SMART WALKR

Biomedical Engineering Design

Department of Biomedical Engineering

University of Wisconsin-Madison

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Client

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Abstract

The rehabilitation process is ever evolving, and now more than ever a data driven approach to rehabilitation is needed. Both the physical therapist and the patient would be beneficiaries of this data. For this reason Dan Kutschera, a physical therapist at an acute stroke clinic in Madison Wisconsin, has requested the creation of a Smart Walker to quantitatively assess the ability for his patients to walk using a walking aid. The Smart Walker will bring an approach that tracks and displays measurements of speed, distance traveled, and pressure applied to the Smart Walker. This will allow the patient in real time to see the progress they have been making on each visit. This also allows the Physical Therapist to give the patient data driven goals on a recovery timeline. The previous team that worked on this project was able to implement some of these specifications, but they struggled to get accurate readings for both the pressure applied and the distance traveled by the walker. They also had the data stored in an app on a phone, and did not show these measurements in pounds and mph. Our goal is to have a display that outputs more accurate, real-time values in pounds for force, mph for speed, and feet for distance traveled. The improvements for this group will be focused on the client's requests for a better clinical use for the walker.

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Introduction

Motivation

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. For example, Dan Kutschera will only allow those of his patients who have a minimum speed of 0.5 mph with the walker to be by themselves outside. 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. This would have a broader impact of remodeling the rehabilitation process to reduce the time individuals spend in therapy and return them to their life and loved ones.

Existing Devices and Current Methods

There are currently patents and existing devices for walkers which include elements of the smart walker envisioned by the client. 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 needs of the client.

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, but is not readily commercially available for consumers.

Finally, on the market there is a Camino Smart Walker (pictured below) 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, even though it only measures speed and not pressure applied. This is far out of the price range for the client and diminishes the effectiveness of the walker as a simple rehabilitation aid.

Figure 1: Camino Smart Walker

Problem Statement

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. Dan Kutschera, a physical therapist at an acute stroke clinic in Madison, Wisconsin, is looking to remedy this situation by tasking the team with creating a smart walker which can record walking speed and pressure placed on the walker. 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.

Background

Physiology and Biology

More than 795,000 people in America have a stroke annually [6]. Specifically, acute strokes, commonly known as “brain attacks”, are a major contributor to disability to those who were able to recover from the stroke in the first place [7]. While the chances for stroke increase with age, 38% of victims in 2014 were less than 65 years old according to the CDC [6], which means that the affected population is quite broad in terms of age and therefore other physical attributes as well. Because the project focuses on the physical rehabilitation aspect of acute stroke recovery, it is important to understand how the recovery process looks. There are a plethora of stroke symptoms that affect the digestive system to the mental state of the patient, but for the purposes of this report the physical symptoms are of greatest concern. These symptoms include weakness or paralysis on one or both sides of the body, numbness or strange sensations, and pain in the hands and feet [8]. As one can imagine, walking while experiencing these afflictions, even with a walker or other such assistive device, could be quite difficult and cumbersome. The possibility of heavy reliance on the Smart Walker during tests, and the wide range of potential users of the device mean that it is important that the Smart Walker be up to par with design specifications.

When using a walker, the gait cycle implements discrete segments of walker frame and lower leg movement [9]. This allows the weight usually carried fully by the lower limbs to be distributed through the upper body as it applies force through the handles of the walker. By measuring this pressure distribution as well as the speed of the patient the physical therapist can then customize rehabilitation plans to ensure the lower limbs have recovered functional strength and ensure gait symmetry is restored. The physical therapist can also evaluate if the patient is already healthy enough to return home based on how quickly they walk and how dependent they are on the walker.

Design Specifications

A more detailed explanation of the design specifications for the Smart Walker can be found in *Appendix A.* at the end of the report. That being said, there are important specifications that are brought here to be explicitly outlined, as they will guide the entire design for the most part. The Smart Walker will be used in a clinical setting with up to 10 different patients a day, each doing up to 5 trials with the walker to determine their recovery status. The aforementioned trials will be 10 m of walking distance, and should take no longer than 30 min at the very maximum to complete. Due to the variety of potential users of the Smart Walker, it should be able to accommodate a variety of heights from 0.8-1.1 m, widths of 0.64-0.74 m, and weights of up to 140 kg. The patient's speed, distance traveled, and force/pressure data will be transmitted to a screen attached to the Smart Walker, and should display these metrics converted to imperial units. Sensor measurements are expected to be within 5% accuracy of the real value. The client has specified $350 as the budget for this project.

Preliminary Designs

The Smart Walker device will feature two integrated systems to capture both speed and pressure data. The average values after each walking trial would be displayed on a screen mounted onto the walker. The sensors chosen to record both the speed and pressure would then determine how each could be integrated into the device.

Speed Sensor 1: Accelerometer

The first preliminary design for tracking the speed and distance of the walker is an accelerometer. An accelerometer will detect accelerations that occur in the x, y, and z axis and measure them in units of gravitational force, or g force. The accelerometer will output a voltage value proportional to the acceleration measured. This voltage value will be converted back to an acceleration and derived once to calculate the speed and again to calculate the distance.

The accelerometer can be placed anywhere on the walker since the walker is a rigid body. This means that the accelerations induced on the walker by the patient are also induced on the accelerometer. The accelerometer will need to have a high level of sensitivity to measure the acceleration of the patient walking.

Speed Sensor 2: Rotary Encoder

The second sensor for measuring the speed and distance of the walker is a rotary encoder. A rotary encoder converts the angular position of an axle into a voltage output. This sensor would measure the number of revolutions the wheels undergo during a trial. This amount of revolutions can then be multiplied by the circumference of the wheel to calculate the distance traveled. It would also require an internal clock to keep track of the amount of time that has passed, from this the speed can be calculated.

The rotary encoder would be located at both of the wheels. Fabrication of an axle that originates from the wheel would be necessary to drive the rotary encoder and evaluate the amount of revolutions that occur since clinical walker wheels do not have axles.

Speed Sensor 3: Hall Effect Sensor

The final potential sensor to be evaluated for measuring the speed and distance of the walker is a Hall effect sensor. A Hall effect sensor detects magnetic fields along an axis and once the measured field surpasses a threshold the sensor's output is turned on.

The Hall effect sensor would be located at the wheel and would require small magnets to be attached at equal distances about the wheel. When the Hall effect sensor outputs a voltage signifying that a magnet has passed, the arc length between these distances can be used to evaluate how far the walker has traveled. An internal clock keeping track of the time in the trial can then be used to calculate the speed of the walker.

Pressure Sensor 1: Load Cell

A load cell uses a strain gauge which detects changes in electrical resistance as pressure is applied and the strain gauge is stretched. The load cells would be integrated into the feet or legs of the walker. Building sensors into both sides of the walker could potentially allow the sensors to detect if the user is applying asymmetric pressure to the walker.

Pressure Sensor 2: Piezoresistive Pad

A piezoresistive pad functions similar to a strain gauge, with an applied pressure causing the piezoresistive material to deform causing a change in its conductivity. These pads are thinner with a greater surface area, allowing them to be integrated into the walker handles. In this way the pressure measured in these pads would be directly applied through the hands of the user.

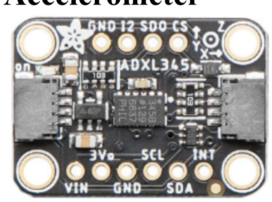
Pressure Sensor 3: Capacitive Force Sensor

A capacitive force sensor uses two metal plates with a dielectric medium in between. As pressure is applied to the sensor the distance between the plates decreases which causes a change in capacitance. This change is then calculated and converted into an electrical signal. The capacitive force sensors would also be integrated into the feet or legs of the walker.

Design Evaluations

Speed Sensor Design Matrix

Table 1: Design Matrix for Speed Sensor

Categories	**Accelerometer** 		**Rotary Encoder** 		**Hall Effect** 	
Accuracy (30)	5/5	30	5/5	24	3/5	18
Ease-of-use (25)	5/5	25	5/5	25	4/5	20
Price (20)	4/5	16	2/5	8	5/5	20
Fabrication (15)	4/5	12	3/5	9	3/5	9
Reusability (10)	4/5	8	3/5	6	3/5	6
Total (100)	91		72		73	

Speed Sensor Design Criteria

Accuracy: This design criteria scored the highest since without a device that is able to accurately measure the distance and speed traveled by the patient on the walker, the sensor's function is useless. The sensor must measure values within 10% accuracy and 5% precision, these metrics are suitable for the client.

Ease of Use: This design criteria scored the second highest due to the fact that the product will be used multiple times a day for various patients and for multiple years (see Appendix A); therefore the walker must be easy to use for the patient and easy to set up and evaluate the metrics by the client.

Price: The Smart Walker project has a budget of $300, so maining a low cost for the electrical components is a must for the walker to stay within the budget.

Ease of Fabrication: There is a limited amount of time for fabrication and testing of the sensors, so it is necessary that it is easy to do so. If it is not, then the device will not be able to be fabricated to its complete potential and specifications.

Reusability: The Smart Walker will be used multiple times a day for various patients and for multiple years (see Appendix A). This means that it is necessary that the sensors use minimal power and are durable to withstand the use that it will undergo.

Speed Sensor Design Matrix Evaluations

Accelerometer

The accelerometer had the highest evaluation from the design matrix was a score of 91/100. This sensor scored highly across all design criteria, with 5/5 in both the accuracy and ease-of-use categories. This can be attributed to the high level of sensitivity of the accelerometer, specifically 3.9 mg/LSB (milli-g-force per least significant bit), which is less than 1% error [10]. This error and sensitivity is well within the necessary accuracy limits expressed in the Design Product Specifications (see Appendix A) of 10%. The accelerometer also scored highly in the ease-of-use criteria due to the fact that it requires no set up by the client and has no effect on the patient using the device. The accelerometer also scored the highest fabrication due to existing code and methods on how to use the device existing [11]. And finally it scored the highest in reusability due to the low power consumption of the accelerometer since it requires 3.3 V and 23 uA of supply [9].

Rotary Encoder

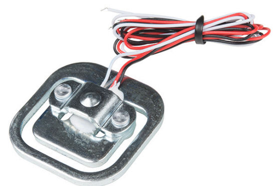
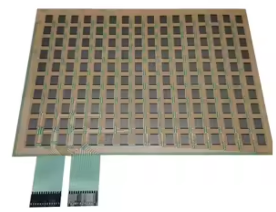
The rotary coder scored the lowest from the design matrix with an evaluation of 72/100. The sensor scored highly in its accuracy due to the incremental encoder's sensitivity being 0.2 degrees [12]. It also scored a 5/5 in the ease-of-use since it requires no setup for the client and does not obstruct the patient in any way. The device scored the worst in the price category due to each rotary encoder being $51.17, which is a large portion of the $300 budget. The sensor would also require additional fabrication of an axle that originates at the wheel, and additional support so both the axle and rotary encoder can withstand the forces applied from the user and the walker. This additional fabrication and concern of durability is what led to 3/5 scores for both the ease of fabrication and reusability criteria.

Hall Effect Sensor

Finally the hall effect sensor scored in the middle of the pack with a 73/100; though it nearly tied with the rotary encoder. The hall effect sensor scored a 3/5 in accuracy due to the potential for error since other magnetic fields could affect the ones induced by the magnets on the wheels. Along with this, the ease-of-use scored a 4/5 due to the added need for awareness of devices and objects that can hinder or enhance magnetic fields in the room or on the patient. The hall effect was the lowest cost out of all the products with the sensor being $0.62 each [13]. Similar to the rotary encoder, the hall effect scored a 3/5 in both the fabrication and reusability categories due to the added fabrication steps to have it function properly and the concerns of durability with the design.

Pressure Sensor Design Matrix

Table 2: Design Matrix for Pressure Sensor

Categories	**Load Cell** 		**Piezoresistive Pad** 		**Capacitive Force Sensor** 	
Accuracy (30)	5/5	30	2/5	12	4/5	24
Ease-of-use (25)	3/5	15	4/5	20	3/5	15
Price (20)	4/5	16	3/5	12	2/5	8
Fabrication (15)	4/5	12	4/5	12	2/5	6
Reusability (10)	4/5	8	2/5	4	3/5	6
Total (100)	81		60		59	

Pressure Sensor Design Matrix Criteria

Accuracy: This design criteria scored the highest since without a device that is able to accurately measure the pressure applied by the patient on the walker, the sensor's function is useless. The sensor must measure values within 10% accuracy and 5% precision, these metrics are suitable for the client. The load cell scored the highest in this category compared to the piezoresistive pad and the capacitive force sensor due to its ability to accurately measure and withstand higher force loads, such as a human.

Ease-of-use: There isn't much set-up required for any of the sensors here, both in regards to the patient and the physiologist. Each of the sensors would need to be calibrated initially, to ensure that voltage readings coincide with the correct point on the calibration curve. That being said, both the load cell and capacitive force sensor would most likely need to be calibrated throughout the use of the walker (each day, perhaps), so the piezoresistive pad has the highest rating at 4/5.

Price: Sensor price often increases dramatically with improved accuracy. For this reason it was important to choose a sensor that would deliver accurate readings for a reasonable price. The piezoresistive pad was the most cost effective option giving it the highest rating of a 4/5. The capacitive force sensors tended to be priced higher to measure a similar weight range to the load cell and were therefore given the lowest rating.

Fabrication: The team has two semesters to complete the project; however, the project plan is to finalize the sensors of the device within the first semester. To do so, the sensor must be easily integrated into the device to meet this timeline. The load cell and piezoresistive pad both scored a 4/5 in this category. They scored the highest since it would be simple to integrate the sensor into the wheelchair, and the code required to gain meaning from the outputs of the sensors is easy to write and comprehend.

Reusability: Each of these options consume relatively little power, so there isn't a big discrepancy there. However, the load cell accels in this category because of its high durability compared to the other two sensors that struggle to pick up large weight signals, therefore the load cell has the highest in this category with a 4/5, given that it still has a fairly limited weight requirement.

Load Cell

The load cell scored the highest of the pressure sensors with a 81/100. This is largely due to its high accuracy (5/5) and affordable price (4/5). The Sparkfun load cell chosen by the team has a sensitivity of 1 ± 0.1 mV/V which is more precise than either of the other sensors [14]. It also only costs $4.50 per unit making it easy to test and iterate off of. The load cell tied for the highest score in fabrication with a 4/5 as a result of its use in the previous semesters design for the smart walker. They 3D printed a component to integrate the load cell into the walker which the team still has access to. Lastly the load cell scored the highest in the reusability category with a 4/5 due to its low power consumption and overall durability.

Piezoresistive Pad

The piezoresistive pad had the next highest score of 60/100. It scored the highest in ease of use (4/5) as it would require less calibration between trials compared to the other two sensors. It also scored the highest in fabrication with a 4/5 as its placement on the handles of the walker would make it easy to integrate into the overall design. However, it scored the lowest in accuracy (2/5) due to it sensing only up to 50 lbs in weight. Also due to its placement in the handles, the user would need to place their hands carefully over the sensor to accurately transmit all of the forces through the pads. The piezoresistive pad also scored the lowest in reusability with a 2/5 due to its direct contact with the user diminishing the durability of the design.

Capacitive Force Sensor

The capacitive force sensor had the lowest overall score of 59/100. It had a relatively high score for accuracy (4/5) with a sensitivity of 2 ± 0.2 mV/V. It also scored well for reusability (3/5) due to its low power consumption. However, it scored the lowest in price with a 2/5 due to its cost of $133 per unit. It also scored the lowest in fabrication (2/5) as its placement in the feet or legs of the walker would require more fabrication than the load cell or piezoresistive sensor.

Final Design

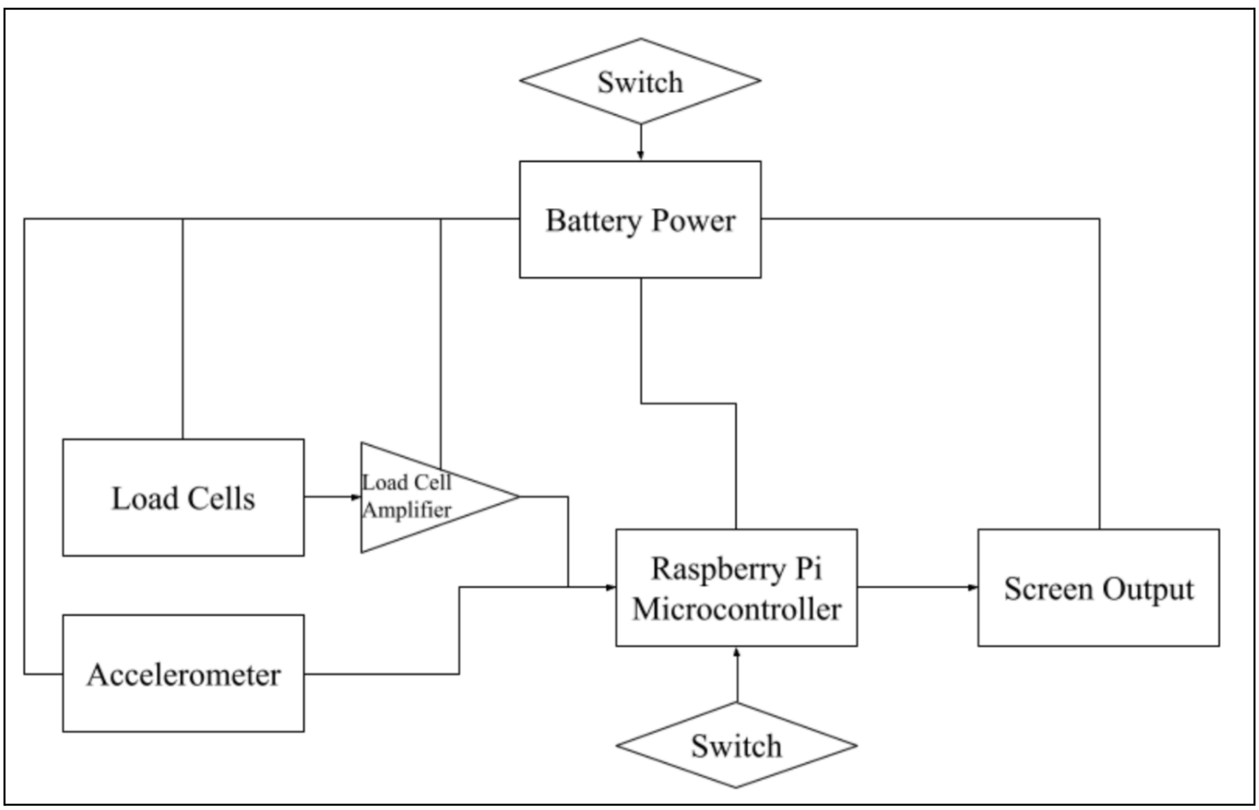


Figure 2: Hardware block diagram of the final design

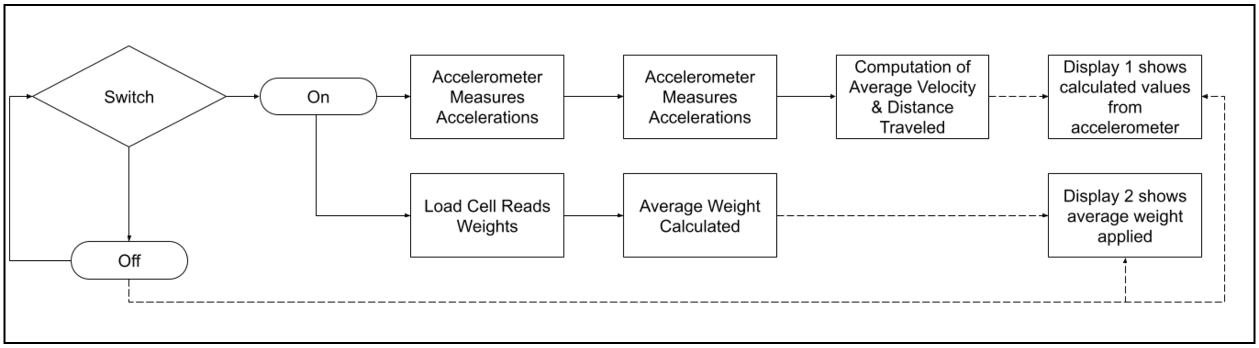


Figure 3: Software diagram of the final design

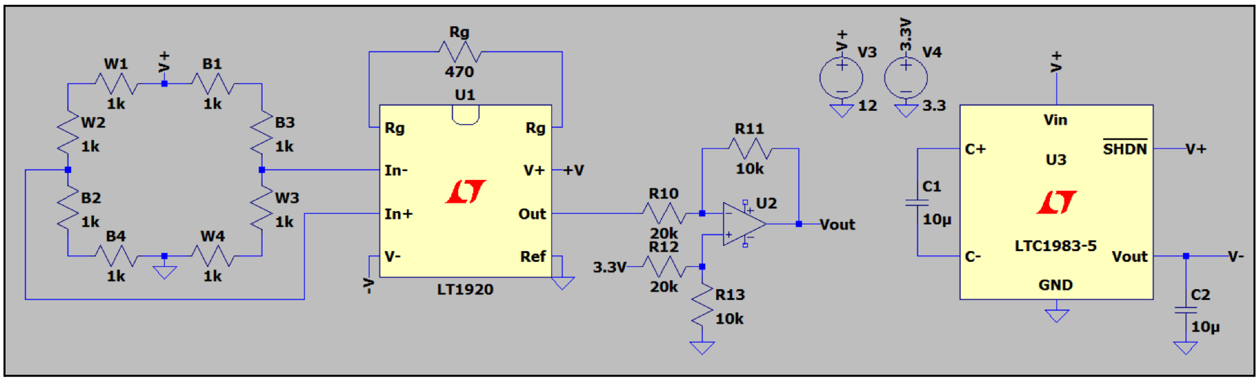


Figure 4: LTSpice electrical diagram of load cell circuit

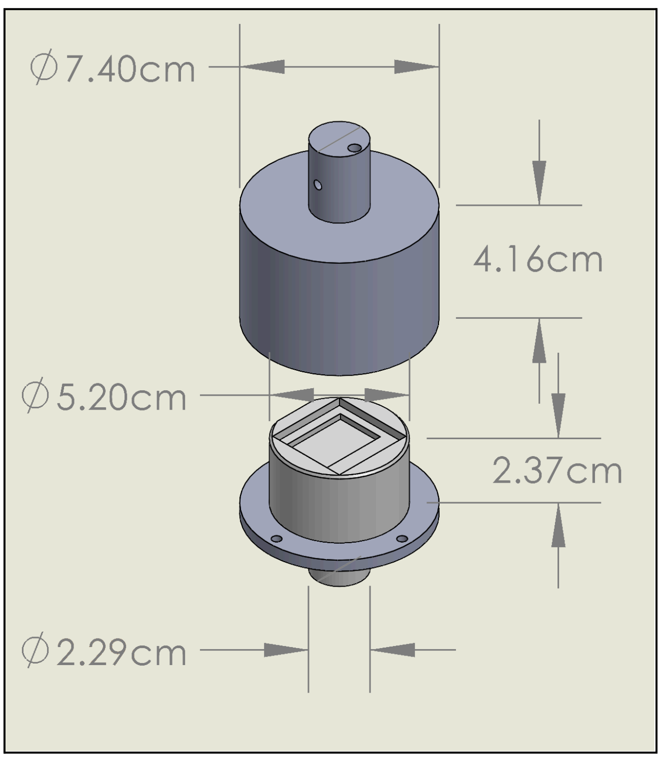


Figure 5: Dimensioned SolidWorks assembly of housing chambers for the load cells

The final design will consist of a standard 2 wheeled clinical walker with load cells integrated into each of the legs within the chambers seen in figure 5. These load cells will be able to measure the total pressure applied through the walker's legs. There will be an accelerometer attached to the frame of the walker that will be used to calculate the speed and distance traveled by the walker. The walker will contain a main housing unit for the power supply, microcontroller, and OLED screen. The force applied, speed, and distance traveled by the walker will all be displayed so the client can evaluate how well the patient is recovering and provide extra motivation to the patients (see figure 2 and 3).

Fabrication and Development

Materials

Circuitry Components

Table 3: List of materials used in the final circuit for the Smart Walker

Part	Description	Rationale for Use
4x Load Sensors	N/A	Provides a voltage output based on the applied weight to the sensor. Placed in each of the walker's legs
ADXL345	Accelerometer	Provides a voltage output based on the acceleration of the sensor.
2x OLED Screens	Digital screens	Used to output data to the user based on calculations from the microcontroller
Raspberry Pi Pico	Microcontroller	Acquires signal from the level shifter output and the accelerometer output, does any necessary calculations, and outputs data to the screens.
LT1167	Instrumentation amplifier	Compares voltage values at opposite corners of the Wheatstone bridge and amplifies the signal.

TL072	Operational amplifier	Used in a level shifter topology to shift signal to be appropriate for the microcontroller
TC962CPA	DC to DC converter	Outputs a negative voltage that is used to supply the other amplifiers
2x 10 μF Capacitors	N/A	Used with the DC to DC converted to get the negative voltage supply.
480 Ω Resistor	N/A	Used as Rg in conjunction with the instrumentation amplifier.
2x 10 kΩ Resistors	N/A	Used in the level shifter stage to get the proper amount of gain.
2x 20 kΩ Resistors	N/A	

Housing for Electronics

The initial prototype for the load cell holder was created using about 250 g of PLA due to ease of printing and cost effectiveness. The future final prototype for the load cell holder will be created using ABS due to its toughness and durability in comparison to PLA [15]. The display box which will contain the circuit board and accelerometer will also be created out of ABS.

Fabrication Process

The fabrication of the circuit for the accelerometer and displays is quite simple. The input voltage for both devices can be run on the 3.3V output pin of the Raspberry Pi Pico, and grounded on the Pico's ground pin as well. The SDA and SCL communication pins of the accelerometer will be respectively connected to GPIO pins 0 and 1 - or physical pins 1 and 2, while the display pins are connected from their SDA and SCK communication pins to GPIO pins 2 and 3 - or physical pins 4 and 5. To simulate the switch - which can be observed in the block and software diagrams in figures 2 and 3, as well as the code in Appendix H - a wire is connected to physical pin 20. This wire is moved from GND to 3.3V to simulate the turning on of the switch, and vice versa for the other direction. The load cell circuit is created using the components in table 3 as the circuit seen in appendix F. The output of this circuit is input into GPIO pin 26 - or physical pin 31 - of the Raspberry Pi pico. This completes the fabrication of the circuitry for the prototype. There is a 12 V power supply supplied to the load cell and load cell circuit, and a USB connection from the Raspberry Pi Pico to a computer.

The fabrication of the final design will require multiple areas of focus. The first area of focus will be measuring the pressure applied to the sensor using the load cells. These load cells will be integrated into each of the 4 legs of the walker so the force can be measured from each one. The initial prototype load cell holders were first modeled on Solidworks and then 3D printed on Bambu Lab printers using PLA at 70% infill. The team then cut the legs of the walker so the load cell holder would fit in between as shown in figure 6. In the future, 4 of the load cell holders will be printed in ABS at 80% infill. Screws will be used to attach the load cell holder to both ends of the walker leg The team will connect the power supply and communication wires to each of the load cells. These wires will be run through the frame to the main housing chamber.

Figures 6 & 7: Image of initial prototype load cell holder (left) and prototype assembled with walker leg (right)

The housing chamber will be a 3D printed box created out of ABS that will hold the battery supply, accelerometer, microcontroller, and display screen. The accelerometer will be secured to the box, which is secured to the frame, and it will receive its voltage supply and be connected to the microcontroller for communication.

Finally, the team will fabricate the hall effect sensor set up exclusively for testing; however, if it performs better than the accelerometer, the team may opt to use it instead. The team will adhere 4 magnets at equal distances about the wheel and wire the hall effect from the base of the frame to the microcontroller and power supply (see *Appendix C*).

Testing

In order to determine whether or not the Smart Walker device is up to par with the previous design specifications, multiple tests are necessary for each different type of specification.

Load Sensor Calibration

The team conducted a test to determine the calibration curve of output voltage vs weight. This test was conducted with non-SI units since the client desired the pressure to be measured in pounds. See Appendix F for the testing protocol for load cells, but in synopsis the team applied known weights (weightlifting weights) onto a scale that was created out of the load cells (see figure 8).

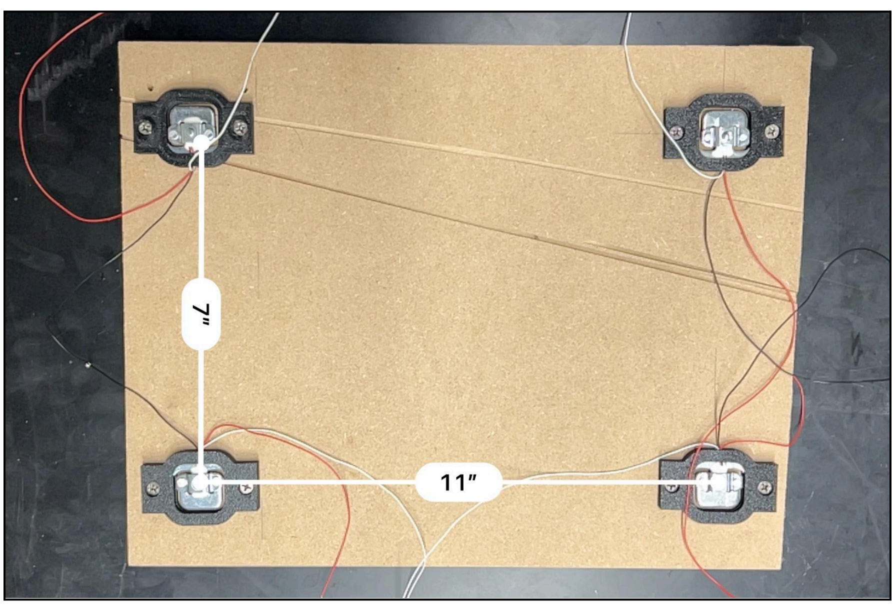


Figure 8: Scale created out of load cells

Load Sensor Testing

After the team created the load cell calibration curve, they implemented this into a series of codes and then evaluated to see how accurate the curves are in practice. Individuals would stand on a bathroom scale, record the weight, then step on the modeled load cell scale where the average weight over 5 seconds was measured. See figure 9 for the set up of this.

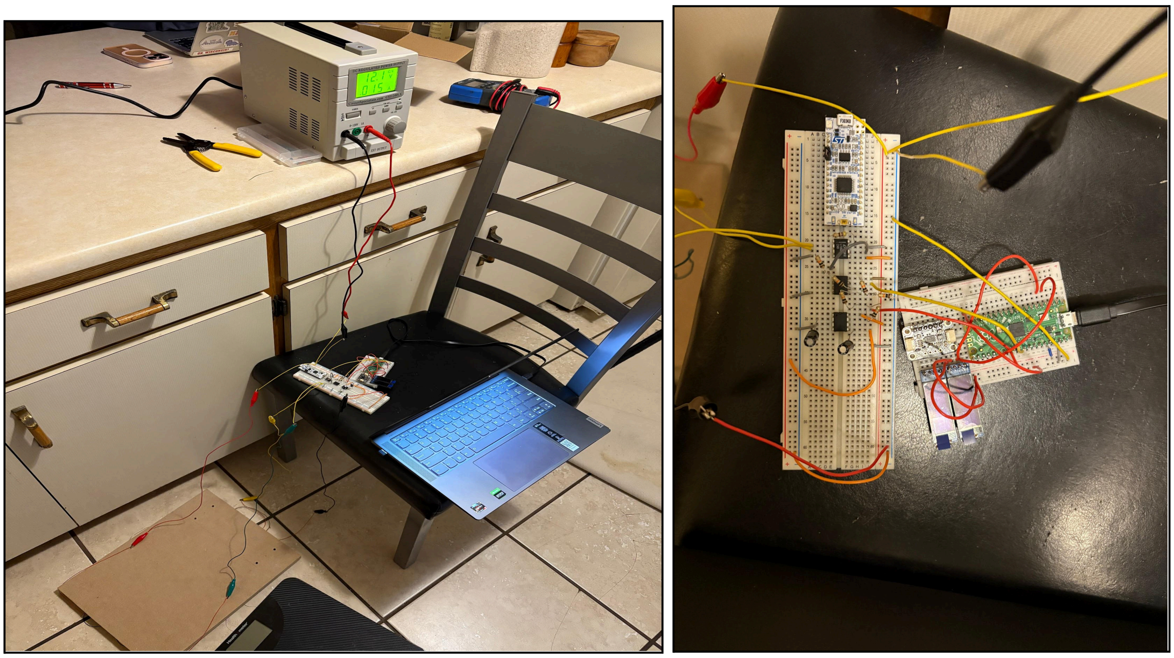


Figure 9: The set-up of the testing system with the bathroom and load cell scale viewed in figure a at the bottom left. The power supply is on top of the counter and is supplying the circuit. The code is being downloaded onto the Raspberry Pi Pico from the computer and the output is being displayed on both the laptop and the OLED displays that can be seen in figure b.

Accelerometer Testing

As delved deeper into in appendix G, the protocol for the accelerometer testing followed having the accelerometer planted stably onto a surface that would then be moved across a known distance. The time it took to travel this distance was recorded and the velocity was calculated. These values were then compared to the measured time elapsed, distance travelled, and average velocity of the accelerometer.

Solidworks Finite Element Analysis Testing

This semester Solidworks Finite Element Analysis (FEA) testing was run on the load cell holder to ensure the chosen material and design dimensions could withstand anticipated stresses that could occur during use. The most likely mode of failure was determined to be the result of a horizontal force placed on the lower leg of the walker. For this reason, in the simulation 200 N of force was applied to the lower end of the load cell holder which would be encased in the lower walker leg. The upper portion of the load cell holder was held fixed as its motion would be prevented by the upper leg of the walker.

Results

Load Sensor Calibration

The load cell was calibrated with the leads into the instrumentation amplifier standard and inverted. This led to 2 different calibration curves being made. The calibration curves showed a linear relationship between the output voltage and input weight (lbs) with R^2 value of 0.996 and 0.999 - which indicates very strong relationships. This can be seen in figure 10 of the graphs overlaid with each other.

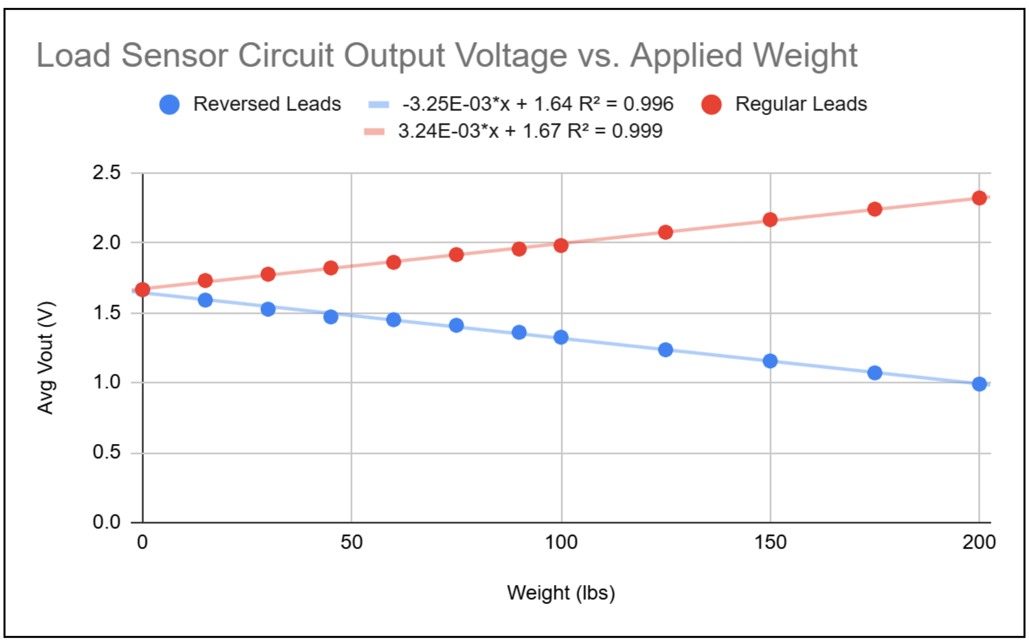


Figure 10: The load sensor circuit output voltage (V) vs Applied Weight (lbs) of both regular leads (red) and inverted leads (blue). This was conducted to obtain the calibration curves of the load cells.

As observed above, the calibration curve for each was -3.25 mV * Input Weight + 1.64 V and 3.24 mV * Input Weight + 1.67 V. These curves were used in the code to evaluate the voltages measured. See appendix J for the full results.

Load Sensor Testing

The testing of the load cell scale, whose results can be found in *Appendix K*, yielded the following graph of expected scale weight (lbs) vs measured load cell weight (lbs).

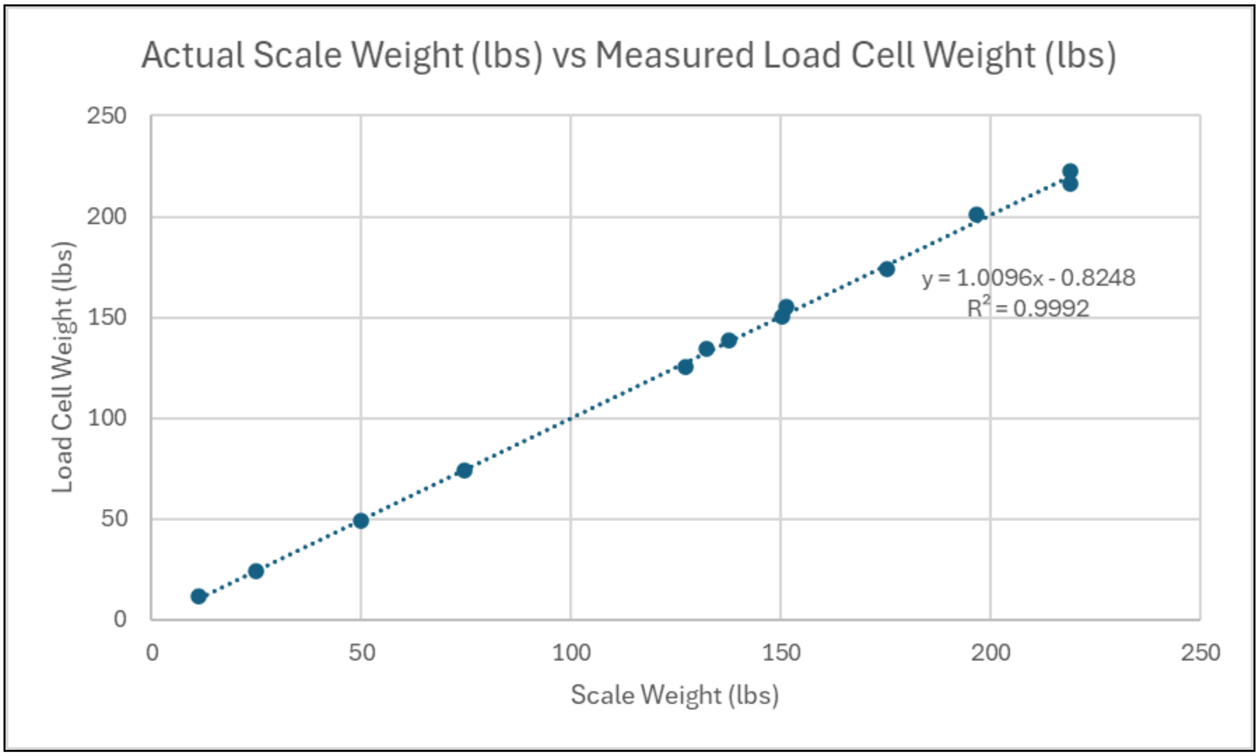


Figure 11. The actual scale weight (lbs) vs measured load cell weight (lbs). With an expected slope of 1.

The team would expect a slope and R^2 value of 1, which the team was very close to with values of 1.0096 and 0.9992.

Accelerometer Testing

The accelerometer testing yielded no comprehensive results, so instead the team pivoted to measure the observed drift that occurs during testing. This required the team to have the accelerometer sit on a table and measure how far it "traveled" over a 10 second period, the complete results can be observed in Appendix L.

Table 4: Results of accelerometer debugging testing where the accelerometer was placed on a table to evaluate how well it measures no movement.

Sensitivity	Average Velocity (m/s)	Standard Deviation (m/s)
+/- 2 g	0.097	0.11
+/- 4 g	-.037	0.006
+/- 8 g	0.053	0.046
+/- 16 g	0	0

Solidworks Finite Element Analysis Testing

Displayed below in figure 12 are the results of the Solidworks simulation testing. Under the above loading conditions 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.

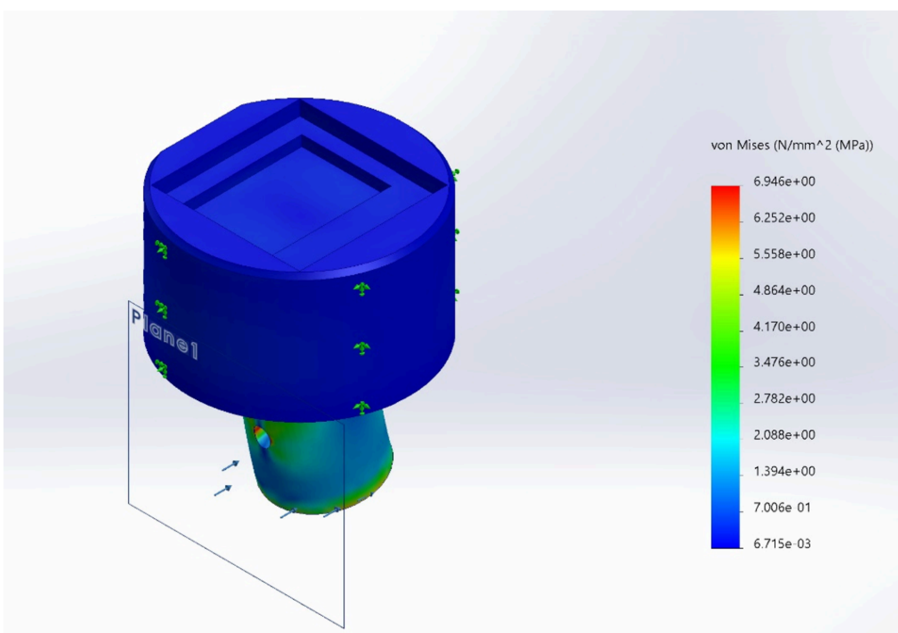


Figure 12: Results from Solidworks Simulation of the load cell holder

Discussion

Evaluation of Prototype

Beginning with the load cell testing and results, the measuring system was observed to be very accurate. With a percent error of 1.37%, the accuracy of the load cells is well within the desired 5% bounds and can begin to be implemented into the walker. When integrating the load cells to the walker, the load cells will be placed into the 3D prints modeled in figure 5. These load cells 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 within an acceptable range; however if the team decides to have a higher safety factor next semester a new material must be considered for fabrication.

The accelerometer results were not as promising as the load cell and its holding chamber. As seen in the results section, the accelerometer had difficulty measuring no motion. The accelerometer, if not perfectly flat, will pick up accelerations in certain directions due to gravity - which will be a rise for error. The code; however, should account for this by having a 0 function at the start of measurement, where it defines the current orientation as the "no motion" state. The higher sensitivity values of the accelerometer still observed accelerations even with this. The lowest sensitivity value was the only one that had results where it measured no motion when it was not moving, but it would inaccurately read the measurements when the device was moving. Further testing will need to be conducted before the accelerometer can be implemented into the final prototype, or a new sensor may need to be selected.

Ethical Considerations

The main ethical consideration of this project is ease-of-use for the patient and the client. The design should be easy to use and easy to set up, and should not take additional time to set up or track the metrics of the walker. If the device is unable to meet these standards, then it would be more helpful to not use the product.

Another ethical consideration is that the walker must be able to be used by any patient the client has. The walker should not impede the space that the patient would use to walk or require a higher level of dexterity to use. If either of these are the case, then the walker would need to be redesigned so it can cater more to the patient.

Sources of Error

Potential sources of error that could have occurred during the testing of the load cells was noise in the output voltages of the circuit. This noise would have the measured voltage on the microcontroller fluctuate about its expected value. To reduce this error the team took measurements over an average amount of time. Another potential source of error could be the residual deflection of the load cells. There may be a lag between the weight being removed and the load cell deflecting back to normal height, this would lead to inaccurate measurements. The accelerometer has a lot of potential for error. First, as mentioned, if the orientation of the accelerometer is altered, then readings of gravity may start to affect the actual measured accelerations of the device. The accelerometer is observed to have difficulties picking up the deceleration of the device or smaller accelerations. This would lead to issues of not measuring the gradual slowing down or speeding up of the walker, which is to be expected by acute stroke patients. This error needs to be eliminated before the device can be integrated.

Conclusion

This rendition of the Smart Walker aims to break away from the costly alternatives there are in the rehabilitation field so that moving forward there can be cost effective solutions for these patients. There is a striking need for our client to have a more efficient way of collecting data to use for his data driven approach to rehabilitation. Having worked this semester on fabricating and testing elements for the pressure measurement feature of the Smart Walker, next semester the team will move into the fabrication and testing of elements related to recording the speed of the walker. Finally both of these systems will have to be integrated and installed in the walker to create a final prototype.

References

[1] M. Bonanno et al., "Gait analysis in neurorehabilitation: From Research to Clinical Practice," Bioengineering, vol. 10, no. 7, p. 785, Jun. 2023. doi:10.3390/bioengineering10070785

[2] R. Gangwani, A. Cain, A. Collins, and J. M. Cassidy, "Leveraging factors of self-efficacy and motivation to optimize stroke recovery," Frontiers in Neurology, vol. 13, Feb. 2022. doi:10.3389/fneur.2022.823202

[3] "US7044361B2 - Walker Distance Measuring Device," Google Patents, https://patents.google.com/patent/US7044361B2/en (accessed Sep. 12, 2024).

[4] "US7826983B2 - instrumented Mobility Assistance device," Google Patents, https://patents.google.com/patent/US7826983B2/en?q=%28walker%2Bsensor%29&oq=walker%2Bwith%2Bsensor (accessed Oct. 9, 2024).

[5] Camino Mobility, https://caminomobility.com/ (accessed Oct. 3, 2024).

[6] CDC, "Stroke Facts," Stroke. Accessed: Oct. 09, 2024. [Online]. Available: https://www.cdc.gov/stroke/data-research/facts-stats/index.html

[7] P. Tadi and F. Lui, "Acute Stroke," in StatPearls [Internet], StatPearls Publishing, 2023. Accessed: Oct. 09, 2024. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK535369/

[8] CDC, "Treatment and Intervention for Stroke," Stroke. Accessed: Oct. 09, 2024. [Online]. Available: https://www.cdc.gov/stroke/treatment/index.html

[9] R. A. Bachschmidt, G. F. Harris, and G. G. Simoneau, "Walker-assisted gait in rehabilitation: A Study of Biomechanics and instrumentation," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 9, no. 1, pp. 96–105, Mar. 2001. doi:10.1109/7333.918282

[10] "ADXL345 Accelerometer," DigiKey Electronics, https://www.digikey.com/en/products/detail/adafruit-industries-llc/1231/4990764?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax+Shopping_Pro

duct_Low+ROAS+Categories&utm_term=&utm_content=&utm_id=go_cmp-202430635
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ad_source=1&gclid=Cj0KCQjwr9m3BhDHARIsANut04bPGPY5jbZcj8F7XtWGCQXB
oB-frsDbSqwsqubekB6EU4K-cDJH8w8aAmDOEALw_wcB (accessed Oct. 8, 2024).

[11] "ADXL345," ADXL345 Datasheet and Product Info | Analog Devices, https://www.analog.com/en/products/adxl345.html (accessed Oct. 8, 2024).

[12] "Amt132s-V," DigiKey Electronics, https://www.digikey.com/en/products/detail/same-sky/AMT132S-V/10269185 (accessed Oct. 8, 2024).

[13] "DRV5013ADQLPGM," DigiKey Electronics, https://www.digikey.com/en/products/detail/texas-instruments/DRV5013ADQLPGM/518
1338?utm_adgroup=Texas+Instruments&utm_source=google&utm_medium=cpc&utm_
campaign=PMax+Shopping_Supplier_Texas+Instruments&utm_term=&utm_content=Te
xas+Instruments&utm_id=go_cmp-17816159938_adg-_ad-__dev-c_ext-_prd-5181338_s
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RIsAMtVz6PD_HDO_P0oGmSIo3DPesBpY68lwtmjRtrsTzsAPZ9u8hhuheGPcUUaAhr
5EALw_wcB (accessed Oct. 8, 2024).

[14] M. #905039 et al., "Load Sensor - 50kg (generic)," SEN-10245 - SparkFun Electronics, https://www.sparkfun.com/products/10245 (accessed Oct. 3, 2024)

[15] 3DSourced is a leading authority in the field of 3D printing and scanning, "Pla vs ABS: Which is best for your 3D printing needs?," 3DSourced, https://www.3dsourced.com/guides/pla-vs-abs-filament/ (accessed Dec. 11, 2024).

Appendix

A. Product Design Specifications

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**

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

[1] “What is the maximum weight capacity for a medical walker?,” TheMedSupplyGuide.com - Medical Supply Company Directory, https://www.themedsupplyguide.com/weight/#:~:text=Most%20have%20the%20ability%20to,often%20manufactured%20using%20welded%20steel. (accessed Sep. 19, 2024).

[2] “ETool : Hospitals - clinical services - physical therapy,” Occupational Safety and Health Administration, https://www.osha.gov/etools/hospitals/clinical-services/physical-therapy/ (accessed Sep. 19, 2024).

[3] “ISO 11199-3:2005,” ISO, https://www.iso.org/standard/41191.html (accessed Sep. 19, 2024).

[4] “Battery Storage, Shelf Life, Self-Discharge, and Expiration.” Microbattery, www.microbattery.com/battery-storage-discharge-expiration. Accessed 22 Sept. 2023.

[5] “Custom Device Exemption - Guidance for Industry and Food and Drug Administration Staff”.

[6] T. Lysechko, “Which standards apply to your medical device?,” StarFish Medical. Accessed: Sep. 19, 2024. [Online]. Available: https://starfishmedical.com/blog/which-standards-apply-to-your-medical-device/

[7] “Recognized Consensus Standards: Medical Devices.” Accessed: Sep. 19, 2024. [Online]. Available: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfStandards/detail.cfm?standard__identification_no=41349

[8] “Recognized Consensus Standards: Medical Devices.” Accessed: Sep. 19, 2024. [Online]. Available: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfStandards/detail.cfm?standard__identification_no=44029

[9] “Recognized Consensus Standards: Medical Devices.” Accessed: Sep. 19, 2024. [Online]. Available: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfStandards/detail.cfm?standard__identification_no=41235

[10] X. Zhao et al., “A Smart Robotic Walker With Intelligent Close-Proximity Interaction Capabilities for Elderly Mobility Safety,” Front. Neurorobot., vol. 14, Oct. 2020, doi: 10.3389/fnbot.2020.575889.

[11] “Meet Camino,” Camino Mobility. Accessed: Sep. 19, 2024. [Online]. Available: https://caminomobility.com/pages/meet-camino

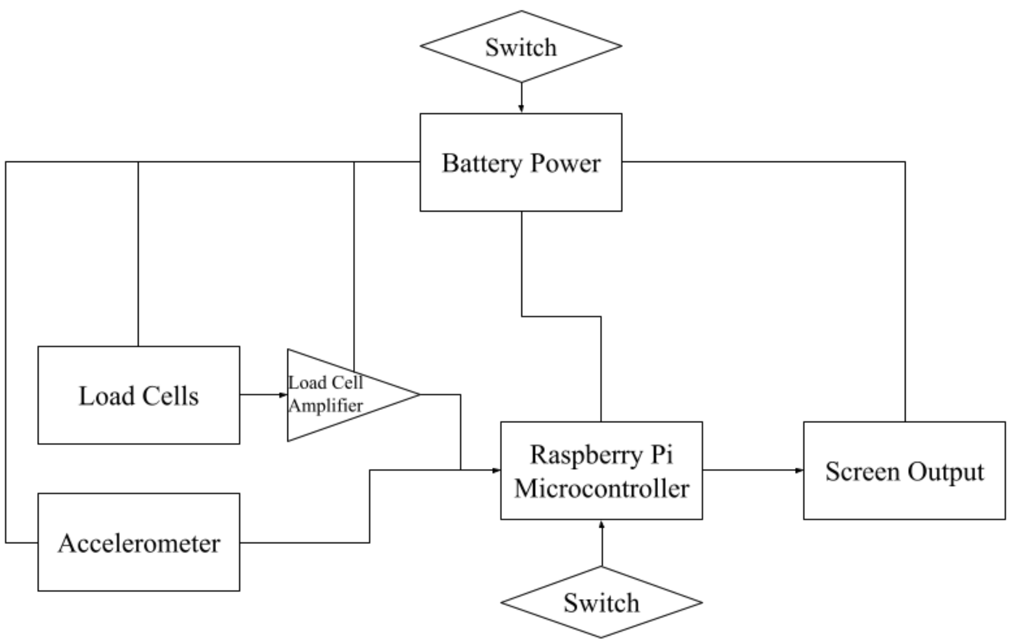
[12] A. AlGhazi and A. Hejazi, “Mobility assistance apparatus,” US20220211568A1, Jul. 07, 2022 Accessed: Sep. 19, 2024. [Online]. Available: https://patents.google.com/patent/US20220211568A1/en?q=(smart+walker)&oq=smart+walker

[13] M. Alwan, G. S. Wasson, P. N. Sheth, A. Ledoux, and C. Huang, “Instrumented mobility assistance device,” US7826983B2, Nov. 02, 2010 Accessed: Sep. 19, 2024. [Online]. Available: https://patents.google.com/patent/US7826983B2/en?q=(walker+sensor)&oq=walker+with+sensor

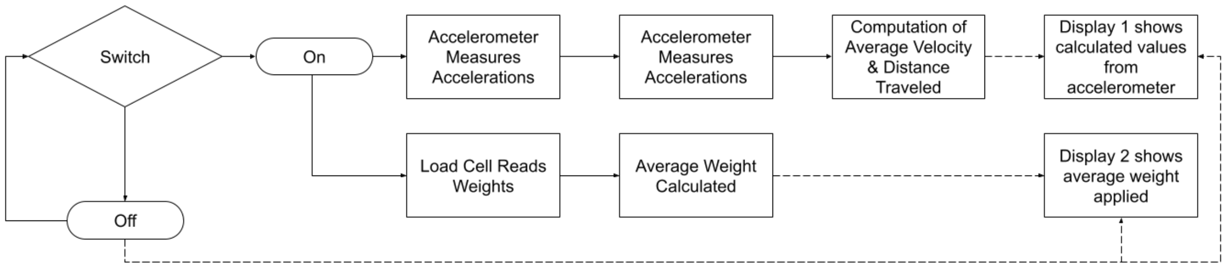
B. BPAG Expense Spreadsheet

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Electronics										
ADXL345	3-axis Accelerometer	Adafruit Industrie	1231	DigiKey	528-1015-ND	10/4/2024	1	$17.50	$17.50	DigiKey
DRV5013ADQLP	Hall Effect Sensor	Texas Instrument	13ADQLPGM	DigiKey	-41077-1-ND	10/4/2024	1	$0.62	$0.62	DigiKey
SEN-10245	Load Cell	Sparkfun	SEN-10245	DigiKey	1568-1661-N	10/4/2024	4	$4.50	$18.00	Digikey
Raspberry Pi Pic	Microcontroller	Raspberry Pi	SC0915	DigiKey	2648-SC0915	10/4/2024	1	$4.00	$4.00	DigiKey
9049	Magnets	Radial Magnets	9049	DigiKey	469-1075-ND	10/4/2024	4	$0.82	$3.28	DigiKey
OLED Display	2 0.91 in OLED display modules	DORHEA	15630-0.91	Amazon	B07FMDB6TF	11/30/24	1	$6.32	6.32	Amazon
Mechanical Compontnets										
Walker Feet	Sliders for back legs of walker	Essential Medical	N/A	Amazon	N/A	11/21/2024	1	$9.32	$9.32	Amazon
3D Prints	Prints for the housing chamber	Makerspace	N/A	Makerspace	N/A	11/15/2024	1	$0.36	$0.36	N/A
								TOTAL:	**$59.40**	

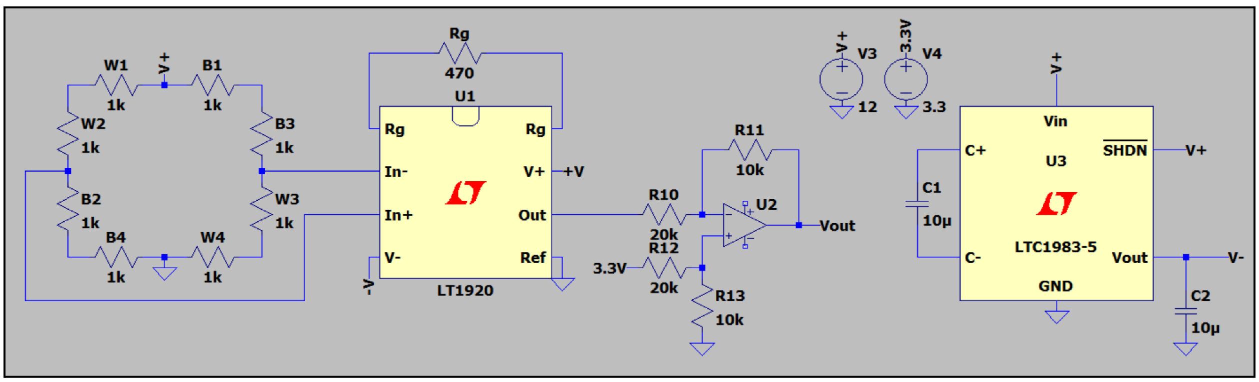
C. Functional Block Diagram



D. Software Block Diagram



E. Circuit Diagram of Load Cell



F. Load Cell Protocol

Load Cell Calibration

Details of Test:

1. Properly wire the load cells into a wheatstone bridge (see figures 1 and 2)
2. Properly construct the amplifier circuit as seen in figure 1
3. Place load cells within weighing shell and evenly place them as seen in figure 2
4. Observe and record the voltage output with no load applied to any of the load cells
5. Do a check out of each amplifier stage to ensure that the voltages make check
6. Weigh a flat piece of wood or metal that can evenly distribute a load to all 4 load cells and place onto the load cells. Observe and record the voltage output here
7. Add and repeat steps 4 and 5 but with incrementally increasing loads added onto the flat object
8. The steps from 4-6 should fill in Table 1 (weight and force may vary)
9. Once complete ensure that all power supplies are turned off before deconstructing the circuit
10. Make a graph of the line of best fit of Vout against weight and use this to program the microcontroller to measure the force outputs.

Table 1: Blank table of the measured output voltages (V) at varying weights/forces.

Weight (lbs)	Force (N)	Avg Vout (V)	Min Vout (V)	Max Vout (V)

0	0			
15	66.75			
30	133.49			
45	200.24			
60	266.98			
75	333.73			
90	400.48			
100	444.97			
125	556.22			
150	667.46			
175	778.70			
200	889.95			

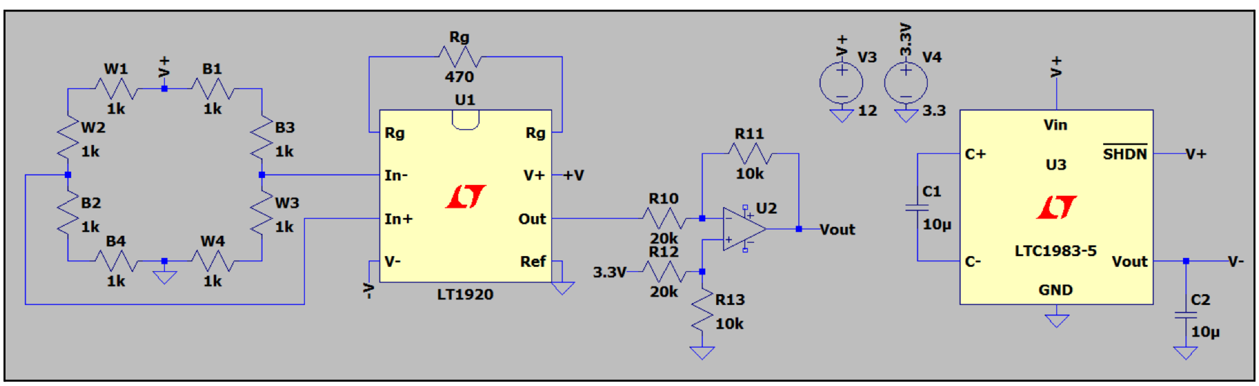


Figure 1: Diagram of complete circuit

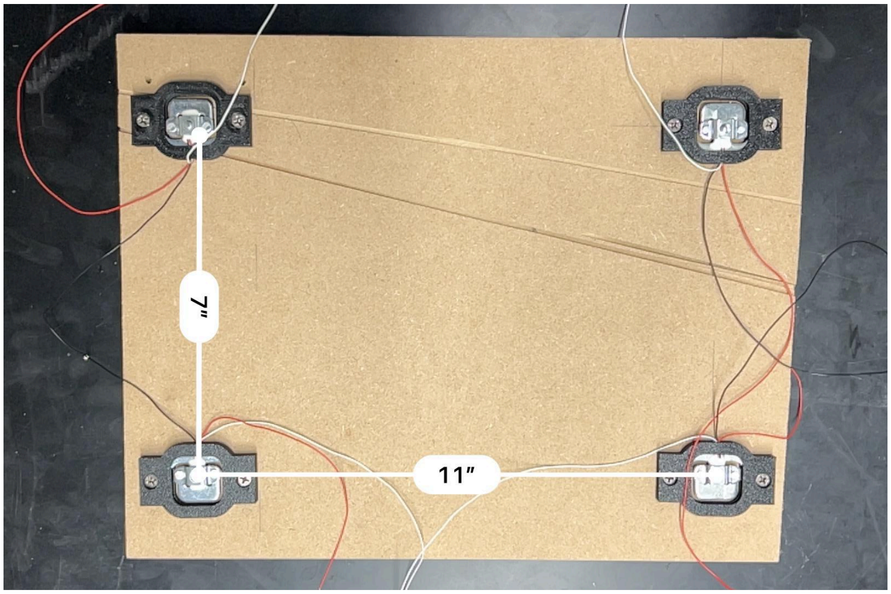


Figure 2: Dimensioned image of evenly spaced load cells

Testing done without non-inverting amplifier stage (just instrumentation amp and level shifter ~50 V/V of gain)

G. Accelerometer Protocol

Accelerometer Testing Procedure

Details of Test:

1. Properly set up the accelerometer circuit with the ground and input voltage wired properly and the SDA and SCL pins paired with GPIO pins 0 and 1 of the Raspberry Pi Pico
2. Connect the accelerometer to a display to read output values
3. Place Accelerometer circuit on movable chair
4. Record starting point as 0m
5. Hit the start button to begin obtaining values on the accelerometer
6. Begin walking in a straight line, while timing on a phone
7. Stop walking and stop the timer
8. Measure the distance between start and finish
9. Record distance and speed (m/s)
10. Repeat steps 4 through 9, 4 more times increasing distance by 20 ft each time
11. Fill in table 1 with all recorded data with comparison of output readings from the accelerometer
12. Once complete ensure that all power supplies are turned off before deconstructing the circuit

13. Make a graph of the line of best fit of Accelerometer vs Measured values for each trial.

Table 1: Blank table of the accelerometer readings and hand measured values

Time Elapsed(s)	Measured Distance (m/ft)	Accelerometer Distance (m)	Measured Speed (m/s)	Accelerometer Speed (m/s)

H. Accelerometer Code

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

# Constants
ADXL345_ADDRESS = 0X53
ADXL345_POWER_CTL = 0x2D
ADXL345_DATA_FORMAT = 0x31
ADXL345_DATAX0 = 0x32
G_CONVERSION = 0.15298374  # Adjust this based on the sensitivity setting (0.0039)

# Initialize I2C
i2c = I2C(0, scl=Pin(1), sda=Pin(0))
```

```
# Initialize the wire (acting as a switch)
switch = Pin(15, Pin.IN, Pin.PULL_DOWN)  # Ensure this matches your GPIO setup

def init_adxl345():
    i2c.writeto_mem(ADXL345_ADDRESS, ADXL345_POWER_CTL, bytearray([0x08]))  # Enable measurement mode
    i2c.writeto_mem(ADXL345_ADDRESS, ADXL345_DATA_FORMAT, bytearray([0x02])) # 00, 01, 02, 03

def read_accel_data():
    data = i2c.readfrom_mem(ADXL345_ADDRESS, ADXL345_DATAX0, 6)
    x, y, z = ustruct.unpack('<3h', data)
    # Convert raw data to g-force using the scaling constant
    x = x * G_CONVERSION
    y = y * G_CONVERSION
    z = z * G_CONVERSION
    return x, y, z

def calculate_velocity_distance():
    velocity = 0
    distance = 0
    total_velocity = 0
    sample_count = 0
    start_time = time.ticks_ms()
    previous_time = start_time

    while switch.value():  # Keep running while the wire is connected to 3.3V
        current_time = time.ticks_ms()
        delta_time = (current_time - previous_time) / 1000  # Convert to seconds

        # Read acceleration (only x-axis for simplicity; modify if you want to use y or z)
        ax, ay, az = read_accel_data()
        print("Acceleration (G): X={}, Y={}, Z={}".format(ax, ay, az))  # Debugging print to verify values

        # Update velocity: v = v0 + a * t
        velocity += ax * delta_time
```

```
        # Update distance: s = s0 + v * t + 0.5 * a * t^2
        distance += velocity * delta_time + 0.5 * ax * (delta_time ** 2)

        # Accumulate velocity for average calculation
        total_velocity += abs(velocity)  # Use absolute value for average
        sample_count += 1

        print("Velocity: {:.2f} m/s, Distance: {:.2f} m".format(velocity, distance))  # Debugging output
        previous_time = current_time
        time.sleep(0.1)  # Sample rate

    end_time = time.ticks_ms()
    elapsed_time = (end_time - start_time) / 1000  # Calculate total time in seconds

    # Calculate the average velocity
    average_velocity = total_velocity / sample_count if sample_count > 0 else 0
    return average_velocity, distance, elapsed_time

# Main Program
init_adxl345()

while True:
    if switch.value():  # Start measurement when the wire is connected to 3.3V
        print("Wire connected to 3.3V, starting measurement...")
        avg_velocity, total_distance, total_time = calculate_velocity_distance()
        print("Measurement stopped.")
        print("Average Velocity: {:.2f} m/s".format(avg_velocity))
        print("Total Distance: {:.2f} m".format(total_distance))
        print("Total Time Elapsed: {:.2f} seconds".format(total_time))
        time.sleep(1)  # Debounce delay to avoid multiple triggers
    else:
        print("Waiting for the wire to connect to 3.3V...")
    time.sleep(0.5)
```

I. Load Cell and Display Code

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

```
import time

# Set up the ADC
adc = ADC(Pin(26))  # GP26 corresponds to ADC0

# Set up the switch
switch = Pin(15, Pin.IN, Pin.PULL_DOWN)  # Ensure this matches your GPIO setup

# 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 - 1.68) / 0.0032
    return weight

# Set up the I2C connection for the OLED display
i2c = I2C(1, scl=Pin(3), sda=Pin(2), freq=100000)

# Initialize the OLED display
oled_width = 128
oled_height = 32
oled = ssd1306.SSD1306_I2C(oled_width, oled_height, i2c)

# Clear the OLED display
oled.fill(0)
oled.show()

# Main loop
try:
    while True:
        if switch.value():  # Start measuring when switch is "on"
            print("Switch is ON. Measuring weight...")
            measurements = []  # List to store weight measurements
```

```
            while switch.value():  # Continue measuring until switch turns off
                voltage = read_voltage(adc)  # Measure voltage
                weight = calculate_weight(voltage)  # Calculate weight
                measurements.append(weight)  # Store weight measurement
                print(f"Voltage: {voltage:.3f} V, Weight: {weight:.2f} lbs")
                time.sleep(0.5)  # Sampling delay

            # Once switch is turned off
            print("Switch turned OFF. Calculating average weight...")
            if measurements:  # Ensure there are measurements to average
                average_weight = sum(measurements) / len(measurements)
            else:
                average_weight = 0

            # Display the average weight on the OLED for 10 seconds
            oled.fill(0)
            oled.text("Avg Weight:", 0, 0)
            oled.text(f"{average_weight:.2f} lbs", 0, 10)
            oled.show()
            print(f"Average Weight: {average_weight:.2f} lbs displayed for 10 seconds.")

            time.sleep(10)  # Keep the average weight displayed for 10 seconds

            # Clear the OLED display
            oled.fill(0)
            oled.show()
            print("Display cleared.")
        else:
            print("Waiting for the switch to turn ON...")
            time.sleep(0.5)  # Polling delay
except KeyboardInterrupt:
    print("Program stopped.")
```

J. Results of Load Cell Calibration Testing

Weight (lbs)	Force (N)	Avg Vout (V)	Min Vout (V)	Max Vout (V)
0	0	1.665	1.64	1.69
15	66.75	1.59	1.57	1.61
30	133.49	1.525	1.51	1.54
45	200.24	1.47	1.45	1.49
60	266.98	1.45	1.43	1.47
75	333.73	1.41	1.39	1.43
90	400.48	1.36	1.34	1.38
100	444.97	1.325	1.31	1.34
125	556.22	1.235	1.22	1.25
150	667.46	1.155	1.14	1.17
175	778.7	1.07	1.05	1.09
200	889.95	0.99	0.97	1.01

Weight (lbs)	Force (N)	Avg Vout (V)	Min Vout (V)	Max Vout (V)
0	0	1.665	1.64	1.69
15	66.75	1.73	1.71	1.75
30	133.49	1.775	1.76	1.79
45	200.24	1.82	1.8	1.84
60	266.98	1.86	1.85	1.87
75	333.73	1.915	1.9	1.93
90	400.48	1.955	1.94	1.97
100	444.97	1.98	1.96	2
125	556.22	2.075	2.05	2.1
150	667.46	2.165	2.14	2.19
175	778.7	2.24	2.22	2.26
200	889.95	2.32	2.3	2.34

K. Results of Load Cell Testing

Scale Weight (lb	Code Weight (lbs)
150.4	150.24
175.4	174.16
24.8	24.07
49.8	48.99
74.6	74.19
219	216.47
127.4	125.3
137.8	138.8
151.4	154.92
196.8	200.72
11.4	11.23
219.2	222.5
132.4	134.14

L. Accelerometer Drift Results

- Taped to the table
- Plugged in before starting
- Start with plugged in
- Time out 10 seconds
- Remove switch
- Measure accelerations over time, final velocity, total distance traveled, and time elapsed

Trial	Sensitivity	Time (s)	Distance (m)	Velocity (m/s)
1	+/- 2 g	10.00	2.24	0.22
2	+/- 2 g	9.99	-0.03	0.01
3	+/- 2 g	10.00	-0.62	0.06
4	+/- 4 g	9.48	0.43	0.04

5	+/- 4 g	10.00	0.34	0.03
6	+/- 4 g	10.10	0.43	0.04
7	+/- 8 g	10.61	-0.02	0.00
8	+/- 8 g	10.50	0.80	0.08
9	+/- 8 g	10.47	0.81	0.08
10	+/- 16 g	10.20	-0.00	0.00
11	+/- 16 g	10.20	0.00	0.00
12	+/- 16 g	10.20	0.00	0.00

Sensitivity	Average Velocity (m/s)	Standard Deviation (m/s)
+/- 2 g	0.097	0.11
+/- 4 g	0.037	0.006
+/- 8 g	0.053	0.046
+/- 16 g	0	0