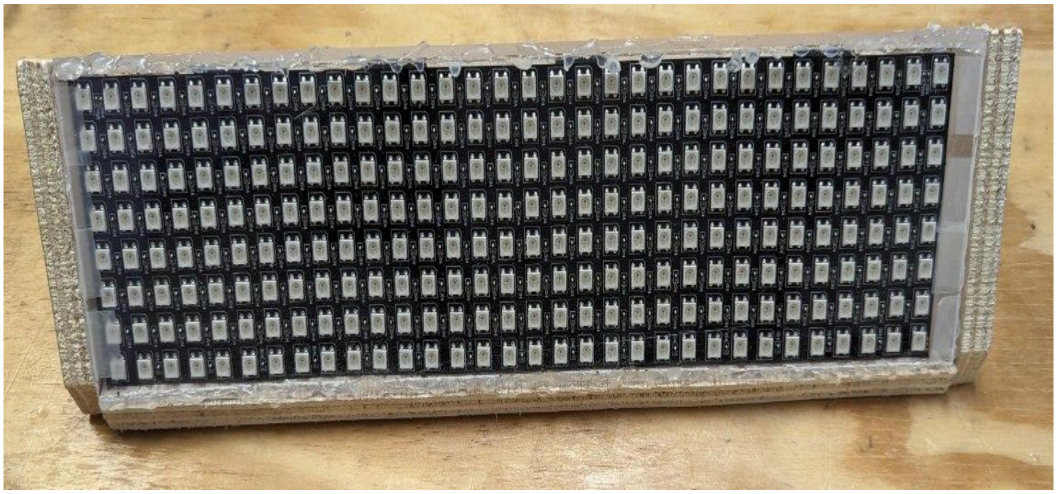

Figure 8: Neomatrix LED display panel

Enclosure in Nylon Plastic

Surrounding the Neomatrix display is an enclosure made of Lyon plastic. This material was selected for its transparency, which allows for unobstructed visibility of the display. The lightweight nature of the nylon plastic keeps the overall device easy to move and handle.

Secure Attachment

The Neomatrix display is securely attached to the nylon plastic enclosure. This attachment is meticulously engineered to ensure that the display remains firmly in place, even in the event of impacts or movements, maintaining the integrity and functionality of the display unit.

Connection to ESP32

The display is connected to an ESP32 module, which acts as the brain of the unit. The ESP32 provides the necessary computing power to control the display, manage the Bluetooth Low Energy (BLE) communication with the smart scale, and handle the data processing and visualization tasks.

Rationale

Software and Hardware Synergy

The integration of the ESP32 with the Neomatrix display is a key aspect of the design. This synergy allows for efficient and real-time representation of data received from the scale, offering users an immediate and accurate visual feedback of their weight measurements.

Cohesive Design

The final assembly of the display unit is a testament to thoughtful engineering and design. The fusion of wood, nylon plastic, the Neomatrix display, and the ESP32 module results in a product that is not only functionally superior but also aesthetically pleasing and durable.

User-Centric Approach

The design of the display takes into account the user's interaction and experience (see Appendix C). Most importantly, it is portable and visible to see. The display can be placed on any surface and can be seen from eye level, and clearly displayed to multiple people at once (see Appendix I).

Customizability

The use of a neomatrix display also allows for maximum customizability in terms of displayed numbers, letters, words, and images in all supported rainbow light colors. In the future, this can be changed to fit different application scenarios, or can be used to have a more intuitive display such as a growing visual bar for exerted weight (see Appendix D and F).

Future Developments

We believe our prototype can be further modified with emphasis on better connectivity and stable design.

We recommend the following improvements and potential add-ons in the following areas:

- **Bluetooth Module Integration**: One drawback we faced working on our prototype was successfully integrating the ESP32 connected to the load amplifiers to the ESP32 connected to the wireless display using the Bluetooth module. This required a lot more time and coding experience than we had on our hands. However, in the future, with advanced bluetooth libraries and more time, a stable connectivity can be achieved to properly display the weight from the scale onto our wireless display.
- **Data Management and Control**: The control system for the ESP32 is, at the moment, entirely managed using the Arduino IDE on a computer. As a potential upgrade, a more intuitive user interface should be implemented. This will allow users to control the inputs and other variables easily without the need for coding experience.
- **Power Consumption**: The matrix display can be modified so that it consumes less power. We do not have an accurate measurement for the consumed power now but it requires a continuous supply of 5V (volts) to work properly, which can only be supplied by a direct power source.
- **Data Analytics and Cloud Integration:** A major area for future development and improvement can be integrating data analytics and cloud capabilities into the weight wizard, revolving around the creation of a secure, cloud-based data platform. This platform will serve as a repository for longitudinal weight distribution data, accessible only by authorized medical professionals through a user-friendly interface designed for ease of monitoring and customizable data visualization.
- **Smartphone App for Personal Health Management:** In future developments, we envisage the creation of a comprehensive smartphone application that seamlessly interfaces with our innovative Weight Wizard. This application is projected to be a robust tool in personal health management, offering the capability to track and analyze weight distribution data in real-time. By harnessing Bluetooth connectivity, the app will not only record daily metrics but also employ sophisticated algorithms to generate visual representations of weight distribution patterns. Such visualizations are intended to provide users with actionable insights, guiding them toward optimal weight-bearing practices.

Conclusion

Our device, Weight Wizard, is designed to meet the needs of our primary user, Bryan, as well as the specifications of our project partners, Eileen Brodecki and Jennifer Solloway at the Shirley Ryan AbilityLab. This device facilitates the recovery process for patients with lower extremity injuries by providing a precise method to monitor weight-bearing progress, eliminating the need for constant visual checks.

Integrating a standard bathroom scale with step-on technology and a wireless display, the Weight Wizard supports up to 400 lbs, making it commercially viable. Its large display screen ensures easy readability. The device's core components, including an Arduino microcontroller with Bluetooth, load cell amplifiers, and the display, work together seamlessly to ensure accurate readings.

Furthermore, the Weight Wizard excels in programmability. It is designed for easy operation by users of varying experience levels, with customizable Arduino controller code to meet individual needs. Additionally, it features a convenient power switch for simple on/off control.

In conclusion, the Weight Wizard stands as a significant advancement in aiding patients recovering from lower extremity injuries. It aligns with the objectives of the Shirley Ryan AbilityLab, enhancing the quality of occupational and physical therapy sessions. We are confident that this innovative device will contribute positively to the rehabilitation journey of patients like Bryan and facilitate a smoother path towards full weight-bearing recovery.

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Appendices

Appendix A: Project Definition

Project name: Solutions for Weight-Bearing Precautions
User: Bryan - current patient at Streeterville DayRehab with right lower extremity weight-bearing precautions
Clients: Mrs. Eileen Brodecki and Jennifer Solloway, from the Shirley Ryan Ability Lab
Primary contact: Jennifer Solloway (jsolloway@sralab.org)
Team members: Leeland Zhang, Yvonne Cheng, Hayeon Yun, Yafet Hailu
Date: November 16th, 2023
Version: Three

I. Mission Statement

To create a device that enables individuals with lower extremity injuries to assess the weight applied to their injured limb by displaying static weight-bearing measurements without requiring the user to look down or disturb others in the immediate vicinity during their therapy sessions.

II. Project Deliverables

- A conceptual design of the weight measurement device and a model to demonstrate how it works
- Final prototype
- Presentation and poster during DTC Fair
- Final report (printed and bound)

III. Constraints

- Must be built within the budget constraint of $150
- Must be built within the quarter (12 weeks)
- Patent laws
- Existing solution copyright
- Limited materials and tools from the Shop - Limited expertise in fully utilizing tools from the shop

IV. Users/Stakeholders

- Mrs. Eileen Brodecki and Jennifer Solloway, from the Shirley Ryan Ability Lab (this is who will be supervising the use of the device), they are also responsible for the care of patients
- Patients with lower extremity injuries (the main users), will use the device to comfortably measure and track lower extremity body weight pressure
- Therapists needing to look at the digital display of weight
- Other patients in the surrounding vicinity (these patients will be going through other therapy, but can be affected by the device's sound and other external forces)

V. Project Requirements - Needs Identification, Metrics, Values, and Specifications

Table 2: Project Requirements and Specifications

Categories	**Needs**	**Metric**	**Ideal Value**	**Allowable Value**	**As-built Value**
Durability	The scale and display have to have a minimum of 2 hours of battery life. When we talked with Eileen and Jennifer and Bryan, we were told that this device should last during the full duration of the user's therapy session, hence the scale and the wireless display will need to last at least 2 hours.	Hours	≥2	≥1.5	2.5
	The scale has to be hard since it will be mounting significantly large amounts of weight at times. The scale should be capable of measuring up to 100% body weight of a human. This is important so that the device does not break.	lb	600	200	400
		in x in (area)	11x11	12x12	11x11
		cm (height)	0.8	1.5	0.8
Weight Measurement	The device has to measure weight on a digital scale and display it accurately (measurement accuracy).	%	≥99	≥95	N/A
	The device should not have any attachable weight on the user.	lb	0	≤0.5	0
Weight Notification Display	The user should be able to see the weight that their foot is exerting and be alerted if it's over or under their target body weight exertion for both PT and OT sessions. This is important to allow both the person aiding the user as well as the user to go through both sessions as smoothly as possible.	Visibility	N/A	N/A	N/A
User Experience	The device should be able to allow users of cognitive ability to easily interact with and use. This is important as we	N/A	N/A	N/A	N/A

	want our device to be able to be easily used and understood.				
Feedback Mechanism	The device should have a feedback mechanism that, ideally, does not disturb other patients and staff around the user while alerting the patient when they approach their weight bearing limit. This is important as there will be other patients trying to do their own therapy sessions nearby, hence we should respect the communal space.	N/A	N/A	N/A	N/A
Accessibility	Compact Design: The device is designed to be lightweight and compact, facilitating easy transportation to various locations without the need for specialized equipment.	lb	≤5	≤10	3.4
	Plug-and-Play Hardware: The device components are engineered for quick assembly, ensuring minimal setup time and eliminating the need for specialized tools. This is important as it'll allow the user to minimize the time it takes to set up and focus solely on completing their tasks during the therapy sessions.	Minutes	≤1	≤5	0.5
Biocompatibility	Any materials in contact with the patient should be tested for biocompatibility to ensure they don't cause allergic reactions or other adverse effects.	N/A	N/A	N/A	N/A
Electrical Safety	The device must meet electrical safety standards to prevent electrical hazards to the user or surrounding equipment.	N/A	N/A	N/A	N/A
Electromagnetic Compatibility (EMC)	The device should not emit electromagnetic interference that might disrupt the operation of nearby electronic equipment, and it should be immune to external electromagnetic interference. This is important so that it does not interfere with other devices around them.	N/A	N/A	N/A	N/A

Sterilization & Cleanliness	If the device or parts of it require sterilization, they should be designed to withstand standard sterilization procedures without degradation. This is important to ensure that the device does not break easily so that it stays clean for a long period of time.	N/A	N/A	N/A	N/A

Appendix B: Bill of Materials

Table 3: Bill of Materials

Item	Description	Qty	Source	Unit Cost	Total Cost(w/ shipping and tax if applicable)
ESP-32	Built in USB-to-Serial converter, automatic bootloader reset, Lithium Ion/Polymer charger, GPIOs, a dual-core ESP32 chip, 4 MB of SPI Flash, tuned antenna, WiFi *and* Bluetooth Classic/LE support	2	https://www.adafruit.com/product/3405	$19.95	$39.90
Battery	Output ranges from 4.2V when completely charged to 3.7V, a capacity of 500mAh for a total of about 1.9 Wh, pre-attached with a 2-pin JST-PH connector as shown and include the necessary protection circuitry	2	https://www.adafruit.com/product/1578	$7.95	$15.90
Amplifier	A small breakout board for the HX711 IC that allows you to easily read load	2	https://www.amazon.com/Amplifier-Breakout-Converter-Raspberry-Microcontroller/dp/B07MTYT95R/	$9.49	$20.92

	cells to measure weight		ref=pd_lpo_sccl_3/139-7642187-7530556?pd_rd_w=Kjl78&content-id=amzn1.sym.116f529c-aa4d-4763-b2b6-4d614ec7dc00&pf_rd_p=116f529c-aa4d-4763-b2b6-4d614ec7dc00&pf_rd_r=PHTMHVEH2FXKBXTTHGK3&pd_rd_wg=sJ7mh&pd_rd_r=f8c49c4a-cd43-48bb-982b-dff551d4c8d4&pd_rd_i=B07MTYT95R&psc=1		
Display	8X32 256 LEDs. 32 horizontal LED and 8 vertical LED. Each 5050SMD LED is individually addressable. High quality, The LED material is the best, Using pure gold wire.	1	https://www.amazon.com/BTF-LIGHTING-0-24ft0-96ft-Flexible-Individually-addressable/dp/B01DC0IPVU/ref=pd_lpo_sccl_3/134-3324285-2336007?pd_rd_w=DUDoD&content-id=amzn1.sym.116f529c-aa4d-4763-b2b6-4d614ec7dc00&pf_rd_p=116f529c-aa4d-4763-b2b6-4d614ec7dc00&pf_rd_r=Z6M3FQDF873FTYGWHJ0W&pd_rd_wg=Y33B3&pd_rd_r=36666449-eb1c-49fb-9a6b-3ec34a077a79&pd_rd_i=B01DC0IPVU&th=1	$29.99 $33.06 (including tax)	$33.06

Scale	Malama Digital Body Weight Bathroom Scale, Weighing Scale with Step-On Technology, LCD Backlit Display, 400 lbs Accurate Weight Measurements, Silver	2	https://www.amazon.com/Malama-Precision-Bathroom-Technology-Measurements/dp/B07MJG1FLP/ref=sr_1_5?crid=3U16ANV3M0Z1L&keywords=one%2Bleg%2Bscale&qid=1699501345&s=industrial&sprefix=one%2Bleg%2Bscale%2Cindustrial%2C98&sr=1-5&th=1	$13.95	$28.81
Nylon plastic	Nylon is a strong, stiff engineering plastic with outstanding bearing and wear properties. Nylon is frequently used to replace metal bearings and bushings often eliminating the need for external lubrication.	30 x 30 x 0.5 (cm) 450 cm^3	DTC Shop	$0.28/cm^3	$126
Wood	Wood has aesthetic appeal, versatility, and durability, making it suitable for enhancing the visual appeal and supporting the weight of the base of the display.	13 x 4.5 x 0.25 (in) 14.625 in^3	DTC Shop	$0.58/ ft	$0.71

Shipping (Non-Amazon orders)					$10.82
Tax (Non-Amazon orders)					$5.72
					$281.84

Appendix C: Background Research Summary

I. Introduction

At the beginning of the project, we conducted background research on definitions and terms mentioned by our client: Elieen Brodecki and Jennifer Solloway of the Shirley Ryan Ability Lab - in their description of the project. Jennifer Solloway is our primary contact. The project involves designing a method or creating a device that allows a patient to know the amount of weight they apply to their lower extremity without needing to look to the floor to see the number in pounds. Our solution must work for both sessions where the patient is practicing standing and where the patient is practicing functional movements. Our background research allowed us to start to understand multiple aspects of this problem so that we were prepared for the upcoming client interview. Specifically, we researched: (1) basic information about the project partner; (2) the environment of use of the user; (3) current solutions to the problem.

II. Project Partner

The Shirley Ryan Ability Lab is a global leader specialized in rehabilitation. Our project partners, Eileen Brodecki and Jennifer Solloway, are experts in the field. Eileen is specialized in helping the patients reach maximum independence with her research mainly focusing on helping patients complete daily tasks. Jennifer's experience is more centered around complex neurological injuries on the other hand, showing a clear difference in how Eileen is more specialized in physical motor actions, and Jennifer perhaps with issues more neurological.

III. Environment of Use

The Streeterville Day Rehab is a state-of-the-art clinical environment. The clinic is equipped with both Wi-Fi and Bluetooth connectivity, ensuring seamless integration of digital tools into the therapy process. Among the available technologies they have, but are not limited to, the ceiling harness, walkers, and manual standing wheelchairs.

In terms of therapeutic sessions, patients have the flexibility of attending both group and individualized sessions. The range of exercises incorporated into the therapy is comprehensive, including walking up and down stairs, flat ground ambulation, and static exercises. Importantly, patients at Streeterville Day Rehab benefit from robust clinical supervision. This oversight comprises a multidisciplinary team of professionals, including physiatrists, nurse practitioners, nurses, vocational counselors, social workers, psychologists, and orthotists.

IV. Current Solutions

Bathroom Scales

The bathroom scale is the most commonly used device for weight measurement. It is a cost effective solution for patients, but can only measure weight in static situations. Also, the device is not portable, and users must look down to get the data.

Force Plates
A force plate accurately measures applied force and provides more information (e.g., velocity, power, displacement, left/right symmetry) compared to bathroom scales. However, the device is expensive, difficult to install and maintain, and not portable.

SmartStep Biofeedback
Smartstep Biofeedback is an effective device to estimate load on injured legs while walking with real-time feedback. The device is easy to install with user-friendly software, but is unavailable for average patients in terms of cost.

Limb Load Monitor Devices (LLM)
LLMs are devices that give users feedback through two different audio signals controlled by transducers (see Figure 3). Users don't need to look down, but they must carry a box, affecting the design's portability.

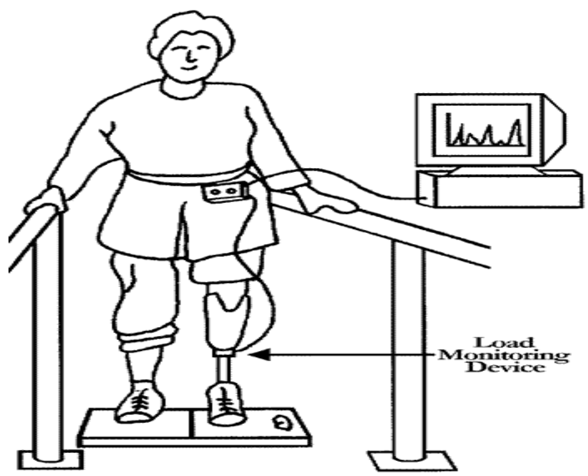

Figure 9: Limb Load Monitor Devices (LLM)
Source: "Clinical evaluation of a sensory feedback device: the limb load Monitor." <https://europepmc.org/article/med/698464>

Smart Crutches
The Smart Crutch is a device measuring the load on the injured limb by subtracting the amount of weight on the crutches from the patient's body weight, with a monitoring system that allows communication between patients and doctor (including prescription and modification of the program according to patient's condition) (see Figure 4). The device is commercially available, with a price range anywhere from $100-$500+; pricey ones come with advanced features such as sensors to monitor usage or even GPS.

Figure 10: Smart crutch
Source: “ComeBack Mobility | For Healthcare Providers.” ComeBack Mobility, https://comebackmobility.com/.

Smart Insoles

Smart insoles are insole inserts with sensors that measure the impact and pressure on knees and feet (see Figure 5). They utilize technology such as accelerometers, gyroscopes, and pressure sensors to monitor and analyze movement. Data can be transmitted wirelessly to devices such as smartphones or tablets. They are commercially available but quite expensive, ranging from $150-$500.

Figure 11: Smart insoles
Source: “SmartStep 2.0 - A Completely Wireless, Versatile Insole Monitoring System.” <https://doi.org/10.1109/BIBM.2015.7359779>

Augmented Reality Glasses

Augmented Reality glasses are optical see-through glasses which are currently being utilized to aid surgeons through AR glasses (Birlo, Manuel, et al.) (see Figure 6). While this technology is not currently applied to the physical therapy and occupational therapy field, we hypothesize that the technology could be cross applied to solve the issue of the user needing to look down constantly. AR glasses could allow the patient to receive obvious and constant feedback on their pressure strain.

Figure 12: Augmented reality glasses

Source: “Smart Glasses: Bringing Mission Impossible to the Hospital”

<https://community.connection.com/smart-glasses-bringing-mission-impossible-to-the-hospital/>

Appendix D: User Observation Summary

I. Introduction

We pursue human-centered design, so we met therapists and users for an interview and an observation. The purpose of this observation was to understand the limitations of the current solution and the considerations for our expected prototype.

II. Methodology

Team 3 and Team 4 in DTC section 6 met at Shirley Ryan AbilityLab DayRehab Center (12th floor of 345 E Superior St.) on October 9th at 3:30 PM (see Figure 7). Hayeon Yun and Yafet Hailu participated in the meeting as representatives of our team and met Jenny Solloway, Eileen Broderick, and Bryan. Our project partners, Eileen Brodecki and Jennifer Solloway, are experts in the field. Eileen is specialized in helping the patients reach maximum independence with her research mainly focusing on helping patients complete daily tasks. Jennifer's experience is more centered around complex neurological injuries on the other hand, showing a clear difference in how Eileen is more specialized in physical motor actions, and Jennifer perhaps with issues more neurological. Bryan is a current patient at Streeterville DayRehab with right lower extremity weight-bearing precautions.

Figure 13. Shirley Ryan Center

During the meeting, we asked several questions and Bryan showed us what his typical therapy sessions look like according to the instructions of Ms. Solloway and Eileen.

III. Results and Discussion

During the meeting, we observed typical activities of OT and CT sessions and learned some limitations of the current solution, which is a bathroom scale (see Figure 8). First, the therapists and Bryan showed us the setup of typical rehabilitation therapy sessions. Bryan took off his shoes and placed his injured leg on the scale and the other leg on the box acting as a leveler. Therapists lifted the table and put cones all around the table. Then, the therapists asked Bryan to hand them the cones while monitoring the weight-bearing on his injured leg. They explained that this is one of the most basic activities they do in the session, but they prepare various activities including throwing "an extra balance challenge like reaching down low."

Figure 14. Setup of a therapy session.

Here, they shared some challenges. The biggest difficulty was accurately gauging weight-bearing, as it requires the constant attention of therapists. Therapists should lead the sessions while checking both the patient's steadiness in the balance and the number on the scale; they have issues constantly looking down since the bathroom scale is located on the floor. Another important point was that their activities only focused on static standing tasks. Dynamic activities and walking exercises can foster patients' recovery and make their daily activities easier, but they were unable to perform those activities while using the bathroom scale as a weight-bearing measuring device. We might have to consider this challenge the most when making a prototype since these are the major problems people in the field are facing.

We also asked opinions on our design ideas to the therapists and users. We shared mockup ideas we are having such as smart insoles and smart crutches; they were concerned with issues of universality. For insoles, they questioned how we can make the device for patients of various body types and shapes so that it can be shared among various patients in the center. They suggested a smaller device that can be put on any side of the foot or shoe. They also pointed out that the device should be universal enough to accommodate various therapeutic disciplines, including physical, occupational, and speech therapy. Along with universality, they briefly talked about sanitation since the device will be shared between different people. For smart crutches, they said it would be better if we could design a device that can be attached to the leg without adding on extra weight, rather than a device that patients should bring together with them.

Then, we also asked about specific functions possibly needed for a device. First was data storage. We asked how many data points therapists usually record per session and how that data is used for upcoming sessions. They explained that they usually record their sessions in words without including lots of numerical data, so our prototype is not required to store data. Another function we discussed was a feedback mechanism. We worried about disturbing other patients in the center while alarming excessive weight bearing, so we asked their thoughts on using sound or light as a feedback mechanism. They told us that we should consider having no impact on both others in the therapy sessions and the users. Our user, Bryan, also suggested another possible method to start from lower volume/intensity of sound/light and "getting to that level, and then, boom" when reaching capacity. Finally, they suggested for us to ensure the surface of our device is not slippery, like a rubber stabilizer on their bathroom scale.

Table 4: User Observation: What We Saw, What Was Said About It

What We Saw	What Was Said About It
During the start of the session Bryan came walking by himself without using any kind of physical support to aid his movement. He had velcro type cushioned materials wrapped around his right leg.	When we asked how he was doing that and how much he has progressed since our last meeting, Jennifer explained that Bryan used the walker for 3 months before being able to walk by himself. She also told us the injured leg is the right leg and that they wrapped the injured area (up to the knee) with a special

	material as recommended by his surgeon. Bryan also said, “For me, the idea is that I'm able to kind of stand up and just do things on my own without having to have the therapist kind of be there to help me. They're there if something does happen but the objective is nothing happens and I am able to stand on my own”.
Bryan was wearing running shoes as he walked in. Key questions asked: - Is this the type of footwear that is usually recommended to patients with similar injuries to Bryan? Is it ideal? What are the alternatives - How often does Bryan wear running shoes? - When did Bryan’s surgeon allow him to wear any type of shoe he wanted? Context: These questions were raised to aid the design of some mockups like the shoe insoles, smart crutches, etc.	Bryan answered, “So, prior to me having the clearance (from his surgeon) to what you're seeing me today, I was in a boot, a light boot specifically. So I would actually have to take the boot off for sessions and then put my bare leg on the scale to scale how much weight I’m applying and pressure throughout the like. So you'll have patients in my case, that may actually not be in a running shoe, could just very well be in a boot, or could variable maybe be in some sort of cast. I would assume it's like a normal hardcast.” This observation led us to believe that not all patients may have the same conditions which is something we did not consider during our primary research. Some patients might be in casts, specially those in the early stages of therapy. Other patients might wear boots that go as high as their knees to aid movement. And some, like Bryan, wear all sorts of shoes they are comfortable with as long as they can support their upper body weight. This is an important point to consider when designing mockups that are in any way attached to the lower body of patients.
After we requested they go on their usual clinical session, we noticed the OT assisting Bryan as he took his shoes off and stepped on the scale.	The OT told us that Bryan is able to do most of the things by himself during OT sessions, but in the specific case of stepping on the scale, it is really difficult. This is due to the scale being a few inches above ground. Bryan has to put his injured leg on the scale throughout the entire OT session. This makes balancing both feet hard for Bryan and also affects his performance during the tests.
In the clinical tests, Jennifer puts objects like cones on the table and asks Bryan to pick	Jennifer told us how critical monitoring Bryan’s activities is. This is due to the fact

them up one by one as his right (injured) leg stays on the scale. She monitors the value of the scale while also observing Bryan pick up the cones. Key questions asked: - How hard is it to monitor Bryan's weight applied on the scale, while observing his performance at the same time? (For Jennifer) - Do you lose focus trying to pick up the cones as you too want to look at your applied weight from the scale? (For Bryan) - How many people are present during each OT session? And how many of them view the scale as Bryan performs the tasks?	that she has to look down everytime he picks the cones is becoming a problem as it is hard to follow his performance at the same time. Jennifer emphasized this by saying how this is a struggle with monitoring most patients during PT sessions. Furthermore, the scale used for the therapy sessions is analog. This makes it hard to read unless seen from a 90 degree angle. A 90 degree angle view downwards is not ideal and will halt the performance testing session. Furthermore, Bryan loses focus every time that he tries to observe how much weight he is applying through his injured leg.

IV. Conclusion

During our brief visit to Shirley Ryan AbilityLab, we gathered detailed information about our project client and their current status. We also discussed specific cases and addressed our questions with the occupational therapist (OT) and Physical therapist (PT). Ms. Jennifer and Ms. Brodeki provided insights into Brian's regular therapy sessions, explaining each step as they performed it. We observed a real therapy session, which helped us envision our potential mockups in a clinical setting and ask more advanced and technical questions to determine the ideal prototype. Observing Brian and his sessions was the most important takeaway from our visit. We will use our user interviews and observations to inform the design of our mockups and prototype. We will also continue to discuss ways to address Bryan and the clinical staff's concerns and suggestions regarding an ideal weight bearing measurement device.

Appendix E: Project Partner Interview Summary

I. Introduction

We are designing a device that allows lower extremity fracture patients to know the weight they are applying to their lower extremity without looking down to see the number. We pursue human-centered design, so we interviewed our project partner and user to understand the client's needs and consider those while designing a prototype.

II. Methodology

Every group in DTC section 6 met in Ford 2.210 and interviewed our project partner Jenny Solloway and the user Bryan via Zoom on September 26th at 3:30 PM. Leeland Zhang, Yvonne Cheng, and Yafet Hailu were at the interview. We kicked off the meeting by introducing our teams and what year we are in. We then gave Ms. Solloway and Bryan a chance to talk a little bit about themselves. Next, Ms. Solloway gave us a brief walkthrough of Bryan's current situation and clinical progress. We then started asking our questions. It was a fruitful conversation. All representatives from each group participated. Bryan was really helpful in clarifying specific questions as well. He was very interactive in his responses.

III. Results

i. *Information about the user*

During the interview, we obtained detailed information about the user, Bryan. He was in a wheelchair, restricted to no weight, and uses a walker to move around. He also said he is in the final phase of rehabilitation, increasing his weight-bearing precautions by 10% every 3-4 days.

ii. *Lower limb injury and its treatment*

In terms of typical lower limb injury and its treatment, our project partner shared that fractures on the tibia or fibula through car accidents, bicycle accidents, and traumatic events are the most common. To retrieve mobility function, the typical treatment for lower limb injury includes trying different levels of weight-bearing precautions from no weight bearing to toe touch, partial weight bearing, and so on. In this process of treatment, patients put their foot on an analog scale and therapists document and monitor the weight bearing.

iii. *User's weight-bearing experience*

Our user, Bryan, also uses an analog scale to measure the weight and reports the number to his therapist so that the therapist can keep track of his progress. He shared that the main current issues in measuring weight are the necessity to look down constantly to read the weight and time spent on reading possibly inaccurate weight on a non-digital scale.

iv. *Typical therapy sessions*

Our project partner also talked about typical therapy sessions. Activities during occupational therapy (OT) for lower extremity fracture patients include standing at a table, reaching down high and low, retrieving things and assembling them on a table, and walking around the kitchen or to the grocery store. Patients usually participate in 1-3 activities each section. For physical therapy (PT), the main focus is the range of motion (ROM) of the patient. Patients are expected to take part in creative exercises and activities which are limited to weight bearing restrictions.
In the clinic setting, the patient works at the mat table, which can be adjusted up and down. Common activities the OT takes note of include completing simple tasks such as picking stuff up, doing laundry and taking a shower. The OT observes Bryan's hip and knee movement as he performs these tasks and takes note.

v. *User's experience in therapy sessions*
Bryan shared his experience in therapy sessions as well. He said his usual time of a session is 55 minutes, but he uses his device for around 50 minutes per session. Since he attends several sessions, he said that the device should be portable and easily removable. The device should also work for all of his sessions, so it has to have a minimum of 2 hours of battery life. In addition, he said that we could attach something weightless to his leg or make a device relying on sound, if the sound is not too loud to disturb other patients.

IV. Discussion

Bryan's feedback offers crucial insights into the practical requirements of a portable weight measuring device tailored for patients with lower limb injuries. His current non-digital scale solution underscores several limitations that can potentially hinder the rehabilitation process. These identified issues not only provide insights into areas of improvement for existing devices but also illuminate the direction for our research and product development.

The emphasis on portability and easy removability shows that it's essential to strike a balance between functionality and user-friendliness, ensuring patients remain engaged and compliant with their therapeutic regimen: in Brian's case, a stable standing balance with a precise percentage of body weight pressure upon a foot for an extended period of time.

Furthermore, Bryan's feedback about battery life provides a clear direction for assessing existing products and their limitations. For our research, it's essential to identify if current market solutions meet this 2-hour operational benchmark and, if not, explore innovative ways to extend battery life without compromising device efficiency or portability.

Another reported drawback is the uneven surface of the scale. A non-flat surface poses significant challenges for patients, particularly when the focus is on achieving balance, stability, and a sustained precise pressure placed upon a single limb. Therefore, our research should prioritize developing a device with a completely flat and stable surface, a device or scale either large enough to encompass the entire patient, or a device that is capable of measuring the weight of the user without any padding underneath the patient.

Further concerns pertain to the display of the non-digital scale. Difficulty in reading the display due to its non-digital nature coupled with its ground placement can be detrimental in two ways. Firstly, it might cause strain for patients as they constantly look downward. Secondly, an unclear display can lead to inaccuracies in measurements, potentially affecting the therapeutic outcomes. Addressing these concerns, our research direction should emphasize the incorporation of a digital, clear, and elevated display. Potential solutions could include an adjustable arm with a digital display that allows patients to easily view readings at eye level, or integrating wireless connectivity to relay the readings to a secondary device such as a smartphone or tablet.

The insights into typical therapy sessions from both an OT and PT perspective provide a broader canvas of the rehabilitation process. The variability in sessions, from addressing lower body fractures to brain injuries, and the range of activities—be it functional mobility tasks like walking around the kitchen or exercises focusing on the range of motion—emphasizes the need for our device to be versatile. Moreover, the challenge highlighted by the PT, regarding adhering to weight-bearing restrictions, reiterates the importance of our device offering precise measurements. The clinic's environment, with activities spanning tables, mat tables, and real-world tasks like laundry, showcases the need for our device to be adaptable across different settings.

Appendix F: User Feedback and Testing Summary

I. Introduction

We pursue human-centered design, so we met therapists and users for an interview and an observation. The purpose of this observation was to test our 3 mockup ideas in detail, and ask questions to determine which mockup should be pursued for our final prototype design.

II. Methodology

Teams 1, 2, 3, and 4 in DTC section 6 met at Shirley Ryan AbilityLab DayRehab Center (12th floor of 345 E Superior St.) on October 27th at 3:30 PM (Figure 1). Hayeon Yun and Leeland Zhang participated in the meeting as representatives of our team and met Jenny Solloway, Eileen Broderick, and Bryan. Our project partners, Eileen Brodecki and Jennifer Solloway, are experts in the field. Eileen is specialized in helping the patients reach maximum independence with her research mainly focusing on helping patients complete daily tasks. Jennifer's experience is more centered around complex neurological injuries on the other hand, showing a clear difference in how Eileen is more specialized in physical motor actions, and Jennifer perhaps with issues more neurological. Bryan is a current patient at Streeterville DayRehab with right lower extremity weight-bearing precautions.

The teams brought different designs, but there were common products shared among them such as smart walker, split scale, and smart crutches. Instead of going through the demonstrations and discussions team by team, the session was organized around the products, with all the teams sharing a particular product design presenting together. By doing so, we could ask all relevant questions and issues pertaining to a specific idea instead of having to recap or repeat. This approach facilitated a more focused and product-centric feedback process. After explaining the idea of our mockup, we would ask special questions concerning any possible issues that Bryan, Eileen, or Jenny might suggest. The methodology during this phase was structured to ensure a comprehensive understanding and feedback collection. Each team prepared a list of specific questions aimed at gathering insightful feedback on the functionality, usability, and relevance of their mockups. The questions were crafted to elicit constructive criticism and suggestions for improvement.

Smart Walker:

- The teams with the smart walker design engaged Bryan, Eileen, and Jenny in a discussion on the potential benefits and challenges of measuring the weight and use during mobility.
- Questions regarding comfort and ease of use were directed towards Bryan to understand the patient's perspective.

Split Scale:

- Teams 3 and 4, who both brought split scale designs, inquired about the display of weight measurement in real-time therapy sessions from Eileen and Jenny.
- Bryan was also asked to share his experience and preferences regarding the utility of such a device in his therapy.

Smart Crutches:

- Teams with smart crutches designs explored the potential for enhanced mobility and independence that smart crutches could offer.
- A discussion on ergonomic design and real-time feedback was facilitated with all three individuals to gather insight on design refinement.

This product-centric approach promoted open communication and fostered a deeper understanding of the practical needs and challenges faced by both the therapists and patients. The feedback collected during this session is instrumental in refining our designs and aligning our project objectives more closely with the real-world needs of the rehabilitation community.

III. Results

Upon arrival at the Shirley Ryan AbilityLab DayRehab Center, our initial focus was directed towards the split scales' design. Our introduction of a split scale was well-received as it appeared to address several existing challenges. The discussion then transitioned to the display technology to be used—whether a standalone physical display or a wired flexible display would be more suitable. The consensus leaned towards the flexible display due to its portability and lesser interference with other concurrent activities.

Further clarification on the display technology was provided by Team 4, who introduced the concept of a multi-color display to signify varying levels of weight-bearing. The idea was to have a color spectrum where yellow indicated a cautionary zone, and red represented an excessive weight-bearing scenario. This proposal was well-received, and Brian further enriched the discussion by suggesting auditory feedback. Leeland also proposed a vibration feedback mechanism, which Brian and Jenny thought that the two, vibration and color coding, could be a good combination and vibration as a better alternative to a sound alert, which may affect nearby patients. The discussion then steered towards identifying the most suitable device to house the vibration mechanism, with Brian advocating for integrating it into the digital display of the weight itself. This approach could potentially cater to individuals with color vision deficiencies or visual impairments, adding a layer of inclusivity to the design.

Transitioning to the smart walker design, feedback indicated that the 'step-up' feature, where the user must raise a leg to put their foot on a slightly elevated scale platform, might not entirely replicate the natural standing posture, thus falling short of the desired real-life simulation. Moreover, the discussions around the smart walker and smart crutches revealed a trend of activities primarily revolving around static standing or transitioning between sitting and standing from an occupational therapy (OT) standpoint. While the smart crutches offered an enhanced mobility aspect, they were critiqued for potential inaccuracies in weight measurement and the fact that not all patients would require or be able to use them. The perceived advantages in mobility were overshadowed by these inconveniences, prompting a re-evaluation of the design's practicality and efficacy.

The discussions unraveled invaluable insights and feedback that underlined the necessity for a more user-centric design approach. The creative solutions proposed, such as the multi-color and vibrational feedback mechanisms, signified the potential for innovative features that could augment the user experience while addressing the diverse needs of the patient demographic. Conversely, the critique on the smart walker and smart crutches emphasized the importance of ensuring that the designs not only enhance mobility but also align accurately with the therapeutic objectives and the real-world scenarios that patients encounter. This session has laid a solid foundation for refining our designs, steering our project towards a more inclusive, practical, and user-friendly trajectory.

IV. Discussion

Post-discussion and comprehensive review of the feedback received, our team has decided to proceed with the development of the split scale design. This design will resemble a conventional bathroom scale, however, it will be enhanced with twice the number of weight sensors to accurately measure weight distribution on either side. This enhancement is pivotal for our target demographic, aiding in their therapy and recovery journey.

One significant alteration from the initial design is the removal of the physical display. Although the soft-wired display concept was discussed during the meeting, further deliberation led us to the conclusion that a completely wireless display would be markedly preferred for its ease of use and minimal setup requirements. This transition to a wireless setup aligns with the user feedback emphasizing portability and minimal interference with other activities.

The wireless display, as envisioned, does not necessitate a large screen; the key requirement is clarity and ease of interpretation. During our discussions, it was clear that a color-coded system would provide an intuitive understanding of weight distribution. Incorporating a vibration feature will further enhance the user experience, especially catering to individuals with visual impairments.

For the wireless communication between the split scale and the display, Bluetooth Low Energy (BLE) is recommended due to its low-cost, low-power consumption, and reliable communication capabilities. This technology is well-suited for this application, ensuring real-time feedback while maintaining a user-friendly setup.

Our next steps involve the development and testing of a prototype, integrating the color-coded and vibration features into the wireless display, and ensuring the accuracy and reliability of the weight measurement system. The insights garnered from the meeting have significantly shaped the direction of our project, steering us towards a design that encapsulates inclusivity, practicality, and user-centricity. Through iterative testing and continuous feedback collection, we aim to refine our product to meet the real-world needs and expectations of both the therapists and patients at the rehabilitation center.

Appendix G: Instruction for Use

The following steps describe the process of using the Weight Wizard:

Step-1: Turn on the scale using the button on it.

Step-2: Place the display in your desired location where it can be clearly seen. The display has a movable stand that can be mounted anywhere on a flat surface (see Figure 15).

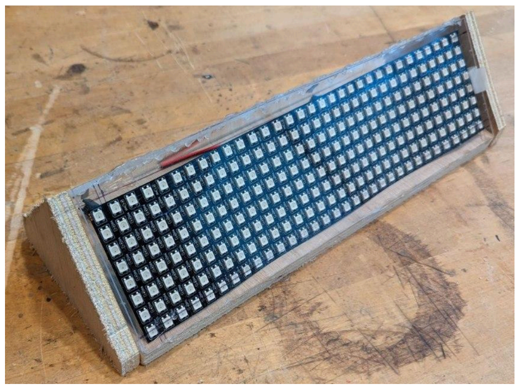

Figure 15: Wireless display with mountable case

Step-3: Step on the scale (see Figure 16).

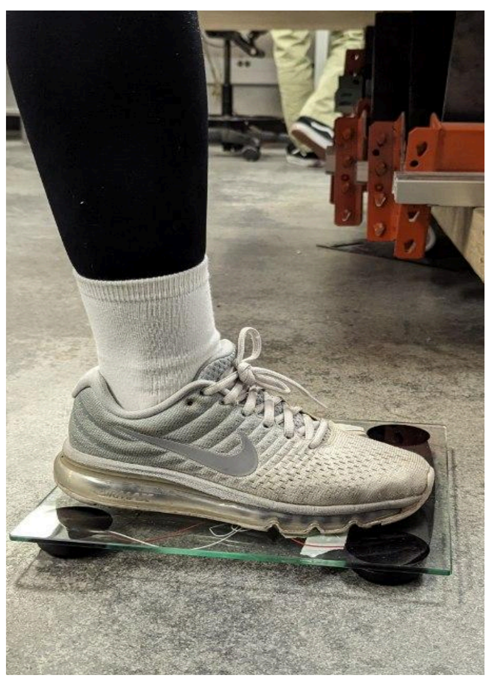

Figure 16: Person stepping on a bathroom scale

Step-4: Perform the activities while you are on the scale following the occupational therapist or clinical therapist instructions.

Step-5: Read the value of weight bearing on the display scale.

Appendix H: Instruction for Construction

Instructions for Constructing Weight Wizard

The steps below are instructions that should be followed when using this product.

The following is a list of materials needed to construct the Weight Wizard:

Table 5: Materials Used for Constructing the Weight Wizard

Item	Description	Qty
ESP-32	Built in USB-to-Serial converter, automatic bootloader reset, Lithium Ion/Polymer charger, GPIOs, a dual-core ESP32 chip, 4 MB of SPI Flash, tuned antenna, WiFi *and* Bluetooth Classic/LE support	2
Battery	Output ranges from 4.2V when completely charged to 3.7V, a capacity of 500mAh for a total of about 1.9 Wh, pre-attached with a 2-pin JST-PH connector as shown and include the necessary protection circuitry	2
Amplifier	A small breakout board for the HX711 IC that allows you to easily read load cells to measure weight	2
Display	8X32 256 LEDs. 32 horizontal LED and 8 vertical LED. Each 5050SMD LED is individually addressable. High quality, The LED material is the best, Using pure gold wire.	1
Scale	Malama Digital Body Weight Bathroom Scale, Weighing Scale with Step-On Technology, LCD Backlit Display, 400 lbs Accurate Weight Measurements, Silver	1
Nylon plastic	Nylon is a strong, stiff engineering plastic with outstanding bearing and wear properties. Nylon is frequently used to replace metal bearings and bushings often eliminating the need for external lubrication.	30 x 30 x 0.5 (cm) 450 cm^3
Wood	Wood has aesthetic appeal, versatility, and durability, making it suitable for enhancing the visual appeal and supporting the weight of the base of the display.	13 x 4.5 x 0.25 (in) 14.625 in^3

Note: See Bill of Materials (Appendix B) for prices and part numbers.

The following tools are needed to construct the Weight Wizard:

- Vertical band saw
- Hot glue
- Ruler
- Pencil
- Soldering station
- USB-micro to USB-A transfer cable

The following steps are required in order to construct the Wireless Weight Display:

1. Selecting and Disassembling the Bathroom Scale:

- Purchase the Malama Digital Body Weight Bathroom Scale, though other standard bathroom scales can be used as well.
- Carefully disassemble the scale to expose the four load sensors. This is typically done by removing the screws or fasteners from the bottom of the scale.
- *While disassembling, ensure the load sensors and their connections are not damaged.

2. Preparing the Load Sensors:

- Each load sensor has wires attached to it. Identify each sensor's wires and carefully detach the wires.
- Create a Wheatstone bridge circuit by connecting the four white wires from the sensors together and the four black wires together. The Wheatstone bridge is essential for accurate measurement of the load (see Figure 11).

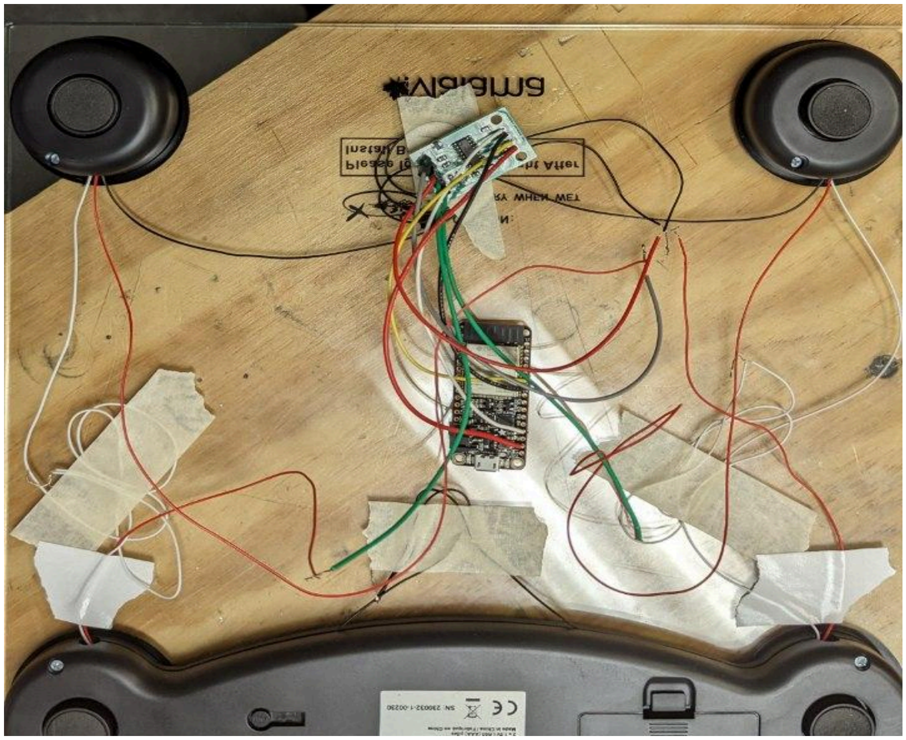

Figure 17: Creating Wheatstone bridge circuit

3. Amplifying the Signal:

- Connect the red wires from the sensors to a load amplifier. This device amplifies the small signal generated by the load sensors, making it readable by the microcontroller.
- Connect the output of the load amplifier to an ESP32 board microcontroller. The ESP32 will process the signal and enable wireless communication.

4. Setting Up the Arduino IDE for Programming the ESP32:

- Download and install the Arduino IDE from the official Arduino website.
- Open the Arduino IDE, go to File -> Preferences.
- In the "Additional Board Manager URLs" field, enter the URL for the ESP32 board manager (this can be found on the ESP32 GitHub repository or the manufacturer's website).
- Open the Board Manager by going to Tools -> Board -> Boards Manager, search for ESP32, and install the latest version.
- Select the correct ESP32 board from Tools -> Board.

5. Installing the HX711 Library:

- In the Arduino IDE, go to Sketch -> Include Library -> Manage Libraries.
- Search for the HX711 library and install it.

6. Calibrating the Scale:

- Load an example sketch for the HX711 library.
- Define the load cell factor (this will require calibration using known weights).
- Adjust the code to include the WiFi credentials and any other settings specific to your project.
- Upload the sketch to the ESP32 board.

7. Testing and Troubleshooting:

- After uploading the code, test the scale with known weights to ensure accuracy.
- If the readings are off, recalibrate the load cell factor.
- Ensure the wireless connection is stable and the ESP32 is transmitting data correctly.

8. Final Assembly:

- Once the calibration is verified, reassemble the scale.
- Secure the ESP32 and any additional circuitry inside the scale. The wires should not interfere with the load cells themselves, and the wires should be properly and orderly layered such that it is easy for any engineer to understand the wiring scheme upon glance.

9. Building the Display Housing:

- Cut two rectangles from nylon plastic, ensuring they have differing widths but equal lengths. This plastic is chosen for its durability and transparency.
- Use hot glue to attach these rectangles at right angles to each other. This configuration maximizes surface area and will serve as the main body of the display housing.
- For the base and sides of the housing, use inch-thick wood. Cut pieces to the required size to cover the bottom and two sides of the plastic structure.

10. Assembling the Light Display Board:

- Inside this housing, place a 256-light display board. The transparency of the nylon plastic will allow the light from the display to be visible.
- Secure the display board in place, ensuring it is aligned correctly and firmly attached within the housing.

11. Wiring the Second ESP32 for the Display:

- Wire the second ESP32 board to the light display board. Ensure proper connections for power and data transfer.
- Double-check all connections for stability and correctness.

12. Programming the ESP32 for Display Communication:

- In the Arduino IDE, write a sketch to program the ESP32 connected to the display.
- This involves writing a function to receive weight data wirelessly from the ESP32 on the scale and implementing a communication protocol (such as MQTT or HTTP) to transmit data between the two ESP32 boards.

```
#include the necessary libraries:
#include <WiFi.h>
#include <PubSubClient.h>

#Set up the WiFi and MQTT server details:
const char* ssid = "your_SSID";
const char* password = "your_PASSWORD";
const char* mqtt_server = "your_MQTT_server_address";
#Initialize the WiFi and MQTT client:
WiFiClient espClient;
PubSubClient client(espClient);

#Connect to the WiFi network and MQTT server:
void setup() {
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
  }
  client.setServer(mqtt_server, 1883);
}

#Subscribe to the MQTT topic that the scale ESP32 publishes the weight data #on:
void reconnect() {
  while (!client.connected()) {
    if (client.connect("displayESP32")) {
      client.subscribe("scale/weightData");
    }
    delay(5000);
  }
```

```
}

#Handle the received message:
void callback(char* topic, byte* message, unsigned int length) {
  String messageTemp;

  for (int i = 0; i < length; i++) {
    messageTemp += (char)message[i];
  }

  if (String(topic) == "scale/weightData") {
    displayWeight(messageTemp);
  }
}
```

- *Ensure the ESP32 is configured to connect to the same network as the ESP32 on the scale for seamless data transfer.

13. Displaying the Weight Data:

- Code the ESP32 to convert the received weight data into a format suitable for the light display board.
- This involves writing a function to program the display board to show the weight readings in real-time as the scale measures weight.
- *Test the communication between the scale and the display. Adjust the network settings or code as necessary for reliable data transfer.

```
#In the main loop, keep checking and maintaining the MQTT connection:
void loop() {
  if (!client.connected()) {
    reconnect();
  }
  client.loop();
}
```

14. Displaying the Weight Data with Color Indicators:

- In your Arduino IDE sketch, add functions to control the display board. This involves writing a function to display text on the board in different colors:

```
void displayText(String text, uint32_t color) {
   // Code to display the text on the board in the specified color.
   // Implementation depends on your hardware specifics.
}

uint32_t RED = 0xFF0000;
uint32_t YELLOW = 0xFFFF00;
uint32_t GREEN = 0x00FF00;
```

Write the displayWeight function to include logic for changing the color based on the weight threshold:

```
void displayWeight(String weightStr, float redThreshold) {
   float weight = weightStr.toFloat();
   uint32_t displayColor;

   if (weight >= redThreshold) {
      displayColor = RED;  // Weight exceeds the threshold, display in red.
   } else if (weight >= redThreshold * 0.9) {
      displayColor = YELLOW;  // Weight is close to the threshold, display in yellow.
   } else {
      displayColor = GREEN;  // Normal weight, display in green.
   }

   displayText(weightStr, displayColor);  // Display the weight with the appropriate color.
}
```

Modify the MQTT callback function to include the weight threshold when calling displayWeight:

```
void callback(char* topic, byte* message, unsigned int length) {
   String messageTemp;

   for (int i = 0; i < length; i++) {
      messageTemp += (char)message[i];
   }

   if (String(topic) == "scale/weightData") {
      float redThreshold = 100.0;  // Define the red color threshold.
```

```
    displayWeight(messageTemp, redThreshold);
  }
}
```

15. Loop to Keep the Connection Alive:

- In the main loop, maintain the MQTT connection. This involves writing a function to continuously check for new weight data.

```
void loop() {
  if (!client.connected()) {
    reconnect();
  }
  client.loop();
}
```

16. Finalizing the Display Unit:

- Assemble the display unit with the ESP32 board connected to the light display board inside the nylon plastic housing.
- Attach the wooden base and sides to complete the housing (see Figure 18).
- *Test the entire setup to ensure the display accurately reflects the weight readings and changes colors appropriately based on the set thresholds.

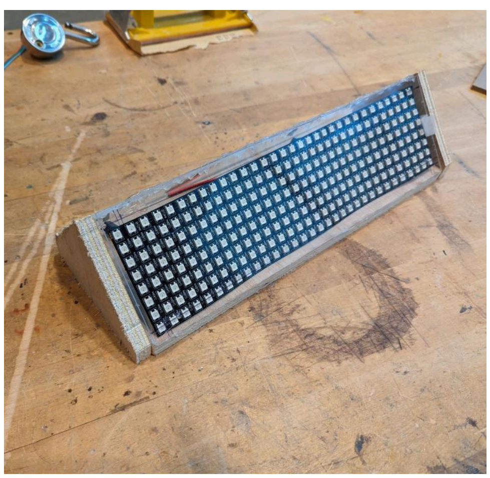

Figure 18: Assembling the display unit and housing

Appendix I: Design Review Summary

Introduction:

On Thursday, 10/26/2023, we came with our three mockups for our in-class mockup presentation: Smart Walker, Smart Crutches, and Split Scale. We finished designing and building our mockups before class and we brought pictures and design descriptions to class for this presentation.

We took turns explaining the basic design and projected mechanism of our three mockups: the Smart Walker, the Smart Crutches, and the Split Scale. Our classmates provided feedback in different categories, such as features to add or remove, and raised concerns regarding the convenience, durability, universality, and functional endurance of our mockups. We replied to questions asked and took note of the recommendations forwarded by our classmates. We will put all suggestions to consideration and apply them to our prototype design.

Summary of the feedback:

Table 6: Summary of the Feedback

Reviewers like:	Smart Walker: - Scale can move up and down Split Scale: - Idea is very simplistic and easy to understand, but is also very practical Smart Crutches: - Many thought vibration feedback was a creative idea of notification for the user
Reviewers dislike:	Smart Walker: - Concerns about ledge was raised about OT and PT - How would the walker be low enough so that the user could bend over to reach for objects during static therapy sessions - Comfortability of walker - Creates imbalance between injured leg and uninjured leg - Scale is not on the ground Split Scale: - N/A Smart Crutches: - Would we locate the vibrations response to be in a place where the hands are occupied with other work?

	- How would the user be able to do their activities that need ROM? - Do we need a separate device?
Features to be added:	Have the split scale be able to move Maybe add wheels? Vibration with the split scale?
Features to be removed/fixed:	Smart Walker and Crutches are not going to be able to be used during free standing exercises, hence we need to modify it, if possible, to make it so that the ROM for the patient is possible. Smart Walker: - Adding scale on the top of the walker can make the walker heavier, which can lead to safety concerns.
Additional comments:	Smart Walker: - How are we going to do use this when the user doesn't need a walker to move - Answer: Asked current user: we asked bryan about this, but he said he can use a walker - Will ask other users to see their input Split Scale: - N/A - Check with Professor Marchuk at DTC Shop

Action Plan:

In order to enhance the mobility and functionality of the split scale, we will be attaching wheels to its base. These wheels will have a locking mechanism to ensure stability and prevent any unintended movement while the scale is in use. The addition of these wheels will make it easier to move the scale around, especially in OT or PT sessions, where frequent repositioning is required.

To ensure that the modifications align with the specific requirements and expectations of the project, we will set up a meeting with Professor Marchuk at the DTC Shop. This meeting will provide an opportunity to discuss the proposed changes in detail, address any concerns or preferences, and determine if there are any additional adjustments needed to optimize the split scale's performance and functionality. By collaborating with Professor Marchuk, we can make sure that the final design of the scale meets all the necessary criteria and delivers the desired outcomes for its intended use.

After meeting with Professor Marchuk, we will begin looking for commercial scales to buy off of Amazon. That way we can begin creating the software we'll need to display the weight to the user.

After going to the end-user observation, we were told by Jenny and Bryan that the Smart Crutches or Smart Walker won't work for standing exercises. Hence, they suggested we focus solely on the Split Scale which all members have agreed with.

Appendix J: Code For Display

For further use, the following arduino code below is highly suggested for modification and review. The code uses the Adafruit NeoMatrix library to control an LED matrix display. When the system finds a BLE device advertising the specified service UUID, it connects, reads a characteristic (interpreted as weight), and displays this weight on the LED matrix. The display color changes based on the weight value. The system also sets up notifications to update the weight display when the BLE device sends new data.

```
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_NeoMatrix.h>

#include <Adafruit_BusIO_Register.h>
#include <Adafruit_I2CDevice.h>
#include <Adafruit_I2CRegister.h>
#include <Adafruit_SPIDevice.h>
#include <gamma.h>
#include <Adafruit_GrayOLED.h>
#include <Adafruit_SPITFT.h>
#include <Adafruit_SPITFT_Macros.h>
#include <gfxfont.h>
#include <Adafruit_NeoPixel.h>
#include <BLEDevice.h>
#include <BLEUtils.h>
#include <BLEScan.h>




#define SERVICE_UUID        "4fafc201-1fb5-459e-8fcc-c5c9c331914b"
#define CHARACTERISTIC_UUID "beb5483e-36e1-4688-b7f5-ea07361b26a8"


// Replace these with your specific settings
#define PIN 13
#define MATRIX_WIDTH 32
#define MATRIX_HEIGHT 8
#define SCAN_TIME 5 // Scan for 5 seconds

Adafruit_NeoMatrix matrix = Adafruit_NeoMatrix(MATRIX_WIDTH, MATRIX_HEIGHT, PIN,
  NEO_MATRIX_TOP     + NEO_MATRIX_LEFT +
  NEO_MATRIX_COLUMNS + NEO_MATRIX_ZIGZAG,
  NEO_GRB            + NEO_KHZ800);


BLEScan* pBLEScan;
bool deviceConnected = false;
float weight = 0.0;

// Forward declaration of notifyCallback
```

```
void notifyCallback(BLERemoteCharacteristic* pBLERemoteCharacteristic, uint8_t* pData, size_t
length, bool isNotify);

class MyAdvertisedDeviceCallbacks: public BLEAdvertisedDeviceCallbacks {
  void onResult(BLEAdvertisedDevice advertisedDevice) {
    Serial.print("Device found: ");
    Serial.println(advertisedDevice.toString().c_str());

    // Check if this is the device we are looking for
    if (advertisedDevice.haveServiceUUID() &&
advertisedDevice.isAdvertisingService(BLEUUID(SERVICE_UUID))) {

      Serial.println("Scale found! Connecting...");

      // Stop the scan
      BLEDevice::getScan()->stop();

      // Connect to the scale
      BLEClient* pClient = BLEDevice::createClient();
      pClient->connect(&advertisedDevice);

      // Obtain a reference to the service we are after in the remote BLE server.
      BLERemoteService* pRemoteService = pClient->getService(BLEUUID(SERVICE_UUID));
      if (pRemoteService == nullptr) {
        Serial.print("Failed to find our service UUID: ");
        Serial.println(SERVICE_UUID);
        return;
      }

      // Obtain a reference to the characteristic in the service of the remote BLE server.
      BLERemoteCharacteristic* pRemoteCharacteristic =
pRemoteService->getCharacteristic(BLEUUID(CHARACTERISTIC_UUID));
      if (pRemoteCharacteristic == nullptr) {
        Serial.print("Failed to find our characteristic UUID: ");
        Serial.println(CHARACTERISTIC_UUID);
        return;
      }

      // Read the value of the characteristic.
      if(pRemoteCharacteristic->canRead()) {
        std::string value = pRemoteCharacteristic->readValue();
        weight = atof(value.c_str());
      }

      // Set up notifications
      if(pRemoteCharacteristic->canNotify()) {
        pRemoteCharacteristic->registerForNotify(notifyCallback);
      }

      deviceConnected = true;
    }
  }
```

```
};
void notifyCallback(BLERemoteCharacteristic* pBLERemoteCharacteristic, uint8_t* pData, size_t
length, bool isNotify) {
  if (length == sizeof(float)) {
    memcpy(&weight, pData, sizeof(float)); // Convert bytes back to float
    Serial.print("Received Weight: ");
    Serial.println(weight);
    displayNumber(weight); // Update the display with the new weight
  }
}

void setup() {
  Serial.begin(57600);
  Serial.println("Starting Display...");


  matrix.begin();
  matrix.setTextWrap(false);
  matrix.setBrightness(40);
  matrix.setTextColor(matrix.Color(255, 255, 255));
  // Initialize BLE
  BLEDevice::init("");
  pBLEScan = BLEDevice::getScan(); //create new scan
  pBLEScan->setAdvertisedDeviceCallbacks(new MyAdvertisedDeviceCallbacks());
  pBLEScan->setActiveScan(true); //active scan uses more power, but get results faster
  pBLEScan->setInterval(100);
  pBLEScan->setWindow(99);  // less or equal setInterval value
}

void loop() {
  if (!deviceConnected) {
    BLEScanResults foundDevices = pBLEScan->start(SCAN_TIME, false);
    pBLEScan->clearResults();   // delete results fromBLEScan buffer to release memory
  } else {
    displayNumber(weight);
  }
}

void displayNumber(float num) {
  matrix.fillScreen(0);
  matrix.setCursor(0, 0);

  if (num < 1000) {
    matrix.setTextColor(matrix.Color(0, 255, 0));
  } else if (num < 5000) {
    matrix.setTextColor(matrix.Color(255, 255, 0));
  } else {
    matrix.setTextColor(matrix.Color(255, 0, 0));
  }

  char buf[10];
  dtostrf(num, 7, 2, buf);
```

```
  matrix.print(buf);
  matrix.show();
}

void clearDisplay() {
  matrix.fillScreen(0);
  matrix.show();
}
```

Appendix K: Code For Scale

For further use, the following arduino code below is highly suggested for modification and review. This code sets up a BLE (Bluetooth Low Energy) server on an ESP32 microcontroller for a digital scale using the HX711 load cell amplifier. It initializes the load cell, calibrates it, and starts a BLE service with specified UUIDs. When a client connects, it reads weight from the load cell and sends the data to the connected BLE client via notifications.

```
#include <HX711_ADC.h>
#if defined(ESP8266)|| defined(ESP32) || defined(AVR)
#include <EEPROM.h>
#endif
#include <BLEDevice.h>
#include <BLEUtils.h>
#include <BLEServer.h>


// BLE UUIDs
#define SERVICE_UUID        "4fafc201-1fb5-459e-8fcc-c5c9c331914b"
#define CHARACTERISTIC_UUID "beb5483e-36e1-4688-b7f5-ea07361b26a8"


const int HX711_dout = 4;
const int HX711_sck = 5;

HX711_ADC LoadCell(HX711_dout, HX711_sck);

BLEServer *pServer = NULL;
BLECharacteristic *pCharacteristic = NULL;
bool deviceConnected = false;

// Callbacks for client connection and disconnection
class MyServerCallbacks: public BLEServerCallbacks {
    void onConnect(BLEServer* pServer) {
      deviceConnected = true;
    };

    void onDisconnect(BLEServer* pServer) {
      deviceConnected = false;
    }
};

void setup() {
  Serial.begin(57600);
  Serial.println("Starting Scale...");

  LoadCell.begin();
  unsigned long stabilizingtime = 2000;
  boolean _tare = true;
  LoadCell.start(stabilizingtime, _tare);
  if (LoadCell.getTareTimeoutFlag() || LoadCell.getSignalTimeoutFlag()) {
    Serial.println("Timeout, check wiring");
```

```
    while (1);
  } else {
    LoadCell.setCalFactor(-17.8);
    Serial.println("Startup is complete");
  }

  // Create the BLE Device
  BLEDevice::init("ESP32_Scale");

  // Create the BLE Server
  pServer = BLEDevice::createServer();
  pServer->setCallbacks(new MyServerCallbacks());

  // Create the BLE Service
  BLEService *pService = pServer->createService(SERVICE_UUID);

  // Create a BLE Characteristic
  pCharacteristic = pService->createCharacteristic(
                      CHARACTERISTIC_UUID,
                      BLECharacteristic::PROPERTY_READ   |
                      BLECharacteristic::PROPERTY_NOTIFY
                    );

  //pCharacteristic->setCallbacks(new MyCallbacks());

  // Start the service
  pService->start();

  // Start advertising
  pServer->getAdvertising()->start();
  Serial.println("Waiting a client connection to notify...");
}

void loop() {
  if (LoadCell.update()) {
    float weight = LoadCell.getData();
    Serial.println(weight); // Print weight to Serial monitor for debugging

    if (deviceConnected) {
      // Convert float to bytes
      uint8_t weightBytes[sizeof(weight)];
      memcpy(weightBytes, &weight, sizeof(weight));

      // Set the value and notify
      pCharacteristic->setValue(weightBytes, sizeof(weightBytes));
      pCharacteristic->notify();
    }
  }
}
```