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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 [1]. One of their most common symptoms is gait impairment, a condition which greatly reduces quality of life and increases the risk of future falls [2]. Furthermore gait impairment can prevent reintegration back into society by diminishing walking speeds and complicating everyday actions like crossing the street. In order to ensure these patients have regained functional mobility, physical therapists use basic walking tests to assess characteristics such as speed and reliance on assistive devices [3]. 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 [4]. 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. Approximately 85% of those recovering from strokes take up to 6 months to regain functional walking ability [5]. 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 [6]. 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 align with the intended vision 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 [7]. 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 [8]. 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 [3]. Physical therapists often gauge reliance on assistive walking devices through observational measures of speed and applied pressure on the walker [9]. 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 applied pressure, is vital for proper patient rehabilitation. The pressure measurements should track load distribution in order to ensure symmetry while walking. This data needs 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 circuitry components that are used in the smart walker design. Furthermore, there are four 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 work simultaneously while the device is powered on.

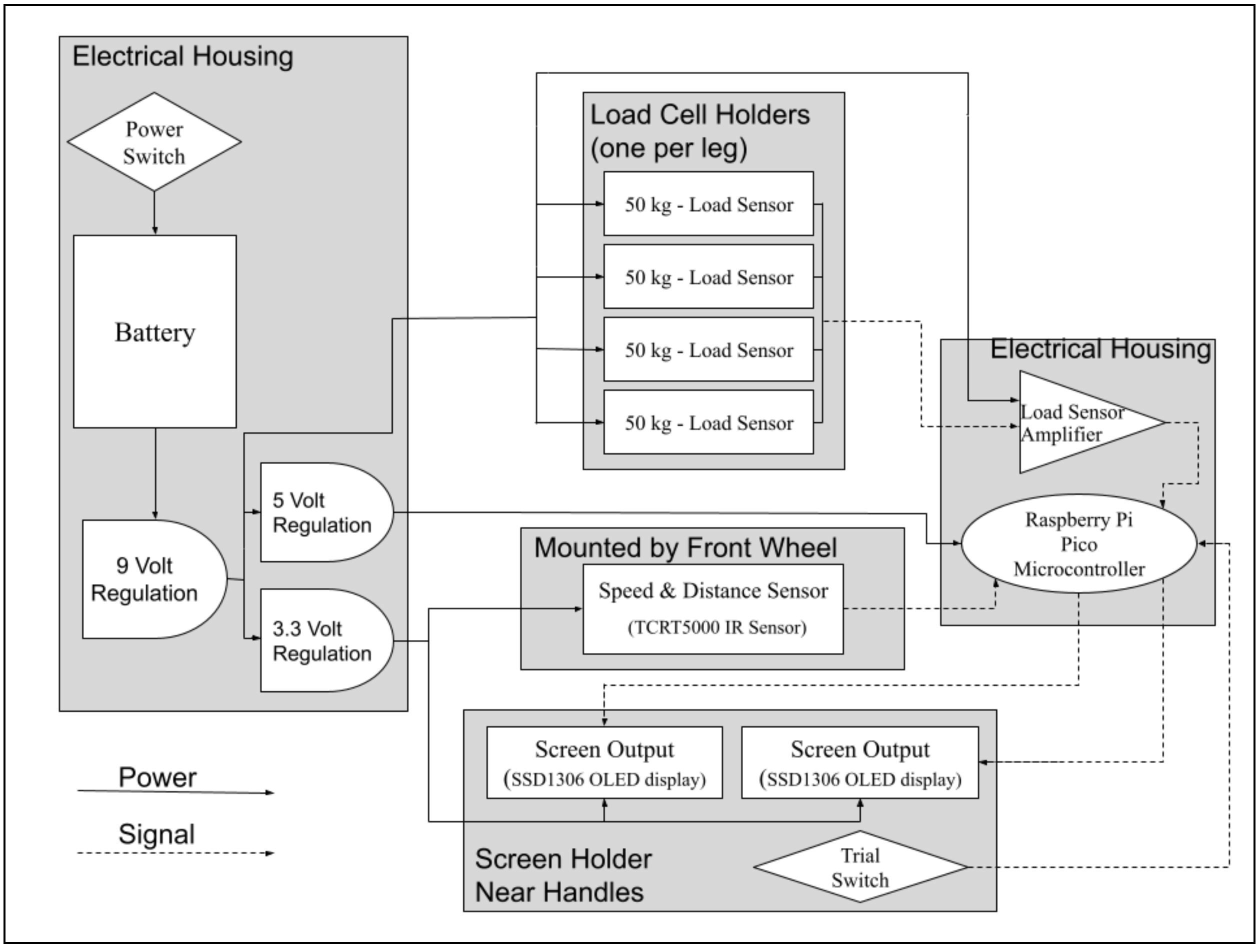

Figure 1. Block diagram of smart walker design and components. This schematic shows the power and signal connections between components, as well as the relative position of each component on the smart walker.

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 [10]. 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, shown using resistors labeled B or W in Fig. 2, can 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 positive and negative input terminals of the amplifier, and a 470Ω feedback resistor Rg is placed across the amplifier to determine the gain using Eq. 1, which is roughly 106V/V.

$$Gain = 1 + (\frac{49.4k}{Rg}) \quad (1)$$

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 R6 and into the inverting terminal of the op-amp, where the output of the op-amp is also fed back via feedback resistor R7. 3.3V regulated voltage from the Buck down regulator (not pictured in Fig. 1.) is sent through R8 and into the non-inverting terminal of the op-amp, which is connected to ground via R9. Assuming resistance values from R6 and R8 are equal, and resistance values from R7 and R9 are equal, Eq. 2. describes the gain for the level shifter. For this instance, R6/R8 are 20kΩ and R7/R9 are 10kΩ, leading to a signal attenuation of 0.5V/V. The final, fully processed signal is sent to the microcontroller ADC input.

$$Gain = R7/R6 = R9/R8 \tag{2}$$

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 to be used for power.

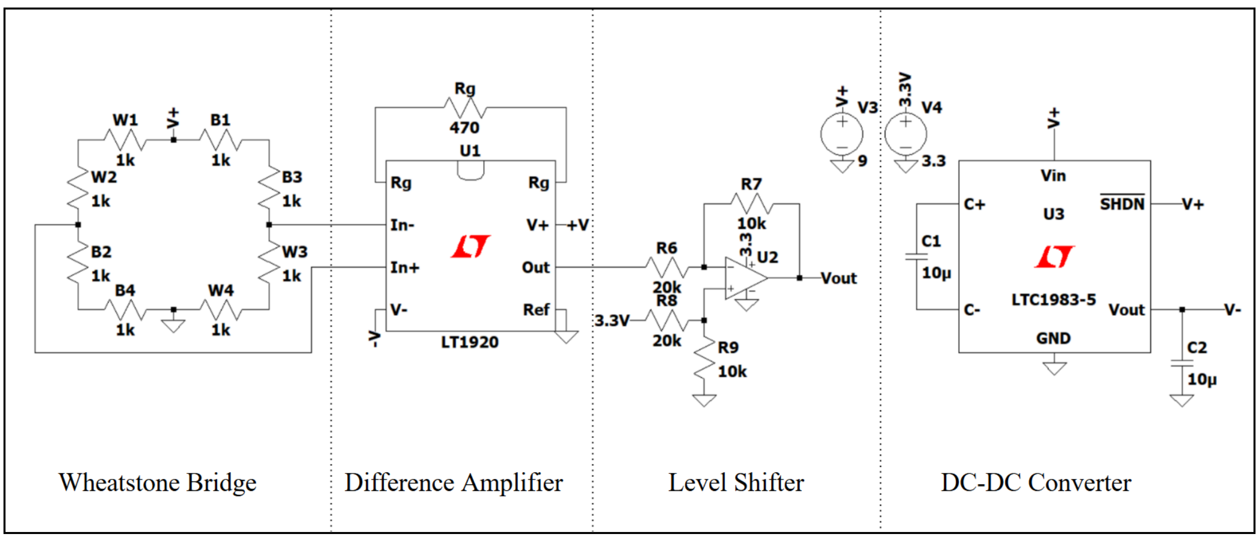

Figure 2. Circuit diagram of the load sensor amplifier. From left to right, the Wheatstone bridge of load sensor, with each node representing a load sensor embedded within each leg, LT1920 (U1), level shifter (U2), and LTC1983-5 (U3) constitute the load sensor amplifier.

2.2.4 Speed and Distance Sensor. The speed and distance sensor selected was the TCRT5000 IR sensor [11]. 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, "sleep" or "trial" modes, while the bottom screen displays sensor biometric data, depending on the mode of the device. The mode of the entire system is dictated/toggled by a trial switch positioned adjacent to the displays shown in Fig. 6. While the trial switch is toggled off, the system hibernates, displaying "Not Running" on the top screen. 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. During a trial, the instantaneous speed and applied load values are displayed in real-time. Then, upon completion of a trial by toggling the switch off, the device outputs average speed and load values, as well as total distance traveled and time elapsed during the trial. The averages are displayed on the screen for a total of 10 seconds before the walker re-enters hibernation, awaiting the next trial.

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 sensor holders, (2) sensor and power circuitry housing, (3) display housing, (4) and Infrared sensor holder.

2.3.1 Load Sensor Holder Design. The load sensor holders allow the load sensors to be inserted into the four hollow legs of the walker. The load sensors rest within the wells in the lower housing components as displayed in Figure 3 below. The cylindrical components are then inserted into the walker legs, these schematics can be seen in Appendix B. These cylindrical components feature a small hole for the wires from the load sensors 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 sensor holders then transmit pressure applied to the walker through the load sensors at focused points of contact. The load sensor holders are keyed as demonstrated at figure 6 in Appendix B to prevent internal rotation.

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 can be observed in Fig. 3 along with its dimensions in Fig. 7 in Appendix B. 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 attaches to the top crossbar to maintain the walker's folding capability, and two clamps 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. 3. 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.

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. These can be viewed at the handle of Fig. 3, as well as an image of the design and dimensions is shown in Fig. 8 of Appendix B. 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. 3.

2.3.4 Infrared Sensor Holder. It is imperative that there is no movement of the Infrared (IR) sensor, as movement will reduce measurement accuracy. Thus, the IR sensor holder is designed to prevent the IR sensor from shifting away from the marked wheel. The cross support arm of the IR sensor holder achieves this by sliding between the outer frame of the walker and the emitter and receiver, preventing backwards rotation. This holder is mounted to the right leg of the device by fitting over the main right wheel axis to secure the component in place. Positioning of the IR sensor holder can be seen in Fig. 3. The holder was 3D printed using PLA. The component is lightweight to minimize weight asymmetry to ensure the device can be lifted easily.

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 added weight 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 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. The load cell holders must withstand the force of their own weight as well as the loads transmitted through the walker. Though PLA has a low yield strength relative to the aluminum frame, because the main mode of loading for the load cell holders is compressive and PLA's compressive strength is 54.20 MPa, the material is sufficient for this application [12]. 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 sensor 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 sensor 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 sensor 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 sensor 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 sensor 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.

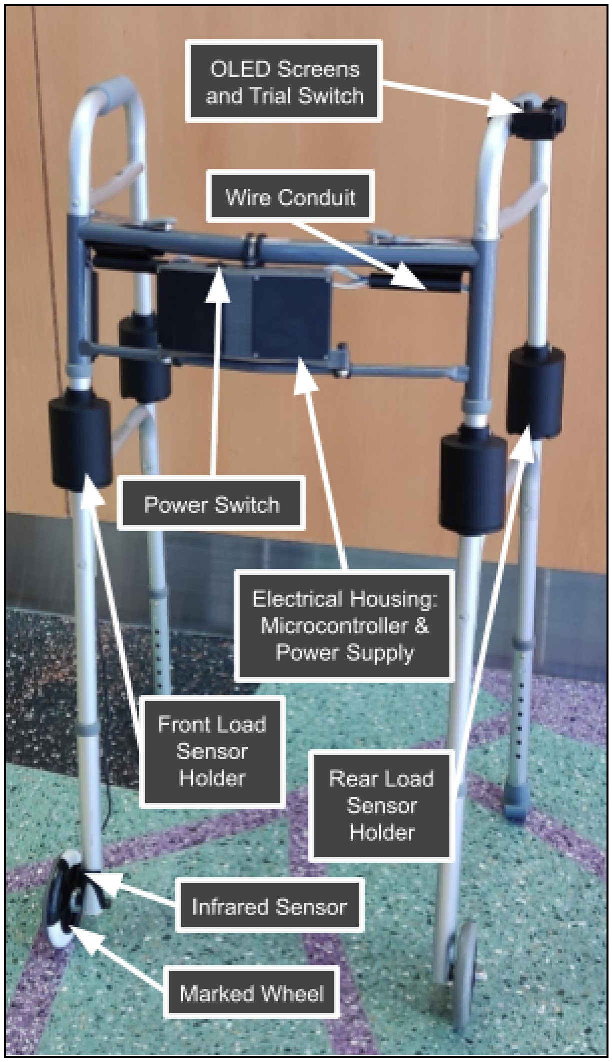

Figure 3. Labeled Final Prototype Design.

2.5 Calibration. In order to ensure that the smart walker properly measures and displays the correct pressure applied, calibration of the load sensors was conducted with known weights. Following the protocol laid out in Appendix C1, multiple trials of weight from 0 kg to 93.53 kgs were applied to the walker with the corresponding ADC values measured. From this, a curve of best fit following a quadratic equation was applied between voltage and weight applied. This equation was implemented into the code, which can be seen in Appendix D and Fig. 4. The applied quadratic fit has a correlation coefficient of 0.9948, which indicates a strong relationship between the applied weight and output voltage. During this calibration, up to 90 kilograms was regularly applied to the walker frame, indicating the device can withstand load up to this weight.

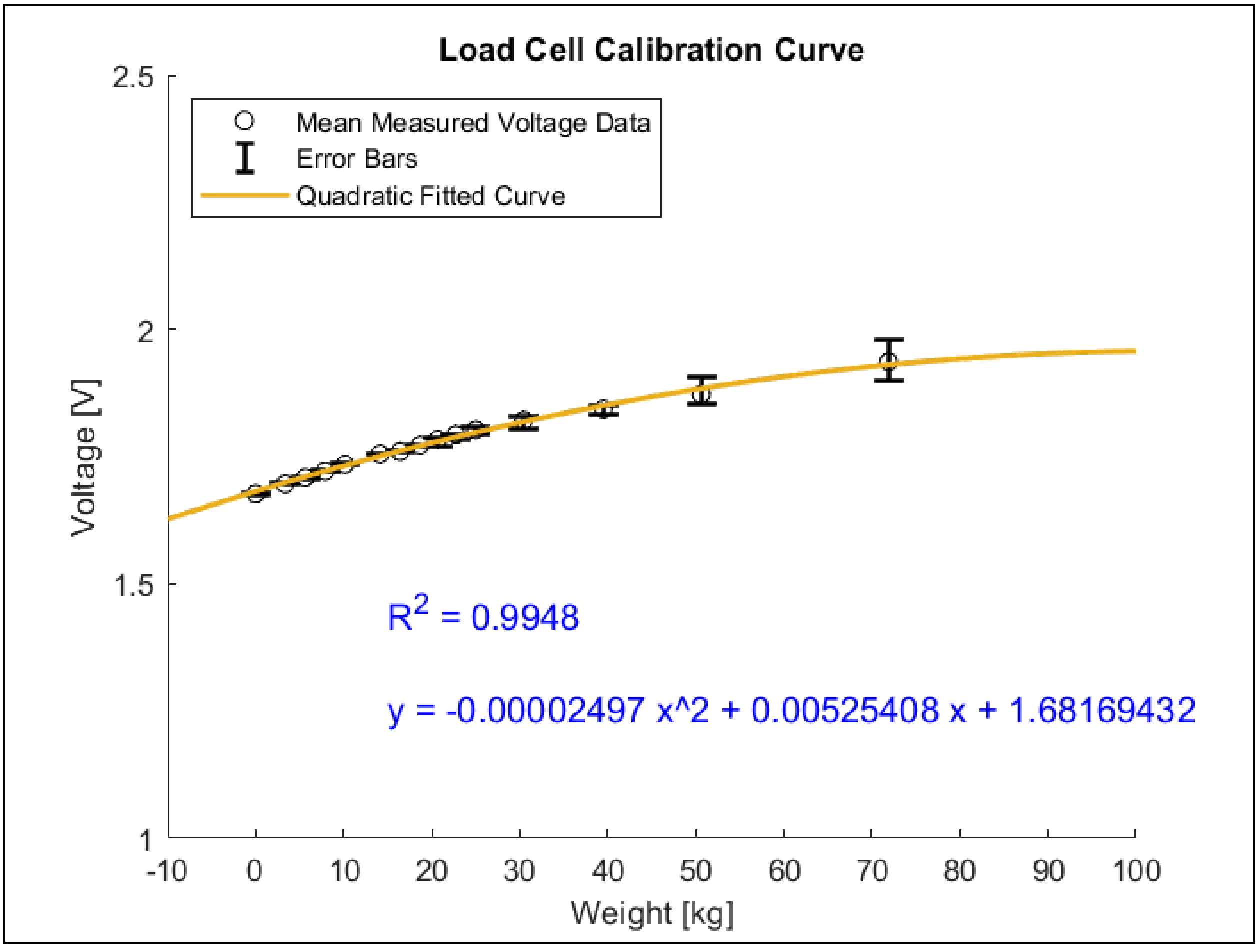

Figure 4. Calibration curve of weight applied (kg) and output voltage (V).

3 Testing and Results

3.1 Load Sensor Testing and Results. Accurate measurement of applied load is essential for assessing a patient's reliance on a walker. Therefore, testing was performed to evaluate the accuracy of the device's calculated load. For testing, two in-ground force plates were used as a reference to validate the applied load measured by the device. During testing, the walker was placed on the force plates while a subject applied load through the walker handles. Both the force plates and the walker simultaneously recorded instantaneous load values, and time-frames between the measurement methods were synchronized due to the different sampling rates.

Two subjects each performed five trials, for a total of ten trials. For each trial, plots of the walker and force plate measurements were generated to compare instantaneous load values, as shown in Fig. 5. Additionally, the load was averaged over the duration of the applied loading period for both the force plate and the smart walker. The relative error between the averaged values was then calculated. Across all trials, the average relative error was 2.43%.

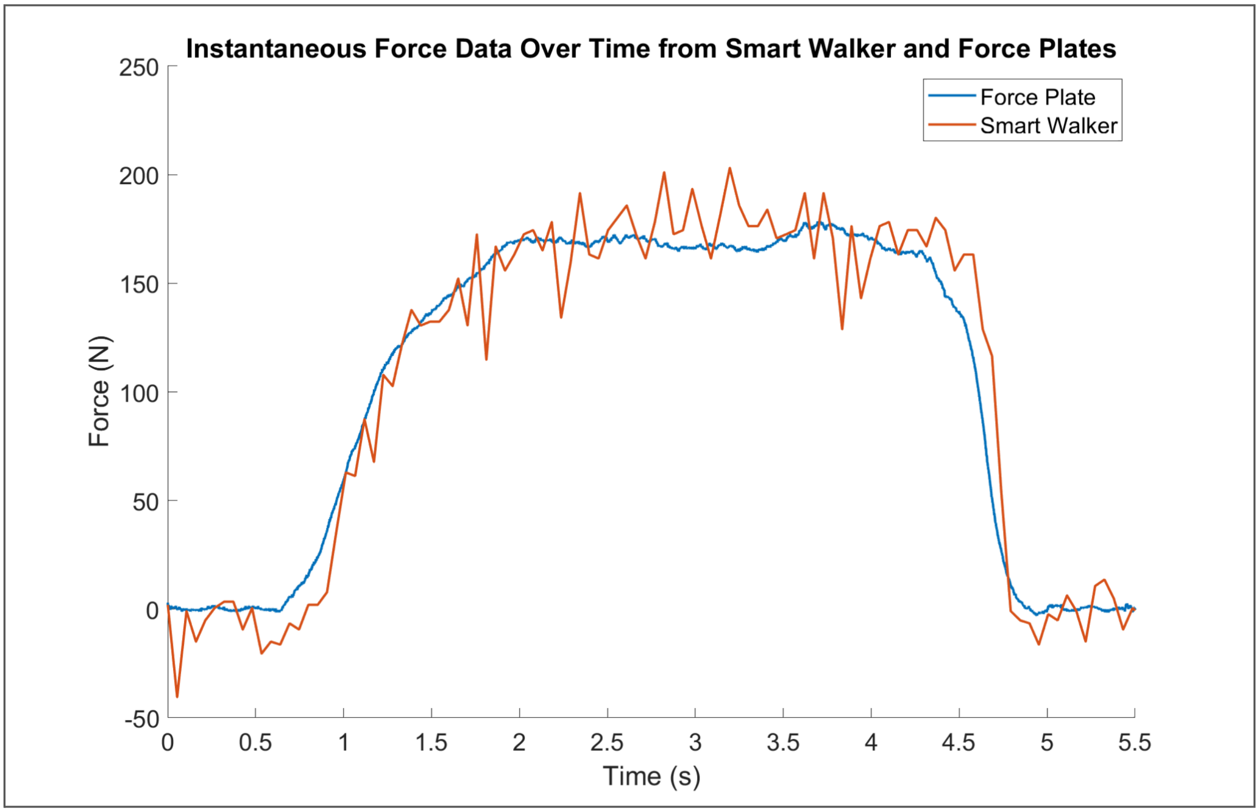

Figure 5. Measured applied load (N) comparison between in-ground force plate data (N) over time for one trial.

3.2 Distance and Velocity Testing and Results. Testing was performed to assess the accuracy of the Infrared (IR) sensor and determine whether the device meets the necessary operational specifications. To evaluate distance measurement accuracy, the walker was pushed along marked straight-line paths of 15.24, 30.48, and 45.72 meters. Three trials were conducted at each distance for three relative speeds: slow (~0.33 m/s), medium (~0.66 m/s), and fast (~1 m/s). For each of the 27 trials, the IR sensor's distance measurement was compared to the actual distance traveled. The average relative error across all trials was 1.25%.

Additionally velocity testing was conducted to confirm the accuracy of the device's velocity measurements. Unlike distance, the smart walker reports both average velocity over a trial and instantaneous velocity. During the distance trials, the time required for the walker to travel each marked distance was recorded. Average velocity was then calculated using the known travel distance and time and compared to the device's measured average velocity. The average relative error was 1.20%.

To assess instantaneous velocity, a 9.144 meter path was divided into three equal-length intervals. The device was pushed along the full 9.144 meters while the device's instantaneous velocity readings and time stamps were recorded at the end of each interval. As with the previous tests, nine trials were conducted–three for each of the three speeds. Time and known interval distances were used to calculate the expected instantaneous velocity. Relative errors for the slow, medium, and fast trials were 18.17%, 17.69%, and 26.06% respectively.

4 Discussion

Through testing of the final design, it was determined that the product met the desired design criteria expressed in the Product Design Specifications (Appendix A). The average force, distance, and speed measurements all had low errors 2.43%, 1.25%, and 1.20% respectively. This low percent error validates the design's ability to accurately and consistently provide average metrics of the user during each trial. Potential causes for the error in the average force measurements could be due to increased noise from the distance the wires travel or due to the close proximity of wires within the housing unit, wearing away of the wire insulation, or inconsistent transfer of load to the sensors within the legs due to friction of their housing units. In order to reduce the error of these load cells, the first area to tackle would be the wiring. A more uniform wiring through the legs could have occurred where the wires are wrapped about each other to help reduce noise. Smoothing of the exit holes the wires leave the walker at along with a protective sheath would assist in reducing the wear that occurs. The housing chamber could be designed to be slightly larger to allow for easier management of the wires within the chamber. If the reason for the error is due to the inconsistencies in mechanical load, another iteration of the load cell holders could be made to ensure the most efficient transfer of weight through the load cells. These are all potential areas of future work where the device can be improved.

In order to reduce the error for distance and speed, a wheel with smaller increments could be used. The current setup has 4 total strips on the wheel, which means there could be up to 0.098 m of error per run. This means that trials with longer distances will have a smaller percent error compared to trials where the user does not go as far. In order to do this, an 8 segment or higher segment wheel could be used instead. In order to do this; however, the efficiency of the code would need to be improved so the MCU can process the incremental changes without skipping any. Skipping increments would lead to a larger percentage of error than what is currently implemented

The largest average errors occurred in evaluating the accuracy of the instantaneous velocity. As mentioned above, the relative errors for the slow, medium, and fast trials were 18.17%, 17.69%, and 26.06% respectively. This large percent error is due to limitations in testing. As laid out in the instantaneous velocity testing protocol (Appendix D3), the user would call out the velocities measured by the walker at each interval and compare it to the video based calculated velocity. This method is inefficient and leads to a large amount of error. An alternative method to measure and evaluate instantaneous velocity would be to use methods laid out by a study conducted by the BioRobotics Institute - where they utilize inertial sensor-based algorithms to estimate the instantaneous velocity of the inertial measurement units (IMUs) applied to the user [13]. This method would allow for a more accurate calculation of the instantaneous velocity and would likely reduce error. However, the importance of instantaneous velocity to stroke rehabilitation is not clearly defined. The average velocity is referred to as the "sixth vital sign" for assessing mobility post-stroke due to it offering a strong correlation to independence, discharge outcomes, fall risk, and social participation [14]. So while the inaccuracy of the instantaneous velocity can be improved, this error does not invalidate the utility of the developed smart walker.

The standard clinical walker has 8 peg holes at the wheel attachment that allows for 8 levels of height adaptability. In order to properly integrate the IR sensor to measure speed, the bottom two adjustment pegs cannot be used. This raises some ethical concerns as very short users are not able to use the adapted clinical walker as it is. In future iterations, a smaller IR sensor could be used to allow for the use of all the pegs. This would provide a more universal design that can accommodate more users. Additionally, the walker has been tested with up to 90 kg of load. This may also limit the walker's use for certain patients, however, in future versions more testing can be conducted to verify a higher weight capacity.

Finally, the battery life of the walker needs to be discussed. The power consumption of the entire smart walker system is 50 mA, and the battery that is used is a 2400 mAh battery. This allows - under ideal conditions - 48 hours of continuous use. This is plenty of excess battery for a daily use walker where it can be recharged every night. Even if the physical therapist forgets to charge the walker overnight, there is an excess battery present that will not hinder rehabilitation timelines.

5 Conclusion

The team was successful in creating a prototype walker that measures speed, distance, and applied force. The future use of such a walker in a stroke clinic setting will be able to provide physical therapists with accurate data of key variables in determining stroke patient health, meaning that neurorehabilitation decisions will be informed by both qualitative and quantitative data. Use of data-driven rehabilitation methods will likely lead to an improvement in rehabilitation timelines, but that has not been studied as of yet.

There are multiple places where the smart walker design excelled. The first of which is the cost of the final design, where each component sold separately totals up to approximately $150.00, including the generic walker used in the prototype. Furthermore, the smart walker design is extremely easy to use and set up. In order for the walker to be ready for trials, the physical therapist simply has to retrieve the walker from its storage space and flip on the power switch. To start recording measurements for a trial, they only have to flip the trial switch near the handle. Gait analysis tools such as Robot-assisted gait training (RAGT) devices can be very valuable in assessing and improving gait speed and balance [15]. However, RAGT devices do not mimic realistic walker-assisted ambulation, are extremely expensive, and require ample set up time to strap in the patient from the waist down [16][17]. In comparison, while it doesn't have as much measurement capability as an RAGT device, the smart walker is ready to use in seconds.

That being said, there are multiple avenues where the smart walker design could be improved. For example, adjustment of wiring methods so that there is less interference between wires, and that wire connections are more durable and easy to manage. An increase in segments on the wheel used with the infrared sensor would also give more accurate results, but would require more efficient code or a better MCU. Due to the price being kept as low as possible, there is room for improvement when it comes to some individual parts of the walker. Specifically, an increase in infill and higher quality material for the 3D printed components could improve durability of the walker and help to reduce some of the left and right translation inherent to the design. Furthermore, the OLED screens could be swapped out for larger versions for ease-of-viewing for the patients that have complications to their eyesight. Finally, a power indicator, displayed outside of trials, could be implemented using power consumption calculations or a purchased battery meter sensor.

To further understand the specs of the smart walker, there are also some suggested future tests that need to take place. Implementing a method to accurately evaluate instantaneous velocity, such as research done with IMUs [13], will help get a better idea of the accuracy of the smart walkers real-time velocity measurements. To gauge the battery life of the smart walker realistically (rather than using calculations based on power consumption of the circuitry), trials will be done to assess how long the smart walker is able to be on and running, likely measured by the MCU. To gauge the strength of the walker, applying known loads to a duplicate smart walker along different directions will be done to assess failure strength in that direction, which ideally would be similar to the unaltered walker.

Because there is so much potential for instrumented walkers in therapy applications, the smart walker has the potential to change the landscape for ambulation rehabilitation methods. This would likely be realized as a collaboration with walker manufacturers, to produce a line of smart walkers that can be used for rehabilitation and therapy purposes. Iterations of the smart walker design could include a gyroscopic fall-detection system, ability to upload data to an external device, gait asymmetry measurement ability, and much more.

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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
Leader/Communicator: Nolan BlomWillis (blomwillis@wisc.edu)
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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 the 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 the 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.

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B. Component Drawings and Dimensions

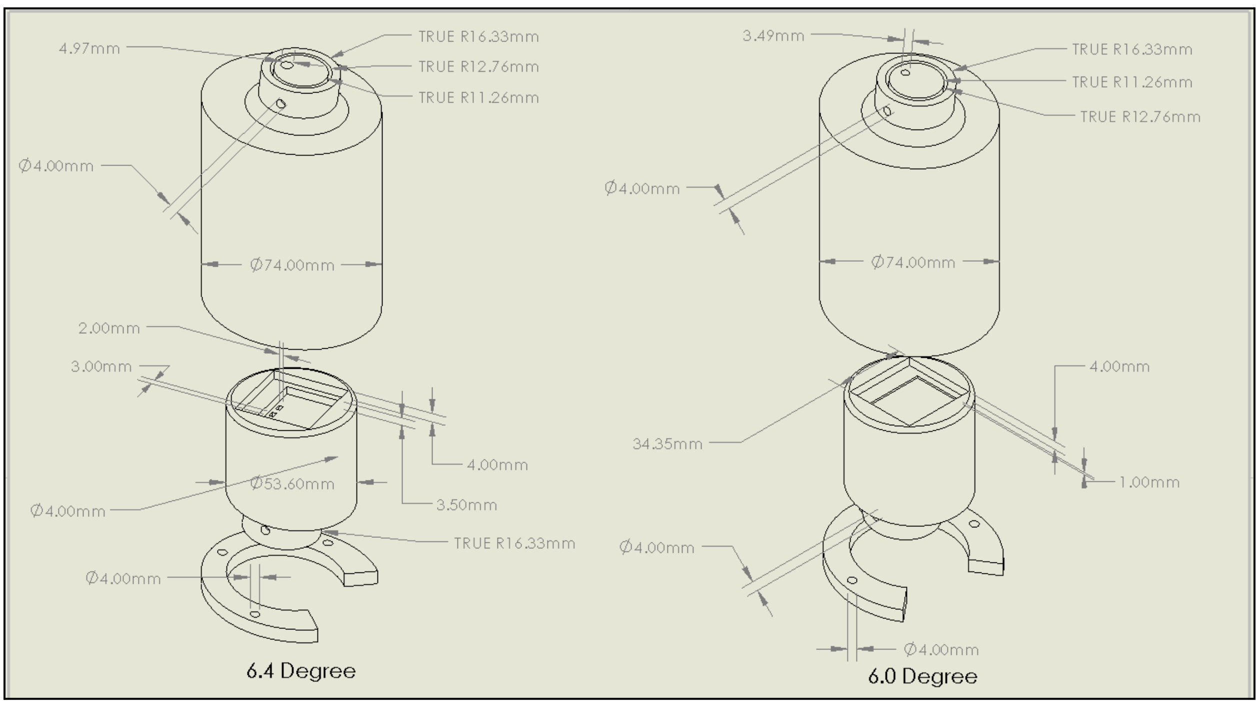

Figure 6. Annotated Solidworks drawing of the Load Sensor Holders (mm).

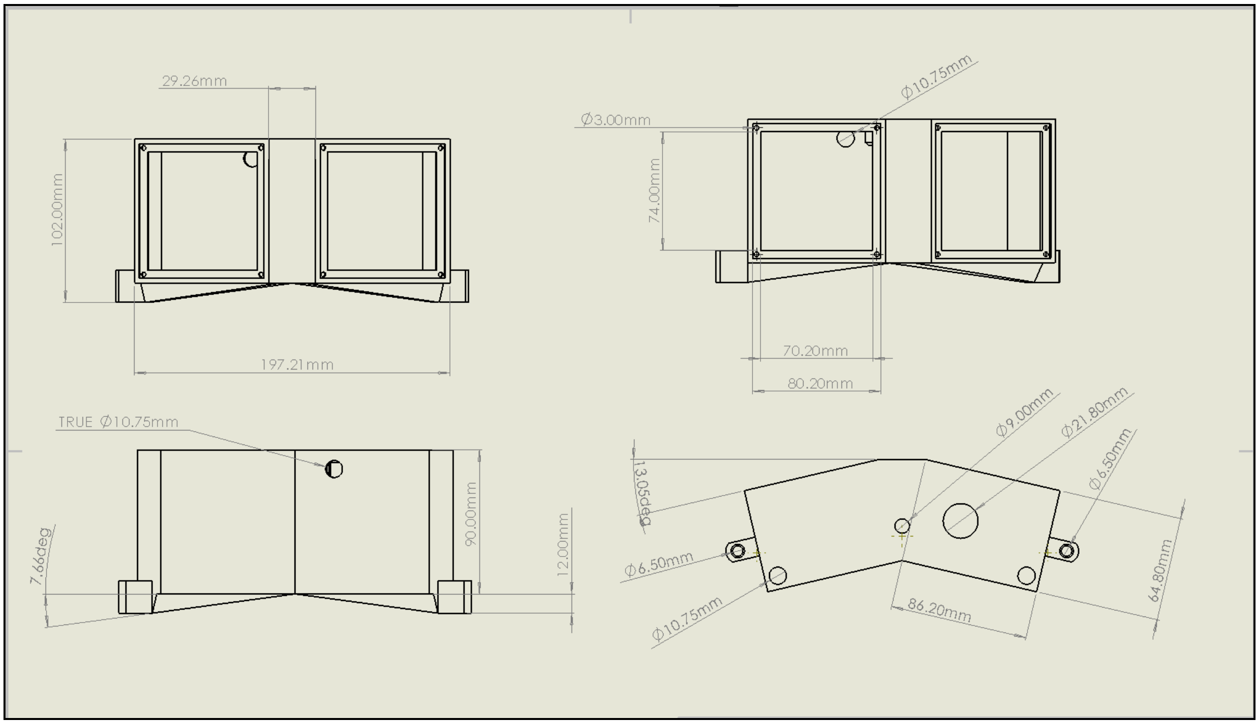

Figure 7. Power and Sensor Circuitry housing CAD and dimensions (mm).

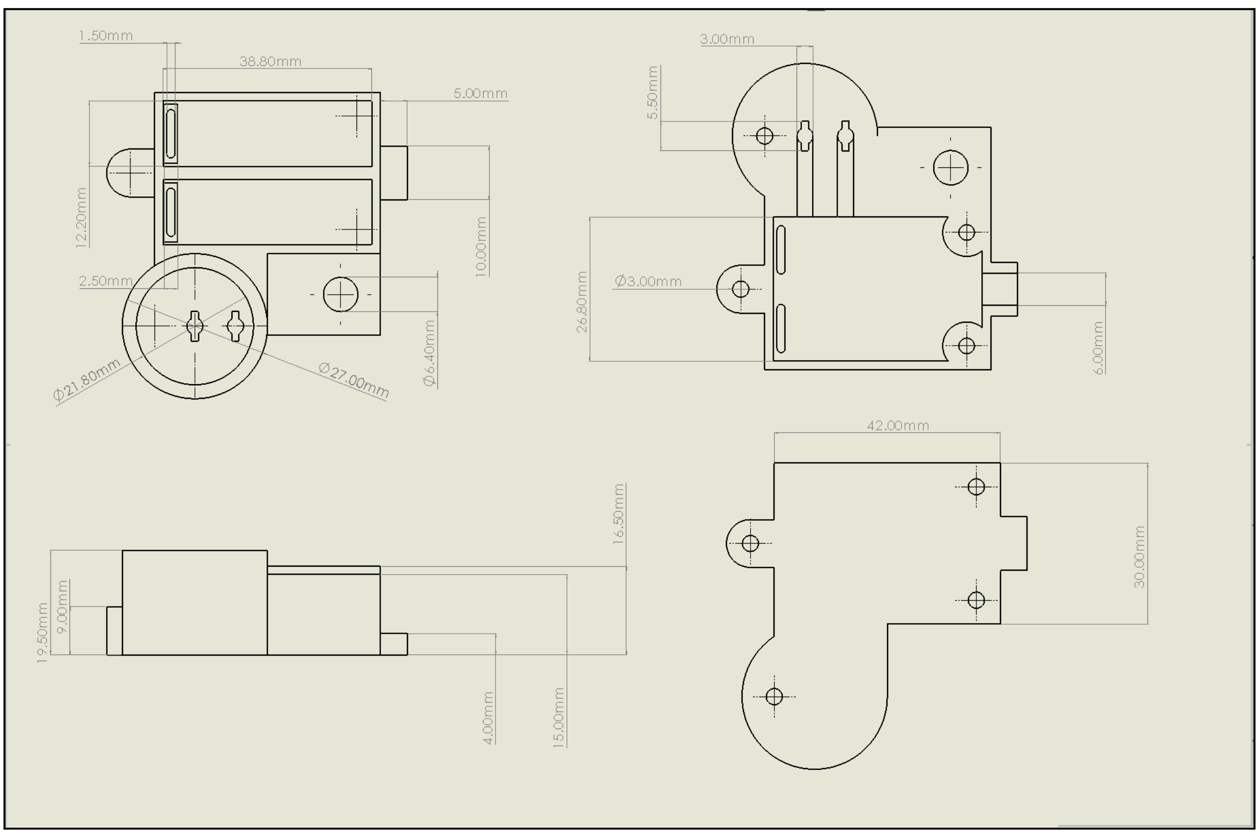

Figure 8. Display and trial switch holder CAD and dimensions (mm).

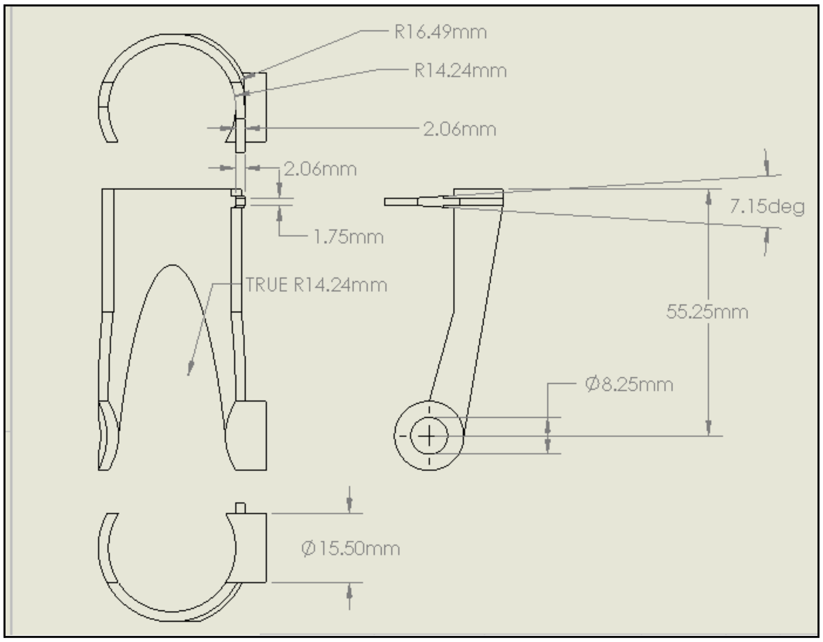

Figure 9. Infrared sensor holder CAD and dimensions (mm).

C. Fabrication and Assembly Protocol

C.1 Load Sensor Holder Attachment

1. To introduce load sensing capabilities to a standard walker frame, load sensors must be integrated into all four legs.
2. Thus perpendicular cuts were made, using a level and a hand saw, in each of the four legs.
3. Subsequently, a standard rotary tool was used to smooth out the cuts and remove sharp edges.
4. Next, the front and rear load sensor holders were designed in SolidWorks, and then printed out of PLA using a standard FDM Bambu Labs 3D printer.
5. These holders were then attached to the walker frame, and marks were made through each holder component's bolt holes and onto the walker frame.
6. The holders were then removed from the frame.
7. These markings were used to accurately position a hand drill using a 0.149" drill bit to drill bolt holes into the frame (The result of this step can is shown in Fig. 10).
8. Then the top and bottom holders were reattached and secured to the frame using a 1 ½ " #6 bolt and nut (Fig. 11 shows a fully attached top load sensor holder).

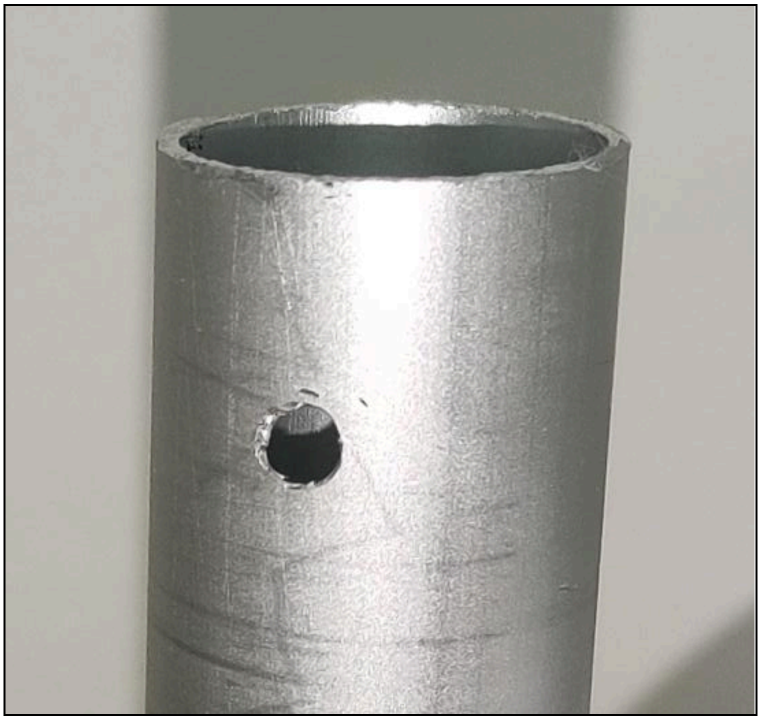

Figure 10.   Bolt hole for the load sensor holder.

Figure 11.   Bolt hole for a top load sensor holder.

C.2 Mounting the Electrical Housing

1. The electrical housing must be centered and forward on the walker frame to ensure the device remains balanced.
2. Thus, rubber pipe clamps were used along with nuts and bolts to mount the electrical housing to both crossbars.
    a. A 1” diameter pipe clamp and a 2” long, ¼” diameter bolt were used to secure the housing to the top crossbar.
    b. Two ½” diameter pipe clamps were used to secure the housing to the bottom crossbar along with 1” long, ¼” diameter bolts.
3. The housing was then positioned centrally, and nuts were used to secure the clamps to the housing (the mounting is shown in Fig. 12).

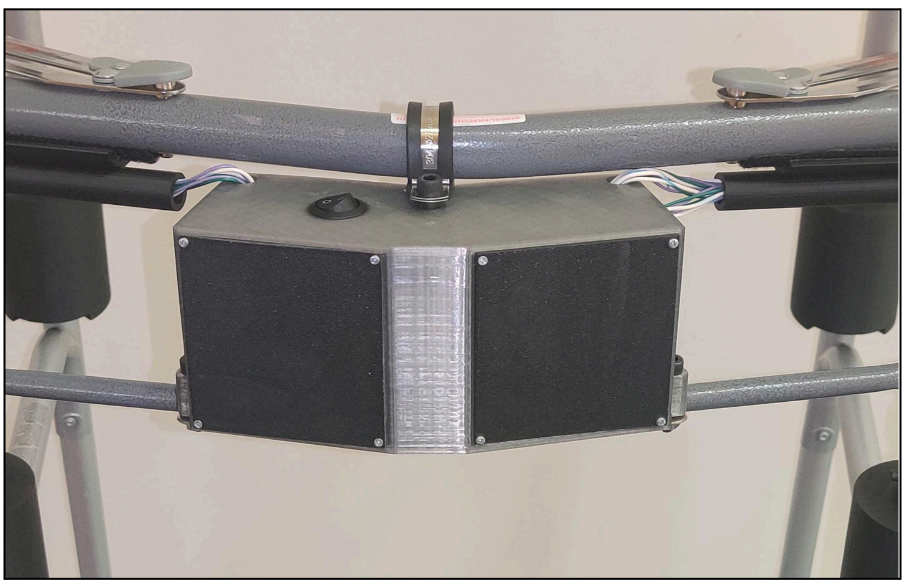

Figure 12. Image showing the electrical housing, and how it is mounted to the smart walker, along with how the wires feed into the housing.

C.3 Wiring the Walker Frame

1. Most wiring is required to pass through the walker frame to ensure that no wires interfere with the patient's gait.
2. Thus, using ⅜” drill bit and hand drill, holes were made in the walker’s two front legs just below the top crossbar.

3. With the load sensor holders off, a guide wire attached to a weight was dropped down these holes and out through the legs where the perpendicular cuts were made.
4. This guide wire was then tied in a loop to ensure it was not pulled out of the walker tubing.
5. 22-gauge wire, for the load sensors and OLED displays, was then attached to the guide wire and pulled through the walker frame.
6. The wiring exiting the hole near the top crossbar was then passed through a wire conduit for support before entering the electrical housing (This is shown in Fig. 13).

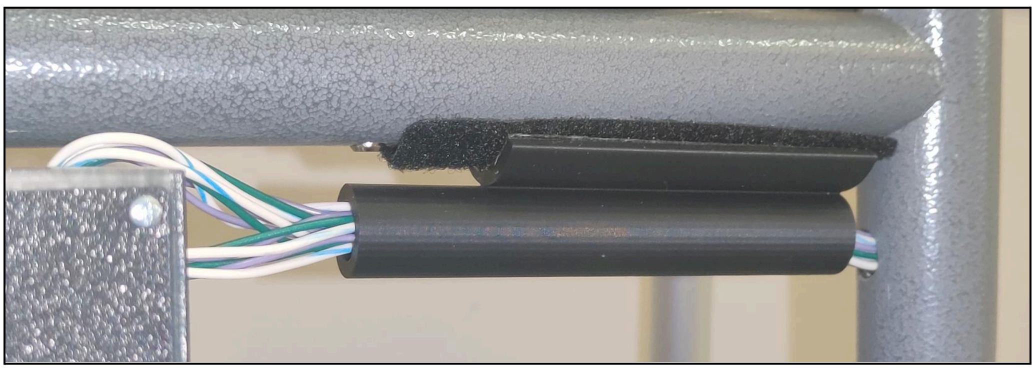

Figure 13. Upper wiring leaving the walker frame and travelling through a wire conduit before entering the electrical housing on the left.

C.4 Soldering of Electrical Components

1. Soldering of electrical components is done on two 3.5” by 2.05” breadboards using a soldering iron and solder material.
2. Large components are placed first, leaving open pins around them to make connections
    a. Large components are not soldered directly to breadboards.
        i. For amps, 8-pin headers were soldered to the board.
        ii. For regulators, 4-pin headers were soldered to the board.
        iii. For the Raspberry Pi Pico, four 10-pin headers were soldered to the board, forming two rows of 20 pins.

3. Connections between components on each breadboard are made using 22 gauge wire soldered directly onto the board.
    a. For wires traveling to sensors/circuitry not contained by a breadboard, screwable wire connectors were soldered in their stead.
    b. Resistors and capacitors were soldered directly to the boards
4. Ensure that ground connections are made across rails within each breadboard, and between the breadboards.
5. For reference to specific connections, see Fig. 14 below.

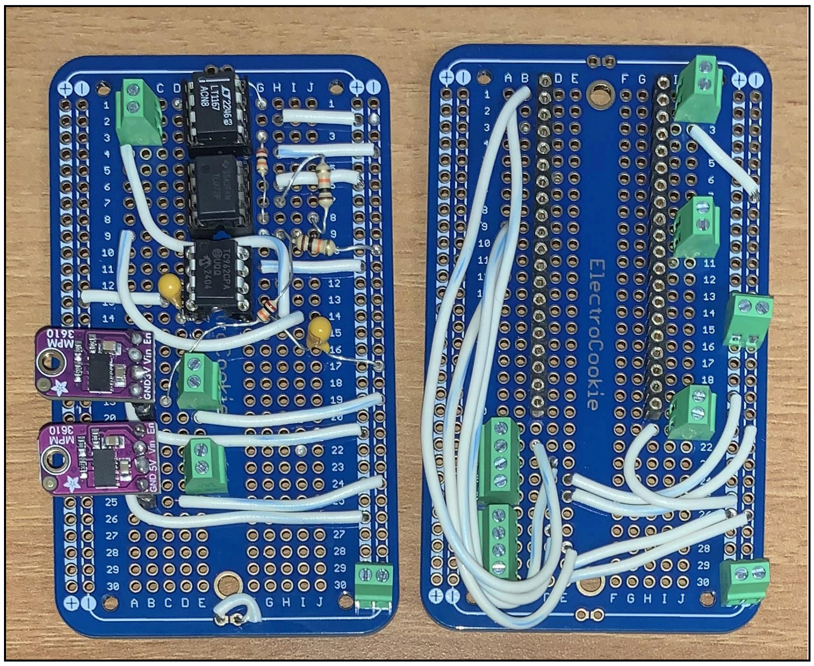

Figure 14. Image showing soldered connections made on each of the breadboards.

C.5 Attachment and Positioning of the IR Sensors

1. In order to secure and ensure proper positioning of the Infrared (IR) sensor, concentric bolt holes and a larger viewing hole were drilled into the walker frame flush with the right wheel.
2. The IR sensor was then soldered to three wires.
3. The front right leg was removed and the sensor, along with the wires, was run down the leg towards the wheel.

4. A 1.5” long, $^{1}/_{16}$” diameter bolt was passed through the previously mentioned bolt holes and through the IR sensors circuit board within the tubing, securing the sensor.
5. The emitter and receiver portions of the sensor were then pushed forward along this bolt so that they peeked out of the walker frame through the viewing hole.
6. This positioned the emitter and receiver toward the marked wheel for proper measurement.
7. The IR sensor holder was then mounted to the main wheel bolt, and then the cross support of the holder was run underneath the emitter and receiver on the outside of the right leg tubing to secure the sensor further (Fig. 15 shows the final mounted IR sensor position).
8. Then the IR's wires were pulled out of the bottom adjustment pin hole to enable them to travel to the upper wire conduits outside the tubing.

Figure 15. Mounted IR sensor and holder.

C.6 Attachment and Positioning of the Load Sensors

1. Each strain gauge wire was run from the inside of the top holder and out through the top wire hole to ensure the sensor’s wires passed into the frame.

2. These wires were then soldered to the 22-gauge wires that had already been run through the walker’s frame for this purpose.
3. Then the sensors were positioned in the top face of the bottom load sensor holder component in the cut out.
4. The top and bottom components, with the load sensor properly placed, were then connected concentrically.
5. Then a c-ring was screwed into the bottom face of the top load sensor holder component to ensure the top and bottom components were unable to vertically translate independently (Fig. 16 shows this c-ring).

Figure 16. C-ring that connects the bottom and top components of the load sensor holder.

C.7 Attachment and Positioning of the OLED Displays and Trial Switch

1. To avoid loose wires by the handles, a hole was drilled into the walker’s tubing, forward of the handle pads on the left side.
2. Wiring exiting this hole was then soldered to the trial switch and OLED displays while these components were positioned within the screen holder.
3. Using a 1” pipe clamp and a ½” diameter bolt, the screen holder was mounted just forward of the left handle (this is shown in Fig. 17).

Figure 17. The mounted screen holder on the left handle with the two OLED screens and trial switch within the component.

D. Testing and Calibration Protocols

1. Calibration Protocol

Details of Test:

i. Measure weight of wood planks
ii. Have nothing resting on walker
iii. Press switch on walker to start run for values
iv. Leave switch on for 5 seconds
v. Collect value outputted on screen in spreadsheet
vi. Repeat steps 2-3 two more times for a total of 3 runs
vii. Place planks across the walker and do steps 3-5 again 3 times.
viii. Place 5lbs and do steps 3-5 ten times.
ix. Continue by adding 5lbs on for the most precision.
x. Create a scatter plot of data points with weight on the x-axis and voltages on the y-axis.
xi. Apply a quadratic polynomial fit to determine the equation of the line of best fit.
xii. Upload this equation to the microcontroller to calculate applied load.

2. Average Distance and Velocity Testing Protocol

Details of Test:

i. In a long, straight hallway, mark three distances from a common starting line:
    1. 15.24 meters (50 feet)

2. 30.48 meters (100 feet)
3. 45.72 meters (150 feet)

ii. Place the walker behind the starting line.

iii. Begin recording the time as the subject starts walking.

iv. Push the walker in a straight line at a consistent pace (as specified below).

v. Stop timing when the front wheels of the walker cross the end mark.

vi. Repeat steps 2-5 three times for each marked distance (15.24 m, 30.48 m, or 45.72 m).

vii. At three target walking speeds (9 trials per distance, for a total of 27 trials):

1. ~0.33 m/s
2. ~0.66 m/s
3. ~1.00 m/s

viii. Record the known distance traveled based on floor markings.

ix. Record the measured time for each trial.

x. Calculate the expected average velocity by taking distance divided by time.

$$Average\ Velocity = \frac{Distance}{Time} \tag{3}$$

xi. Compare calculated values to the device's measured velocity and distance.

3. Instantaneous Velocity Testing Protocol

<u>Details of Test:</u>

i. In a long, straight hallway, mark three distances from a common starting line:

1. 3.048 meters (10ft)
2. 6.096 meters (20ft)
3. 9.144 meters (30ft)

ii. Place the walker behind the starting line.

iii. Begin timing as the subject starts walking.

iv. Push the walker past all three markers at a consistent pace.

v. At each marker:

1. Record the time elapsed at each marker (i.e., time since the previous marker).
2. Record the instantaneous velocity displayed by the device.

vi. Upon reaching the 9.144 m (30 ft) mark:

1. Stop pushing the walker
2. Record the final elapsed time since the previous marker.

vii. Repeat steps 2-6 three times for the 30ft path at each of the following target speeds (9 total trials):
    1. ~0.33 m/s (slow)
    2. ~0.66 m/s (moderate)
    3. ~1.00 m/s (fast)

viii. For each interval (0-10 ft, 10-20 ft, 20-30 ft):
    1. Calculate the instantaneous velocity (expected velocity):

$$v = \frac{Distance\ Interval}{Elapsed\ Time\ for\ Interval} \tag{4}$$

ix. Compare each expected velocity to the corresponding device-reported instantaneous velocity.

4. Average and Instantaneous Load Testing Protocol

Details of Test:

i. Place the walker device securely on top of in-ground force plates.

ii. Ensure both systems (walker and force plates) are capable of recording synchronized time-series data.

iii. Instruct a subject to apply load to the walker handles in a natural steady motion.

iv. Ensure minimal movement of the walker during loading to reduce dynamic artifacts.

v. Recording the instantaneous load data from the in-ground force plates.

vi. Simultaneously, record instantaneous load data from the walker device.

vii. Ensure that the recording windows are synchronized due to the different sampling rates.

viii. Plot the following instantaneous load vs. time for both measurement modalities:
    1. Force-plate readings.
    2. Walker device readings.

ix. Identify the time window during which load was consistently applied.

x. Compute the average load over this interval:
    1. For the in-ground force plates.
    2. For the walker device.

xi. Compare the average values and overlay plots to assess accuracy, consistency, and potential lag or deviation.

E. Code

Final Code

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

# ----- Display Setup -----------------------------------------------------
i2c0 = I2C(0, scl=Pin(1), sda=Pin(0), freq=100000)
i2c1 = I2C(1, scl=Pin(7), sda=Pin(6), freq=100000)
oled_width = 128
oled_height = 32
oled0 = ssd1306.SSD1306_I2C(oled_width, oled_height, i2c0)  # Status display
oled1 = ssd1306.SSD1306_I2C(oled_width, oled_height, i2c1)  # Data display

def clear_displays():
    oled0.fill(0)
    oled0.show()
    oled1.fill(0)
    oled1.show()

# ----- Load Sensor Setup -------------------------------------------------
adc_load = ADC(Pin(27))

def read_voltage(adc, vref=3.3):
    return (adc.read_u16() / 65535) * vref

def calculate_weight(voltage):
    return (1199.13020935 * voltage**2) - (3714.22313599 * voltage) + 2856.99179985

# (735.06557716 * voltage**2) - (2074.99645015 * voltage) + 1410.09462896  # old one

# ----- IR Sensor Setup ---------------------------------------------------
sensor = ADC(Pin(26))
threshold = 10000
tape_width_m = 0.098
distance_m = 0
prev_state = sensor.read_u16() > threshold

# ----- Switch Setup ------------------------------------------------------
switch = Pin(16, Pin.IN, Pin.PULL_DOWN)
trial_running = False
```

```
start_time = 0

# ----- Data Queues ----------------------------------------------------------
speed_queue = []
weight_queue = []
time_queue = []
all_weights = []  # Stores ALL weights during trial for final averaging

# ----- Initialization ------------------------------------------------------
clear_displays()
oled0.text("Not Running", 0, 0)
oled0.show()

# ----- Main Loop -----------------------------------------------------------
while True:
    if switch.value() == 1:
        if not trial_running:
            trial_running = True
            start_time = time.time()
            distance_m = 0
            speed_queue.clear()
            weight_queue.clear()
            time_queue.clear()
            all_weights.clear()
            clear_displays()
            oled0.text("Measuring", 0, 0)
            oled0.show()
            print("\nTrial started...")

        # IR Distance Detection
        ir_val = sensor.read_u16()
        current_state = ir_val > threshold
        if current_state != prev_state:
            distance_m += tape_width_m
            prev_state = current_state

        # Weight Measurement
        voltage = read_voltage(adc_load)
        weight = calculate_weight(voltage)
        all_weights.append(weight)

        # Queue Updates
        current_time = time.time()
        speed_queue.append((distance_m, current_time))
```

```
    weight_queue.append(weight)
    time_queue.append(current_time)

    # Trim old values (>1 second)
    while current_time - time_queue[0] > 1 and len(time_queue) > 1:
        speed_queue.pop(0)
        weight_queue.pop(0)
        time_queue.pop(0)

    # Moving Averages
    delta_d = speed_queue[-1][0] - speed_queue[0][0]
    delta_t = speed_queue[-1][1] - speed_queue[0][1]
    recent_speed_mps = delta_d / delta_t if delta_t > 0 else 0
    recent_speed_mph = recent_speed_mps * 2.23694
    avg_weight = sum(weight_queue) / len(weight_queue) if weight_queue else 0

    # OLED Display (Clamp negative weights for live display only)
    display_weight = avg_weight if avg_weight > 0 else 0.0
    oled1.fill(0)
    oled1.text(f"Speed: {recent_speed_mph:.1f} mph", 0, 0)
    oled1.text(f"Weight: {display_weight:.1f} lbs", 0, 16)
    oled1.show()

    utime.sleep_ms(50)

else:
    if trial_running:
        trial_running = False
        total_time = time.time() - start_time
        avg_speed_mps = distance_m / total_time if total_time > 0 else 0
        avg_speed_mph = avg_speed_mps * 2.23694
        distance_ft = distance_m * 3.28084
        total_avg_weight = sum(all_weights) / len(all_weights) if all_weights else 0

        print("\nTrial ended.")
        print(f"Distance: {distance_ft:.2f} ft")
        print(f"Time: {total_time:.2f} sec")
        print(f"Avg Speed: {avg_speed_mph:.2f} mph")
        print(f"Avg Weight: {total_avg_weight:.1f} lbs")

        clear_displays()
        oled0.text("Trial Over", 0, 0)
        oled1.text(f"W: {total_avg_weight:.1f} lbs", 0, 0)
        oled1.text(f"S: {avg_speed_mph:.1f} mph", 0, 8)
```

```
    oled1.text(f"D: {distance_ft:.1f} ft", 0, 16)
    oled1.text(f"T: {total_time:.1f} s", 0, 24)
    oled0.show()
    oled1.show()
    time.sleep(10)

    clear_displays()
    oled0.text("Not Running", 0, 0)
    oled0.show()

time.sleep(0.25)
```