The GaitKeeper

Prepared for:
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Shirley Ryan AbilityLab
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Executive Summary

Problem

Some patients have sternal precautions after open-heart surgery that advise against overexerting their pectoral muscles. The same patients also use walkers during rehabilitation to help them recover after the surgery. However, the physical therapists assisting the patients currently have no way of measuring how much force the patient exerts on the walker; they cannot monitor the patient's sternal precautions. Thus, they often resort to unconventional methods such as having the patient step over the therapists foot to measure the weight exerted. Our client, Ms. Erin Walaszek, asked us to create a device that can measure the force a patient exerts on the walker.

Purpose and requirements

The purpose of the design is to measure and display the force that a patient exerts on the handles of a walker in real-time during a walking exercise. The design should be safe, compatible with a standard Guardian walker, and easy to use.

Methodology

We observed a patient and physical therapist at the Shirley Ryan AbilityLab to understand how they typically interact with the walker and the difficulties that they encounter. Then, we developed four mockups, conducted performance testing on each mockup, and interviewed the client about the viability of each design concept. Using the client's feedback, we narrowed down our options to one of the four mockups and tested that mockup in a controlled environment. With this data, we developed a final design for a prototype and built it.

Design

Our design, the GaitKeeper, consists of three major components: the force sensors on each handle, the display box, and the electrical hub. The force sensors are load cells, designed to sense a load up to 50 kg each. The load cells send an electrical signal in the form of a potential difference to the display box. The display box is a 3D-printed box with a transparent surface for the digital display. The display box stores and protects the electrical hub and is attached to the walker via a rolling clamp. The electrical hub contains all of the electrical equipment minus the sensors. This includes the display, the microprocessor, and the signal amplifier. The signal from the sensors is sent to the amplifier, which increases the amplitude of the incoming signal. This amplified signal is sent to the microprocessor, an Arduino Nano, which evaluates the information from the incoming signal and generates an outgoing signal for the display. The outgoing signal is sent to a 1.8” x 1” thin-film-transistor display, which finally gets read by the supervising physical therapist.

Introduction

Several patients at the Shirley Ryan AbilityLab are required to limit the amount of upper-body weight they exert on a walker during rehabilitation (see Appendix A: Background Research Summary). The physical therapists do not currently have a way of telling how much force the patient is exerting. To get a more precise measure of this, Erin Walaszek, a physical therapist at the Shirley Ryan AbilityLab, asked us to design an apparatus to monitor how much force a patient exerts through the walker (see Appendix B: Project Definition).

Current possible solutions include an expensive force measurement tool called a FlexiForce sensor that has extra features not desired by the physical therapist (see Appendix C: Client Interview Summary). Due to the cost of the device, physical therapists prefer not to buy it. As a result, the physical therapist revert to using their own perception by having the patient step on the therapist's foot to "feel" for overexertion. This method can be uncomfortable for physical therapists and is highly inaccurate(see Appendix D: User Observation Summary).

The GaitKeeper (see Figure 1) addresses the aforementioned issues (see Appendix E: Design Review Summary). The physical therapist is given only a force reading, unlike the expensive FlexiForce sensors. The patient simply places their hands on the walker handle and walks normally; the design does the rest once it is attached (see Appendix F: Instruction for Use). A force reading is outputted to a small display visible to the physical therapist to help monitor the patient's exertion.

Figure 1: The finished prototype

The following report includes various parts of the design and how it addresses the problems the users face. The first section discusses the users and requirements for the design, followed by our design concept and our rationale behind the concept. The report concludes with a discussion of various limitations (see Appendix G: FMEA), considerations (see Appendix H: Ethical and Sustainability Considerations), and recommendations for future development.

Users and Requirements

Main users of the design

Physical therapists at the Shirley Ryan AbilityLab

Physical therapists are our primary users (see Appendix B). They will be the users attaching and detaching the design, as well as using them to monitor the amount of downward force exerted by the patient on the walker. While the design can be used by both patients and the physical therapists, we designed the device primarily for the physical therapists. This is because physical therapists are responsible for helping patients with gait trainings and making sure they conduct gait training safely and effectively (see Appendix C). With this device, they can closely monitor the amount force exerted by the patient on the walker and issue warnings when the force exceed the sternal precaution limit.

Patients undergone open heart surgery

Our secondary users are patients undergone open heart surgery. They can read the real-time force measurement from the display screen and get an idea of how much force they are exerting on the walker (see Appendix F). If the reading exceeds the sternal precaution limit, they can adjust accordingly. However, the patients are classified as the secondary users because it might be distracting for some patients to focus on walking as well as reading the force. Hence, the design is supplementary for patients who underwent open heart surgery.

Requirements of the design

More information about requirements and specifications for the design can be found in the Project Definition (see Appendix B).

Safety

The design must be built securely enough that it does not fall off during use. If the design fell off during use it could injure the patients and the physical therapists. It also cannot be potentially dangerous because the primary and secondary users do not have to track the force exerted on the walker by the patient. The physical therapists and patients would not be alerted when the force exceeds the sternal precaution limit.

Functionality

The main objective of this design is to display an accurate reading of how much force the patient's upper body is applying. This includes properly updating the force in real-time with minimal delay between readings. Additionally, the sensor needs to output a consistent unit of measurement.

Ease of use

The device should be easy to use for the physical therapists. Specifically, the physical therapists should be able to attach or detach the force sensing attachment on or from the walker within 5 minutes. Furthermore, the display of the force sensor should be easy to see at standing height or sitting height from a reasonable distance and the device should be cleanable and easy to maintain.

Appeal

The force sensor's instructions for use should be intuitive and the device should look elegant and clean.

Versatility

Ideally, the device should be compatible and attachable to multiple types of walkers and the device has adjustable clamps to be attached to walker cross-bars of different sizes.

Design Concept and Rationale

Design description

<u>Overview</u>

Our design, the GaitKeeper, is a real-time force-sensing apparatus for cardiac patients who have undergone open-heart surgery to measure how much force their upper body exerts on the walker during movement exercises. The force is then displayed for the supervising physical therapist(s) to monitor. Additionally, the design is removable and works on a wide range of walkers.

The GaitKeeper (see Figures 2, 3, 4, and 5) consists of mainly three components: the sensor wrap attachment, the display box and battery, and the printed circuit board (PCB). The sensor wrap attachment is how the force sensors are attached to the handlebar. Load cells are located within the wrap on the portion that lies on the top of the handlebar of the walker and will measure the force. Wires connect the load cells to the display box that is clamped to the crossbar on the front of the walker. Within the display box, the front of which is transparent, the PCB is located. It holds a microprocessor, a load cell amplifier, and the actual display (see Appendix I: Dimensioned Graphics Sketches).

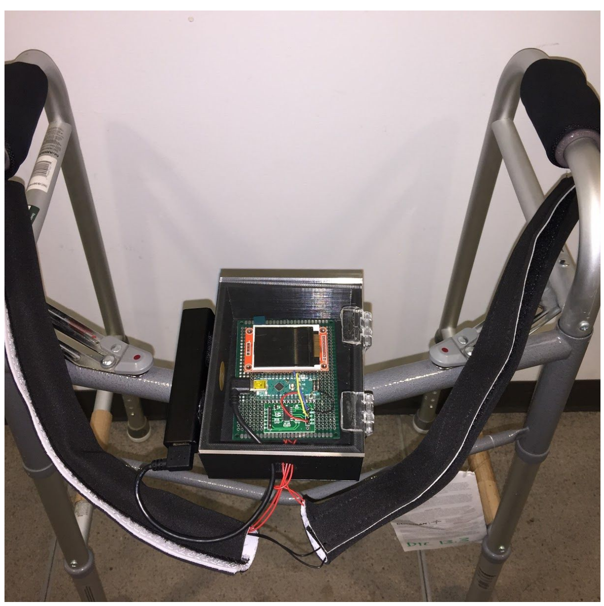


Figure 2: The GaitKeeper

Figure 3: Front view Figure 4: Side view Figure 5: Top view

1. Sensor and wrap attachment

Use and Specifications

In order to measure the force exerted by the patient's upper body accurately, two load cell sensors are located above the handlebars of the walker. The sensors we are using are 1.35" x 1.35" x 0.31" load cells which are insulated between a standard 4" wide and 0.5" thick walker handle cover (see Figure 6 and 7) (see Appendix J: Bill of Materials). In addition, the excess wire that connects the sensor wrap attachment to the display box was covered with velcro wrap to insulate it from the environment.

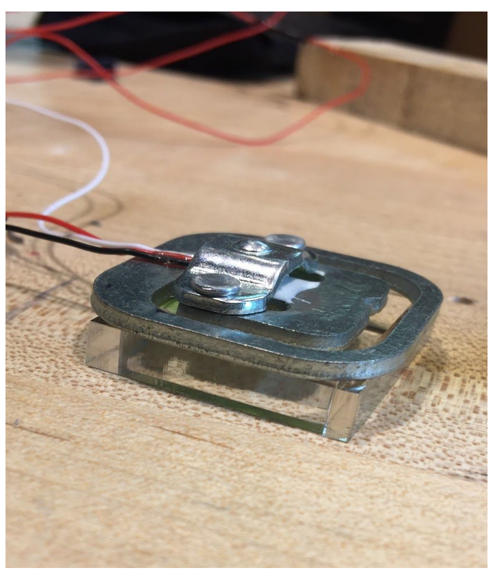


Figure 6: The sensor

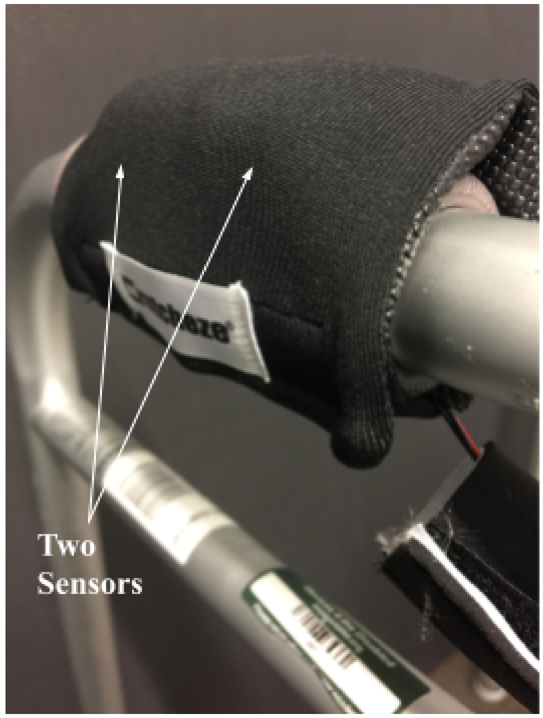


Figure 7: Sensor wrap attachment

Rationale

We chose to use a wrap attachment that surrounds the handlebars of the walker since this method of attachment is the least intrusive on the walker's functionality. Attachment by other means is difficult because it has to fulfill the same safety standards as the walker, i.e. being able to sustain 250 lbs of weight (see Appendix K: User Testing Report). A wrap attachment also allows this design to be compatible with multiple types of walkers.

The load cells are insulated by the handle cover so that the load cells do not come into direct contact with the user or the walker to prevent damage to the sensor, protect the user from electrical hazards, and maintain cleanliness (see Appendix L: Performance Testing Report). The handle cover is wipeable, but load cells are not as easy to sanitize. The wire covers provide a barrier between the wires and the user, keeping those near the device safe from electric shock.

We chose to measure the force electronically because a mechanical force measurement tool involving springs would likely be too bulky or complicated as described by our client (see Appendix K). Also, we wanted to be able to add the forces from both of the handlebars and knew that a microprocessor would be involved. Thus, an electronic approach was the most feasible.

2. Display box and battery

Use and specifications

We designed a black box with a transparent acrylic face. The black box creates storage space for the wires and different electronic components and allows us to use only one clamp to connect the box to the walker. This makes it easier for our primary and secondary users attach and detach the device as well as making the design simpler and more elegant. The box's dimensions are 5" x 4" x 2". The acrylic face is 5" x 2". The dimensions have been chosen in order to accomodate all electrical components of the design. A display on the printed circuit board is visible through the transparent face of the box for the user to see the force readings. Attached to the opposite face of the box is a rolling walker clamp. On the top face of the display box (4" x 2"), in between the transparent face and the clamp face, a hole of diameter 0.5" is located at the center, providing an opening for wiring (see Figure 8 and 9).

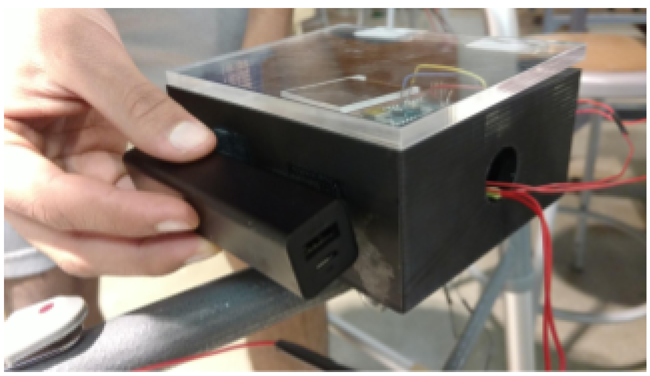


Figure 8: The display box with battery

Figure 9: The rolling clamp

Rationale

In order to enclose all the electronic parts and ensure the safety of the primary and secondary users, we enclose the display screen, printed circuit board, wires inside of a black plastic box as recommended by our peers during our design presentation (see Appendix E). Likewise, having a display box allows us a space to attach the battery to its exterior so that the power supply is close to the microprocessor. The battery attaches on the outside for ease of replacement.

We chose the rolling clamp to attach the black plastic box to the walker because it received positive feedback during the mockup testing session (see Appendix M: Mockup Testing Report).

The clamp attaches the black box securely onto the walker. It is also very easy to remove the clamp compared to velcro straps, which might be less effective over the time. Hence, the rolling clamp is ideal for our design.

Considerations

If internal components within the display box get damaged, they may be hard to access. We considered leaving the transparent face unglued to the display box so that the interior of the display box remains accessible.

3. Printed circuit board (PCB)

Use and specifications

The PCB has dimensions of 3.6” x 2.8” x 0.05”. Pinned to the PCB are the color thin-film-transistor liquid crystal display, the Arduino Nano microprocessor, and the load cell sensor amplifier, with dimensions as laid out in Table 1 below.

Table 1: Dimensions of circuit components

Component	Dimensions (in.)
PCB	3.6 x 2.8 x 0.07
Color TFT LCD display	2.2 x 1.4 x 0.25
Arduino Nano microprocessor	1.8 x 0.8 x 0.8
Load cell sensor amplifier (ADC)	1.4 x 0.8 x 0.2

The wires from the load cell connects to the load cell sensor amplifier, which then connects to the microprocessor (see Appendix N: Instructions for Construction). Then, the microprocessor is connected to the LCD display, which displays the sum of the forces measured from the load cells, calculated by the microprocessor (see Figure 10). All the connections are soldered together in the Mechatronics Lab.

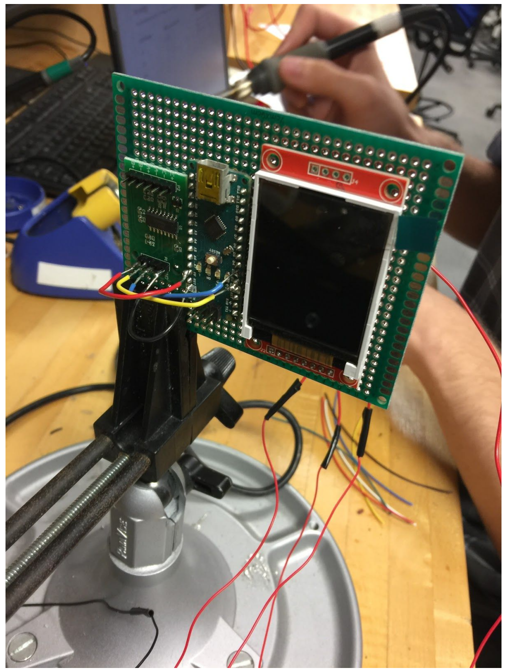


Figure 10: PCB board and attached components

Rationale

The reason behind choosing a digital method to display force is to avoid otherwise potentially invasive designs of a mechanical system. The user preferred a non-invasive design, and suggested that a mechanical design such as the Brace Attachment is not favorable (see Appendix K). In addition, a microprocessor is required for summing the forces from each of the handlebars. An authentic Arduino was chosen for the microprocessor as a guarantee for quality and safety (see Appendix O: Meetings with Prototyping Specialists). We chose to store all of these components on a single PCB so that less wiring would be necessary, the components would be easier to surround and protect, and the design would be more compact.

Considerations

There may be manufacturing defects of the PCB. The pins could be non-conductive, preventing wiring of the electronic components. Additionally, the PCB is a sensitive piece of material, so keeping this component surrounded and protected is essential.

Future Development

The following document describes potential improvements to the design process and our final design.

Future testing

Throughout our design process, we were only able to observe and talk with one patient at the Shirley Ryan AbilityLab. In the future, we would like to be able to have access to more patients in order to see a wider range of issues that our users could face and to gather more input on the mockups and ideas we brought to user testing.

Additional performance testing on the load cells used in the final design should also be completed. Because it took time to finalize the design concept, we were unable to order the load cells early on so that tests could be conducted on their accuracy or sensitivity. Future tests would focus on further testing of these load cells.

Future considerations

The first consideration we have for our design involves the wrap portion of our design. One of the reasons for putting the sensors inside the padded hand grip is to protect the electronic parts and make the device removable and versatile for a wide range of walkers. However, one of the potential problems associated with this design is that if the reading is inaccurate, it is hard to diagnose and fix the problem unless we cut open the padded covers. This may affect the durability of the design. One possible future development of this prototype is to create a reusable padded handle cover to accommodate the load cells.

Another consideration is that the maximum capacity of force each load cell can detect is around 110 lbs. If the user somehow exerts more than this capacity, it could affect the measuring sensitivity/capability of the load cells. In the future, we will look into load cells with larger capacity.

Additionally, some components of our design are especially vulnerable to damage because of the design's electrical nature. For example, our design involves many wires to connect the load cells to the display box. If these wires were accidentally cut, the design would no longer be operable. If parts within the display box like the microprocessor got damaged, this would also cause it to no longer function, and repairing it would be difficult. Future iterations of the design should take these vulnerabilities into better consideration by protecting the wires through wire-management and insulation and making the display box more secure.

Future features

During our client interview, our client expressed interest in a design that would be able to give audio feedback if the patient did indeed exceed the sternal precaution force limit. We were unable to incorporate this into the design in time, but by adding this feature to the design, it would increase its ease of use.

Additionally, our client also would have liked to see a design that would be able to collect and save data from the force measurements throughout the duration of the gait-training exercise. By exporting the data from the design to a phone or computer, physical therapists would be able to study the amount of force exerted at different points of the exercise. We were also unable to incorporate this into the design in time; however, this feature, if added, would make our design much more versatile for physical therapists to study and apply to their rehabilitation techniques.

Conclusion

To summarize, our design meets the key requirements for changing the orientation of the walker attachment and other requirements stated in the Project Definition (see Appendix B).

- **Safety:** All electrical parts are insulated from the external environment. This eliminates any potential of electric shock from exposed circuitry. The four sensors combined are very light and non-invasive to the walker; they do not force the user to change the way they move with walker. The sensor system is also symmetric about the center of the walker, which does not raise concerns about balancing and uneven weight distributions.
- **Functionality:** The design does not include unnecessary features like the FlexiForce sensors. The primary user is given a force reading in pounds that has a refresh rate of __ Hz. This rate is fast enough to provide accurate readings of a dynamic load on the walker.
- **Ease of Use:** Because the core of the design is placed on a rolling clamp, it can be moved to different positions on the walker. Thus, the primary user does not have to compromise their location for the ability to see the force readings. Also, as a result of the rolling clamp attachment, the display can be tilted to any desired angle. The primary user may set this angle where they feel it is comfortable to see the display. In addition, the sensors themselves are covered with an insulating material that is naturally antimicrobial. It can be wiped down with a bleach wipe like a normal handle, and it will be ready for its next use.
- **Appeal:** All the design's components are localized onto a single PCB board. The wires connecting this core to the sensors are zip-tied underneath the skeleton of the walker so as to be out of sight of the user. The design is minimal in its appearance. That is, it does not stand out to the user. The design also does not have any buttons aside from a power button. Simply push it and the system is ready to go.
- **Versatility:** The device is compatible with the oversize walker due to the rolling clamp that was implemented into the design.

Primary users wanted a simple, noninvasive design that is able to monitor how much force a patient exerts on a walker. Our design accomplishes this without overcomplicating its components so that primary users can accurately monitor their patients.

Appendix A:

Background Research Summary

We began our project by conducting background research on topics mentioned in the project description given by our client, Ms. Walaszek, a physical therapist at the Shirley Ryan AbilityLab. Ms. Walaszek works with cardiac patients who have undergone open-heart surgery. These patients have sensitive sternums as a result of surgery which puts a restriction on the amount of force their upper body can exert. The goal of our project is to design a device that is able to measure and show the amount of force the patients are exerting while moving with a rolling walker. By conducting background research, we were able to collect valuable information to prepare important questions for our client interview. The following summary includes the topics we researched: rolling walkers, walker attachments, the cardiac population, sternal precautions, and existing methods of measuring force.

The cardiac population

For our design project, our primary users for our device will be the cardiac population. Thus, it is essential that we learn more about the background behind the cardiac population and the patient's medical conditions.

The cardiac population refers to people that suffer from cardiovascular or heart disease. Heart disease is a very important issue, because in the United States, it remains the leading cause of death, causing 1 in 4 deaths. The average age of cardiac patients is 64.7 years old for men and 72.2 years old for women.

Heart disease encompasses many heart conditions. It includes coronary artery disease (atherosclerosis), irregular heart rhythm (arrhythmia), congenital heart diseases, and more. The most common heart disease is atherosclerosis, accounting for 61% of heart disease related deaths alone. Atherosclerosis occurs when fatty plaque builds up in the coronary arteries, narrowing blood flow and increasing the risk of heart attack (Figure 1). To treat atherosclerosis, open heart surgery is required. The chest of a patient is opened up and a surgical operation called a coronary artery bypass graft is performed. A healthy artery or vein is grafted to the blocked coronary artery, bypassing the blocked artery and resuming healthy blood flow to the heart.

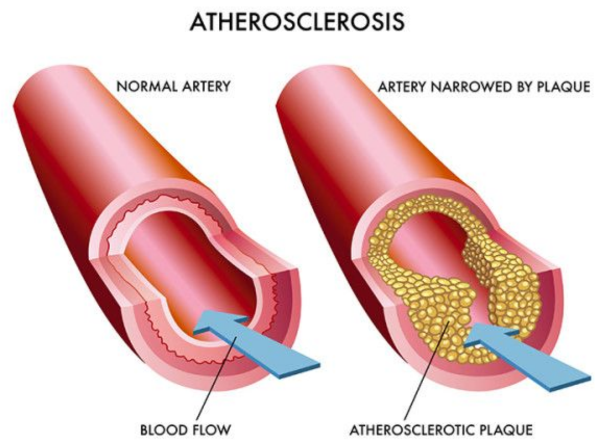


Figure 1: Atherosclerosis

Sternal precautions

During open heart surgery, wires are placed within the sternum, also known as the breastbone, a long flat bone located at the center of the chest. The wires are placed in order to keep the bone together as it heals. After the surgery, certain precautions must be followed to prevent these wires from cutting into the sternum and causing injury. These precautions are known as sternal precautions and include many warnings to the patient: keep your arms down and close to your torso, don't push or pull anything, don't drive, don't lift anything heavier than 10 lbs., be careful when getting up or sitting down, and more. The general rule is the tube rule, where the patient's arms should not leave a certain tube-like radius away from the torso (Figure 2).

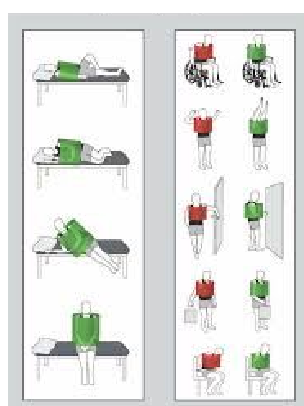


Figure 2: The tube rule for sternal precautions

Sternal precautions most commonly represent a wide variety of functional restrictions. In fact, the word ‘precautions’ should probably be replaced by the word ‘restrictions’ since this is what many physical therapists have encountered in clinical practice over the years. Restrictions in shoulder range of motion, lifting, reaching, dressing, exercise, driving, and a variety of other tasks have been reported. However, the exact origin of such restrictions is difficult to find. Furthermore, there appears to be no consistency in the type or duration of restriction.

Rolling walkers

Also known as “Rollators”, the rolling walker’s defining feature are the wheels located at the bottom of each leg of the walker (Figure 3). Most rolling walkers will have three or four wheels. They can be steered either with front-wheel steering or all-wheel steering. A walker has front-wheel steering if only the front wheels can change direction. A walker has all-wheel steering if all the wheels have the ability to rotate.

Figure 3: A rolling walker

The rolling walker has handlebars to grip for each hand and squeeze-brakes as well. The walker costs roughly $100 - 300, and are able to traverse the outdoor environment like the sidewalk or curb. It provides the user with both support and stability.

Methods of attaching objects to walkers

This section discusses how an object may be attached to a walker. The first method uses nuts and bolts. As you can see in Figure 4 below, a forearm rest uses these to secure itself to the bars of the walker. This method of clamping objects to bars is universal to walkers with side bars. If, in the case where there is a walker without side bars, this method falls apart. This method must be adapted then, to accommodate different geometries of the side of a walker. One potential application of this type of attachment would be to measure a force exerted at the elbow.

Figure 4: Nuts and bolts are used to clamp the walker attachment to the walker.

A second attachment method is to use straps (Figure 5). These are, by definition, universal to all walkers, a good advantage when building a prototype that can fit a wide variety of walkers. Many tote bags use this method to attach themselves to the walker. These objects are good for holding items, but not very good at securing them in place. One potential application of these straps may be to have them securely fit a device onto a walker.

Figure 5: Straps are used to secure a tote bag to the walker.

The third attachment method is to use a pushpin system. This system is unique to the bottom of the walker, and is used mainly to attach wheels to the frame of the walker (Figure 6). The pushpin system universal to standard walker, but not to rollators. The system can be migrated to another part of the walker without much difficulty, since the only thing needed is to drill the appropriately sized holes in the frame of the walker. One potential application of the pushpin system is to have a device connected to a rod with pins. This rod can be snapped onto the frame of the walker using the pushpin system.

Figure 6: Holes on the rod are snapped into the frame of the walker.

Existing methods of measuring forces

There are two main methods of measuring forces. The first method uses electronic sensors, called piezoelectric sensors (Figure 7). These sensors offer little to no latency between the force being exerted and the electrical signal generation. The process involves two charged plates placed close to each other. Exerting a force on the plates displaces a charge, called an electrical signal, which can then be interpreted by processor systems in a device. The amount of charge displaced is proportional to the magnitude of the force exerted, so piezoelectric sensors could be a potential solution to the design problem.

Figure 7: A piezoelectric sensor

The second method uses a more mechanical approach. Springs are the most common approach (Figure 8). The distance that the spring stretches is directly proportional to the force exerted on it. Using this proportionality relation, many spring scales have a dial that indicates how much force an object is exerting on the spring. However, unlike piezoelectric sensors, there is no latency between the force exerted and the updated dial reading.

Figure 8: A spring scale with marks indicating force measurements

Appendix B: Project Definition v5

Project name: Real-Time Force Sensing Apparatus for Safer Movement of Cardiac Patients
Client: Ms. Walaszek from the Shirley Ryan AbilityLab
Team members: Alex Manka, Malav Patel, Sherlyn Weng, Kevin Wu
Date: May 21, 2019
Version: Five

Mission statement: To design a real-time force-sensing apparatus for cardiac patients who have undergone open-heart surgery in order to help monitor how much force their upper body exerts on the walker during movement exercises.

Project deliverables: A prototype of the design, a PowerPoint presentation and a final report.

Constraints

- Must be built within $100 budget.
- Must be completed within a time frame of 2 months (final deliverables are due June 12th, 2019).

Users/stakeholders

1. Primary users
   a. Physical therapists at the Shirley Ryan AbilityLab
2. Secondary users
   a. Patients that have recently had open-heart surgery (typically ages 45 - 60 years old) and need to use a walker at the Shirley Ryan AbilityLab
3. Stakeholders
   a. The Shirley Ryan AbilityLab

Table 1: Requirements and specifications

Requirements	Specifications
Safety ● The design should be usable without having the patient break any sternal precautions.	● The design should be usable without having the patient move their arms up (have their elbows at an angle of 90° or greater) or behind their back. ● The sensor should be as light as

- The design should not affect the safety of the walker for either the patient or the therapist. - The sensor should not disrupt the balance of the walker	possible (less than 5 lbs.) to maintain the walkers balance and mobility. Should be compatible with a Guardian walker with dimensions of length 20 inches and width 18 inches. The walker's weight is 10 lbs.
Functionality - The force sensor should display an accurate reading of how much force the patient's upper body is applying. - The force sensor should properly update the force in real-time with minimal delay between readings. - Sensor needs to output a consistent unit of measurement.	- The force sensor should update the readings as fast as possible. - For electronic displays, the refresh rate of the screen should be a minimum of 10 Hz. - Sensor will display the force in lbs.
Ease of use - The physical therapists should be able to attach or detach the force sensing attachment on or from the walker within 5 minutes. - The display of the force sensor should be easy to see at standing height or sitting height from a reasonable distance. - The device should be cleanable and easy to maintain.	- The sensor should be able to be read from at most 10 feet from the physical therapist. - Alternatively, the font size on the sensor should be roughly 1 inch in height and 0.6 inches in width. - The design must be able to be wiped down by the therapists before and after use.
Appeal - The force sensor should not be humiliating or ugly to the primary user. - The force sensor's instructions for use should be intuitive.	- The sensor should be the same color as the walker. - The sensor should have minimal controls (on/off switch, calibration button, and a weight limit notification).
Capability - The device can give audio feedback when the patient exceeds the sternal precaution weight limit (10 lbs.). - The device collects data about the	- The device should have an output a notification when the user is over the sternal precaution. - The device can collect force

upper body force exerted by the user throughout the exercise. ● The device is compatible and attachable to multiple types of walkers. ● The device has adjustable clamps to be attached to walker cross-bars of different sizes.	measurements, save the data, and have the exportable data. ● The device can be attached to the handle bar of any type of walker, particularly the Guardian walker (17.5” x 24” x 32”)

Appendix C: Client Interview Summary

The first interview with our client, Erin Walaszek, a physical therapist at the Shirley Ryan AbilityLab (SRAL), was conducted through a video call at 9 am on April 12th, 2019, and lasted approximately an hour. The video call was organized through BlueJeans video conference software. Ms. Walaszek called from the SRAL, while representatives from Team 13.3 (Alex Manka and Kevin Wu) and Team 13.4 (Rossoneri Jing and Davis Miller) called from the ISP House at 616 Noyes St, Evanston. During the call, Ms. Walaszek answered the many questions we had about the project. The following appendix summarizes the information we collected about the project's primary users, the walker and lab environment, the force sensor, existing solutions, other requirements and priorities to consider in our design, and other logistics.

Patient

- Our primary users will be patients that have recently had any kind of open-heart surgery (bypass, transplant, etc.)
  - Typically, these patients will have lower body impairments in tandem with general weakness from the surgery, requiring them to use a walker during physical therapy
- Patients that have had open-heart surgery must follow sternal precautions for roughly 6-8 weeks to ensure that their sternum stays safe.
  - Patients cannot reach above the head.
  - Other institutions have different standards, but at the SRAL, patients will have a 10 lb limit for pushing or pulling.
  - Patients can't put both hands behind the body at the same time.
  - Grasping with the hands does not affect the sternum, so gripping is safe but not pushing or pulling.
  - Patients must also follow the general tube rule, where a patient's arms must stay within a tube-like radius next to the torso.
  - At Northwestern and UChicago, there is a shoulder height limit to the motion of a patient's arms.
  - For any other restrictions, prevent any clicking noises from the patient's sternum.
- We should prioritize measuring the force exerted by the patient's upper body over whether if the patient is breaking sternal precautions.
- Users are typically between the ages of 45 and 60.
- Patients will have to use a walker after surgery for approximately 6-8 weeks.

Walkers/lab

- The standard walker for this will be the Guardian four-legged walker with two wheels in front and two pegs in the back and with weight limit 250 lbs.
  - The two wheels in the front of the walker do not turn.
  - The walker is very light and is easy to move forward.
  - Users will grip these walkers handles; the force they exert on the walker can be measured at this point.
  - If possible, Ms. Walaszek would like this design to be able to work on multiple different kinds of walkers.
- The lab will also have Guardian walkers that have a weight limit of 500 lbs.
- During rehabilitation, there are two types of walking distances (the patients will predominantly focus of the first):
  - Household distance (50-100 ft)
  - Community distance (>200 ft)

Force sensor

- The force sensor should ideally be dynamic, meaning that the measurement will be in real time and during motion.
- The client expressed no preference between an electronic or mechanical display for the force.
  - She emphasized the importance of a real-time feed, so we should minimize latency if we use an electrical device.
  - The units of measurement should be lbs.
- There are no requirements for size and weight except that the walkers are lightweight so the force sensor and display shouldn't unbalance the walker.
  - There will be a crossbar in the front of the walker, which could be an ideal attachment point.
- The client pictured a standard force gauge attached to the walker.
- Cleanliness and sanitation should not be an important requirement, it is unlikely that the user will come in contact with the device
  - Otherwise, the SRAL uses bleach wipes to disinfect.
- The source of the force measured will be from the patient's arms and upper body— the pectoralis major mainly.
- The direction of the force measured will be primarily downward. There will also be a forward force, but this force should be much smaller because of the lightweightedness of the walker

- The client expressed interest in some kind of visual or audio cue for either the patient or the therapist when the patient's upper body force exceeds the 10 lb limit
    - She preferred an auditory cue, with calibration and the ability to turn off.
- The client expressed interest in a device that can collect data about the amount of force throughout the movement exercise, because the cardiac population is a lot less studied than spinal-cord populations since spinal-cord patients stay in rehabilitation longer.

Priorities/requirements

- Safety
    - The design must be safe for all users (cardiac patients and the physical therapists).
    - The design should not affect the safety of the walker in general.
    - The design should be usable without having the patient break any sternal precautions.
- Functionality
    - The force sensor should properly display a reading of how much upper body force the patient is applying.
    - The force sensor should properly update the force in real-time, with minimal delay.
- Ease of use
    - The physical therapists should be able to put on the force sensing attachment on the walker within 15 minutes.
    - The display of the force sensor should be easy to see at standing height.
- Other Optional Features to Consider
    - The design can provide audio feedback to the therapist and the patient if the patient exceeds the 10 lb sternal precaution.
    - The design can collect data about the force applied the patient throughout the movement exercise
    - The design is flexible and can be compatible with different non-Guardian walkers.

Existing solutions

- There are no existing solutions for this specific purpose.
- The client did mention a colleague that provided a stationary force measurement software available, but it has to be attached to a laptop.
- The client mentioned dynamometers and pinch gauges.

Logistics and conclusion

- Final notes: the cardiac population has a variety of reasons and complications, but main common factor is the sternal precautions they must follow.
- The client expressed no preference between interacting with Teams 13.3 and 13.4 separately or together. However, she believes one point person would be convenient
- User observation will probably occur on an afternoon sometime the week of April 15 to 19 at the SRAL.

Appendix D: User Observation Summary

Introduction

On Thursday, April 18th 2019, we conducted our observation session at the Shirley Ryan AbilityLab, with Alex Manka, Malav Patel, and Kevin Wu representing our team. We met with our client, Ms. Walaszek, who currently works at the Shirley Ryan AbilityLab as a physical therapist and observed a 46-year-old male patient in wheel walker. The purpose of this observation session was to see how a typical user would interact with the walker, to understand what difficulties users or clients have with measuring the force exerted on the walker, and to determine the specifications of a possible solution. The observation session lasted approximately 45 minutes. This appendix covers the methodology we used to conduct the observation, information we collected about each user and their exercises, existing solutions at the lab, and a table that foregrounds design opportunities afforded by our observations.

Methodology

All exercises took place within a hallway of the Legs + Walking Lab. First, the client gave us a basic tour of the lab where we were able to observe existing solutions. Next, we were able to meet our user. After we secured their permission to record the session, we interviewed our user to gather basic information like demographics, medical conditions, and his state of recovery. Then, the user demonstrated a walking exercise while the client and other supervising therapists explained what they were doing. Afterwards, the users were asked follow-up questions about the exercise. Throughout the observation session, the client provided us with feedback.

Information about user and his condition

<u>User</u>

1. The user is a 46-year-old male from the United Arab Emirates.
2. The user is recovering from open-heart surgery.
    - User has sternal precautions.
        - They may not push of pull more than 10 lbs. of force.
    - User has weakness in their left leg.
        - This was a result to a complication during surgery.
    - User requires an LVAD [left ventricular assistance device] (see Figure 1).
        - An LVAD assists the user’s heart in pumping blood throughout the body.

Figure 1: A virtual image that demonstrates how an LVAD is connected.
https://stanfordhealthcare.org/medical-treatments/l/lvad.html

The user had their sternal precaution timeframe extended due to slow recovery. As a result they must continue practicing walking with a physical therapists; this method of rehabilitation does not measure how much force the user is inputting. This can be dangerous since the user may be going over there sternal precaution limit without the physical therapists knowing.
*In general, the user can be anyone recovering from open-heart surgery with sternal precautions.

User's interaction and difficulties

The steps prior to the user's interaction with the walker are outlined below.

1. The user was harnessed to a gait track overhead.
2. The user was harnessed on his wheelchair to prepare for standing upright (see Figure 2).
    a. During the process, the user was encouraged to grasp onto the walker to help with his stability.
    b. The user was heavily assisted during this process. The physical therapist had mentioned a weakness in his left leg that prevented him from standing upright himself.

Figure 2: The user is harnessed to a track above him.

The following procedure outlines the interaction -- focusing more on the difficulties -- between the user, walker, and physical therapist during exercise with the walker.

1. The user was asked to move the walker in a systematic fashion: push walker, advance right leg, advance left leg, and repeat.

    a. It was observed that the user was unable to push the walker far enough, and so he found himself standing too close to the front of the walker, making it even more difficult to push it forward. It was suspected that this was due to the sternal precautions from his open heart surgery.
    b. The physical therapist needed to push his left leg forward, indicating a weakness on the lower left half of his body.
    c. During the procedure, the user was unable to stand upright himself; it was observed that he was limping into the harness, causing him to drag his feet while he walked (see Figure 3).

Figure 3: The user was physically supported by harness.

d. This became increasingly apparent as the user remained upright. A second physical therapist was needed to assist the user (see Figure 4).

Figure 4: A second physical therapist assists the user.

   e. The physical therapist voiced concern that she has no way of accurately determining how much force the user is exerting onto the walker. This is a risk she must take, knowing that sometimes the user will exert more force than advised by the sternal precautions.

2. The exercise was stopped once the therapist noticed that the user was not feeling well.
   a. The physical therapist mentioned that a reading on the user's left ventricle assistive device was not at a normal value. It was suspected that this was caused by overexertion during the exercise.
   b. The user was given ice water, presumably to cool down and/or bring the device's reading to a normal level.

3. Post-Exercise Observations/Comments from the User
   a. The user mentioned that he puts much more weight onto his left arm while walking due to the weakness in that part of the body.

b. The user squeezed the grips considerably. While this does not pose a threat to his sternal precautions, it is an indicator of the difficulty he has with his left side (see Figure 5).

Figure 5: The physical therapist assists the user with the left side of his body.

Information about the walker

The walker that will be typically used by patients is the two-button folding walker (see Figure 6).

Figure 6: A picture of the standard two-button folding walker used at SRAL.

1. This walker has two wheels (non-turning) in the front and two pegs or slides in the back.
2. The height of the walker can be adjusted on the attachable leg sections
   a. The user just has to push the pins and slide the bottom portion of the leg up or down.
3. The design has two handlebars for the user to support their body weight with.
4. The walker can be folded by pressing the two buttons on the top of the crossbar.
   a. This allows the walker to be stored or transported with ease.

The purpose of this project is to create a design that can be attached to this walker that will measure the force exerted by the user and display that information to the physical therapist.

User observation table

The following table foregrounds design opportunities afforded by our observations (see Table 1).

Table 1: Opportunities table

Observations/Follow-up	Opportunities	Development
The therapist cannot tell how much upper body strength the user is using on the walker to stay upright during the walker exercise, posing a health risk because of sternal precautions.	Make a device that can measure and display the upper body force the user is applying on the walker in real time.	Use piezoelectric sensors that are connected to a microprocessor to measure force, and then display the force digitally to the therapist.
The user requires a lot of support from the therapist and the walker to stand up.	Ensure the device does not inhibit the therapist from helping the user and the user from using the walker.	Make the device small and lightweight, in a way that the walker is still balanced and the therapist can still easily reach and help the user.
The therapist is on the left side of the walker on a rolling chair when assisting the user, because the user's left leg is weaker.	Ensure that the force display is visible to the therapist at all times during the exercise.	Make the device attachable on both the left, center, and right side of the walker to accommodate different users.
The user grasps the walker handlebars tightly during the	Ensure that the force measurement tool does not	Make the force measurement device subtract the grip

walking exercise.	measure grip strength because this doesn't affect sternal precautions.	strength or place the measurement device on the walker so that grip strength is negligible.
The user uses considerably more force on the left side of the walker because of weakness in the user's left leg.	Ensure that the force measurement tool is still able to give an accurate reading even though the force may not be symmetrical.	Have multiple force sensors located along the walker so that the sum of the forces measured is accurate.
The user used a Guardian-model two-button folding walker, and this model is used by many other patients as well.	Ensure that the device will be compatible with the Guardian walker.	Build off of the Guardian walker when creating mockups so that all ideas will at least be able to fit on the walker that the SRAL employs.
The height of the walker is adjustable to the user's height using attachable leg sections with pins.	Make the device so that it is still functional even when the walker is set to different heights.	Have the device and display be located somewhere away from the legs so that various heights do not affect their performance or attachment to the walker.
The therapist will be in a rolling chair, moving alongside the user during the walking exercise.	Ensure that the therapist is always able to clearly see the force display for the entire duration of the walking exercise.	Make the display bright and the force's font be large enough so that the therapist can easily see the force measured.

Appendix E: Design Review Summary

Our design review session took place in room G.201 of the Ford Design Center on May 15, 2019 for 25 minutes. All members of Team 3 (Alex Manka, Malav Patel, Sherlyn Weng, and Kevin Wu) presented our design, the Wrap-around Sensor, to the rest of the section. The team presented sketches of the design, along with a description of materials and uncertainties about the design (see Figure 1 and Figure 2). The audience received a questionnaire about the design in order to give written feedback, which supplemented the oral feedback they offered us during a Q&A period that followed our presentation. Table 1 below records all of the feedback we received from our reviewers. Table 2 clarifies how we plan to implement those suggestions.

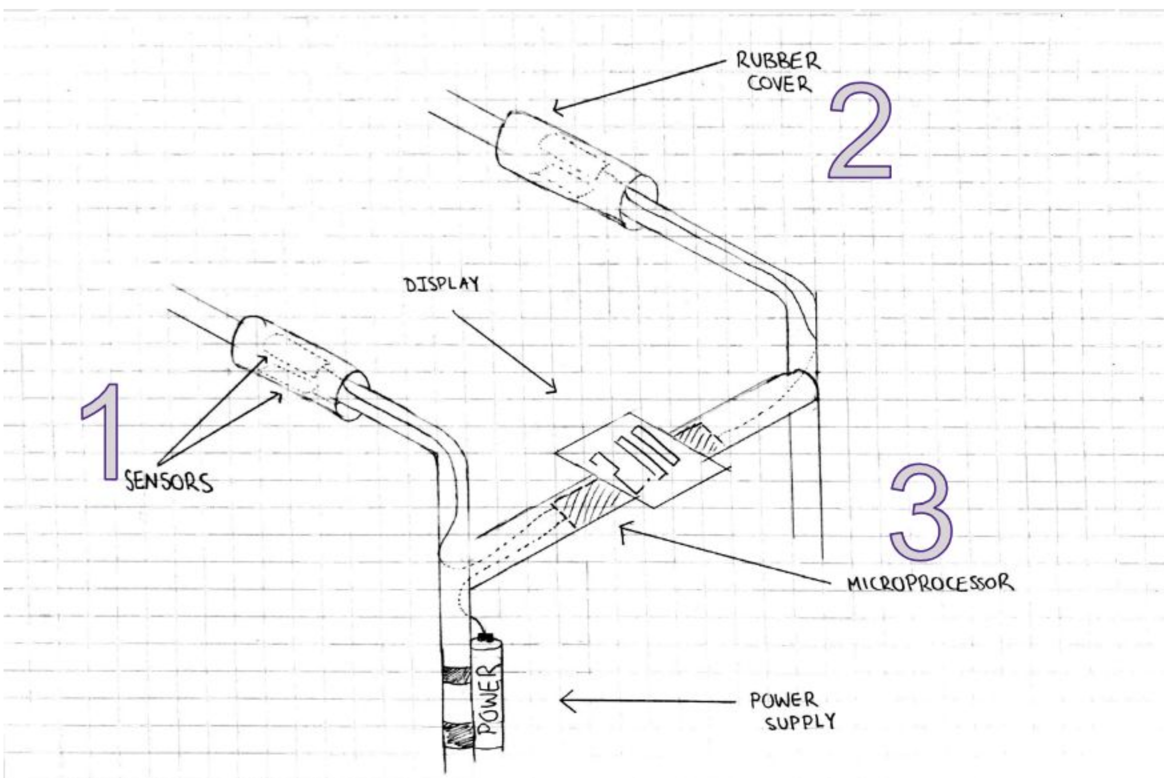


Figure 1: A sketch of the entire design (materials listed)

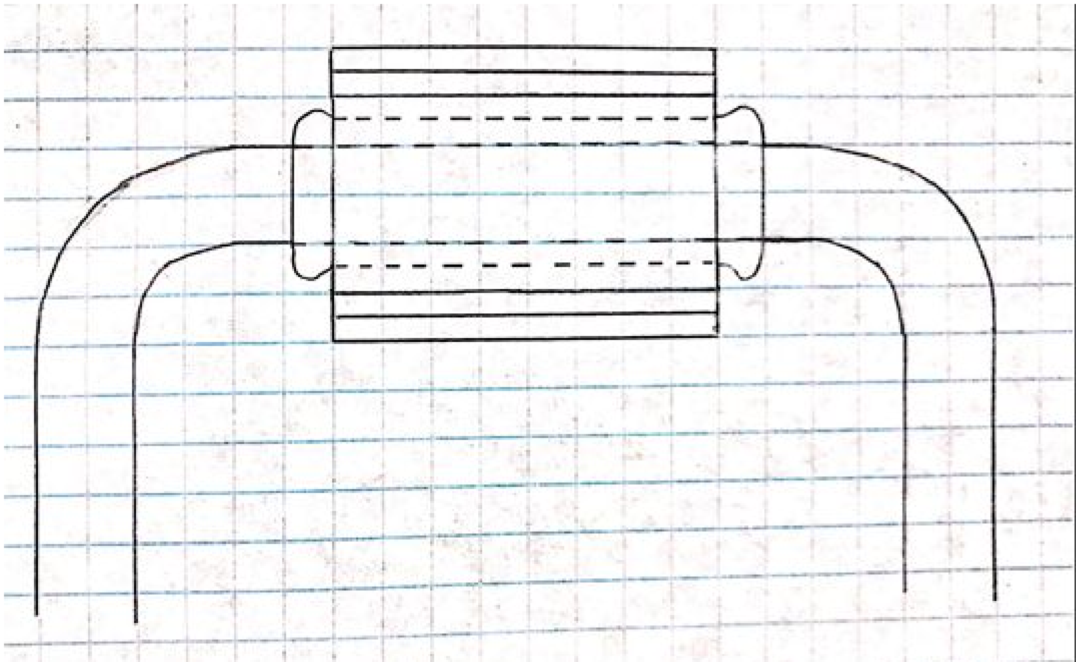


Figure 2: Wrap attachment covering the sensor

Table 1: Feedback from the design review presentation

Reviewers like	Reviewers dislike	Features to be added	Features to be modified/removed	Additional Comments
<u>CONDUCTIVE SHEET</u> Malleability Large surface area	Accuracy of measurement (higher weights Position of sheet Question of durability	Two separate sheets for each handle	Place electrical leads at opposite ends of sheet Cut the sheet into the proper shape and size	FSR (Force Sensitive Resistor) may be another option Load cells another option
<u>WIRES</u> Velcro straps would be good portable wire	Single color for all wires	Wires guided along outside of walker skeleton	Velcro straps need to be made more secure or removed entirely	Hide all wires from user’s view

management technique Aesthetic advantage over zip ties Easily removable	Compromised portability/security Could possibly break	Other methods of attachment	Wires must be long enough so the display can be moved around	Silicone zip ties as another method of attachment
<u>WRAP ATTACH.</u> Minimal modification to walker Will not compromise integrity of the handle	Too thick Sensor protrusion from wrap Low traction	NA	Thin the material but do not allow sensor to protrude Add semi-rough texture to the outer layer	Cloth may be a better option for outer layer (cleanliness?)
<u>INSULATION</u> Insulated wires Outer rubber layer of wrap around sensor	Might break or get cut	A small box around the microprocessor / battery	NA	NA
<u>MICROPROC.</u> <u>& DISPLAY</u> Low power consumption Display size	Display attachment to walker Display position	Portable clamps Invertible display	Power pack capacity decreased to 2400 mAh.	NA

Table 2: Implementations of design review advice

Suggestion/Criticism	Implementation
• We should not use Velcro to hold the wires in place; it could slide around or become undone.	• Look into the silicone zip ties as an alternative.
• We should have excess wire length in case the user wants to change the position of the display.	• Loop excess wire when not needed and tie with Velcro (like a laptop charger).
• The load cells might make the design uncomfortable to grasp; as well, it might not fully cover the design.	• Make a cover that fully encompasses the handle and pinpoints the force onto the load cells.
• The conductive sheet has a 'limited' weight bearing capacity.	• **Find a solution to resolve this.
• The shape of the walker handle is not a perfect cylinder, yet your design does not account for this.	• Form the wrap to either mold around the shape of the handle or make it rigid on the outside but so that it attaches properly to the handle.
• We must have a place to hold the microprocessor.	• Create a holding box for the Arduino Nano.
• The top layer of the wrap is too slippery and hard.	• **Find a new material to cover this.
• The battery should be covered/protected.	• Put the battery in a 3D-printed box with the Arduino.
• The bottom layer of the wrap is too slippery (will slide while in use).	• **Find a new material for this.
• We might want to add some sort of alarm to tell whether the user is over the sternal precaution limit.	• Put a flashing light on the display when this happens, while still displaying the force.

Conclusion

From the discussion with our section, we found many areas of improvement for our design. The most important feedback we received regarded the material of wrap attachment. It must be cleanable, soft, and have traction in order to keep it hygienic, comfortable, and secure respectively. We plan on talking to prototyping specialists to further look into this. Additionally, reviewers found the thickness of the attachment excessive and expressed concern that a thick wrap may reduce the accuracy of the sensor's reading. Some suggestions to remedy this were to thin out the material and make it more rigid. The rigidity would keep the sensor from protruding from the wrap, but still malleable enough to be bent into a cylinder.

For the force sensing aspect of the design, there were suggestions to replace the sensor sheet altogether. Some reviewers were worried about the sensor sheet not being accurate enough in its measurements, so they suggested we use load cells or force sensitive resistors. Load cells are engineered to measure weight and give accurate readings and could be a promising alternative. Force Sensitive Resistors (FSRs) are not as common and are not typically used to measure a weight being placed on it.

Finally, for the display and its attachment, most reviewers liked the current design, however they pointed out the fact that we must take into account the wires for the design. Dangling wires would be a safety hazard and would compromise the functionality of the design. The prevalent suggestion was to run them along the skeleton of the walker. Some reviewers suggested Velcro since it is easy to use and removable; however, other reviewers recognized that Velcro might slide around or loosen while the walker is in use. A lot of people recommended that we use silicone zip ties instead. We plan on ordering some of these and conducting further tests. We have learned a lot from our design review and will be using the feedback to improve upon our current design.

Appendix F: Instructions for Use

The following report describes how to use the GaitKeeper. The first section explains where the device should be used and how to attach the design to the walker. The second section describes the operation of the GaitKeeper. The final section explains how to detach the design from the walker for safe storage.

Setup and attachment

1. First, obtain a standard Guardian walker. Place the display box on the center of the front bar that is positioned highest using the rolling walker clamp (see Figure 1).

Figure 1: Attaching the display box to the walker

2. Consult Figure 2 and construct the setup seen. Note the positioning of the wires and the topside of the sensors. Now place the sensors inside the wrap. Place them as far back inside the wrap as possible. See Figure 3. Place the white wire inside the wrap and concentrate all other wires to one corner of the wrap. Next,

Figure 2: The setup

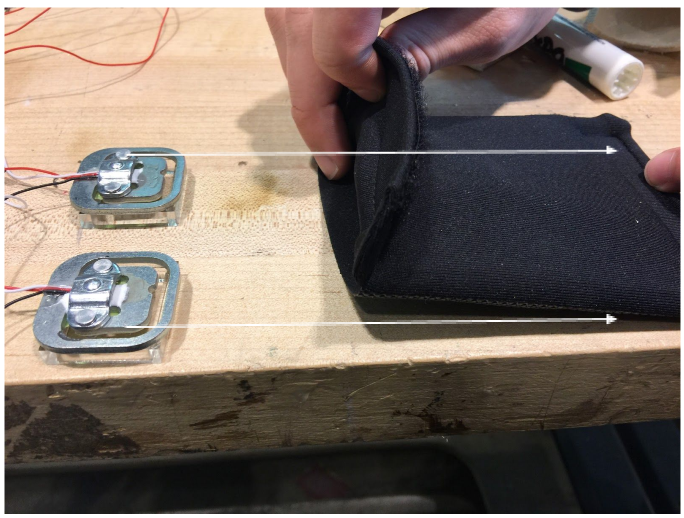


Figure 3: How to place sensors in the wrap

3. Once the sensors have been placed securely within a wrap, place it around the handlebar of the walker so as to have the sensors facing upward toward the ceiling. Notice also how the wires are localized as they leave the wrap (see Figure 4).

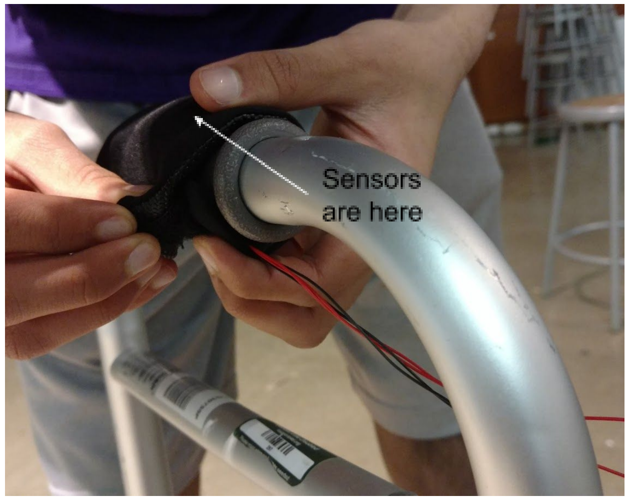


Figure 4: Placing the wrap on the handle bar.

4. If the power supply has not already been Velcroed onto the electrical hub, Velcro it securely to the side of the hub. Note: keep the USB port facing the same direction as the hole in the electrical hub (see Figure 5).

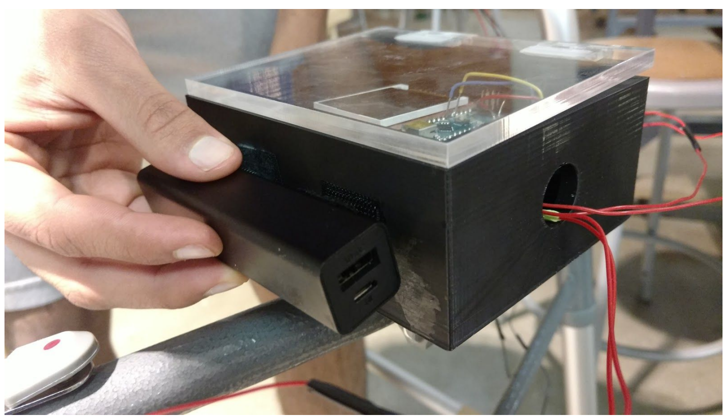


Figure 5: Velcroing the battery to the display box

5. Connect the Arduino Nano inside the hub with the power supply using a mini-USB cable. The cable should run through the hole in the electrical hub (see Figure 6).

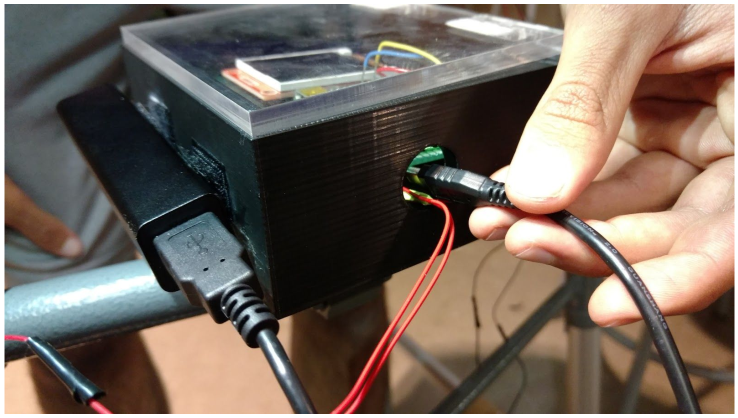


Figure 6: Connecting the battery to the Arduino.

6. The setup is almost complete. Place wire covers around the exposed wire connecting the sensor wrap to the display box (see Figure 7).

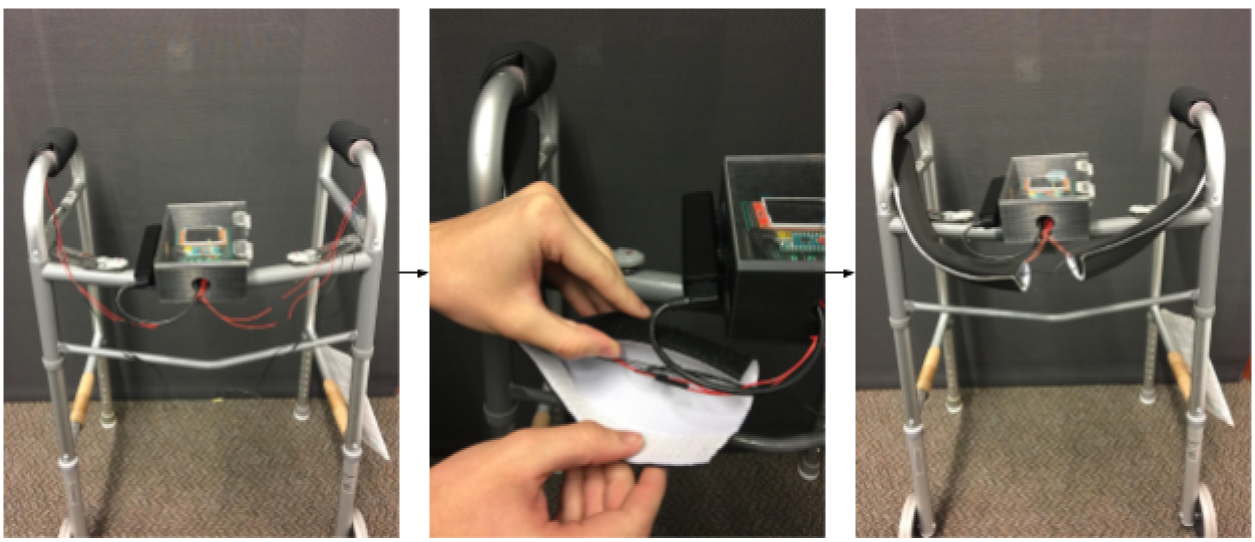


Figure 7: Attaching wire covers.

Using the device

1. Once the mini-USB cable has been attached to the Arduino Nano, the display in the hub should light up. Please wait for the hub to display a screen measuring the force exerted on the walker. The initial reading should be 0 lbs (see Figure 8).

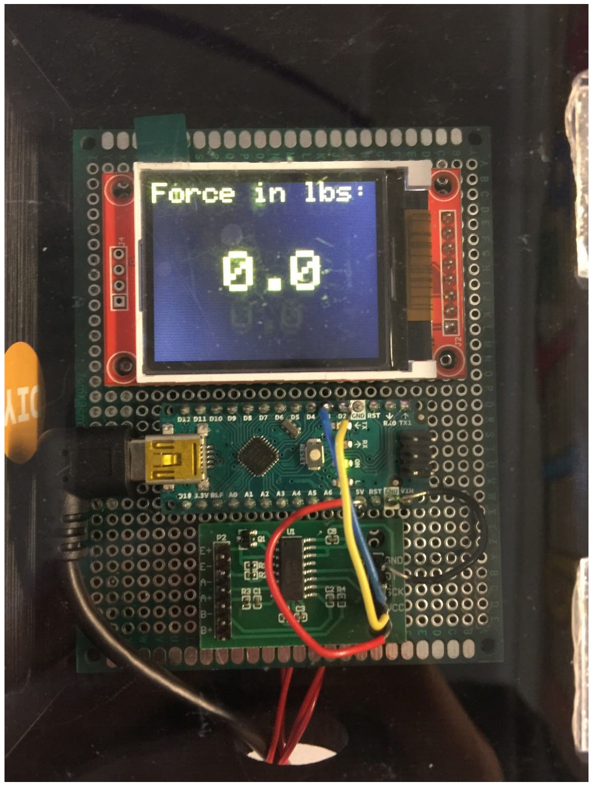


Figure 8: Zero reading upon startup

2. The user should then be instructed to place their hands on the handlebars of the walker. They should feel the sensors underneath the palm and ball of their hands (see Figure 9).

Figure 9: The user places their hands on the walker before beginning to walk.

3. Good to go! The sensor will automatically update the force reading as time passes.

Detachment

1. Unplug the battery pack from the Arduino Nano, taking off the battery pack and the wire.
2. Unwrap the the wrap attachment and remove them from the handles of the walker.
3. Remove the display box by pulling on the rolling clamp. The box should easily come off.
4. Take the wraps and load cells and the display box together for storage, taking care to not stretch the wires.

Appendix G: Failure Modes: Effects and Analysis

Table 1: below summarizes the possible failure modes of each component in the design. These failure modes are analyzed, listing the effect on the design as a whole. We also offer suggestions to remedy each failure mode.

Table 1: Failure modes

Item	Failure mode	Failure cause	Failure effect on component	Failure detection method	Failure effect system	Sev.	Freq.	Score	Action
Sensor	Break	Overload	Unresponsive	Constant Display Reading	Unresponsive	2	2	4	Replace sensor
	Disconnection	Excessive shear force	Nonfunctional	Display reading one side only	Partially functional	2	3	5	Solder components again
	Unresponsive	Mfg defect	Nonfunctional	Display reading one side only	Partially functional	2	2	4	Replace sensor
	Responsive	Object other than hand on sensor	None	Display reading a force	None	2	1	3	Ignore
Processor	Break	Accidental hit by user	Unresponsive	Display Reading 0	Unresponsive	2	1	3	Replace sensor
	Nonfunctional	Mfg defect	Inaccurate signal processing	Display reading not representative of user exertion	Nonfunctional	2	2	4	Replace microprocessor OR reprogram
Display	Break	Accidental hit by user	Unresponsive	Cracked screen; disconnection from wires	Unresponsive	2	2	4	Replace display/solder connection again
Wire	Shellac Wear	Normal wear and tear	None	Visible copper wire	None	3	1	4	Replace wires
	Disconnection	Tugging on wire	Nonfunctional	Loose/hanging wire	Partially functional	1	3	4	Reconnect wires
	Tangled Wires	Loose ties/ Impulse from user	None	Wires not guided by walker's structure	None	1	2	3	Gather wires and tighten connection to walker

Item	Failure Mode	Failure Cause	Failure Effect on Component	Failure Detection Method	Failure Effect System	Sev.	Freq.	Score	Action
Electrical Insulation	Break	Normal Wear OR Impulse	Nonfunctional	Exposed processor/power supply components	Potential for electric shock	3	2	5	Cover tear with electrical tape. Otherwise replace insulation
Sensor Cover	Tear	Normal Wear and Tear	Nonfunctional	Exposed Sensor Component	None	1	2	3	Disinfect tear region and apply rubber tape. OR replace cover.
Power Supply	Non-functional	Loss of power	Unable to power other components	Display reading black	Unresponsive	2	3	5	Replace/charge batteries
	Nonfunctional	Battery placement	Unable to power other components	Display reading black	Unresponsive	1	2	3	Reorient batteries in power supply to correct positions

<u>Severity values</u>
1: Mild annoyance; part may require reassembly by user
2: Nonfunctional part affects system performance; need to replace part
3: Nonfunctional part poses a threat to user's safety; product cannot be used until fix is implemented

<u>Frequency values</u>
1: Failure occurs every 1/100000 uses
2: Failure occurs every 1/10000 uses
3: Failure occurs every 1/1000 uses or more

*As we were unable to test these fully, the frequency values are estimates. Thus the score column is an estimate of the true failure mode.

Appendix H:

Ethics and Sustainability Considerations

The following document outlines the top three ethical and sustainability considerations we have made for our design, and how we will incorporate ethics in the testing phase of our design.

Ethical considerations

By far the most important ethical consideration we have to make for our project is the safety of our users. As engineers, according to NSPE code of ethics, it is our intrinsic duty to hold paramount the safety of the public. To fulfill this consideration, we will not have any of our users be actually using our mockups during user testing. This is because mockups will not hold up to safety standards of the established Guardian Walker, and we want to eliminate all safety risks associated with them. Rather, we will use user testing as an opportunity to have the client and user see the mockups and confer with them to gather their opinions.

Furthermore, according to the NSPE Code of Ethics I.1, “Engineers, in the fulfillment of their professional duties, shall hold paramount the safety, health, and welfare of the public.” This has two implications for our design. From user observation, we learned that sanitation is a priority in the Legs + Walking Lab. That means any surface that comes into contact with more than one person (i.e. the handles of a walker) must be wiped down with each use to prevent the spread of bacteria or viruses. Because we are working directly on the handle of the walker, we must be mindful of this fact. If any aspect of our design is to cover the handle bar, we must have that surface be clean-able or naturally antibacterial. The second implication this brings up is safety from electric shock. Because the design contains electrical components, they must be insulated from the environment. This ensures that any hazard of electric shock is eliminated or at least mitigated to a significant extent.

Lastly, “Engineers shall be objective and truthful in professional reports, statements, or testimony.” This was particularly important when we test our mockups. Often, performance testing is not done genuinely, which leads to complications during material selection for the prototype. We have been good about this during performance testing, and plan to create a purely objective performance testing report. We learned that a very promising sensor sheet works well, but it does not satisfy the specifications as outlined in the project definition. Thus, we must look for alternative methods of measuring forces. The objectivity in the performance testing reports lays the groundwork for the final design concept and rationale.

Sustainability considerations

Because our client has nothing to fall back on if our design fails, we must do our best to maximize the product's lifespan. This means the design should minimize the number of moving parts if it is to be mechanical. Also, any electrical components should minimize their power consumption. That is why we have focused our attention on finding microprocessors that consume as little power as possible. The display also needs consume a minimal amount of power. That is why we do not want to the display to be too large. In accordance with what the client needs, we will choose a display that is small in size.

Another aspect that we aim to consider is resource efficiency. Cradle to cradle design advocates for the idea that any design should be efficient in its resource use. That is why we have opted to use a rechargeable power pack as our power supply. This method is more efficient compared to batteries. Batteries must be disposed of after use, and are often thrown into the trash where they pose serious environmental threats to local water tables. At the end of the product's life, the number of batteries consumed will be much greater than the the number of rechargeable power packs consumed. This is a prime example of resource efficiency. We minimize the number of parts replaced over the product's lifespan.

Finally, we plan on implemented a circular economy design. At some point, the rechargeable battery will lose its ability to store power. At this point, instead of having to purchase an entirely new version of the product, all the user will have to do is buy a new rechargeable battery pack. This utilizes replaceable parts to ensure that the design can be easily fixed/altered by the user to ensure a long lasting device. As well, the user can then properly recycle the old parts. Most of these part will include electrical elements that can be reused in part. These reused parts often end up back in the market (part of the old rechargeable battery will end up in a new one). This demonstrates the conservation of materials; the user will be inclined to keep the working part of the design and fix the broken part rather than having to completely replace the broken design with an entirely new one.

Appendix I: Dimensioned Graphics Sketches

This appendix displays the dimensioned graphics sketches of each part of the design, including the overall design (Figure 1 and 2), sensor and wrap attachment (Figure 3 and 4), display box and battery (Figure 5 and 6), and the printed circuit board (PCB) (Figure 7 and 8).

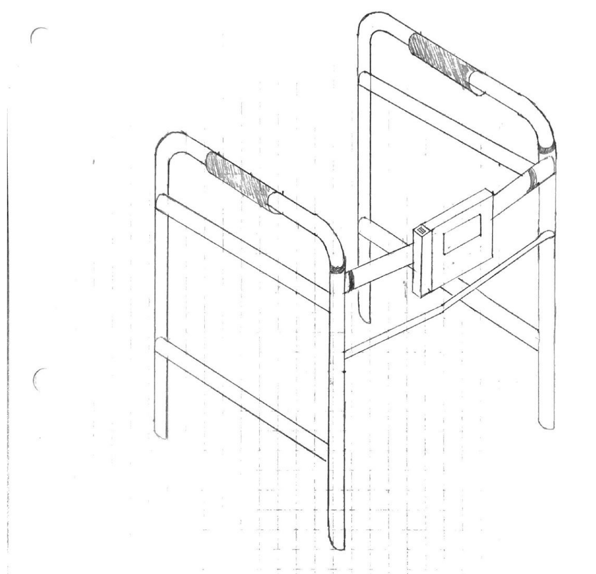


Figure 1: Isometric view of the device on the walker

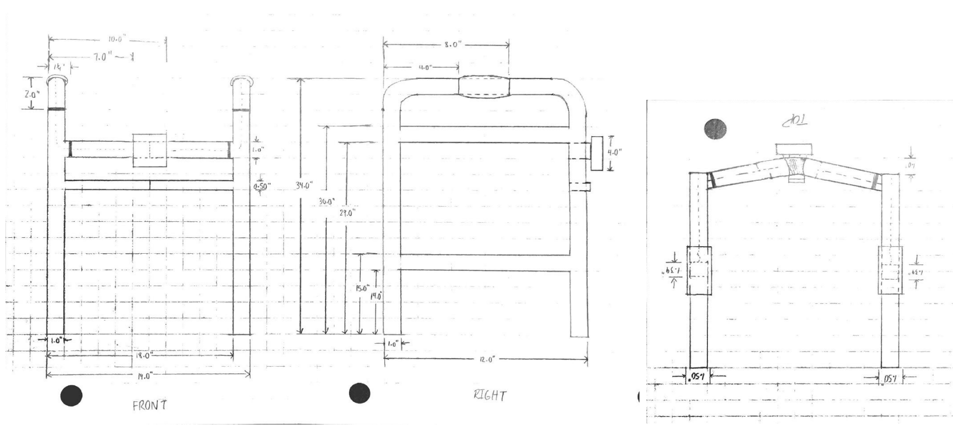


Figure 2. Orthographic view of the design on the walker

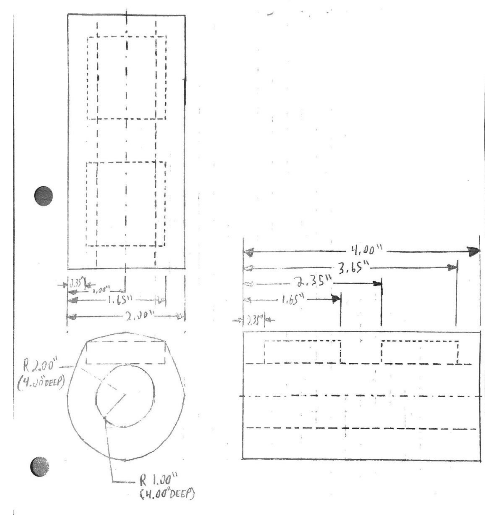


Figure 3: Orthographic view of the sensor and wrap attachment

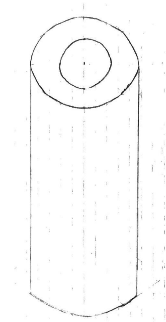


Figure 4: Isometric view of the sensor and wrap attachment

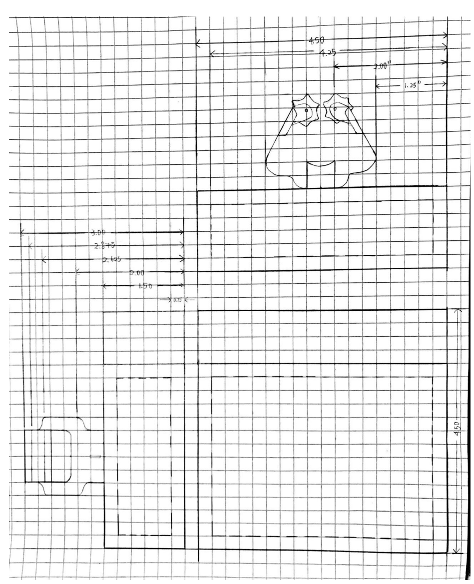


Figure 5: Orthographic view of display box and battery

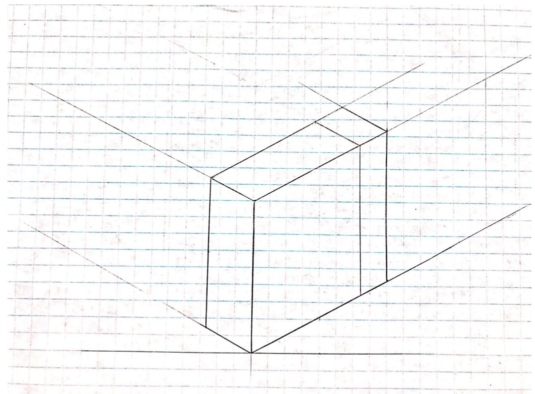


Figure 6: Isometric view of display box and battery

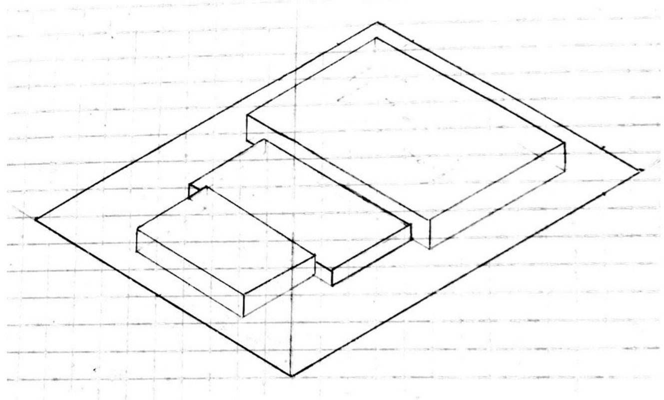


Figure 7: Isometric view of the PCB

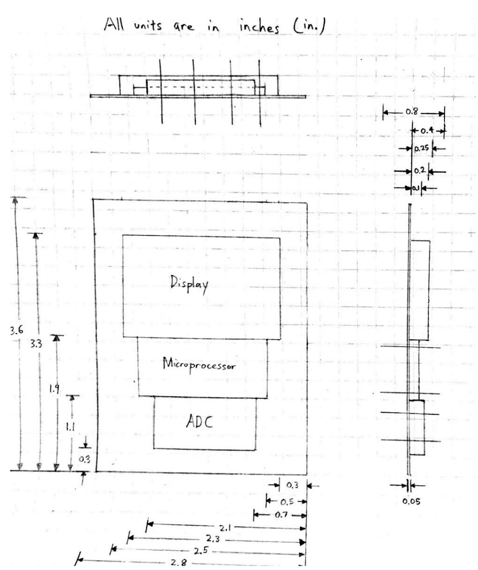


Figure 8: Orthographic view of the PCB

Appendix J: Bill of Materials

Tables 1 and 2 summarize the bill of materials we purchased and shop materials used respectively.

Table 1: Bill of materials

Description of Purchase	Qty	Vendor	Part Number	Unit Cost	Total Cost
Adafruit pressure sensitive sheet	1	Adafruit	1361	$4.95	$4.95
Load cells	1	Amazon	B07D6HYYSN	$9.50	$9.50
Walker Handle Cover	1	Amazon	B004D0HWUE	$19.99	$19.99
Power Pack	1	Amazon	B00L9F95RO	$15.99	$15.99
Display Screen	1	Adafruit	358	$19.95	$19.95
PCB board	1	Digikey	2670	$4.95	$4.95
Arduino	1	Amazon	A000005	$22	$22
Wire Cover Sleeve	1	Amazon	B01DDIMMLA	$9.45	$9.45
Mini USB Cable	1	Amazon	B01NAT82AC	$6.99	$6.99
Total:					$104.80

Table 2: Shop materials used

	Description	Qty	Estimated Cost
PVC	A PVC pipe (1” diameter, 6” long)	1	$1.00
Rubber	Think rubber sheet (1 sq ft)	1	$2.00
Leather	Thin crafting leather (1 sq ft)	1	$5.00
Shellac wire	Wire for circuitry (1 ft - 4 ft)	10	$2.95 (25ft wire)
Transparent Acrylic Sheet	8” x 4” x 0.25”	1	$5.00
Plastic Hinges	1.5” x 1.5” x0.2”	2	$0.50
Plastic Filament	NA	NA	$4.95

Velcro	NA	NA	$8.00
Nuts	8-32	2	$0.05
Bolts	8-32 0.75”	2	$0.05
Washers	8-32	2	$0.05

Appendix K: User Testing Report

Purpose

The purpose of this testing was to gain feedback for our mockups and see if the users (cardiac patients and physical therapists) could see themselves using it. We wanted to ask people who are not engineers and would be directly interacting with the design about what their perspectives and to discover insights that we might not have. This information could help us modify specific parts of our mockups and adjust them so they are as useful as possible for the users. Modifications could include adjustments to our design and material selection.

Methodology

User testing took place at the Shirley Ryan AbilityLab on May 13, 2019. Team members Malav Patel and Alex Manka were present along with Erin Walaszek, the physical therapist, and Mohammed, the patient seen at user observation. User testing was structured as a question-answer process. The user and the physical therapist, who is also the our client, were both asked for their input on a topic. The topic would then be branched out to probe for failure modes in the design. Because the mockups were distributed across the walker well, they were placed on all at once, and each was presented to the user sequentially. Also, the presentation aimed at comparing the mockups, so having them all on the walker was good for observing issues, differences, and advantages.

Results

In Table 1 below, each mockup was given a ranking by the client on how well it satisfies each requirement of the project definition. A "10" signifies that the mockup satisfied it the best, and a "1" signifies that the mockup satisfied it the least. The comments listed in Table 1 below are additional remarks by the user.

Table 1: User testing results

	Mock-Ups			
	Display attachment	Brace attachment	Sensor Sheet	Wrap attachment
Safety	8	3	NA	8
Functionality	10	9	7	9

Ease of Use	8	9	NA	10
Appeal	8	4	9	9
Capability	10	3	6	9

Observations

The user was asked more general questions regarding additional requirements that they would like to see implemented to second generation mockups and eventually the final prototype. Comments are listed below in Table 2.

Table 2: Additional comments

Observations/Comments	Mockup
The Brace attachment may not be able to support 250 lbs. in case the user slips.	Brace attachment
A Wrap attachment needs to be able to be wiped with high strength disinfectant wipes.	Wrap attachment
The Wrap attachment is the least obtrusive to the original walker.	Wrap attachment
The display should be small so as to avoid distracting the user.	Display
Any electronic devices need to be airtight and any loose items should be tethered to the walker.	Sensor

Analysis and conclusions

Analysis of results:

- The physical therapist requires a device that will minimize distractions. This means any display will have to minimize any eye-catching renders.
- Both the user and the physical therapist displayed concern about the Brace attachment. This mockup will likely not be taken to the prototype stage.
- If the mockup comes into contact with the user's hand, then that surface must be disposable for the next person to use the device. Or, the surface must be made of a material such that cleaning it with disinfectant wipes does not change its composition or integrity.

- The design must be able to withstand an unexpected surge in load in case the user slips. This means the device must be able to recognize high voltage electrical signals and respond accordingly to prevent injury.
- In rare occasions, the patient may vomit or excrete other bodily fluids that may come in contact with the design. Precautions must be taken to avoid any shorts in circuitry that may harm the user and/or physical therapist.

Potential changes to design:

- Put an airtight seal over any electrical equipment that insulates it from the environment.
- Optimize the display size and image renders to display only the force reading and nothing else.
- Put a disposable fabric over any surface that comes into direct contact with the user's hands
- Create a failsafe that switches off the device if a high enough potential difference is reached at the terminals of a circuit.

Conclusions:

- Take all and any steps necessary to insulate the design from the elements of the environment. Safety of the user is the utmost priority.
- The user should not be overwhelmed with information from the display. Keep the reading simple.
- The design should be unobtrusive, meaning that any component of it cannot restrict the user's mobility with the walker
- Wire management will be important. Any and all wires need to be secured to the structure of the walker to keep the walker's stepping space free.

Limitations:

- Our first generation mockups were not functional mockups, so they could not actually be tested. Instead, the user gave feedback on the idea's viability and whether or not the possible prototype may be the solution to their issue.
- The client was unable to bring in another patient, who happened to have a greater sternal exertion limit. This would have provided us with insights as to how much weight the sensor needs to be able to read before issuing some kind of alert, whether it be visual, audio, touch, etc. This user would have used an oversize walker, shown below in Figure 1. Input from this user on how the design may work on this oversize walker would have been useful.

Figure 1: The oversize walker.

Appendix L: Performance Testing Report

This report summarizes the results of the performance testing we conducted on each of our mockups. The four mockups that we tested were the visual display and attachment, the brace attachment, the sensor sheet, and the sensor wrap attachment. The data that we gathered gauges how these mockups fulfill the major requirements of safety and functionality for our primary and secondary users.

Methodology

All 4 mockups together satisfy the requirements outlined in the project definition, but no one mockup satisfies all requirements. Thus, the tests done on each mockup differed since they aimed to see how well each mockup satisfied its requirements. Each test was either quantitative or qualitative, and the resulting observations were recorded and analyzed.

<u>Test procedures for the visual display and attachment modification</u>

The testing took place on 5/11/19 from 4 to 6 p.m. at Ford Design Center in the shop. The display will be attached onto the walker via one of the following attachment methods: rolling clamp, screw clamp, or Velcro. The primary purposes for performance testing of the brace attachment were to test the ease and secureness of attachment and the range of users' heights accommodated.The results were shown in Table 1-4.

Procedure:

A. Attach a display onto an attachment method.
    a. Make sure that the screen starts in an upright/readable position.
B. Attach the display onto the walker with the attachment method.
    a. Make sure to try all three attachment methods listed above.
    b. Do this 3 times, the time to attach will be measured
C. Have someone walk with the walker.
D. Make an observation on sturdy the display and attachment seem to be after a certain amount of consecutive steps.
    a. First have the user walk one step.
        i. Note any changes in the display and attachment's position.
    b. Next have the user walk two steps.
        i. Note any changes in the display and attachment's position.
    c. Repeat this pattern until the user walks 10 steps consecutively.

Table 1: Time to attach displays and attachments

	Time to attach Velcro (s)	Time to attach rolling clamp (s)	Time to attach screw clamp (s)
Trial 1	3.5	4	10.0
Trial 2	3.7	3.9	12.4
Trial 3	3.4	4.2	10.2
Trial 4	3.1	2.5	8.9
Trial 5	3.3	3.6	11.3
Average	3.4	3.64	10.56

Table 2: Walking with the Velcro attachment method

# of steps taken	Observations (i.e., display fell off, display/attachment drooping, attachment fell off
1	Fine
2	Display is drooping
3	Display is facing downward
4	Display is facing downward
5	Display is facing downward
6	Attachment and display fell off
7	Display is facing downward
8	Attachment and Display fell off
9	Attachment and Display fell off
10	Attachment and Display fell off

Table 3: Walking with the rolling clamp attachment method

# of steps taken	Observations (i.e., display fell off, display/attachment drooping, attachment fell off
1	Fine
2	Fine
3	Fine
4	Fine
5	Fine
6	Fine
7	Fine
8	Fine
9	Fine
10	Fine

Table 4: Walking with the screw clamp attachment method

# of steps taken	Observations (i.e., display fell off, display/attachment drooping, attachment fell off
1	Fine
2	Fine
3	Fine
4	Fine
5	Fine
6	Fine
7	Fine
8	Fine
9	Fine
10	Fine

Test procedures for the sensor sheet and sensor

The testing took place on 5/16/19 from 3 to 5 p.m. at Tech Room MG11. This room is a laboratory for physics experiments. The test was meant to find and assess the accuracy of the force-to-resistance ratio of the sheet. The sensor will be laid flat on an insulating surface. The following procedure took place on the insulated environment (see Figure 1). The results were recorded in Table 5. A visual representation has been provided in Figure 2.

Procedure:

A. Strap sensor onto a flat surface
    a. Be sure to eliminate the possibility of slippage to the best of one's ability
B. Apply a known force to the sensor's surface
    a. Make an attempt to evenly distribute the force across the surface
C. Make quantitative observations on how the resistance changes when the force on the sheet is changed.
    a. Repeat for multiple trials
    b. Find the time taken for each reading to stabilize to plus/minus 1 kilo-ohm.

Figure 1: The testing setup

Table 5: Force-resistance relationship

Weight (kg.)	Reading (kOhm)				Time Taken (sec)
	Trial 1	Trial 2	Trial 3	Avg.	
0	62.3	62.4	63.7	62.8	20
0.5	60.0	57.2	59.8	59.0	22
1	59.1	60.4	57.4	59.0	18
1.5	59.0	64.7	61.5	61.7	21
2	60.0	60.0	56.1	58.7	22
2.5	56.8	59.3	60.2	58.8	25
3.0	56.0	55.2	58.2	56.5	28

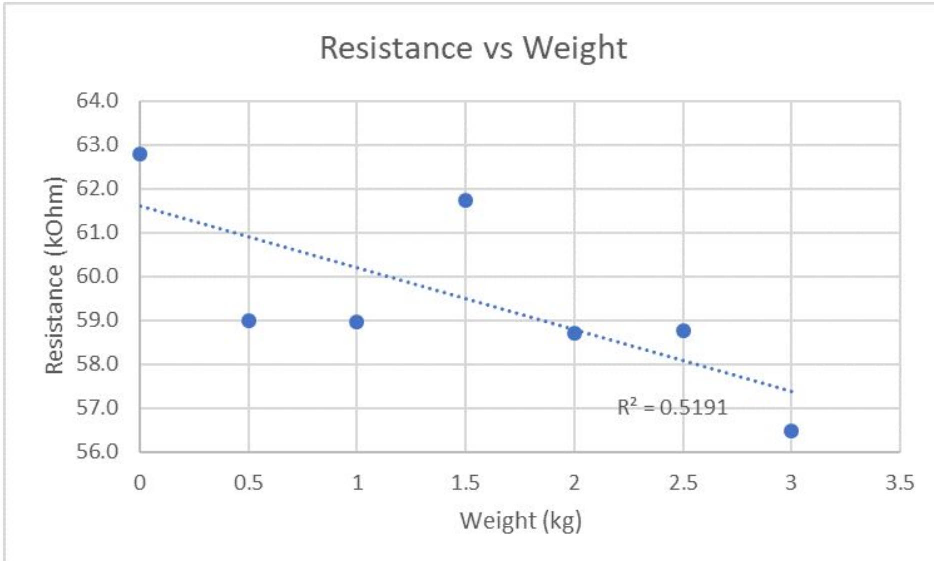


Figure 2: A graph of resistance vs weight

<u>Test procedures for the brace attachment</u>

This mockup is made up of a wooden handlebar that slides into two PVC tubes. The PVC tubes are attached to walker bar clamps. In the future, electric force sensors will be attached to the bottom of the PVC tubes to measure downward force. The primary purposes for performance testing of the brace attachment were to test the ease and secureness of attachment and the range of users' heights accommodated. The results are shown in Table 6-8.

The mockup initially started detached from the walker, but the handlebar was already attached to the tubes.

Procedure:

1. Strap the tubes to the sidebar of the Guardian walker.
    a. Unstrap and repeat 4 more times, observing difficulty and the time it takes to attach.
2. Now, measure the distance from the bottom of the original handlebar to the bottom of the new handlebar.

3. Next, attempt to perform a short walking exercise by walking forward and pushing the walker at the handlebars for 3 meters. Repeat at increasingly fast walking speeds.
    a. Observe any weaknesses in the secureness of the handlebar or difficulty pushing the walker.
4. Then, attempt to apply increasing amounts of force downward onto the handlebar.
    a. Observe any weaknesses in the secureness of the handlebar.

Performance testing was conducted in Bobb Hall on May 13th at 2:00pm and took approximately an hour. Testing involved a digital scale, a Guardian walker, the brace attachment mockup, and around 5 meters of hallway. Results have been summarized in Tables 6, 7, and 8, and also in the analysis section.

Table 6: Attaching and reattaching the brace attachment

Trial	Time taken to attach (s)	Time taken to detach (s)
1	33	8
2	34	7
3	34	7
4	31	8
5	35	7
AVG	33.4	7.4

Table 7: Walking with the brace attachment at various speeds

Time taken to walk 3 meters (s)	Secureness of attachment (on a scale of 1-10, 10 being secure)	Ease of pushing the walker (on a scale of 1-10, 10 being easiest)	Additional observations
10	10	10	If the handlebar was lifted, it would be hard to move the walker
5	10	10	
3	10	10	

Table 8: Applying downward force on the brace attachment

Force applied downward (lbs.)	Secureness of attachment (on a scale of 1-10, 10 being secure)	Additional observations
10	10	
20	10	
30	10	
40	1	Super glue snapped, brace attachment broke

Test procedures for the sensor wrap attachment mockup

This mockup is made of two 4.5 by 4 inches PVC rubber sheets and serves to attach the sensor onto the walker by wrapping around the handle bar. Two 0.5 by 4.5 inches Velcro straps at the end of the sheets help fix the position of the device. The purpose of this performance testing session is to test the (1) the ease of use; (2) the durability of the Velcro straps, and (3) the sturdiness of the material.

Procedure:

1. Ease of use

This part of the performance testing was carried out on May 12th, in the north lounge of 2303 Sheridan Road, from 8:50 pm - 9:50 pm. A PVC pipe and the wrap attachment were first gathered. We started the time when the tester started to wrap the device around the handle bar of the walker, and we ended the timer when the Velcro straps were stuck together and the wrap attachment was adjusted to the right position. The test was repeated for three times and the time was recorded in Table 9.

Table 9: Time used to attach the sensor wrap

	Time used (s)
1	4.86
2	5.41
3	3.43
Average	4.57

2. Durability of Velcro straps

This part of the performance testing was carried out on May 12th, in the north lounge of 2303 Sheridan Road, from 8:50 pm - 9:50 pm.

A. Stick the Velcro straps together within 2 seconds. This time limit is set because in reality usually people take less than 2 seconds to stick together two pieces of the Velcro straps.
B. Rip the Velcro straps apart within 2 seconds.
C. Repeat the process until the straps fell off from the device. Record the number times the Velcro straps are ripped apart.

The result of this test was shown in Table 10.

Table 10: Effectiveness of Velco after usage

Number of times that the Velcro straps are ripped apart until it fell off	Observations
<50	The straps did not fall off and function normally.
>50	The straps became weak. It takes longer and more force to put stick them together but the velcro straps still work.

3. Sturdiness of the material

This part of the performance testing was carried out on May 14th, in Blomquist (617 Foster St, Evanston, IL) from 10:30 pm to 11:00 pm.

1. Place a 20lb weight onto the sheets.
2. Start the timer.
3. Wrap the device around the handle bar of the walker. Adjust to the right position. Stick the Velcro straps together.
4. End the timer. Record the time used.
5. Repeat the experiment for three times.

The setup of this test was shown in Figure 3. The observations of the wrap attachment surface was recorded in Table 11.

Figure 3: Setup for testing the sturdiness

Table 11: Observations of the wrap attachment surface over a time span of 25 minutes

Time	Observations (i.e., cracks, permanent bends, indents from weight)
After 1 minute	No obvious change
After 3 minutes	No obvious change
After 5 minutes	No obvious change
After 7 minutes	No obvious change
After 9 minutes	No obvious change
After 11 minutes	No obvious change
After 13 minutes	No obvious change
After 15 minutes	Slight indentation was observed
After 17 minutes	Slight indentation was observed
After 19 minutes	Slight indentation was observed
After 21 minutes	Slight indentation was observed
After 23 minutes	Slight indentation was observed
After 25 minutes	Slight indentation was observed

Despite the fact there was slight indentation, the wrap attachment was functional after the test. The surface after the test was shown in Figure 4.

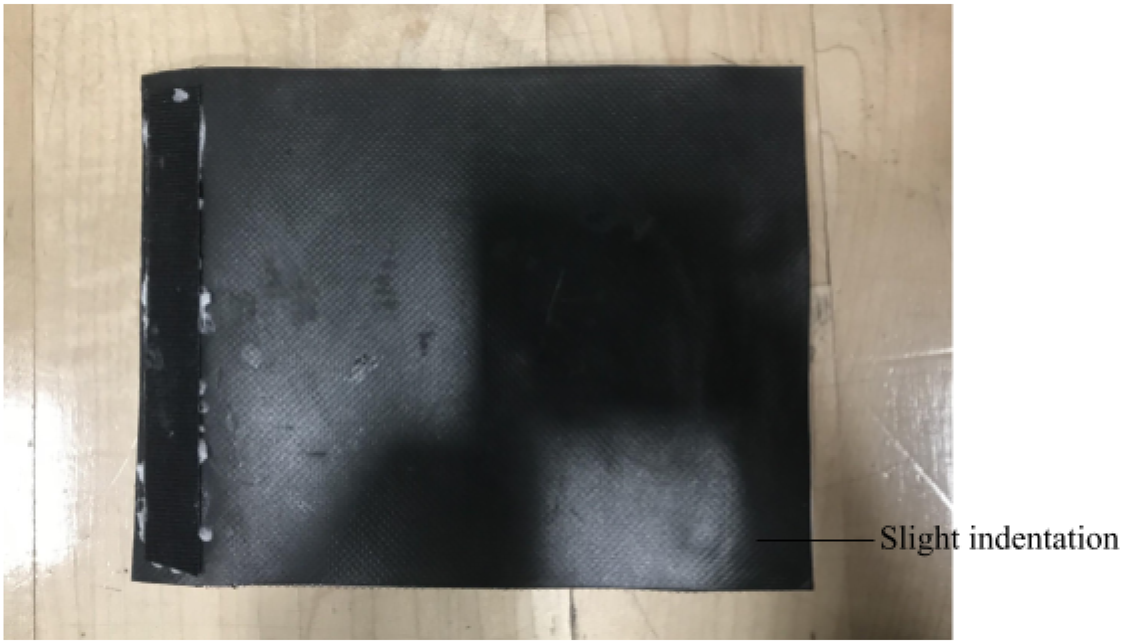


Figure 4: The surface of the wrap attachment after the attachment

Analysis

Visual display and attachment

The main focus of testing was for the attachment (testing the display was completed during mockup testing). Two aspects,time to attach and stability, were tested on the three different attachments (Velcro, rolling clamp, screw clamp):

- Time to attach:
    - The Velcro took the least amount of time with the rolling clamp right behind it. This is because both designs are very simple to use and attach to the walker with little adjustment.
    - The slowest method was the screw clamp design; this design took very long to attach and detach do to the requirement to adjust the screw to the right length to fit onto the walker.

Stability of the attachments:

- After only a few steps, the Velcro attachment would start to droop the display downward, and with a few more it actually fell off.
- On the other hand, both the rolling clamp and the screw clamp successfully stayed on the walker without altering the position of the display.

Brace attachment

Viability of the brace attachment was tested first off by measuring the ease of attaching and detaching the device to the walker. After conducting 5 trials of attaching and detaching, the average time spent to attach was 33.4 seconds and the average time spent to detach was 7.4 seconds. Both of these times are relatively low, by far less than 15 minutes. Thus, in regards to ease of attachment and detachment, the brace attachment does successfully fulfill that requirement.

Another measurement that was recorded was the difference of height of the handlebars; this measurement came out to be 4.0 inches. This means that the minimum height of the handlebar when using the brace attachment is now 4.0 inches higher, which could possibly restrict shorter users from using the device.

The walking test's purpose was to test the secureness of the brace attachment when actually using it during a gait exercise when a user is mainly pushing the walker forward. As seen in Table 12, the brace attachment remained tightly secured to the walker when walking at slow speeds (3 meters in 10 seconds) and even when walking at faster speeds too (3 meters in 3 seconds). This shows that the brace attachment will not inhibit a user that is primarily pushing the walker forward during gait-training.

Finally, the final performance test measured how much weight the brace attachment could sustain before breaking. This test was completed by first weighing myself and then pushing down on the brace attachment on the walker to see how much less a team member weighed as they applied more and more force to the brace attachment. The brace attachment remained secure and intact with 10, 20, and 30 lbs. of force respectively; however, with 40 lbs. of force, the super glue on the brace attachment snapped, breaking and detaching from the walker (see Figure 5).

Figure 5: Broken brace attachment after performance testing

Since the standard Guardian walker is able to support up to 250 lbs., our device must be able to at least support 250 lbs. as well or not involve additional handlebars in order to keep continuity with the Guardian walker's safety standards. The brace attachment was only able to support up to 40 lbs., ultimately proving that such a mockup is not viable for the final project because it is not strong enough to support the weight safety requirement.

Sensor sheet

The aim of the test was to determine first if the sensor was responsive to changes in pressure exerted on its surface. We found that indeed the sensor's resistance decreases as the load on it increases. This reinforces the description given in the item manual.

However, we found that the relationship between the resistance and weight is not linear. It may seem linear from Figure 2, but the R^2 coefficient of this regression is too low. We do not have enough confidence to say that the regression is linear. Thus, we cannot conclude that that the force exerted on the sheet is varies directly with its resistance.

Furthermore, the time taken for the reading to stabilize between oscillations of plus/minus one kilo-ohm was far too long for practical application. In 20 seconds it is very likely that the user may have shifted the weight of their body or begun to exert more or less weight on the system. If the system lags behind by 20 seconds, the user does not get a timely update of the force they exert on the walker.

Sensor wrap attachment

Through testing the ease of use of the sensor wrap attachment, we found out that the average time used to attach the device is 4.57 seconds. This indicates that the device is very easy to use. This corresponds to the mockup testing results which suggested that the device was easy to put on even without instructions.

For the durability of the device, the Velcro straps did not fall off after 50 times of sticking and ripping, suggesting that this version of mockup is durable. This is primarily because of the glue used for this mockup. The glue used for this version of the mockup is Super Glue, which was stronger than the glue used for the previous iterations. We consider this glue suitable for our final prototype.

For the test on the sturdiness of the material, when a 20 pound weight was put on the wrap, Table 12 shows that there was slight indentation after 25 minutes. Despite of the slight indentation, the device was still functional. The indentation was only seen on the top layer but not the bottom layer, suggesting that the pressure on the bottom layer is very small, which is ideal. Hence, this test suggests that the material is sturdy. However, while the pressure does not affect the layers of the wrap attachment, it was not clear whether the electronic component is going to be damaged under the pressure. Further tests need to be conducted when we assembled the sensor together with the wrap attachment.

Conclusion

Performance testing revealed a lot of unknowns about our design. We determined that the most viable method of attaching the force sensor to the mockup was the Sensor Wrap Attachment; this mockup provided an intuitive design that did not decrease the integrity of the walker. On the other hand, the Brace Attachment had to be tested for durability and did not meet our standards, therefore it is not a viable option. We learned that best display attachment was the rolling clamp. This provided both ease of use and stability. The screw clamp was difficult to work with and the Velcro failed to hold the design. Lastly, we determined that the sensor sheet was an unreliable way to measure the force; it was incapable of measuring large forces. As a result, we must look for another force sensor.

Appendix M: Mockup Testing Report

This appendix outlines the process of testing our mockups before user testing and the feedback we received. The results are organized into tables to display the records.

Purpose

Our team created four mockups to test a design that aim to help cardiac patients and physical therapists monitor how much force a cardiac patient is exerting on the walker through their hands. The mockup designs consisted of objects tailored specifically for one or two requirements described by the project definition. Our objective was to test each mockup to find which ideas worked best. Mockup testing allowed us to see what necessary adjustments should be made to improve the designs for user testing.

Methodology

Testing took place on May 2nd, 2019 in our classroom in the Ford Building, and it lasted approximately one hour. The testers were our fellow classmates, and there were different testers for each mockup.

Mockup 1: Brace attachment

The brace attachment is primarily made of two PVC tubes, with a metal walker clamp attached onto the side of each of the tubes. A “mock” handlebar is made out of wood, consisting of two smaller cylinders of wood that slide into the PVC tube, with a flat wooden section at the top representing the handlebar grip (Figure 1).

Figure 1: Brace attachment

For mockup testing, we randomly chose 4 people from the classroom from other groups. Tester information for each person is included in Table 1.

Table 1: Tester information for mockup 1 - Brace attachment

	Tester 1	Tester 2	Tester 3	Tester 4
Age	17	19	18	19
Height	5’4”	5’8”	5’2”	6’
Gender	Female	Male	Female	Male
Have you ever used any walking aids before?	No	No	No	No
Which hand is your dominant hand?	Right	Right	Right	Right

Test methodology for mockup 1 - Brace attachment

Unfortunately, mockup 1 faced operational setbacks immediately before mockup testing. The metal clamps on the sides of the PVC tubes became detached from the tube and some planned tests had to be cancelled. However, other tests were able to be completed and are outlined below.

Testers were asked to try placing the metal clamps onto the side of the Guardian walker and to comment on how easy the clamps were to attach. Testers were originally planned to test the secureness of the attachment by trying to push down or walk with the mock handlebar, but since the clamps were not attached to the PVC tubes, they were asked to comment on the general secureness of the clamp onto the walker. Finally, testers were asked to try detaching the metal clamps from the side of the walker and to comment on how easy it was to detach.

Mockup 2: Visual display and attachment

The visual display and attachment mockup consists of three different screens and three different ways to attach the device. The different types of displays available are a small (less than 1” tall), medium, and larger (9” tall) size screen. The different methods to attach the displays are the Velcro attachment, a screw clamp, and a rolling clamp. As shown in Figures 2, 3, and 4, the attachments are taped onto different screens.

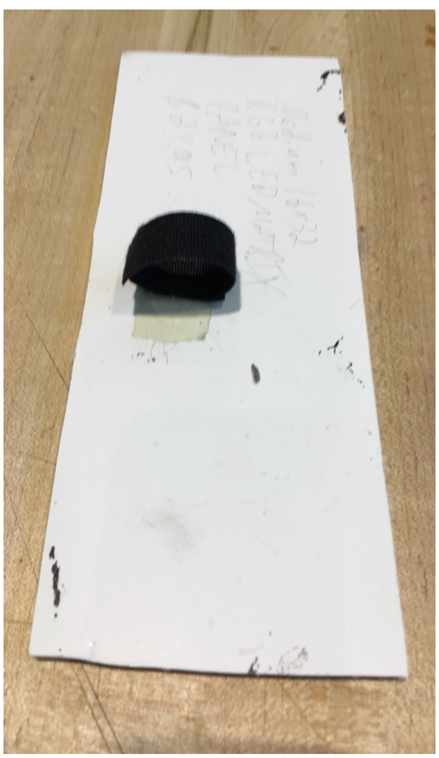


Figure 2: Velcro

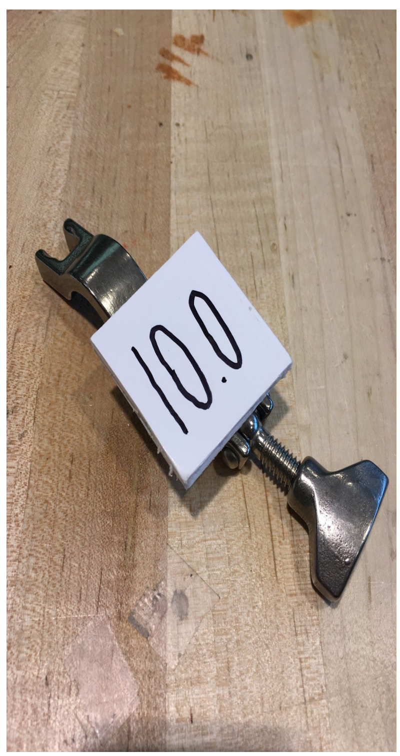


Figure 3: Screw clamp

Figure 4: Rolling clamp

Information about the testers is seen in Table 2.

Table 2: Tester information for mockup 2 - Visual display and attachment

	Tester 1	Tester 2	Tester 3	Tester 4
Sex	M	M	Male	Male
Height (feet/in.)	6’	5’10”	5’9”	5’8”
Weight (lbs.)	135	160	150	140
Age (years)	19	19	19	18
Have you used a walker before?	no	no	no	no
Hand Size (in.)	7.5”	7.25”	7.5”	7.0”

Test methodology for mockup 2 - Visual display and attachment

The test consists of two parts. In the first part, the testers put used each of the three attachments and put the displays onto the walker. In the second part, the user would observe the display from varying distances and angles. A total of four tests were conducted.

Part A. Attaching the display

1. Testers tried attaching one of the following attachments (Velcro, screw clamp, rolling clamp).
2. Testers were asked the following questions:
    a. Using a scale of 1-10 (10 being the easiest), how sturdy was the attachment?
    b. Using a scale of 1-10 (10 being the easiest), how easy is it for you to attach the device to the walker?
    c. Are there any features of this mockup that you liked/disliked?
3. Testers took off the attachments.
    a. Using a scale of 1-10 (10 being the easiest), how easy is it for you to detach the device from the walker?
4. The tester would then move on to the next attachment until there are none left.

Part B. Viewing the display

1. The screen would be attached to the walker.
2. The tester stands about 8 feet away from the walker.
3. The test administrator then asks if the tester is able to see the display.
    a. The test administrator tested different angles and sections of the walker.

4. The test administrator then asks if the tester believes the display would possibly interfere with walking while using the walker.

Mockup 3: Sensor sheets

The sensor sheet mockup is constructed from two leather sheets. The two sheets are meant to model conducting sheets that form a capacitor. From the two ends of the capacitor two insulated wires protrude outwards. These are meant to model the electrical leads of the piezoelectric sensor. The mockup leads are glued onto each sheet. In addition a mockup microprocessor was created to complete the circuit. See Figure 5 below. Two separate sensor sheets were created with different geometries to allow for comparison. See Figures 6 and 7.

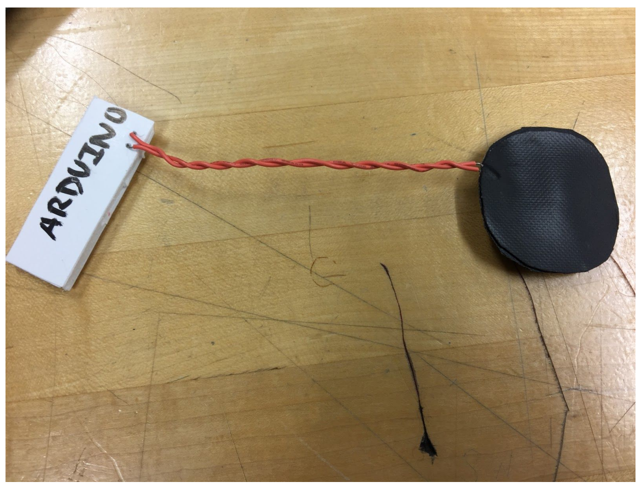


Figure 5: The complete mockup circuit

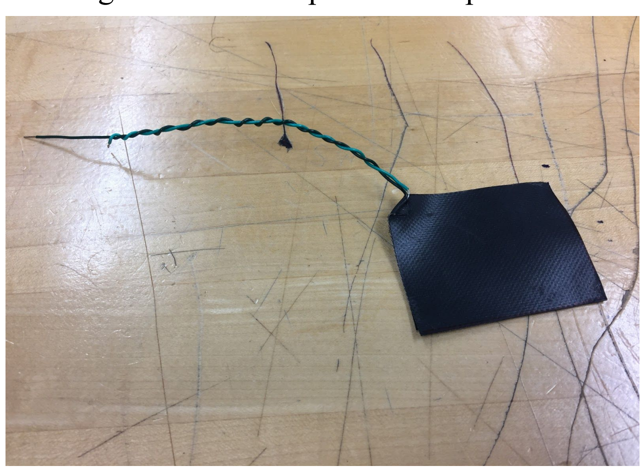


Figure 6: Square sensor sheet

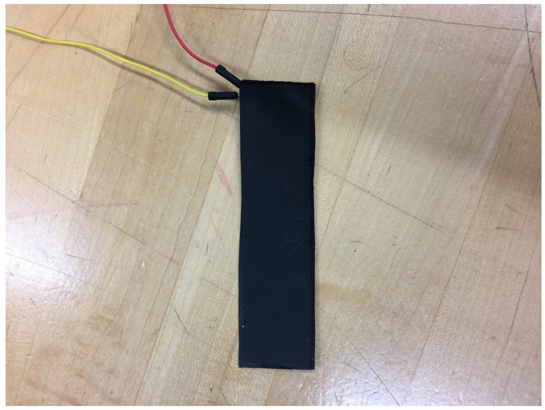


Figure 7: The rectangle sensor sheet

Table 3: Tester information for mockup 3 - Sensor sheet

	Tester 1	Tester 2	Tester 3	Tester 4
Age	19	19	19	19
Gender	Male	Male	Male	Male
Hand Length (in.)	7.5	7	7.5	7.5
Hand Width (in.)	4	3.5	3.5	3.25

Test methodology for mockup 3 - Sensor sheet

Testers were first asked to look at the sensor sheet and then asked where on the walker they would see the sheet most “naturally.” They were then asked to put their weight on the sheet at the location of the walker they specified. During exertion, the testers were asked about concerns they may have or any changes in geometry they would recommend. If the tester recommended a different geometry, that geometry would be then be tested and the same questions asked. To conclude, the tester was asked for final remarks that may not have been covered during testing.

Mockup 4: Sensor wrap attachment

The sensor wrap attachment mockup is made of a thin rubber sheet, a thin foam sheet, Krazy glue, two 0.5’’ by 4.5’’ Velcro straps, and black string in place of the wires of the sensor (see Figure 8).
For mockup testing, we randomly selected 4 classmates (2 male and 2 female students) and asked them to test our design. Information about the testers is included below in Table 4.

Figure 8: Sensor wrap attachment

Table 4: Tester information for mockup 4 - Sensor wrap attachment

	Tester 1	Tester 2	Test 3	Tester 4
Age	19	19	17	18
Gender	Male	Male	Female	Female
Height	6’ 1”	5’ 8”	5’ 4”	5’ 2”
Weight	170 lbs.	150 lbs.	160 lbs.	130 lbs.
Hand size	7.5” long 4” wide	7” long 3.5” wide	6.5” long 3.5” wide	6.5” long 3.5” wide
Hand/arm injury?	No	No	No	No
Leg injury?	No	No	No	No
Used a walker before?	No	Yes	No	No
Dominant hand	Right	Right	Right	Right

Test methodology for mockup 4 - Sensor wrap attachment

The mockup testing session aims to test the following:

- Ease of use
- Comfort

First, the demographics of the testers were collected (see Figure 9). Testers were given a 1 minute introduction on the mockup in terms of its main function and materials. Then they were asked to put on the device without instruction. The time they took to attach the device for the first time was recorded (see Table 4). After the device was put on, they were asked to answer the following questions:

- On a scale of 1-10 (with 1 being hardest and 10 easiest), how easy or hard is it to use this device? Why did you give this score?
- On a scale of 1-10 (with 1 being the most uncomfortable and 10 the most comfortable), how comfortable is it to use the walker with this attachment? Why did you give this score?

The testers were then asked to detach the device. The time they used to detach the device was recorded (see Table 4). One final feedback question was asked:

- If we were to proceed with this design, what is the biggest problem you foresee in this design?

Figure 9: Measuring the hand size of the testers

Results

Below are the results of each of the tests conducted on the four mockups. Table 5, 6, 7, and 8 show the testing results for the brace attachment, visual display and attachment, sensor sheet, and sensor wrap (Mockups 1, 2, 3, 4) respectively.

Table 5: Test results for mockup 1 - Brace attachment

(1-10 scale)	Tester 1	Tester 2	Tester 3	Tester 4	Average
How easy was it to attach? (easy = 10)	10	10	8	7	8.75
How secure was the attachment? (secure = 10)	2	5	6	9	5.50
How easy was it to detach? (easy = 10)	10	10	7	8	8.75
How easy was it to walk with the new handlebars? (easy = 10)	-	-	-	-	-
Notes/ Suggestions	Find a way to attach the clamps to tubes, make the handlebar wider, and make the handlebar more comfortable.	Add an additional set of clamps at the top of the tube to prevent rotation of the clamps.	Attach a fit-able flat surface to the tube to easily glue the clamp. Keep the clamps because they are secure and convenient.	Keep the clamp because there is good tension on the clamp. Grind the side of the PVC tube to create a flat surface for attachment of the clamps, overall a very feasible idea.	-

Table 6: Test results for mockup 2 - Visual display and attachment

Scale [1-10] yes or no	Tester 1	Tester 2	Tester 3	Tester 4	Average
Velcro: Ease of use (10 = easy)	3	0	5	4	3
Velcro: Sturdiness (10 = sturdy)	7	10	9	8	8.5
Screw clamp: Ease of use (10 = easy)	10	10	10	10	10
Screw clamp: Sturdiness (10 = sturdy)	2	7	6	5	5
Rolling clamp: Ease of use (10 = easy)	9	6	9	8	8
Rolling clamp: Sturdiness (10 = sturdy)	9	10	7	7	8.25
Small (able to see, interferes)	yes, no	yes, no	yes, no	yes, no	-
Medium (able to see, interferes)	yes, no	yes, no	yes, no	yes, no	-
Large (able to see, interferes)	yes, no	yes, no	yes, no	yes, no	-
Additional Notes	Did not like the Velcro	Liked the rolling clamp	Liked all but Velcro	Said all displays work	-

Table 7: Test results for mockup 3 - Sensor sheets

	Tester 1	Tester 2	Tester 3	Tester 4	Dominant Consensus
Location	Handle	Handle	Handle or Stud Leg	Handle	Handle
Size	Too small	Too small	Too small	Too small	Too small
Geometry	Circle	Rectangle	Circle	Circle	Circle
Microprocessor Location	Side Bar	Center Bar	Platform on Center Bar	Side Bar	N/A
Additional Notes	N/A	Wires need to be longer to accommodate different walkers.	Make flat platform for the Arduino	N/A	N/A

Table 8 summarizes the results of the mockup testing for the sensor wrap attachment. The foam layer was half-ripped after the first tester used it. However, the damage was not significant and the following testers were still able to use it. Potential influence of on the test results were further discussed in the analysis section.

Table 8: Test results for mockup 4 - Sensor wrap attachment

Questions	Tester 1	Tester 2	Tester 3	Tester 4	Averag e
Time used to attach the device (seconds)	6.52	9.22	9.71	4.13	7.40
Time used to detach the device	2.00	2.61	2.72	1.36	2.17
How easy is it to use? (easy=10)	10	8	9	9	9
Comments on ease of	The outer surface is a little	The handle pads is cylinder. It is	The device does not impede the	The device slides across the	N.A.

use	sticky. The outer surface does not absorb sweat.	different from the original shape of the handle bar.	use of the walker at all.	PVC tube. More frictional force on the inner surface is needed.	
How comfortable is it to use? (comfortable =10)	9	7	7	7	7.5
Comments on comfort	The device slides across the handle bar slightly, but this should not be a big issue.	The device is too thick for the patient to wrap their hands around it easily.	The outer surface is not very nice. Possible alternatives are plastic with no pores, or thick rubber sheets. In addition, Velcro is too thick, it increases the diameter of the handle bar drastically.	The outer foam layer can be thicker to increase comfort. A possible idea is to add indentation to increase comfort and frictional force. Also, a possible material to consider is heavy neoprene rubber sheets.	N/A
General feedback	The outer surface should be able to absorb sweat. Also, The accuracy of force measurement needs further testing.	It might be a good idea to coat the force sensor with rubber directly instead of wrapping it with a pad. In addition, stronger Velcro is needed. They can be sewn onto the bad. Inner surface should be more frictional and	Overall, the device is very non-invasive. One possible improvement is to make the wrap narrower, minimizing its influence on the use of the walker. This also saves materials. Another thing to consider is how to clean the	The idea of the using Velcro straps is smart.	N/A

		the idea of getting rid of the grip force needs further testing.	device effectively.		

Analysis

Brace attachment

The concept of attaching an additional set of handlebars, braced by the walker clamps, overall seems feasible but requires a lot of improvement. The bright point of the mockup was the walker clamps, as testers largely agreed that the clamps were easy to use for attachment and detachment to the walker with an average of 8.75 out of 10 rating for both where a higher rating represents ease of use.

The most apparent missing feature of the mockup was the inability to have the clamps attached onto the PVC tubes so that the mock handlebar could actually be attached to the walker. Because of this lacking feature, we were unable to test if the walking with the brace attachment is uninhibited. The first step to improving this mockup will be to finding a way to attach the clamps to the PVC tubes— this will likely be done by sanding sections of the tube to provide a flat surface to glue the clamps to as per the suggestion of Tester 4.

Testers also gave an average 5.5 out of 10 for the secureness of the clamp onto the walker; a major concern between testers was that the clamp was slightly too loose, and the clamp could rotate along the walker, causing the handlebar to be too unstable for use. One possible solution to this problem is to add an additional set of two clamps to the PVC tubes and then have four total clamps attach to the walker, with two clamps next to the original rubber handlebar grip and two clamps on the sidebar beneath. This would make the brace attachment much more secure by distributing the weight and also preventing unnecessary rotation of the mock handlebar during use.

Additional features to consider include making the mock handlebar more comfortable and more akin to the original rubber handlebar, and also finding a way to prevent the mock handlebar from being pulled up out of the PVC tubes.

Visual display and attachment

In the first part of this test, we were checking the different types of ways to attach the displays onto the walker are viable. What we were looking for in this test is a balance between ease of attaching or detaching the display and how sturdy the attachment would hold the display on the walker. During testing, we saw that the Velcro was very easy to attach, yet was not sturdy whatsoever (the large display would naturally just fall down). The screw clamp was the sturdiest of all the displays, but was the most difficult to attach/detach or adjust (it took the longest time to adjust because of the screw). The rolling clamp was both sturdy and easy to adjust. As well, the rolling clamp was chosen by all testers as the best option.

The second test focused on the displays; the options were small, medium, and large. All of the displays were easy to see from a distance. However, the large display gave some concern as to whether or not it would interfere with walking. This is because the large display takes up possible space that the users hand might need. As a result, either the medium or small display should work according to the testers.

Sensor sheet

There seems to be general agreement that the sensor sheets are too small to fit the palm of most hands. An important point brought up was that some users may exert forces through a specific part of their hand that may not be caught by the sensor sheet. Thus, the sheet must be larger to cover all the possible area that the hand might land on. Secondly, the geometry of the circle is not ideal, but making a more ergonomic sheet will cost too much. A circular piezoelectric sensor is $ 0.95 while a rectangular piezoelectric sensor is rare to find and expensive. Thus, the general consensus was to use a circular sheet. Lastly, the microprocessor location is still ambiguous. There were suggestions to put the sheet on a small, flat platform near the center of the walker. This platform would also allow for a place to put the power supply.

With this feedback, we plan on remaking the circular sensor sheet mockup so that it spans a larger surface area. Also, we plan on attaching longer wires to the sheets so that we may present multiple options for where the microprocessor may be mounted.

Sensor wrap attachment

During the mockup testing for the sensor wrap attachment, we found that the device was easy and convenient to use, as the device scored an average of 9 out of 10 in terms of the ease of use (see Table 8). We can also safely reach this conclusion by the fact the among the 4 testers, it takes an average of 7.40 seconds to attach the device and 2.17 seconds to detach the device (see Table 8). For some testers, the time taken to put on the device was long than expected due to the broken foam layer. Nevertheless, all testers were able to figure out how to use it without instructions in less than 10 seconds. This shows that the design is user friendly.

In terms of comfort, however, the device scored an average of 7.5 out of 10 (see Table 8), meaning there is room for improvement. We received plenty of valuable suggestions centered on the materials of the outer layer and inner layer. For the outer layer, we found that the current foam layer too thin. The texture is not comfortable enough and it does not absorb sweat, which can be important for patients undergoing gait trainings. Synthesizing the comments given by the testers, we found out that the outer layer should not be too thin because it is not comfortable for the user to use. Also, the layer should not be so thick that it becomes difficult for the user to wrap their hands around the device. We will strive to find a delicate balance between the thickness and comfort of this design. The increase in diameter of the in the future iterations of this mockup. In terms of the shape and dimension of this design, we had some interesting ideas such as to imitate the original shape of the handle bar or to introduce indentation to provide extra comfort. Potentially we could also look into narrowing the device to minimize its influence on the original walker and save materials at the same time. For the inner layer, we will increase friction force by either introducing indentation or changing to a different material to provide the device from sliding across the handle bar.

Additionally, in the future, more tests should be designed to test if this mode of measurement gives the accurate downward force measurement.

Conclusions

Overall, from the mockup testing session, the more compact designs (Visual display attachment, Sensor sheet, Sensor wrap attachment) were preferred over the larger design (Brace attachment). The strengths of the first three mockups include that they do not compromise the integrity of the walker and can withstand heavy use while providing an accurate measurement. However, each mockup has its own shortcomings that can be improved during future iterations. For instance, finding a more stable way to attach the brace attachment to the walker so that it will not fall off if too much force is applied or if force is applied in unexpected directions. Furthermore, we plan to implement a sensor sheet that fully encompasses the sensor wrap to account for all force applied on the walker by the users hand.

An interesting observation is that we could combine certain aspects of each mockup to optimize our overall prototype. For example, sensor sheet can be applied to both the sensor wrap and brace attachment mockups; this would provide full coverage for sensing the force. As well, those two mockups will also require a display, which is provided in the visual display and attachment.

Limitations

This round of mockup testing was limited in that the testers were not cardiac patients. They were healthy young adults with no motor impairment. Thus, whether the mockups were actually well-suited to the requirements in the project definitions is ambiguous. A limitation specific to the sensor sheet was the fact that it was not actually conducting, so we could not measure an electrical signal to see that the sensor is indeed working. For the visual display and attachment mockup, none of them were actual displays, but rather cutouts in the shape of the display. The displays might have different levels of brightness, making it either harder or easier to see.

Appendix N: Instructions For Construction

The following report describes the construction process for the GaitKeeper. The first section lists the materials and tools required for building the GaitKeeper. The next ten sections explain the major steps of construction of the design:

1. 3D printing of the display box
2. Attaching the display box to the clamp
3. Attaching parts with Velcro
4. Prepping the load cells
5. Creating the load cell circuit
6. Constructing the PCB unit
7. Assembling the display circuit and program
8. Elevating the PCB in the display box
9. Making the display box hinge
10. Combining the load cells with the handle wrap

Tools and Materials

Tools we used for construction include the soldering clamp, the soldering iron, PCB pins, 3D printer, scissors, epoxy, superglue, hot glue, electric tape, the mill, the laser cutting machine, and gluing clamps. The materials we used can be found in Table 1 below.

Table 1: List of materials

Material/Component	Specification	Quantity
Microprocessor	Arduino Nano	1
PCB board	3.6” x 2.8” x 0.05”	1
Load Cells	1.4” x 0.8” x 0.2”	4
Color TFT Display	2.2” x 1.4” x 0.25”	1
Walker Handle Cover	4” x 7”	2
Power Pack	2400 mAh, 4” x 1” x 1”	1
Velcro	NA	NA

Shellac Wire	36”	1
Wire Cover Sleeve	30”	1
Nuts	8-32	2
Bolts	8-32 0.75”	2
Washers	8-32	2
Transparent Acrylic Sheet	8” x 4” x 0.25”	1
Plastic Hinges	1.5” x 1.5” x 0.2”	2
Plastic Filament	NA	NA

Note: Consult Bill of Materials in Final Report for full list of products ordered.

1. 3D printing the display box

Figure 1 below outlines the CAD drawing of the display box in SolidWorks. 3D print the box with a filament of plastic using 20% in-fill. The print job requires 10 hours.

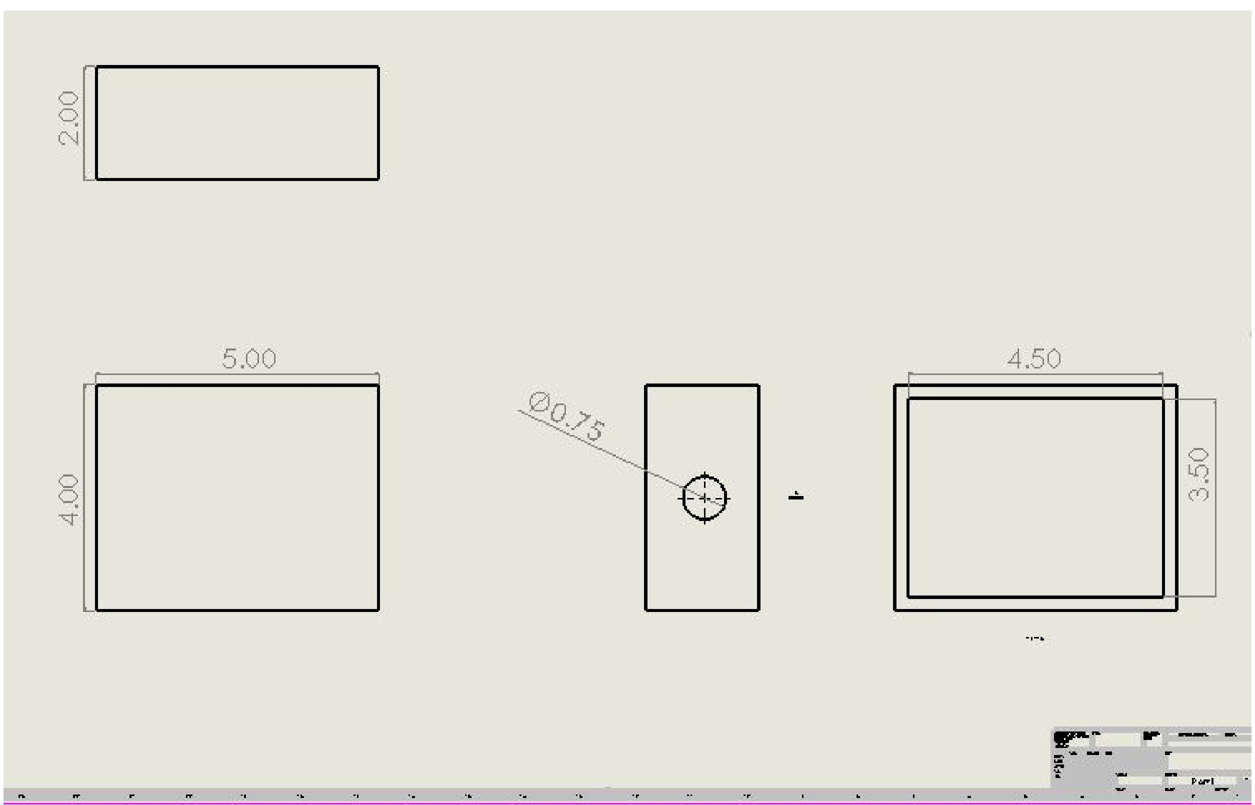


Figure 1: CAD of the display box

2. Attaching the display box to the clamp

Now that the 3D print is complete, move the station to the mill machine. Drill two holes separated by 1.5 inches from the center of box of diameter 0.119”, and then debur the newly drilled holes (see Figure 2).

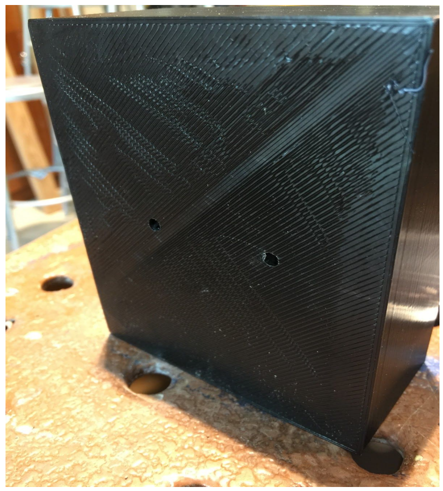


Figure 2: Two holes drilled into the box

Grab two 8-32 0.75 inch bolts and place them through the holes in the clamp (see Figure 3).

Figure 3: Clamp with bolts

Place the clamp with bolts into the two holes in the box (see Figure 4). Place washers on the ends of the both bolts.

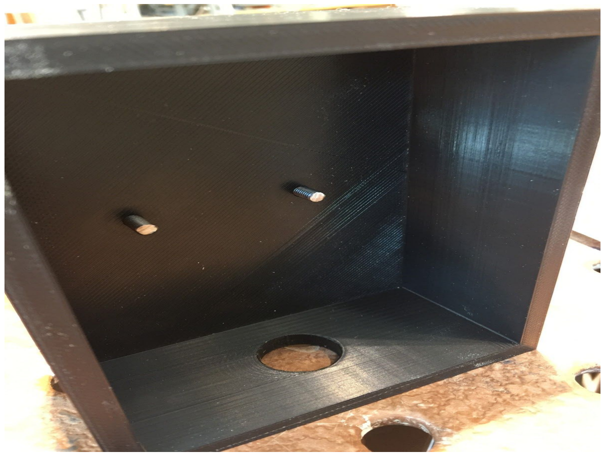


Figure 4: Bolts placed through the clamps and the box

Place nuts on both bolts (see Figure 5). The display box is now finished (see Figure 6).

Figure 5: The clamp is secured via nut, bolt, and washer.

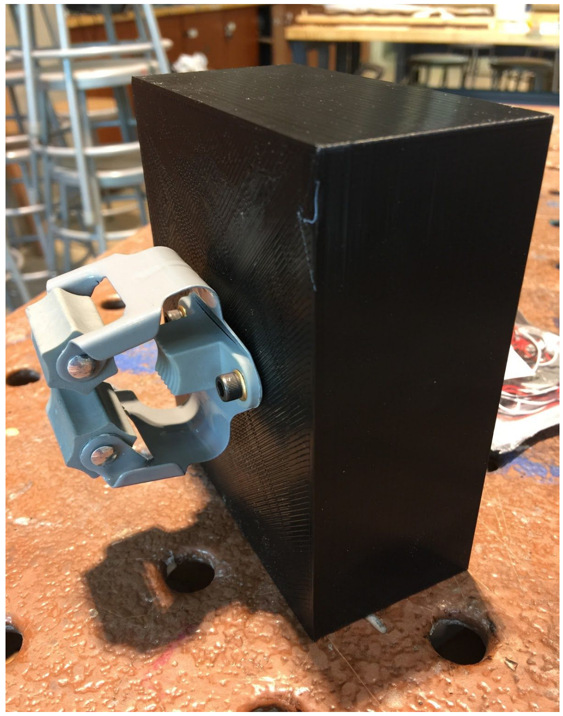


Figure 6: The finished box with clamp

3. Attaching parts with Velcro

Using epoxy, glue one side of the Velcro to the battery pack. With the opposite side of the Velcro, glue with epoxy to the side of the display box of dimension 5” x 2” (see Figures 7 and 8).

Figure 7: Epoxy chemical bond

Figure 8: Velcro on battery

4. Prepping the load cells

The force sensors require a specific circumstance to sense the force; the inner ring must move relative to the outer ring (see Figure 9). Laser cut small rings of acrylic (0.6” x 0.1” x 0.25”) and epoxy them onto the outer ring of the load cells (see Figure 10).

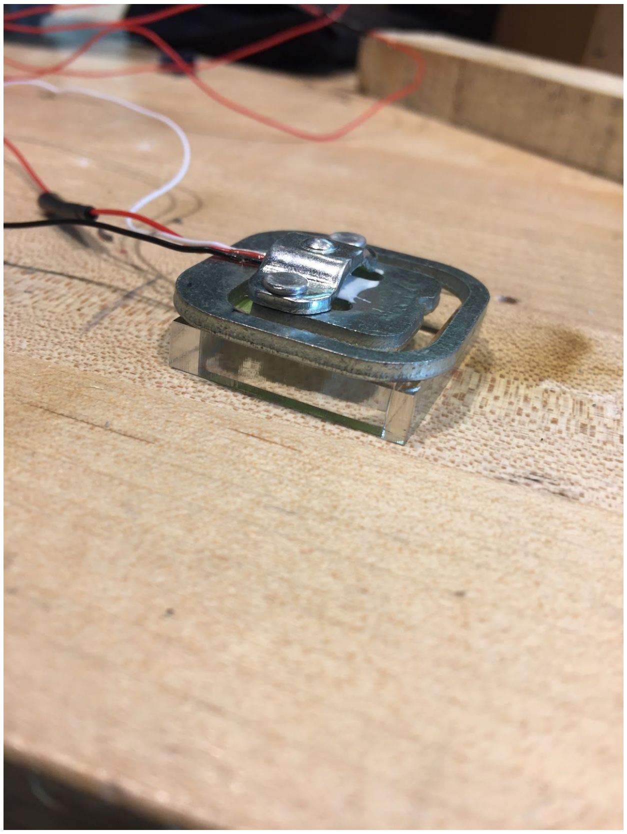


Figure 9: Load cell with ring

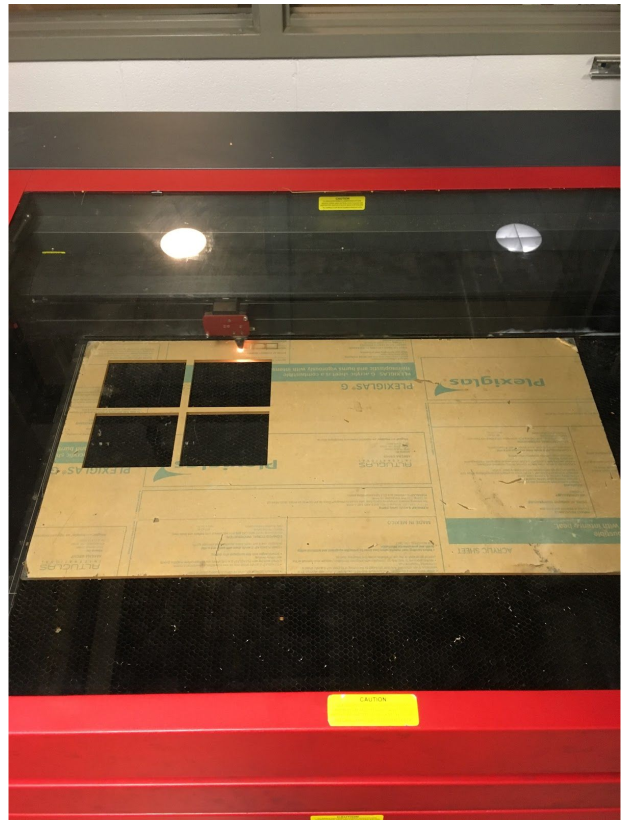


Figure 10: Laser cutting acrylic

5. Creating the load cell circuit

The following circuit diagram shows how the four sensors need to be connected (see Figure 11). Sensors connected by the same white wire are attached onto the same handle (either left or right). Note: Feed all wires through the hole of the display box before soldering (see Figure 12).

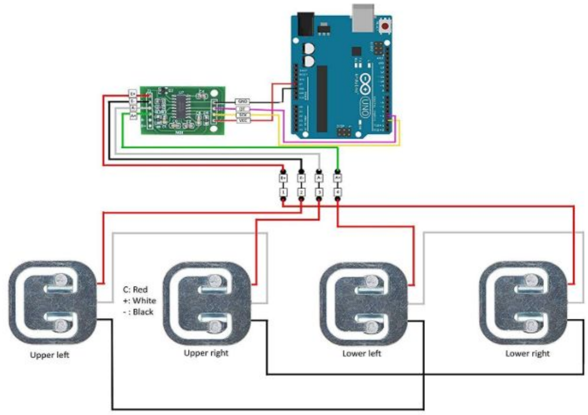


Figure 11: Circuit diagram

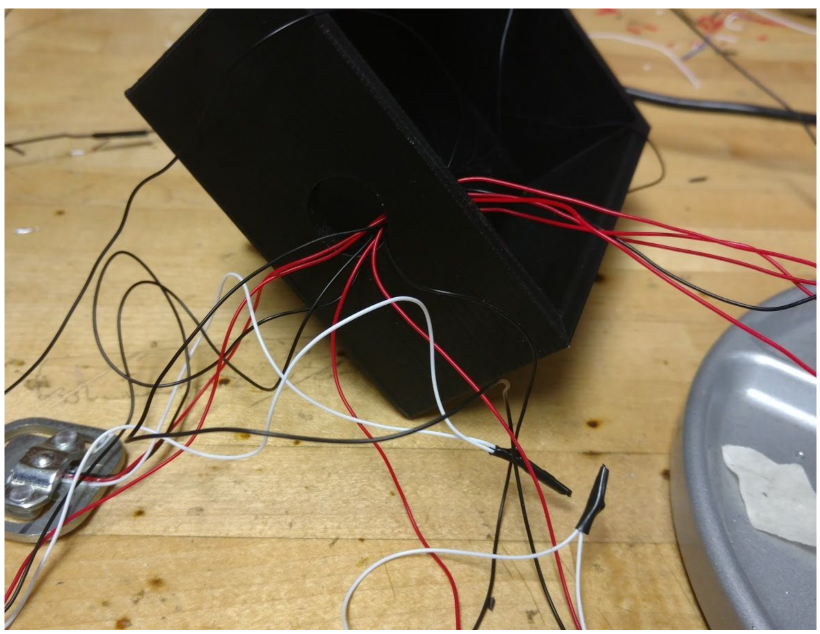


Figure 12: Wire management

Solder the wires together and connect them to the Arduino as shown in the circuit diagram of Figure 11.

6. Constructing the PCB unit

Solder the display, Arduino microprocessor, and the analog to digital converter (ADC or load cell amplifier) onto the PCB board using pins(see Figures 13, 14, and 15).

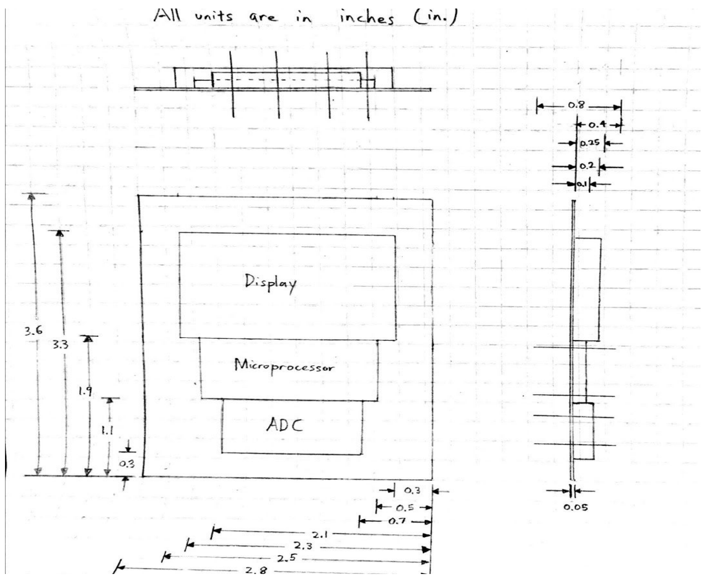
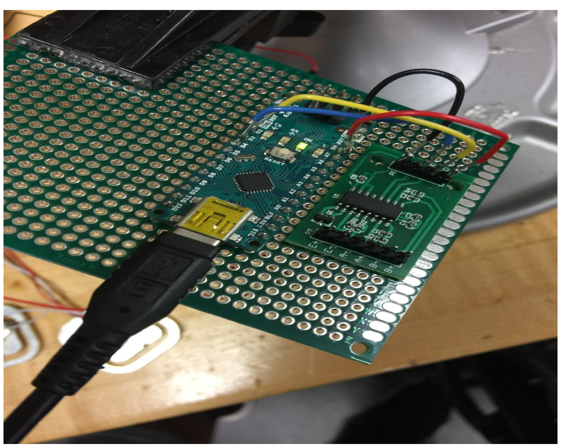


Figure 13: Positioning components on the PCB



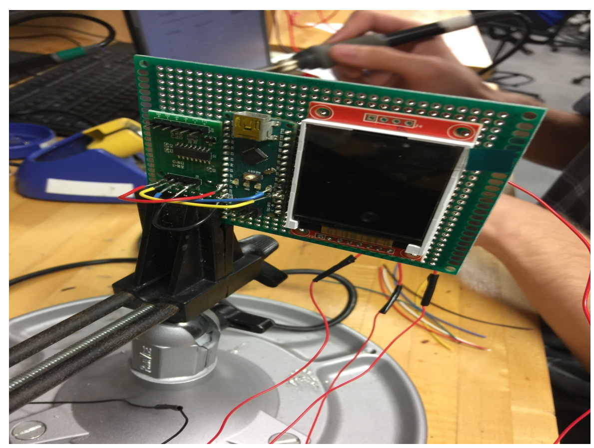


Figure 14: Amplifier and Arduino on PCB

Figure 15: Display on PCB

The amplifier will take in the signal sent out from the force sensors, the Arduino will then calibrate that force, and then this information will be transferred onto the screen.

7. Assembling the display circuit and program

Connect the display circuit to the Arduino with wires in the manner shown in Table 2. A schematic for the Arduino Nano and the 1.8 TFT display are shown in Figures 16 and 17, showing where the wires connect. Then program the display to show a calibrated sum of the forces detected by the load cells (see Figure 18). Set the sampling rate of the sensor to 500 ms.

Table 2: Display to Arduino configuration

1.8 TFT Display	Wiring to Arduino Uno
LED	3.3 V
SCK	13
SDA	11
A0 or DC	9
RESET	8
CS	10
GND	GND
VCC	5 V

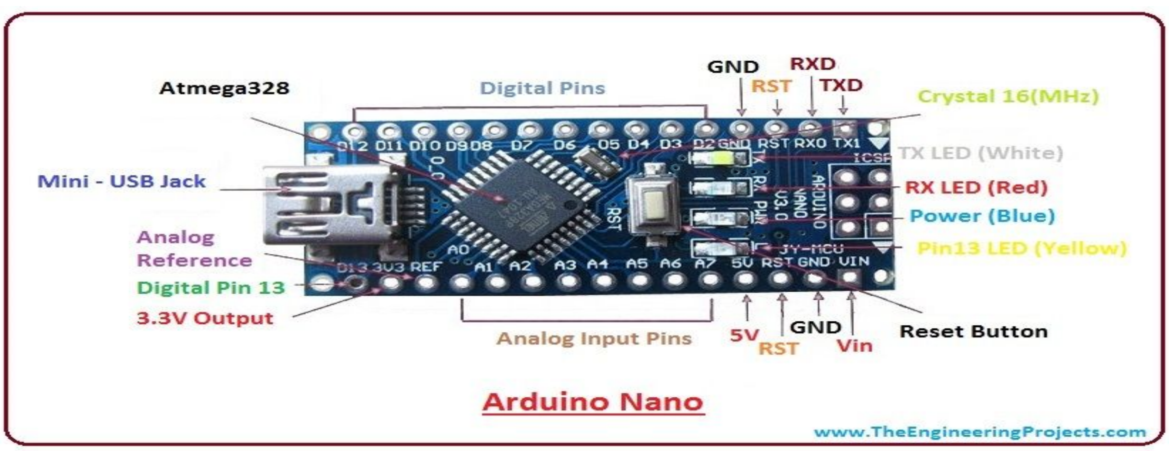


Figure 16: Arduino Nano schematic

Figure 17: 1.8 TFT display with pins

The code for the microprocessor is shown in Figure 8 below. Note that the calibration constant may vary for different load cells.

```
// pin definition for Arduino UNO
#define cs   10
#define dc   9
#define rst  8


// create an instance of the library
TFT TFTscreen = TFT(cs, dc, rst);
char var[4];
#define DOUT  3
#define CLK  2

HX711 scale;

float calibration_factor = -7050; //-7050 worked for my 440lb max scale setup

void setup() {
  Serial.begin(9600);
  Serial.println("HX711 calibration sketch");
  Serial.println("Remove all weight from scale");
  Serial.println("After readings begin, place known weight on scale");
  Serial.println("Press + or a to increase calibration factor");
  Serial.println("Press - or z to decrease calibration factor");

  scale.begin(DOUT, CLK);
  scale.set_scale();
  scale.tare(); //Reset the scale to 0

  long zero_factor = scale.read_average(); //Get a baseline reading
  Serial.print("Zero factor: "); //This can be used to remove the need to tare the scale. Useful in permanent scale projects.
  Serial.println(zero_factor);

  //initialize the library
  TFTscreen.begin();

  // clear the screen with a black background
  TFTscreen.background(0, 0, 0);
  TFTscreen.stroke(0, 255, 255);
  TFTscreen.setTextSize(2);
  TFTscreen.text( "Force in lbs: ", 0, 0);
}

void loop() {

  scale.set_scale(calibration_factor); //Adjust to this calibration factor

  Serial.print("Reading: ");
  Serial.print(scale.get_units(), 1);
  Serial.print(" lbs"); //Change this to kg and re-adjust the calibration factor if you follow SI units like a sane person
  Serial.print(" calibration_factor: ");
  Serial.print(calibration_factor);
  Serial.println();

  if(Serial.available())
  {
    char temp = Serial.read();
    if(temp == '+' || temp == 'a')
      calibration_factor += 10;
    else if(temp == '-' || temp == 'z')
      calibration_factor -= 10;
  }
    TFTscreen.stroke(0, 255, 255);

    String ans = String(2.2/9 * abs(scale.get_units()));
    ans.toCharArray(var, 4);
    TFTscreen.setTextSize(4);
    TFTscreen.text(var, 50, 50);
    delay(500);
    TFTscreen.stroke(0,0,0);
    TFTscreen.text(var, 50, 50);
}
```

Figure 18: The code used for the Arduino Nano

8. Elevating the PCB in the display box

Laser cut two transparent acrylic rectangular prisms of dimension 1” x 0.75” x 0.25”. Tape these prisms to the back of the PCB board so that they act as supports to elevate the PCB from the bottom of the display box. Then tape each support to the bottom of the display box (see Figure 19).

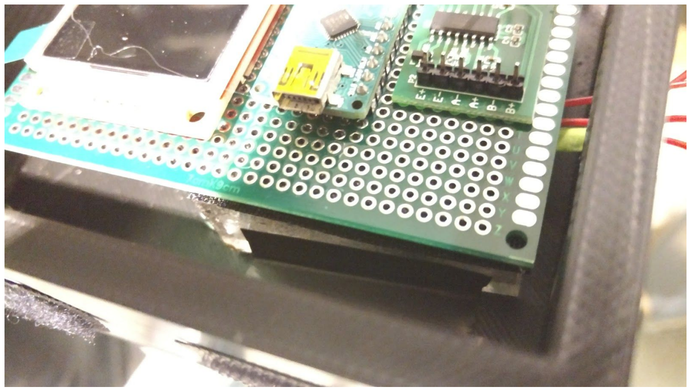


Figure 19. The supports elevating the PCB unit

9. Making the display box hatch

Laser cut a transparent acrylic rectangular prism of dimension 5” x 4” x 0.25”. This represents the transparent face of the display box. On the long side of the acrylic sheet, glue two plastic hinges symmetrically (5/3” and 10/3”). Glue the other ends of each hinge onto the long side of the display box symmetrically (5/3” and 10/3”). See Figure 20.

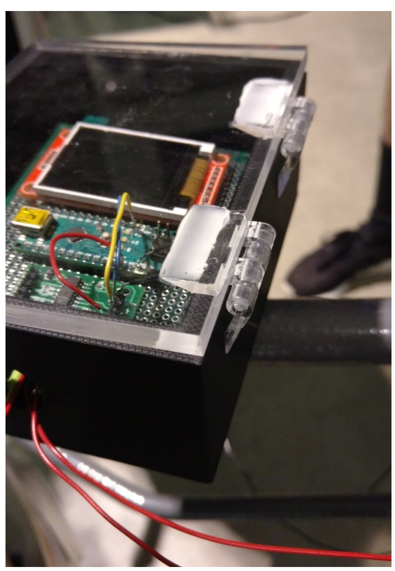


Figure 20. Finished display box hinge

10. Combining the load cells with the handle wrap

Finally, place the sensors into the handle wraps and secure them via tape (see Figure 21).

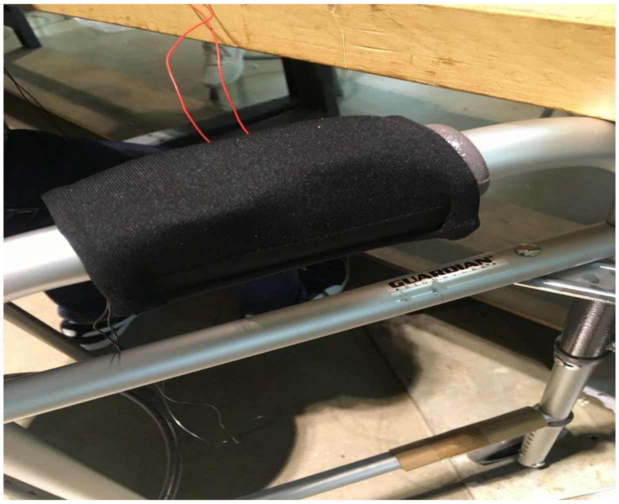


Figure 21: Handle wrap with sensors inside

The following picture shows how the full prototype looks on the walker.

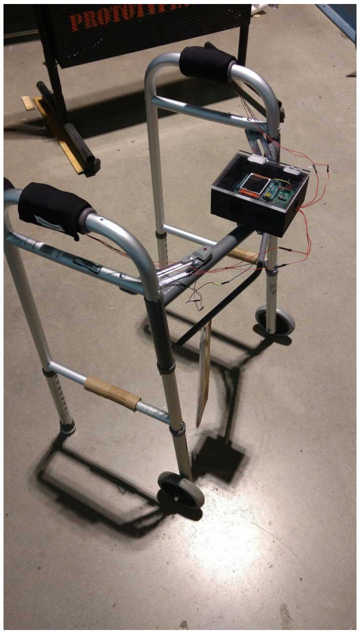


Figure 22: Complete prototype on walker

Appendix O: Meetings with Prototyping Specialists

Table 1 below summarizes the findings during our talks with the prototyping specialists.

Table 1: Meetings with prototyping specialists

Date	Team Members Present	Prototyping Specialist's Name	Topic	Decisions Made	Next Steps
May 16	Malav, Sherlyn	Heidi	Attachment of sensor	Purchase a more comfortable hand cover and place the sensors in between the padded handle covers.	Purchase the desired handle covers and assemble the sensors onto them
May 16	Kevin, Sherlyn	Mike	Location of sensors	Decided the location of the sensors.	Place sensors flush with the ball of the hand
May 16	Kevin, Sherlyn	Mike	Grip Force	Ignore grip force in the measurement but introduced a safety factor	Code the force measurement and introduce a safety factor by overestimating the actual reading
May 23	Malav	Marchuk	Microprocessor	Buy the authentic arduino, a clone has not been safety tested.	Buy authentic arduino from amazon