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A Smart Walker Device for Monitoring Biometric Data for Stroke Neurorehabilitation

The field of neurorehabilitation is continually advancing, and data-driven methodologies are essential for optimizing stroke recovery outcomes. A significant challenge in neuromuscular therapy is determining the appropriate timing for discharging stroke patients from inpatient care. Objective real-time biometric data enhances clinicians ability to assess the patient's readiness to transition out of an inpatient clinical care setting and evaluate their rehabilitation progress. Existing smart walker technologies are often cost-prohibitive for widespread clinical adoption and only measure a single biometric parameter. This paper presents a novel smart walker that overcomes these limitations by incorporating multiple sensing capabilities into a unified system. The device consists of a standard rolling walker that is integrated with load sensors in each of the four legs and a speed sensor, with data processed by a Raspberry Pi Pico microcontroller. Real-time feedback is displayed via OLED screens mounted on the walker, ensuring accessibility for both patients and clinicians. By providing simultaneous measurement of load distribution, velocity, and distance, this system enables clinicians to track biometric trends over time and refine treatment strategies accordingly. Additionally, real-time feedback offers quantifiable performance metrics to patients, promoting engagement in their rehabilitation process.

1 Introduction

People enter neurorehabilitation under a variety of different circumstances. They are often recovering from traumatic brain injury, degenerative neurological diseases or strokes. One of their most common symptoms is gait impairment, a condition which greatly reduces quality of life and increases the risk of future falls [1]. Furthermore gait impairment can prevent reintegration back into society due to diminished walking speeds complicating everyday actions like crossing the street. In order to ensure these patients have regained functional mobility, physical therapists will use basic walking tests to assess characteristics such as speed and reliance on assistive devices. These tests offer insight into the effectiveness of the therapy but also act as motivational tools for those in treatment. Establishing benchmarks in training can encourage more engagement in and adherence to the rehabilitation process [2]. However these indicators are often estimated through observations by the physical therapist as opposed to being collected as objective data. A smart walker which could collect the speed and pressure applied by the user could become an important tool in neurorehabilitation. This device could facilitate the development of a more effective training plan and incentivize those in treatment, hastening their recovery and improving quality of life.

There are currently patents and existing devices for walkers which include elements of the smart walker. A Distance Measuring Walker Patent lays claims to walkers with distance and speed measuring sensors built into its wheels [3]. This data would then be displayed on a sensor attached to the frame of the walker. However this patent does not include any methods of measuring pressure through the walker and therefore does not fully encompass the envision of the product. Another patent for an instrumented mobility assistance device uses sensors in the handles of the walker to measure the force transmitted through the user to the walker [4]. The peaks and valleys of the output force vs. time graph are correlated to parts of the users gait, and can be used to make calculations to infer about the users gait speed, travel distance, and stability/balance when using the walker. Though this design measures applied pressure and speed similar to the proposed smart walker, it also includes gait analysis which would increase the price and complexity of the device. Finally, on the market there is a Camino Smart Walker which uses AI to perform gait analysis and measure 22 different gait parameters [5]. It also incorporates boosts and brakes, facilitating assisted transport. This added technology contributes to the steep price of the walker, each unit selling at $3000. This is an unreasonable price to ask for clinicians and diminishes the effectiveness of the walker as a simple rehabilitation aid.

In the rehabilitation process of acute strokes or similar conditions it is necessary for the patient to be able to walk independently so they can safely return home. Physical therapists often gauge reliance on assistive walking devices through observational measures of speed and applied pressure on the walker. No current devices on the market offer these measurements while requiring minimal setup and employing a standard walker. For this reason, the development of a smart walker which can record walking speed and pressure placed on the walker is vital for proper patient rehabilitation. The pressure measurements should track distribution in order to ensure symmetry while walking. This data will need to be recorded during individual walking tests, after which the average should be displayed on a monitor attached to the walker. This information will help guide physical therapists in shaping therapy goals as well as motivate patients to engage with the rehabilitation process. As a result the smart walker could improve the neurorehabilitation process and send patients home faster.

2 Methods

2.1 Overview. The smart walker design can be fully outlined using two categories of components. Circuitry components make up the electrical aspects of the design, and are used to transduce external stimuli (force and movement) into electrical signals that can be used in calculations and output to the user. To make this happen, there are five stages so to speak of circuitry that are used in the smart walker design. Furthermore, there are three interfacing types of components that are attached to the walker in order to allow the circuitry components to function with their intended use.

2.2 Circuitry Components. A schematic of the circuit components of the smart walker design are shown in Fig. 1. The overall design consists of five distinct systems: (1) Power, (2) Microcontroller, (3) four Load Sensor Complexes, (4) Speed & Distance Sensor, and (5) a Screen Complex. These five systems will be working simultaneously while the device is powered on.

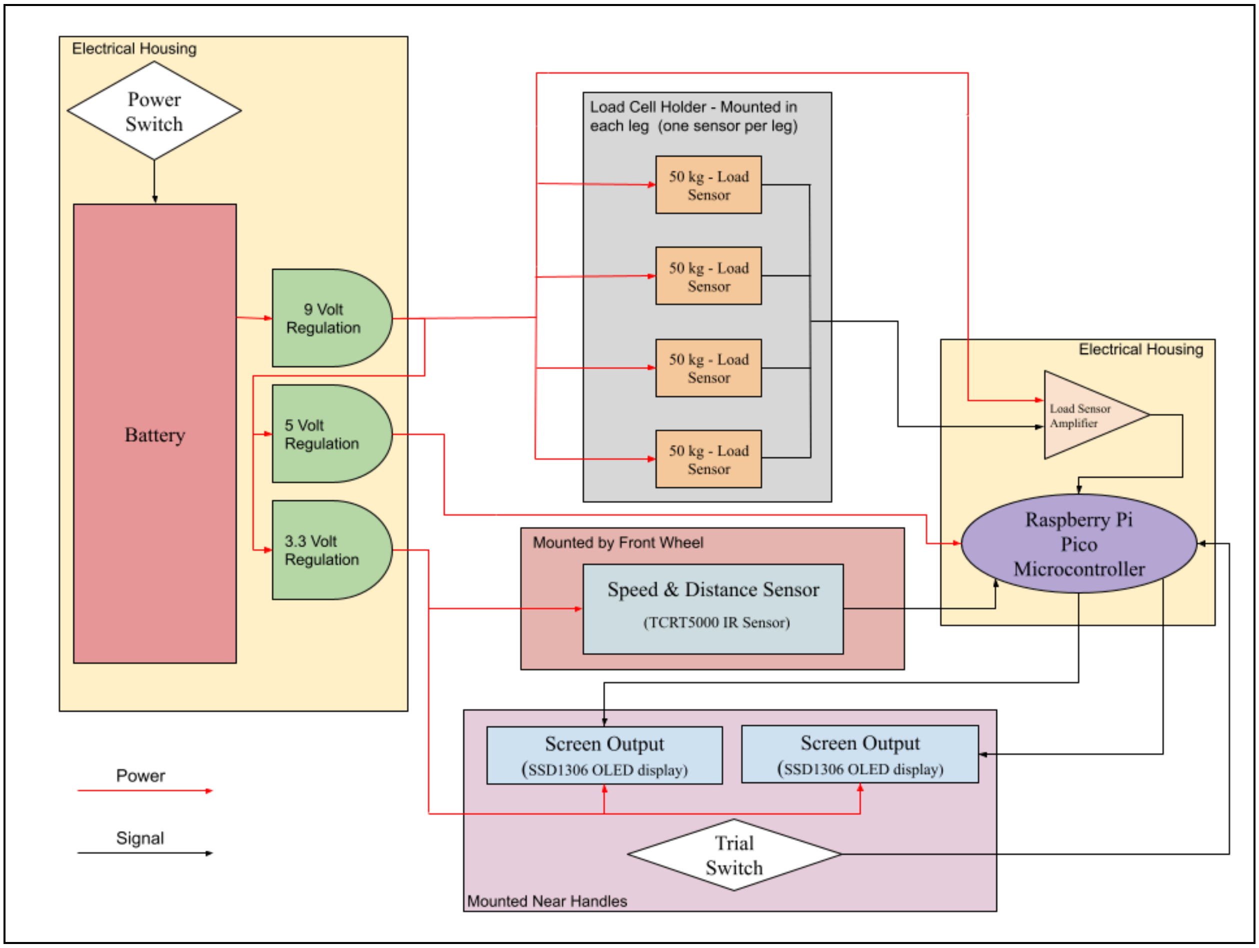

Figure 1. Block diagram of smart walker design and components. This schematic shows the power and signal connections between components, as well as the relative position of each component on the smart walker.

2.2.1 Power Supply. In order to supply energy to the subsequent components, a KBT lithium-ion battery (12V, 2400mAh) was purchased. This specific battery has a female barrel jack that is used for recharging with a standard wall wart. Connected directly to the positive and negative terminals of the battery is a 9V Buck downregulator, which supplies the entire rest of the circuitry with a near-9V signal with attenuated high-frequency signal components, meaning that a steady signal is supplied to the whole circuit. This signal is taken directly to the load sensor complex, elaborated upon further in section *2.2.3*. Two more Buck downregulators are used to supply other components of the circuit with the proper voltages. 5V regulation is used to power the microcontroller (section *2.2.2*), and 3.3V regulation is used to power both the speed/distance sensor and the screen output (sections *2.2.4* and *2.2.5*, respectively).

2.2.2 Microcontroller. The microcontroller selected for the adapted clinical walker was the Raspberry Pi Pico [6]. The “Pico” is a 32 bit, 40 pin microcontroller that contains 2x SPI (serial peripheral interfaces), 2x I2C (inter-integrated circuit), 2x UART (universal asynchronous receiver/transmitter), 3x 12-bit 500 ksps ADC (analog to digital converter), and 24 controllable pulse wave modulation channels. The device utilized the I2C buses to be in communication with the OLED screens, for the speed and load sensors it utilized the ADC lines. The microcontroller was programmed via MicroPython and is able to run independently without connection to an external computer since the code can be uploaded to the microcontroller.

2.2.3 Load Sensor Amplifier. Four load sensors are used in the smart walker design. These sensors are able to pick up on slight deformations in their metal bodies using a strain gauge, which changes resistance depending on its deformation. Placed in each leg of the walker so that they absorb the force through their respective leg, each load sensor is connected via white wire or black wires to adjacent legs excluding the diagonally-opposite one. This Wheatstone bridge conformation, show using resistors labeled “B-” or “W-” in Fig. 2, allows us to pick up on strain gauge resistance changes by measuring the difference in voltage at two diagonally-opposite load sensors, assuming the opposing pair of load sensors are connected to power and ground. The voltages are sent through two more stages of amplification in order for the signal to be fit for the microcontroller.

The first stage is a LT1920 difference amplifier, which is an integrated circuit that outputs the difference in voltage between the two input terminals multiplied by the gain, set by the feedback resistor. The aforementioned voltages are sent to the “In-” and “In+” input terminals of the amplifier, and a 470Ω feedback resistor labeled “Rg” is placed across the amplifier to determine the gain using Eq. 1, which is roughly 106V/V.

Equation 1. $$Gain = 1 + \left(\frac{49.4k}{Rg}\right)$$

The output from the first stage is fed directly into the second. The second stage uses a TL072 operational amplifier (op-amp) and four resistors in a level-shifter conformation to ensure that the signal is a positive value, and can be used with the microcontroller analog-to-digital converter (ADC). To further elaborate, the level-shifter conformation is an application of a differential amplifier used to shift a voltage signal to a specified value. The output from stage one goes through resistor 10 (resistor numbers shown in Fig. 2. following a capital "R") and into the inverting terminal of the op-amp, where the output of the op-amp is also fed back to via feedback resistor 11. 3.3V regulated voltage from the Buck downregulator (not pictured in Fig. 1.) is sent through resistor 12 and into the non-inverting terminal of the op-amp, which is connected to ground via resistor 13. Assuming resistance values from resistors 10 and 12 are equal, and resistance values from resistors 11 and 13 are equal, Eq. 2. describes the gain for the level shifter. For this instance, resistors 10 and 12 are 20kΩ and resistors 11 and 13 are 10kΩ, leading to a signal attenuation of 0.5V/V. The final, fully processed signal is sent to the microcontroller ADC input.

Equation 2. $Gain = R11/R10 = R13/R12$

In order to supply negative voltage to the LT1920, another amplifier is needed. The LTC1983-5 DC-to-DC converter takes the voltage supplied to the Wheatstone bridge and, in conjunction with two 10µF capacitors, inverts the signal. As previously stated, the output from the converted is sent to the "V-" pin of the LT1920 to power it. This stage is necessary for the function of the LT1920 and, as such, is required for the smart walker design.

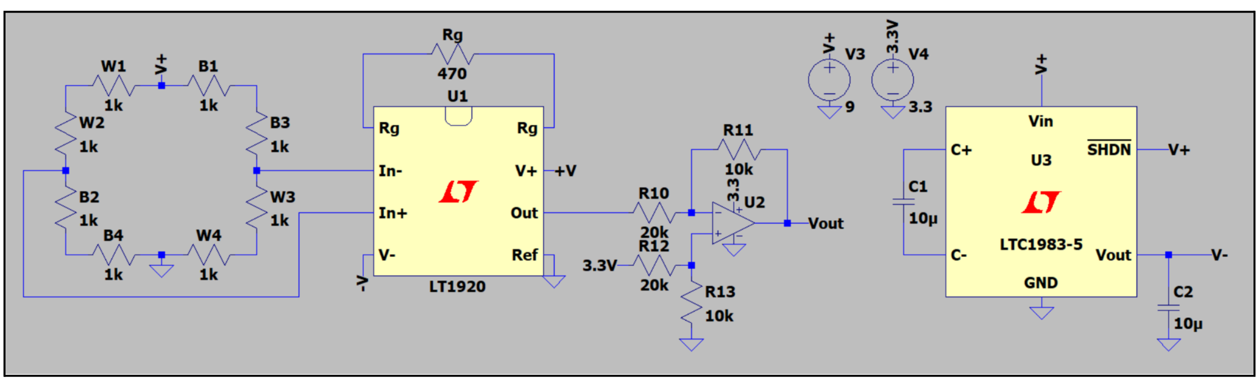

Figure 2. Circuit diagram of the load sensor amplifier. From left to right, the wheatstone bridge of load cells, with each node being a load cell which will be embedded within the legs, LT1920 (U1), level shifter (U2), and LTC1983-5 (U3) constitute the load sensor amplifier.

2.2.4 Speed and Distance Sensor. The speed and distance sensor selected was the TCRT5000 IR sensor. The sensor consists of an IR LED emitter and a phototransistor that detects the reflected IR light from the surface. The sensor then outputs a voltage depending on how much light is reflected; darker colors absorb more IR light and therefore have a lower output whilst lighter colors reflect more light, leading to a higher output. The sensor was programmed to add incremental distances when it detected changes in alternating color strips of tape that line the inside of the walker wheel. This method was selected due to the high precision of the sensor and the cost effectiveness as opposed to other rotary encoders.

2.2.5 OLED Screens and Trial Switch. The output from the load sensor amplifier and the IR sensor data is fed to the microcontroller and then displayed by two SSD1306 OLED displays positioned in the display holder, The top OLED screen is dedicated to display the mode of the device, “real-time” or “trial” modes, while the bottom screen displays sensor biometric data, depending on the mode of the device. The mode of the entire system will be dictated/toggled by a “trial” switch positioned adjacent to the displays. While the trial switch is toggled off, the system continuously reports the current load applied by the patient and the instantaneous velocity of the walker, which is displayed to the screens. Once the trial switch is toggled on, the overall system enters “trial mode,” where it begins recording biometric data throughout an entire trial, which ends once the switch is toggled back to off. Key biometric data includes, travel distance, average speed, time, and average applied load. Upon completion of a trial, and toggling of the switch to off, the device will output the key data via the OLED screens. The top screen will display the duration of the trial, while the bottom will report load, velocity, and distance information. This information will be displayed for 60 seconds, and then the device will resume outputting real-time data to the displays.

2.3 Interfacing Components. One of the core aspects of this smart walker design is that it utilizes existing walker structure as the frame of the device. This design choice lowers the overall device cost, while additionally making the device more adaptable and thus more adoptable in clinical settings. Thus the design necessarily consists of three interfacing components that attach to the walker frame allowing for seamless integration with sensors and accompanying circuitry. These three components are the (1) load cell holders, (2) sensor and power circuitry housing, and (3) display housing.

2.3.1 Load Cell Holder Design. The load cell holders allow the load cells to be inserted into the four hollow legs of the walker. The load cells rest within the wells in the lower housing components at point 1 displayed in Figure 3 below. The cylindrical components labeled 2 are then inserted into the walker legs. These cylindrical components feature a small hole for the wires from the load cells to exit and travel through the legs of the walker. They also have both an inner and outer shell to strengthen the design against shear forces and misalignment. Through the vertical translation of the lower housing cell component, the load cell holders then transmit pressure applied to the walker through the load cells at focused points of contact. The load cell holders are keyed as demonstrated at point 3 to prevent internal rotation.

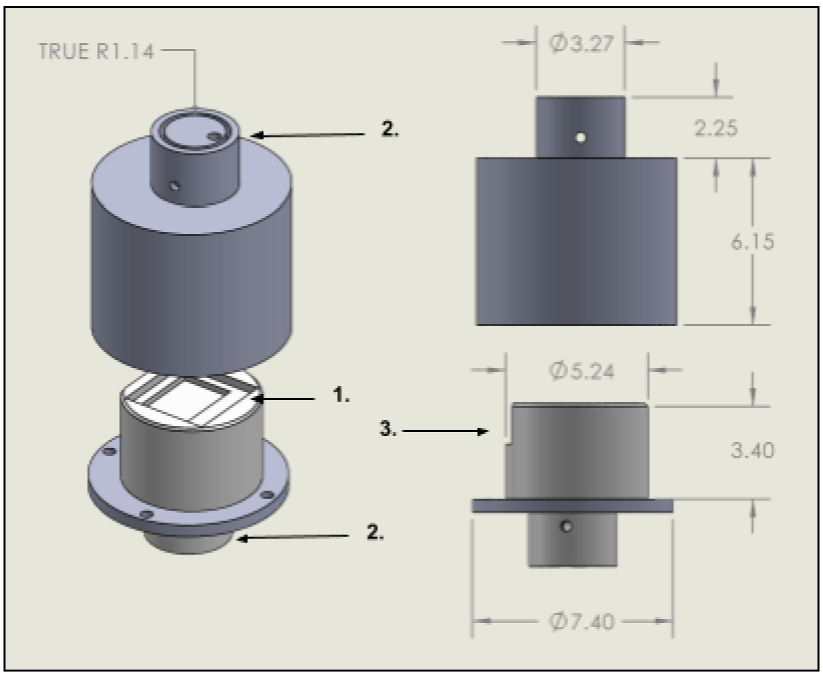

Figure 3. Annotated Solidworks drawing of the Load Cell Holders (cm).

2.3.2 Power and Sensor Circuitry Housing Design (Electrical Housing). The purpose of the electrical housing component is to house and protect the device's power supply, microcontroller, load sensor amplifier, and subsequent circuitry. The electrical housing and its dimensions are shown in Fig. 4. The housing component is mounted centrally with respect to the left and right legs, while being forward of and attached to the two parallel crossbars. Three points of attachment along with rubber cushioned metal cable clamps secure the component to the walker body. Only one clamp will attach to the top crossbar to maintain the walker's folding capability, and two clamps will secure the housing to the bottom crossbar. It is essential that the device's profile remains similar to that of a standard walker so as not to restrict the patient's ability to walk, thus the housing is positioned as shown in Fig. 6. Two front doors allow access to the internal circuitry and provide protection when the device is in use. Wiring exits the component through two holes in the top face to then enter the frame of the walker. An additional cutout exists in the top face for a power switch and the back face includes a battery charging port for ease of use. A lightweight 3D-printed polylactic acid (PLA) design ensures the walker remains easy to lift, providing non-obstructive integration with the frame that doesn't prohibit typical walker functionality.

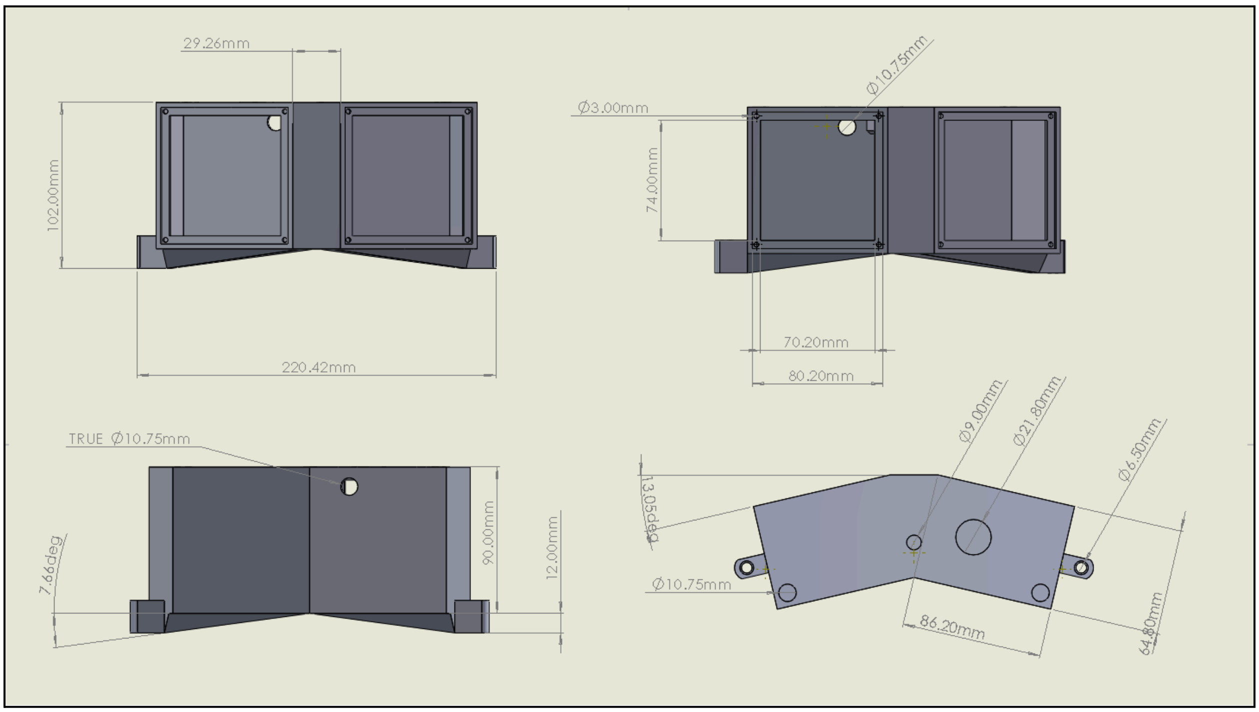

Figure 4. Power and Sensor Circuitry housing CAD and dimensions.

2.3.3 Display and Trial Switch Holder Design. An important aspect of this design is the real-time data output displayed via the OLED screens. The display holder design contains two slots and a cavity to protect, secure, and position the OLED displays and trial switch for accessible viewing and ease of transition between device modes. An image of the design and dimensions is shown in Fig. 5. The component is composed of 3D-printed polylactic acid (PLA) to ensure a lightweight profile and minimize weight imbalances. A door on the bottom face provides access to wiring contained and protected by the holder. An opening on the side closest to the frame allows the wiring to exit the holder and enter the frame. The holder is mounted forward of the left handlebar of the walker to position the screen in a viewable location while being non-obstructive to the patient, as shown in Fig. 6.

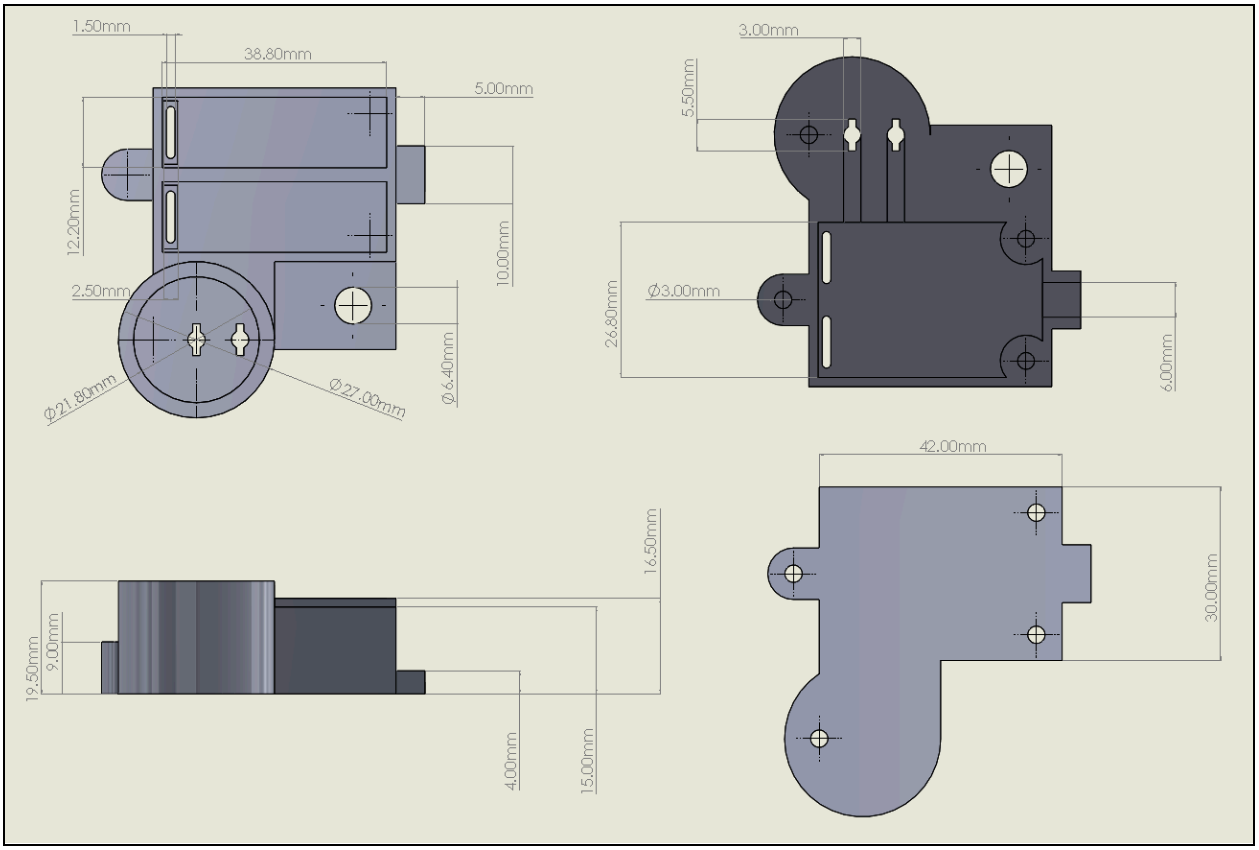

Figure 5. Display and trial switch holder CAD and dimensions.

2.4 Fabrication and Assembly. The interfacing components discussed in the previous section are all fabricated via FDM 3D-printing. Polylactic acid (PLA) was used for all three of these components to minimize cost and the necessary weight added to the standard walker. Minimal weight components were attached to the walker to ensure that the device can be sufficiently lifted by stroke patients with neuromuscular injuries. Using a lightweight plastic minimizes weight imbalances caused by the asymmetrical positioning of various components. For the load cell holder and display and trial switch holder, PLA has sufficient mechanical properties as these components only need to support their weight along with the instrumentation they contain. For the load cell holder PLA is sufficient even though the material has low yield strength relative to the aluminum frame because the main mode of loading will be compressive and PLA's compressive strength is sufficient for this application. In addition, the holders have a much larger cross sectional area to minimize the risk of total shearing of the component.

For attachment of the load cell holders and proper force transduction for the load sensors, four cuts were made through the metal tubing 2” above the horizontal leg supports. At these cuts the holders are inserted into the cylindrical tubing, aligning with the frame’s inner walls to maintain structural integrity and ensure proper force transduction down the length of the four legs. An added effect of attaching the load cell holders in this manner is a minimal extension to the leg height. The display holder and electrical housing are mounted via rubber cylindrical pipe clamps that clamp around existing tubing, thus not requiring any drilling into the frame. However, securing of these load cell holders as well as the IR sensor to the walker frame is achieved through bolt connection through the frame tubing. Because it is imperative that the walker remains rigid and stable, these bolt holes must be drilled through the walker frame for a secure attachment of the load cell holders and sensor. In addition, holes for internal frame wiring are necessary to ensure wiring remains neatly routed and unobtrusive. All modifications, including drilled holes for bolts and wiring, are made directly in the original walker frame to integrate the necessary components; however all hole profiles are minimal and preserve structural integrity. The load cell holder structure, while incurring drilling into the frame, provides additional axial and radial support to the legs to compensate for the decreased cross-sectional area of the legs due to drilling.

The microcontroller and load sensor amplifier are attached to a protoboard via header pins within the electrical housing. Soldering and wiring are utilized to create the device’s permanent circuitry, securing the components in place. The power supply and sensor wiring are connected via unpluggable connectors to allow for easy disassembly and maintenance. The connections and the sensor wiring layout can be seen in Fig. 1. Protoboard soldering enables easy assembly and reduces the cost and time of creating a circuit for this application compared to the high cost, long development time, and manufacturing complexity of a PCB.

Figure 6. Electrical housing CAD and dimensions.

3 Testing and Results

3.1 Load Sensors. The accuracy of the load cells were tested using a predetermined calibration curve which converted the output voltage of the load cell circuit to an applied pressure value. These outputs were then compared with objects of known weight. The results were plotted and yielded a graph of expected scale weight (lbs) vs measured load cell weight (lbs). This graph had a slope of 1.0096 and an R^2 value of 0.9992.

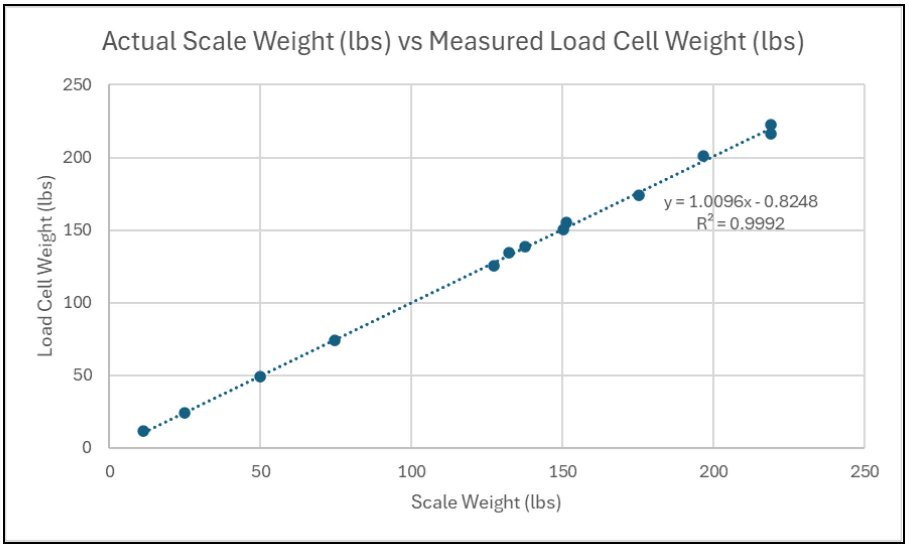

Figure 7. The actual scale weight (lbs) vs measured load cell weight (lbs). With an expected slope of 1.

Preliminary Solidworks simulations were used to determine the strength of the load cell holder design. 50 lbs of horizontal force was applied to the pieces of the load cell holders that would be encapsulated within the walker legs to simulate the most likely mode of failure. This testing produced a max Von Mises stress of 6.946 MPa on the load cell holder. The highest stresses experienced concentrated near the connection point between the load cell holder and the walker as well as at the bottom of the load cell holder where the greatest displacement occurred. The simulation recorded a max displacement of 0.1477 mm.

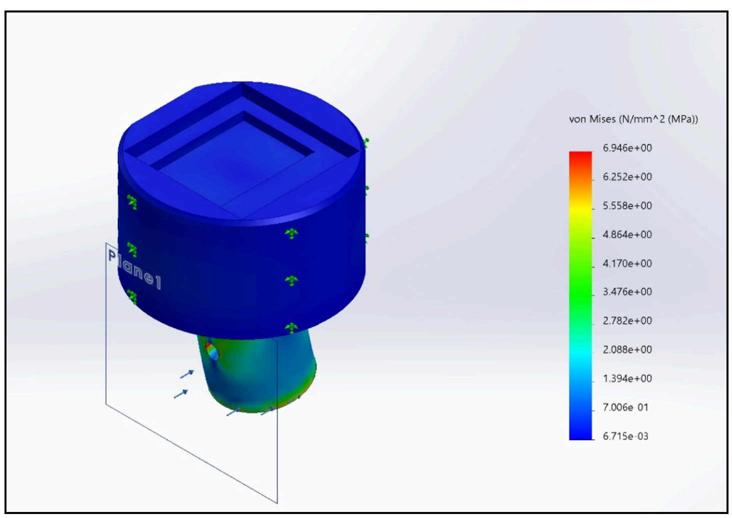

Figure 8. Results from Solidworks Simulation of the load cell holder.

3.2 Speed Sensor. In order to ensure the functionality of the speed sensor, multiple variables must be tested. The first variable to be tested is the tape strip length. Since the average individual walks no more than 6.4 kilometers per hour, testing to see if the sensor can detect the alternating strips exactly at this speed is integral to the function of the speed and distance measuring. Before applying the tape to the wheel, ruler long segments were created with alternating colored tape at varying widths. These strips were then translated in front of the IR sensor at a distance of 10 mm from the emitter/receiver at varying speeds to determine where the cutoff is for the minimum tape width that can measure 6.4 kilometers per hour.

Once this testing was concluded, the team determined that lengths of 0.041 m were sufficient. To confirm the accuracy of this, 8 taped strips were added to the inside face of the wheel at lengths of 0.041 m each. Then, with the IR sensor integrated into the leg, 3.6 m long trials were conducted. These tests yielded 6.6% error.

3.3 Structural Integrity. The walker's ability to measure pressure applied and speed traveled are vital to the clinical analysis of users; however, if the walker does not maintain the ability to provide balance to the user, then it would be a failed device. To test this, the lateral and longitudinal displacement must be measured once complete fabrication is done. These measurements are important to determine if the walker will tip under loading or if the load cell holders will fail: both of these would lead to device failure.

4 Discussion

With a 1.37% error the accuracy of the load cells is well within the desired 5% bounds. No further testing is therefore required before incorporating them into the walker. The load cell holders observed a maximum stress in the Solidworks simulation of 6.946 MPa. This value is well below the yield strength of PLA, which is 26.082 MPa - giving the design a yield factor of 3.75. This yield factor is also within an acceptable range. Future testing will be required to examine the accuracy of the load cells once incorporated with the load cell holders and the rest of the walker.

The current functional testing of the IR sensor did not yield as accurate results as necessary for the walker to be properly functional. Before further testing is conducted, a rework of the code that computes what the IR sensor detects is necessary. According to the datasheet of the TCRT5000, the sampling frequency of the sensor is 1 kHz [7]. If the user of the walker is traveling at speeds of 6.4 kilometers per hour, then the required sampling frequency - 5 times greater than the frequency of the changes in tape strips, is 180.9 Hz. This proves that the sensor itself has the capabilities of detecting changes at the speeds traveled, therefore the code is currently not efficient enough to comprehend this. After updating the code, these trials should be run again to evaluate the functionality of the walker.

Fabrication has not been completed, therefore the structural integrity testing has not been concluded as of yet. The current iteration of load cell holders has been integrated into the walker, and while there is no longitudinal wobble there is lateral displacement that occurs when loads are applied. A redesign of the current iteration of load cell holders is being considered, these would be designed to better “lock” the walker into place. The use of a rubber seal on the pieces are also being considered. Further testing will be done before a final decision is made.

5 Conclusion

The current iteration of the adapted clinical walker is not up to par to be considered a functional prototype. However it is well on the way to being one. The steps required to have a functional clinical walker are: ensuring the load cell holders can withstand the forces of a patient and they do not allow for wobble, have a within 5% accurate pressure measurement via the load cells, have a within 5% measurement of speed and distance via the IR sensor, and have a functional display and switch system that is able to run for a day’s worth of testing.

6 Acknowledgements

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Appendix

A. Product Design Specifications

BMEDesign: Product Design Specification

Date: 9/12/2024

Team project: Smart Walker

Lab section: 400

Group members
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Client: Dan Kutschera
Advisor: Amit Nimunkar

Function

In the rehabilitation process of acute strokes or similar conditions, it is necessary for the patient to be able to walk well enough before returning home to ensure their safety. The client, Mr. Dan Kutschera, is a physical therapist that evaluates patients that come from an acute stroke clinic. He requests a device that will improve his evaluation process of the patients and is able to work in conjunction with a standard clinical walker. In order for the physical therapist to evaluate the patients' ability to walk, they must obtain various forms of data; such as the speed the patient goes, the distance they are able to travel, and the pressure applied to the walker from the patient. All of these sensors will be housed and powered on the walker, and after the metrics are taken, they will be displayed to a screen on the walker. The Smart Walker would enhance the ability of our client to evaluate the rehabilitation process of his patients.

Client requirements

- The device will be designed to enhance a standard physical therapy walker so it can be used in a clinical setting for the client
- The Smart Walker must be durable enough to withstand daily usage, year round with minimal maintenance.
- The device must be manufactured within the budget of $300, what will be purchased with this budget is a walker, electrical components, and other housing components.
- A display module attached to the walker will display measured data from the enhancements to the walker. Such data will be the pressure applied to the walker, the speed of the walker, and the distance traveled.

- An initiation and termination button for the walker will be implemented so the device is only measured during the trial period.
- All measurements will be in customary units so the patients have a better understanding of their performance.

Design requirements

1. **Physical and Operational Characteristics**
    a. **Performance requirements**

The Smart Walker would be required to perform within distances of 10 meters and for time periods within 30 minutes. The Smart Walker would be an enhanced clinical walker and it will retain its standard functions of supporting the weight of the user, no more than 140 kg [1], whilst the user walks across the room. The enhanced performance of the walker will allow it to measure and display the pressure applied to the walker, the speed of the walker, and the distance traveled. The added enhancements of the walker should not make using it more difficult, such as not impeding the walking motion of the user nor adding additional weight to the walker.

b. **Safety**

Safety is a high priority concern for the Smart Walker, given that it is going to be used by patients who are in rehabilitation after an acute stroke, or acute stroke adjacent event. The Smart Walker should follow standard OSHA guidelines regarding clinical services in physical therapy. The Smart Walker should not be used near water and must have both the equipment and electrical components maintained properly to avoid mechanical failure or electrical exposure [2]. The physical therapist should also be properly trained to both handle the device and guide a patient through the use of it.

c. **Accuracy and Reliability**

The Smart Walker would need to measure values within an accuracy of 10% the true value. It would also need to be very reliable and vary from its measured value within 5%. These metrics of accuracy and reliability will need to be true for distances within 10 meters and for time periods within 30 minutes.

d. **Life in Service**

The Smart Walker will be required to be used every day in the lab for no more than 10 patients a day and for no more than 5 trials per patient. Each trial will take no longer than 30 minutes at a time. The Smart Walker should operate for 10 years without maintenance.

e. **Shelf Life**

In storage the Smart Walker should be kept in dry, room temperature conditions (16-26 deg C). The device should be folded while in storage to minimize the space it occupies and reduce the risk of unexpected forces. When lifted while in a folded state the walker should not unexpectedly unfold [3] . The alkaline batteries used for the Smart Walker have a shelf life of approximately 10 years while the Arduino should last much longer [4]. Given the shelf life of the individual parts the device should last about 10 years in storage before requiring replacement parts.

f. **Operating Environment**

The walker will be used in a neurorehabilitation center with a 16-26 °C ambient temperature and relatively flat surfaces. It should not be used outdoors and therefore should not be exposed to unexpected environmental conditions or loading conditions. The walker will need to be sanitized between users and therefore should be able to withstand repeated exposure to alkaline cleaning products. The Smart Walker will often be subjected to uneven force distribution and should be able to maintain stability despite up to 10 kgs pressure difference. The walker should also hold up to 140 kgs pressure for periods of up to 30 minutes [1]. Finally when engaged, the brakes on the walker should be able to withstand pushing forces of up to 6 kgs and pulling forces up to 4 kgs [3].

g. **Ergonomics**

The walker should have an adjustable height of 0.8 m to 1.1 m to accommodate a wide range of user heights. The width should be within 0.64 m and 0.74 m to accommodate users while still allowing room within doorways and hallways. The walker should withstand braking forces of 4-6 kgs and an applied weight of 140 kgs [3]. The Smart Walker display should only show speed and pressure measurements after recorded trials to avoid distracting users interacting with the device.

h. **Size**

The smart walker should have a maximum height of 1.1 m that can be lowered to 0.8 m depending on the user. It's maximum width should be 0.74 m to avoid taking up too much space within hallways and to allow it to easily pass through doorways. Finally for portability, the walker should fold and weigh between 2-4 kgs.

i. **Weight**

The smart walker should be roughly between 4.5 and 9 kilograms. This is so that it is easy to move and the attachments added do not add an unreasonably heavy weight to the walker. This way when used in trials, the walker is realistic. This smart walker should be able to support no more than a 140 kg patient which is what a normal walker will be able to do [1].

j. **Materials**

A typical walker is made of aluminum and the handles of vinyl. These are this way to be anti-perspirant and can withstand the pressures a patient exerts. There are certain materials that should not be used on the walker for health reasons and safety reasons. These include wood, cloth, leather, and other materials that can bring along more sanitization, maintenance, or safety issues. These do not want to be a worry for our client in a clinical setting.

k. **Aesthetics, Appearance, and Finish**

The smart walker should look almost identical to a regular walker. This is so that it is not intimidating for the patient and they feel as though they are working with a walker that is not what they are used to seeing. The handles on the walker should be resistant to perspiration so that proper grip can be used at all times without a worry about the patient's grip being limited. Lastly, wires should be tucked away on the smart walker so that there are no wires dangling that the patient could get caught up on mentally or physically.

2. **Production Characteristics**
   a. **Quantity**

There should only be one Walker designed. The client has asked that there is only one walker to start and use in the clinical setting.

b. **Target Product Cost**

The target cost is between $250-$350 dollars for one of the walkers. There are competing designs that are roughly $2500 at times which the client does not want to spend.

3. **Miscellaneous**
   a. **Standards and Specifications**

While the Food & Drug Administration (FDA) allows custom medical devices to be exempt from pre-market approval and other such requirements [5], the Smart Walker, because it is intended to be used with multiple different patients as opposed to one particular person, will still be subject to regular FDA standards. Similar electronic mobility devices have been classified as a Class II medical device, meaning that this device will most likely also be classified as such, thus requiring compliance with the FDA's quality system regulation, basic and medical performance standards [6], and also a 510(k) premarket notification. Most generally, hazards associated with device use must be identified and controlled as per ISO 14971 [x3], and while the Smart Walker won't be particularly harmful to the user, nor will it be a life-sustaining device, it remains important to understand any possible faults that could cause bodily harm, especially in regards to the batteries/power-supply. These safety concerns are expounded upon by IEC standards numbered 60601-1 and 62366-1, who deal specifically with medical instrumentation [7][8].

b. **Customer -> change to User?**

Mr. Kutschera outlined a few important preferences that he had for the Smart Walker that fit his vision for the most effective version of the device. First of all, he envisioned the device being implemented into/onto an existing 2-wheel walker because most of his patients use something similar. He also believes that having live feedback given to the patient during their walking test with the walker will help boost enthusiasm for the therapy session; as such, some sort of screen is required near the handles of the walker to display metrics about speed, distance, and force to the patient as they are using the device. That being said, he also explicitly stated that these values must be in imperial units because metric units don't mean much to people outside of STEM careers. Finally, any batteries or wires must be fully encased within the walker or their own housing parts, as loose wiring could make the device unwieldy and/or dangerous in some cases.

c. **Patient-related concerns**

Because the Smart Walker is meant to be used by a variety of patients throughout the day, proper sanitization measurements must be taken between uses of this device by different patients. Furthermore, the differing users of this device give rise to concern about its stability, adjustability, and weight outlined in the *ergonomics* and *size* sections (1g & 1h). Finally, the UI for the Smart Walker must be accessible to (usually elderly) acute stroke patients, meaning that tactile buttons would be preferred over a touchscreen interface, as there has been a similar robotic walker by Frontiers in Neurorobotics that experienced difficulty with such a UI [9].

d. **Competition**

There are a few similar devices to the Smart Walker that are either on the market or used for research, but none of them have the exact use-case that Mr. Kutschera desires, plus most of them are egregiously expensive. One such device is called the Camino, which integrates multiple sensors in the walker to detect changes in terrain and drive a motor accordingly to make walking easier for the user. Similar to the Smart Walker, it is also able to track its user's gait, but the Camino incorporates AI to filter through the input data in order to do so [10]. The aforementioned walker by Frontiers in Neurorobotics, while mostly used to prevent the elderly from falling, has a spongy handle that senses changes in air pressure when being compressed [11]. Patents for other proof-of-concept devices also exist online, as seen in patents US20220211568A1 and US7826983B2 that each outline some application of sensors on a walking device, but these devices most likely never made it to fruition [12][13]. That being said, there really doesn't exist a device that works perfectly for Mr. Kutschera's needs, but there are such devices that can help guide the Smart Walker in the right direction.

Citations

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B. Fabrication Images and Assembly

To modify the walker legs for load cell holder mounting, a diamond vise and a hand saw were used. Holes throughout the entire walker frame tubing were made using a standard drill press to ensure straight alignment. A hand drill was used for wiring holes since these holes did not require passing through both walls. A Dremel tool was occasionally used to expand hole diameters for correcting alignment issues with the load cell holders. All holes were treated with a deburring tool, which is especially important for holes with exiting wires to prevent wire damage and signal loss.

For 3D prints, head inserts enable screw fixation for the access doors on the display holder and electrical housing. Additionally, to prevent vertical translation of one end of the load cell holder relative to the other, the 3D printed disc was used along with heat inserts to prevent the bottom component from exiting the top piece. Bambu FDM printers were used to print matte black or silver PLA. Post-processing of the prints involved removing supports and, in some cases, sanding to improve dimensional accuracy.

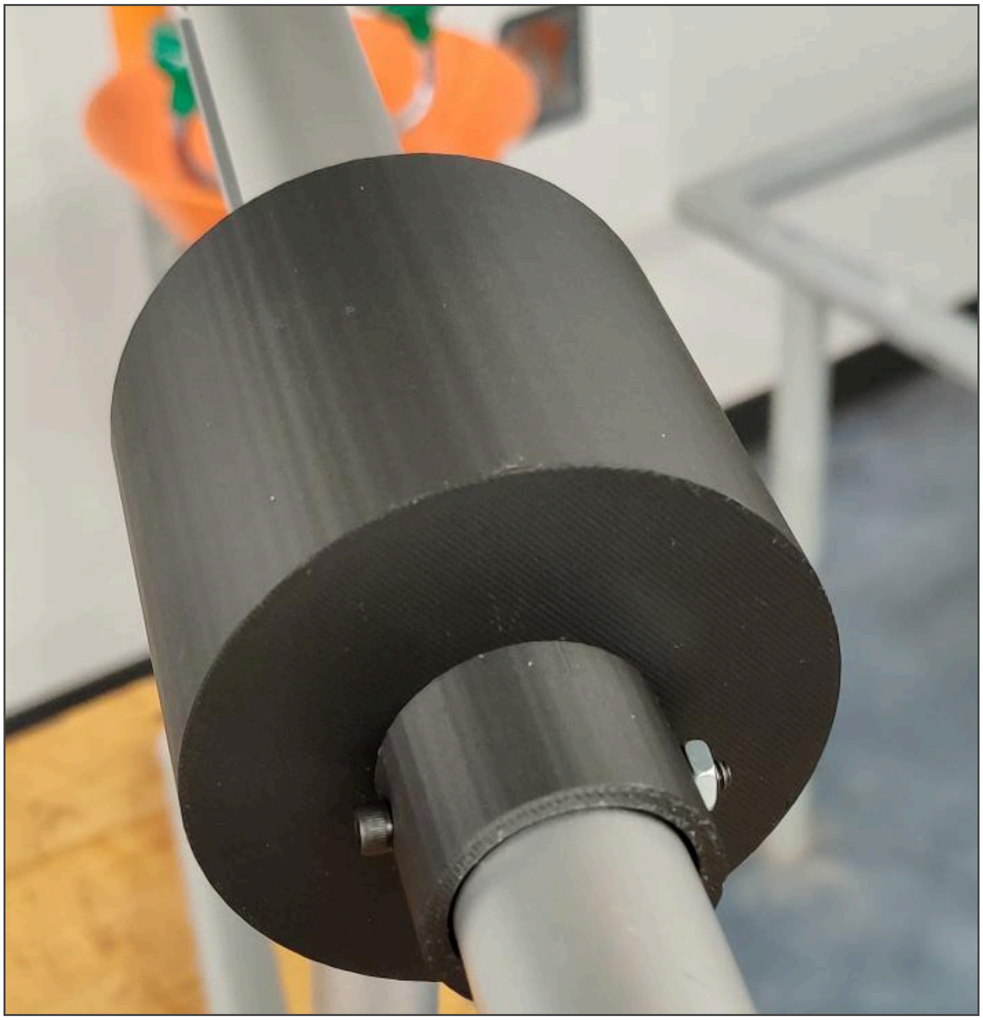

Figure 9. Bolt mounting for the load cell holder.

Figure 10. Load cell holder assembly.

C. Testing Protocols

IR Strip Testing Protocol

Objective:
The team needs to evaluate how effectively the IR sensor can detect changes in reflections from contrast tape. In order to do this, the team has set up an alternating strip of black and white tape with two different strips that have different widths in tape. This is to see how precise the sensor is. In figure 1 there is the testing method for the IR sensor.

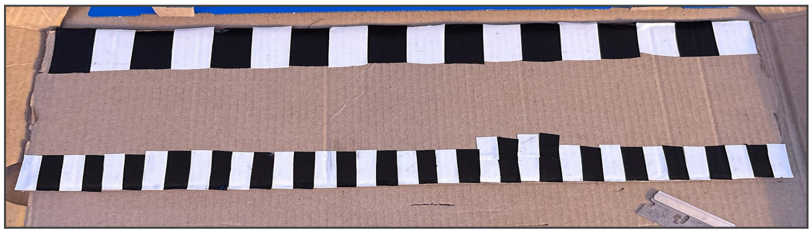

Figure 10. Cardboard strip with alternating black and white electrical tape at 2 different widths.

Method:
1. Supply the TCRT5000 with 3.3 V to the VCC+ pin and ground the GND pin. Have the DO pin of the sensor wired to GPIO pin 26 on the raspberry pi pico (pin # 31).
2. Have the testing strips set at a distance of 5.80 mm from the emitter/receiver of the sensor, this is the distance from the leg to the wheel.
3. Using the code, read the ADC value that the sensor puts out for both the black and white strips in the current room's lighting, then set the threshold value to be the average of these two values, this will ensure that the sensor is calibrated for the ambient lighting.
4. Select either the 1.8 cm or 0.9 cm wide stripe strip and set this as the increment value in the code.
5. Begin running the code on the first marker and slide the strip slowly so the IR sensor picks up on the alternating color strips until the end.
6. Record this distance measurement and repeat steps 4-5 for varying speeds - a slow, medium, and fast speed with 5 trials each
7. Fill in the table below with the data collected from steps 4-6.

Table 1. The measured distances, calculated distances and percent difference for trials of the 1.85 cm strip.

Trial	Relative Speed	Measured Distance (cm)	Calculated Distance (cm)	Percent Difference (%)
1	Slow			
2	Slow			
3	Slow			

4	Medium			
5	Medium			
6	Medium			
7	Fast			
8	Fast			
9	Fast			
Total Average:				

Table 2. The measured distances, calculated distances and percent difference for trials of the 0.9 cm strip.

Trial	**Relative Speed**	**Measured Distance (cm)**	**Calculated Distance (cm)**	**Percent Difference (%)**
1	Slow			
2	Slow			
3	Slow			
4	Medium			
5	Medium			
6	Medium			
7	Fast			
8	Fast			
9	Fast			
Total Average:				

IR Wheel Testing Protocol

Objective:

The team wishes to see if the fully fabricated plans are a viable option to use the IR sensor with. In order to do this, the team has taped 4 black and 4 white pieces of tape along the rim of the wheel.

Figure 11. Inside of the walker wheel with 8 (4 of each) alternating colored taped strips.

Method:

1. Supply the TCRT5000 with 3.3 V to the VCC+ pin and ground the GND pin. Have the DO pin of the sensor wired to GPIO pin 26 on the raspberry pi pico (pin # 31).
2. Have the testing strips set at a distance of 10 mm from the emitter/receiver of the sensor, this is the distance from the leg to the wheel.
3. While the wheel is attached as seen in figure 1, walk with it and determine the revolutions per second, mark this down.
4. Using the code, read the ADC value that the sensor puts out for both the black and white strips in the current room's lighting, then set the threshold value to be the average of these two values, this will ensure that the sensor is calibrated for the ambient lighting.
5. Set 5 cm as the increment value in the code.
6. Begin running the code on the first marker and rotate the wheel - making sure to mark the starting position - for one full revolution.
7. Record this distance measurement and repeat steps 4-5 twice more at alternate speeds, with the average speed being that value determined in step 3.
8. Repeat steps 4-7 for various revolutions.
9. Fill in the table below with the data collected from steps 4-7.

Step 3: Roughly 0.5 second per revolution.

Table 3. The measured distances, calculated distances and percent difference

Trial	**Relative Speed**	**Measured Distance (cm)**	**Calculated Distance (cm)**	**Percent Difference (%)**
1	Slow			
2	Slow			
3	Slow			
4	Medium			
5	Medium			
6	Medium			
7	Fast			
8	Fast			
9	Fast			
Total Average:				

D. Code

Load Cell Code

```
from machine import ADC, Pin
import time

# Initialize ADC on pin GP26 (ADC0)
adc = ADC(Pin(26))  # GP26 corresponds to ADC0

# Function to read and convert ADC value to voltage
def read_voltage(adc, vref=3.3):
    raw_value = adc.read_u16()  # Read the raw 16-bit ADC value
    voltage = (raw_value / 65535) * vref  # Convert to voltage
    return voltage

# Function to calculate weight from voltage using the linear relationship
def calculate_weight(voltage):
    # Apply the inverse of the equation: y = 0.0032 * x + 1.6709
    weight = (voltage - 1.6709) / 0.0032
    return weight

# Continuous loop to read voltage and calculate weight
try:
    while True:
        voltage = read_voltage(adc)  # Measure voltage
        weight = calculate_weight(voltage)  # Calculate weight
        print(f"Voltage: {voltage:.3f} V, Weight: {weight:.2f} lbs")
        time.sleep(0.5)  # Delay for readability
except KeyboardInterrupt:
    print("Stopped reading.")
```

OLED Display Code

```
from machine import Pin, I2C
import ssd1306
import time

# Set up the I2C connection
#i2c0 = I2C(0, scl=Pin(9), sda=Pin(8), freq=100000)
i2c1 = I2C(1, scl=Pin(3), sda=Pin(2), freq=100000)

# Initialize the OLED display
oled_width = 128
oled_height = 32
#oled0 = ssd1306.SSD1306_I2C(oled_width, oled_height, i2c0)
oled1 = ssd1306.SSD1306_I2C(oled_width, oled_height, i2c1)

# Clear the display
#oled0.fill(0)
#oled0.show()

oled1.fill(0)
oled1.show()

# Display "working" on the OLED
#oled0.text("top", 0, 0)
#oled0.show()

oled1.text("bot", 0, 0)
oled1.show()

# Keep the message on the display for a bit
time.sleep(5)
```

```
# Optional: Clear the display after showing the message
#oled0.fill(0)
#oled0.show()
oled1.fill(0)
oled1.show()
```

IR Code

```
from machine import ADC, Pin
import time

# Set up the ADC pin for the TCRT5000 sensor (GPIO 26)
sensor = ADC(Pin(26))  # Analog input

# Calibration values (adjust based on testing)
threshold = 30000  # Adjust this to properly differentiate black vs. white

# Variables for tracking changes
prev_state = sensor.read_u16() > threshold  # Initial sensor state (True = White, False = Black)
distance_cm = 0  # Distance counter
tape_width_cm = 5  # Width of each black/white segment

print("Starting TCRT5000 Sensor Reading...")

while True:
    value = sensor.read_u16()  # Read ADC value (0-65535)
    current_state = value > threshold  # Convert to black/white boolean

    # Detect a transition (black → white OR white → black)
    if current_state != prev_state:
        distance_cm += tape_width_cm  # Increment distance
```

```
    print(f"Transition detected! Distance: {distance_cm} cm")

prev_state = current_state  # Update previous state
time.sleep(0.05)  # Small delay to avoid false triggers, was 0.05
```