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Therawalk: Therapeutic Walking Assistant

Report 3

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Abstract

The orthotic device to be designed, currently named the “Therawalk”, is a therapeutic walking assistant. The goal of the project is to create a versatile orthotic device that will aid patients in mobility and provide relief for ailments such as arthritis. Therawalk will incorporate thermotherapy and vibrational components to help alleviate the pain caused by arthritis. This will benefit patients who need the aid of a cane, but find the use of one difficult due to the pain in their hands or who struggle with maintaining grip on the cane handle.

Development of the Therawalk will focus primarily on the integration of electrical components such as the vibration motors and heart rate sensor to a mechanical cane design. Additionally, the cane design will be revisited to enhance aesthetic characteristics, and ensure optimal integration of all the cane’s functionality, as well as leaving room for future improvements. The goal of this project is to produce a smart orthotic device that will help the patient's mobility in both clinical and home settings. Therawalk will have components to deliver thermotherapy and vibrational therapy, as well as additional electrical components such as a flashlight and heart rate sensor.

Chapter 1 - Introduction

1.1 - General Problem

The rationale behind the Therawalk lies in the fact of its need in today's market. There are nearly 2.1 million people living with limb loss in the U.S.A and that figure is astoundingly going to double by the year 2050 [1]. The knees and hips are the largest joints in the body and often feel the bulk of cyclic loading throughout a human's life. Dr. Donald T. Reilly, an orthopedic surgeon at New England's Baptist Hospital, recently spoke of a patient. The patient was an artist and his canvas were large pieces of wood which he carved into elaborate masterpieces. He mentioned to Dr. Reilly prior to surgery that "you guys must have fabulous tools". Dr. Riley replied that "they are primitive compared to what you have…I have something called healing. In orthopedic surgery, the surgery starts the process. Healing finishes it" [2]. Increased demand from amputees, aging baby boomers, and matured joints, the therapeutic cane serves to be an integral side-kick of the healing process.

First and foremost, it plays the role of a mechanical support that can alleviate the stress on the lower extremities. The much-needed support is crucial to reduce the pressure on the knees and hips after surgery or injury. What separates it from the rest is through its connectivity, it allows the therapist to interact with the patient day in and out. The therapist can remotely monitor and advise the patient about their healing process without physically being present. Using the 'Internet of Things' the Therawalk can sense how the therapeutic healing process is working which is beneficial for the patient and therapeutic process. Therawalk will better support a patient population that is in need of a crutch.

1.2 - Project Goals

The primary goal of the Therawalk is to design and build an electronic programmable cane that connects a patient to their therapist anytime and anywhere by using sensors, a microcomputer, and wireless technology. There are six secondary goals of this project, the first is to investigate and design an electronic cane using simple, inexpensive and readily available COTS hardware and software. Second, to evaluate the advantages of an orthotic device to monitor patient gait, force, location and distance. Third, to investigate how the patient supports and balances weight using either the cane or crutch mode with either or both hands. Fourth, to research the benefits of haptic (tactile) and Text-To-Speech (TTS) feedback regarding patient performance and adherence to therapist protocol. Fifth, to investigate the effects of thermal and vibration therapy in a specific modality to alleviate the pain and discomfort of osteoarthritis (OA) in the hands. Lastly, to identify other possible applications of remote technology to orthotic devices like a walker, a wheelchair, or a helmet.

1.3 - General Procedure

The general procedure of this project will follow the implementation of mathematical models for resistive heating, vibration, and statistical analysis to meet the goals and requirements of theTherawalk design. Furthermore, there will also be the installation of wireless communication between a physical therapist and user via Bluetooth, Raspberry Pi or Arduino, and application development on the smartphone for facilitating communication in a user-friendly way. Finally, we will have trade studies to further analyze if any improvements, additions, and/or removals will be necessary to our design of Therawalk.

Chapter 2 - Literature review

2.1 - Importance of the field

To understand the importance of how crucial a walking aid is in today's society one must realize the benefits and demands of using one. These mechanical aids provide balance support and assist in the daily activities of elderly, stroke patients, and pain from injury or clinical pathology such as hip fracture and arthritis. More than 4 million people use canes globally and more than 1.5 million use walkers in the United States alone in this manner [3].

Canes and walkers have had direct benefits to the physical and emotional wellbeing of its benefactors. They provide confidence and set users at ease making them more independent in their day to day lives. This allows them to be less sedentary which prevents osteoporosis of bone mineral, enhances circulation, and reduces cardiorespiratory deconditioning [3]. A study on 24 elderly patients in which 12 used walking aids while the other 12 initially did not proved through surveys that walking aids enabled continued participation and provided health benefits of well-being [4]. Many of the 12 after being informed on the different views about aging and benefits of walking aids decided to use them as a trial after being informed on the benefits and aging process of the human body. With the onset of inevitable arthritis and generalized weakness, using a support is desirable when it comes to balance control and everyday livelihood.

The biomechanical support and neuromotor benefits are what make a cane so useful. To achieve static postural equilibrium where there is no net force action on the body the body's center of mass (COM) must be placed directly over the base of support (BOS). The use of a cane or walker increases the range of the BOS resulting in a larger area of support for the COM to stay centered. A walking aid also can shift the brute force of the cyclic load onto the more stable limb [3]. In this way, the body is balanced and not at the risk of falling over.

2.2 - Project relates to larger problem area

Individuals who have had a stroke, diabetes, and trauma, as well as wounded warriors suffer from the inability to maneuver without assistive devices; restoration of walking is the primary goal for these individuals and their therapists [5]. In this project, we will primarily focus on individuals who suffer from osteoarthritis (OA), however, other individuals will be able to use the device. According to the Arthritis Foundation, people with OA experience as much as 30 percent more falls and have a 20 percent greater risk of fracture than those without OA. People with OA have risk factors such as decreased function, muscle weakness and impaired balance that make them more likely to fall [6]. Also, due to inflammation in the joint, individuals are not able to take on their daily activities due to overuse of the suffering hand, which causes swelling. The Therawalk's components, such as thermal and vibrational inserts, help alleviate their pain and discomfort. The vibrational insert helps stimulate blood from the OA hand. In the article by Games et al, 'whole-body vibration' was shown to improve strength and flexibility[7]. Stimulating the blood flow brings warmth to the area that is inflamed. Furthermore, the cane will enhance the ability of physical therapists to monitor their patients progress. Mr. Davis states, "it fills that gap between regular therapeutic sessions by enabling more therapists to interact with their patients in a timely basis regardless of time or physical location”. In a clinical setting, typical gait evaluations are limited to thirty to sixty minutes [8], therefore, any information of gait outside of the clinical setting is not captured. The Therawalk will allow therapists to capture, monitor, and evaluate gait

2.3 - Summary of knowns and unknowns of the project

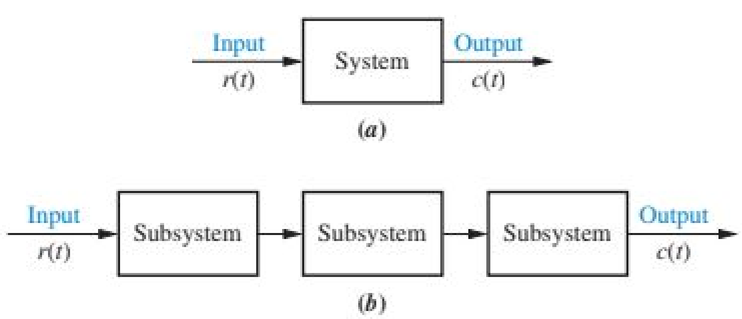
Therawalk's project is a device built to help patients with osteoarthritis have a fast recovery, and allow therapists to see their progress. The knowns of this project is the type of components we will need in order to build the device. The components are the smartphone to track the patients progress, Text-to-Speech, sensors, and vibrational and thermal inserts. The unknowns of this project is to figure out how to incorporate thermal and vibrational inserts into the device. In this project, we use Arduino, and will have to figure out how all of the components function. The main goal of this project is to ensure all of the components, such as the electronic components, thermal and vibrational inserts, smartphone, ON/OFF switch, and battery power, are available for the patient.

2.4 - Summary of current mathematical models

The mathematical models used will primarily be for the operation of vibration and heat dissipation along with some equations for statistical analysis of gait. These equations are as follows.

- **A.** Vibrational output given an electrical input
- **B.** Heat from electrical energy
- **C.** Statistical Equations for analysis

A:



Note: The input, $r(t)$, stands for *reference input*.
The output, $c(t)$, stands for *controlled variable*.

$$\mathscr{L}[f(t)] = F(s) = \int_{0-}^{\infty} f(t)e^{-st}dt \tag{1}$$

$$\mathscr{L}^{-1}[F(s)] = \frac{1}{2\pi j}\int_{\sigma-j\infty}^{\sigma+j\infty} F(s)e^{st}ds = f(t)u(t) \tag{2}$$

$$C(s) = R(s)G(s) \tag{3}$$

Figure 2.4.1 *At the very top is a block diagram relating a function for the input of a system in time to the output in time. The Laplace transform and its inverse are then applied to obtain a different form of these functions that simplifies computation as shown in equations (1) and (2). Equation (3) shows the relationship of the transfer function, (G(s)), to the input, (R(s)), and output, (C(s)), of a system. This will be applied to a vibrational motor and experimentally determined to find an approximation for operation at different frequencies and amplitudes as related to input voltage [9].*

B:

$$V = IR \tag{4}$$

$$W = P * t = I * V * t/R \tag{5}$$

Above are the equations for Ohm's Law and the formula for the energy from Resistive heat respectively. V is the voltage, I the current, R the resistance, t the time, W the energy, and P the power [10].

C:

$$SE = \frac{\sigma}{\sqrt{n}};$$

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}; \tag{6}$$

In equation (6), SE is the standard error, σ is the standard deviation of the sample, *x*-bar is the average, *x* is any of the sample values, and *n* is the sample size. These methods can be further expanded to two or three dimensions [11].

2.5 - Current Research and Devices

Current research into the development of a smart cane takes multiple different approaches to achieve a similar goal. There are some smart canes that are being designed for use in physical therapy, as well as improving patient efficacy in using the cane. One such cane, specifically designed for physical therapy and dubbed the PTCane, explores the potential for canes to be used to track patient data, as well as provide feedback on progress [12]. The designers of the PTCane polled a group of 66 people and found what was useful data for physical therapy - something that many patients with difficulties in mobility, as well as recent injuries and surgeries go through as a part of their health care plan. The results of this poll indicated that some useful data to report include feedback on use, reminders to complete home exercise regimens, and indication that the patient is improving. Furthermore, the researchers found that most of the people they polled would prefer to interface with the device and receive data through a smartphone or similar device over directly through the cane [12]. As a result, a similar logic will be applied to the Therawalk. Future iterations of Therawalk will track the use of the cane by determining and recording information, such as the distance travelled, gait information, and force on the cane. The force on the cane can be measured through a force sensor in the form of a load cell that is integrated into the handle of the cane to ensure that the patient is applying the optimal force onto the cane [13]. Additionally, the sensors within the Therawalk will interface via Bluetooth to an external device. Ideally, this interface will be relayed through a smartphone app. For now, only the heart rate information will be communicated via a smartphone device. The use of such a smart cane will be able to relay to the therapist whether the patient actually used the device as recommended. This will encourage the patient to use the cane, and mitigate therapist concerns that the patient did not adhere to their instructions, which is a common concern among physical therapists [12,13].

Other comparable canes are also in development. One company, Fujitsu, seeks to create a smart cane that is able to provide the user with data on heart rate, number of steps taken, as well as provide navigation and position information through the use of a global positioning system (GPS) [14]. Fujitsu aims to create a cane that caters more to the elderly population. They found that while many need a cane to prevent falls and improve mobility, there is some resistance among the elderly population to use a cane. Some of this resistance stems from embarrassment from using a cane [14]. As a result, in designing the Therawalk, it is important to take appearance and aesthetics into account as well as functionality and technology. In doing so, any embarrassment one may feel from using a cane can be mitigated by having a visually pleasing design and highly functional technology. This may also encourage the user to regularly use the cane, which is a concern that has been expressed by physical therapists [12].

Canes come in many different designs. Some options include single-handed or two-handed. Additionally, canes can have one point of contact with the ground, or four points of contact with the ground, which is seen in quad canes [13]. Quad canes are useful in that they are able to enhance the stability of the cane through their four separate points of contact with the ground [15]. Another consideration to take into account in the design of a cane is the handle. The handle of the cane should be optimized for patient comfort and to increase ease of use of the device. One study evaluated the handle design for single-handed canes [16]. This study found that changing the shape of the handle impacted patient gait and cane loading [16]. As a result, in the design of the Therawalk, it is important to also consider the handle design in terms of comfort and effectiveness for the patient.

2.6 - Deeper look into vibrational and heat therapy

The science behind blood flow and muscle oxygenation are closely related. During exercise, the body is deprived of oxygen that is being used up by the cells. It responds by increasing respiration and shuttling oxygen through blood towards the deprived cells. Oxygen as the final acceptor in the electron transport chain allows aerobic respiration to occur to create ATP. Changes in fuel, exhalation of carbon dioxide and maintaining the pH gradient are other factors that play a role. Studies have proven concrete results of what vibrational therapy can do positively for the body. According to 'A Meta-analysis' by Kenneth E. Games et al.; vibrational therapy can increase peripheral blood flow but not alter muscle oxygenation levels [7]. The variations in the type of vibration used, time, frequency, and amplitude are further aspects of how vibrational therapy can be studied and implemented in the Therawalk. An increased level of blood flow to the affected cells can alleviate some of the pain and stresses due to osteoarthritis and benefit the patient. In a similar way, heat and wax therapy can do more of the same. Moist and dry heat increase blood circulation, reducing stiffness and can reduce pain. This is very important as a lot of the load when using a walking aid can be on the hands and radiate upwards in the arms. When the cells are deprived of oxygen and begin to conduct reduced levels of aerobic respiration this increased level of circulation is crucial so the hands and arms don't fatigue [6].

Chapter 3 - Project strategy

3.1 - Initial Client Statement

Continued patient-therapist communication and efficacy in tracking patient progress is a problem that both patients and therapists face in physical therapy. The goal of Therawalk is to create an orthotic device that integrates sensors and a smartphone app to track patient use of the cane with relevant measurements and data. The device should be versatile and easy to operate for a wide range of patients. Some of the target patients may suffer from osteoarthritis. Since their osteoarthritis may present some challenges in the continued use of the cane due to pain in their hands, the cane should have some way to help alleviate the pain caused by osteoarthritis.

3.2 - Objectives and Constraints

3.2.1 - Project Objectives

The components of the“Therawalk” must meet the requirements listed in Table 1. The purpose of this device is to help patients suffering from Osteoarthritis (OA) by alleviating their pain and discomfort. Different components including sensors, power supply, microprocessor, thermal, and vibrational inserts will be implemented into the cane to benefit the patient. The thermal inserts will be used to reduce the pain and discomfort from OA. As Robinson et al. asserts, “For patients with aching muscles and sore joints, the application of heat can decrease the viscosity of fluids, loosen stiff muscles, improve blood flow to the affected area, facilitating tissue repair, and creating a feeling of relaxation” [17]. Additionally, the vibrational inserts helps blood flow through the suffering hand [18]. The cane must include two handles that allow the patient to lean on the cane without putting too much stress. Furthermore, the cane will include a smartphone app that tracks the patient progress, and transfers the information to the therapist. The cane should be inexpensive, and reusable; it would not make sense to make a one-time use device for the patient. Therefore, the material used to design the cane must be durable enough to last the patient some time.

Table 3.2.1.1- The objective lists with metrics for the Therawalk

Objectives	Metrics
Safe for the user	Device material is not toxic to the patient’s body
Easy to use	Easy for patients to use
Durable	Misalignments of device after regular use
Inexpensive	Estimate dollar amount
Reusable	Can be used multiple times

Versatile	Range of height sizes allowed
Thermal inserts	Reduce pain and discomfort from OA
Vibrational inserts	Allows blood flow in the OA hands
Sensors	Detect gait

3.2.2 - Project Constraints

The "Therawalk" must be inexpensive as we are limited to $1000.00 to create the components of the device. The materials used to make the device must be nontoxic and safe for the user. The height of the device must be 39 inches long, the device could be cut to length for each client. The height will not accommodate 99% of the user population [18]. Another constraint is the battery power, the battery must be rechargeable or replaceable. The device must withstand "6 hard smacks against a brick wall without yielding" [18].
Project Constraints list:

- *Inexpensive:* The cane components include COTS hardware and software, microprocessor, sensor technology, and smartphone test. Therefore, the Therawalk can be an inexpensive dual function mobility aid [18].
- *Materials:* Material must be nontoxic to the human body
- *Battery power*: The battery must either be replaceable or rechargeable with a 110-volt interface [18]
- *Height*: The height of the cane must be 39 inches long. The device can be cut to accommodate the 5th percentile female to 95th percentile male patients [18].
- *Withstand some impact*: Device must be able to withstand force/stress without yield.

3.3 - Revised Project Statement

Development of the Therawalk will focus primarily on the design and integration of a functional sensor array for the implementation into the mechanical Therawalk model. The sensors should be able to determine and relay information about the patient's heart rate, with future iterations potentially adding gait, distance travelled, and force on the cane as other metrics to be relayed. The sensors will use a microprocessor and Bluetooth to process and relay information to an external device such as a smartphone or computer. Ideally, the smartphone will have an app with which to interface with the cane to make it easier for the patient and therapist to view data. A secondary goal of the project is to integrate thermal - heating and cooling - components as well as vibration to aid in the mitigation of pain due to osteoarthritis. Furthermore, a tertiary goal of the project will include a human factors approach to ensure that the device is easy to use and has all necessary components - on/off switch, feedback on battery life, method to charge/access battery, etc. - on the cane in a way that is accessible and intuitive for the patient. Finally, some analysis may be conducted to optimize the design of the cane itself in terms of mechanics and/or aesthetics.

3.4 - Project Approach

The project approach will involve the methodology of systems engineering and the use of trade studies that include but are not limited to (1) heat dissipation by resistive heating, (2) cane color and overall aesthetic appeal, (3) mechanical connection between modules and durability, (4) one-time use or rechargeable battery, and (5) variable operation of vibration motor. These trade studies will use a quantitative Kepner Tregoe Analysis (KTA) form to identify criteria and design alternatives. We will use Microsoft Excel spreadsheet form to process the trade studies. The following list of activities identifies our approach, and may be reviewed and modified upon future examination to further define the system and detail design level requirements [18].

- Research orthotic devices uses and applications.
- Research mobility, capabilities, limitations of cane users.
- Use a cane to understand desirable and undesirable features.
- Interview physical therapists about cane use, limitations, possibilities.
- Identify primary and secondary functions.
- Develop system and detail design level requirements.
- Develop Concept of Operations (CONOPS) scenarios.
- Develop system schematics.
- Develop candidate designs.
- Perform tradeoff studies. See the Appendix for trade study issues.
- Use human computer modeling to visualize cane / user interfaces.
- Identify or develop user interface guidelines for the smartphone application.
- Use Usability Experience (UX) methods and testing of smartphone interface.
- Develop ‘bread-board’ functional electronic prototype.
- Use 3D modeling and printing to create full-scale prototype parts, as needed.
- Develop full-scale functional model(s) using furniture grade PVC and Commercial-Off-The Shelf (COTS) electronic components and software.
- Perform verification and validation (by analysis, test, demonstration or inspection).

Chapter 4: Alternative Designs

4.1 - Alternative Cane Bases

4.1.1 - Non-adjustable Base

Figure 4.1.1.1 *Non-adjustable Base of Previous Cane Design made using PVC*

The previous designs for MightyCane used a non-adjustable base with overall height of 39 inches. The electronic components were housed in the upper portion of the shaft and by the intersection of the handles with the shaft. These components included but are not limited to vibration motors, battery packs and microprocessors with controllers. On the bottom, a rubber stopper is present for added friction with the surface of the ground thus minimizing any chances for the user to slip while operating MightyCane. As noted in previous trials with this design of MightyCane, a downside of the non-adjustable base is that about 5 inches have to be added for a total height of 44 inches when operated by a taller user.

Figure 4.1.1.2 *Previous two-handed design with external casing removed to show inner electrical components and circuitry.*

4.1.2 - Adjustable Base

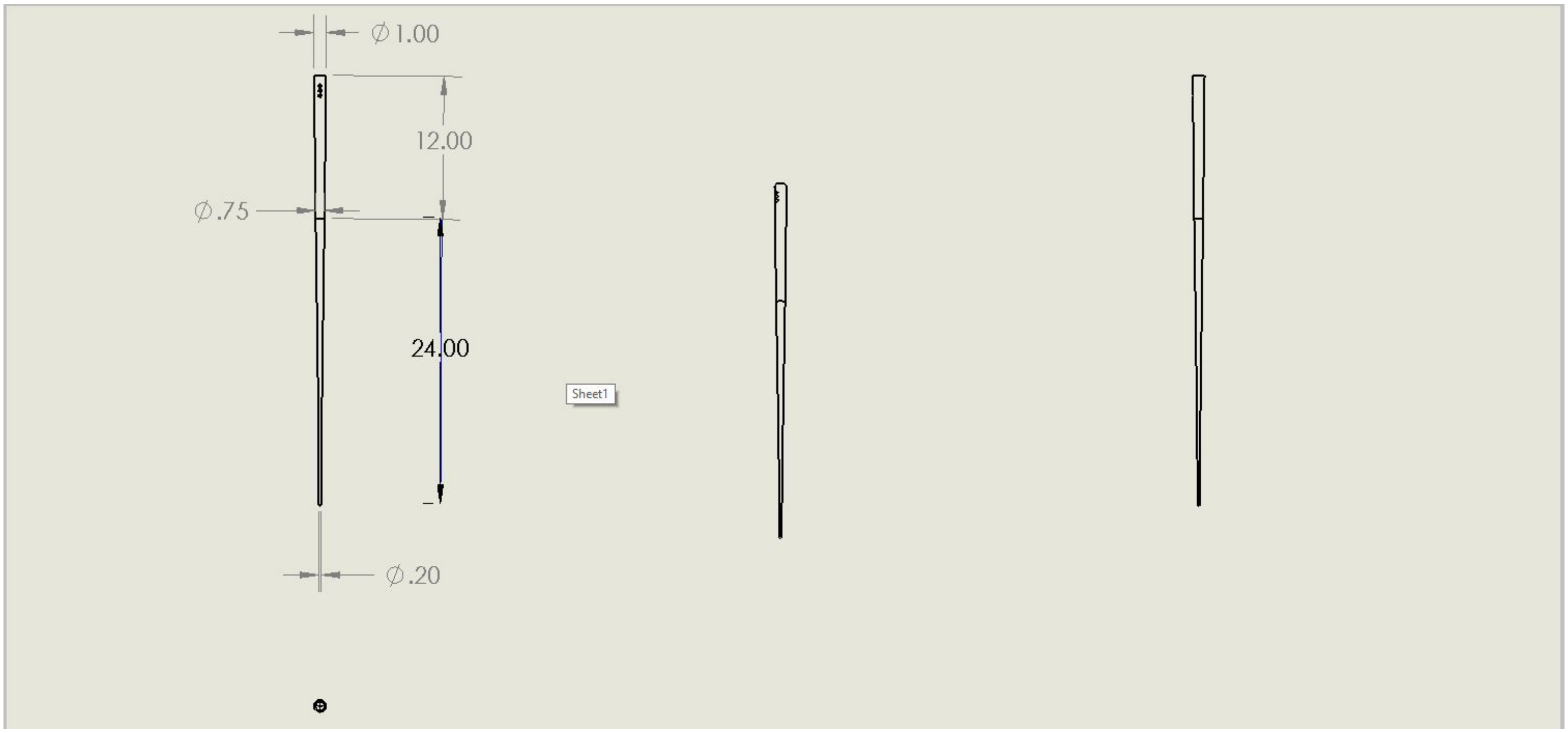


Figure 4.1.2.1 - *Base of Cane*

The adjustable aluminum base shown in Fig. 4.1.2.1 offers ample space to house the electronics and sensors needed to bring this project to fruition. It provides patients with the adaptability as it features a punch hole mechanism in which the bottom half can be adjusted to various heights. This will be done with an easy to press button connected to a spring that will be shortened when compressed. The spring will be attached to the outer framework of the inner cylinder and the inner cylinder will slide up and down the outer one giving the cane different heights. All of the electronics and sensors will be housed on a sled that sits in the inner portion of the upper cylinder. This will include the circuitry needed for the heart rate monitor, vibrational unit, and a power source. This will be accessible by the patient if the battery needs to be changed. The wires will connect up to the handle where the vibrational sensor unit and heart rate monitor is located.

4.2 - Alternative Handle Designs
4.2.1 - Ergonomic Design

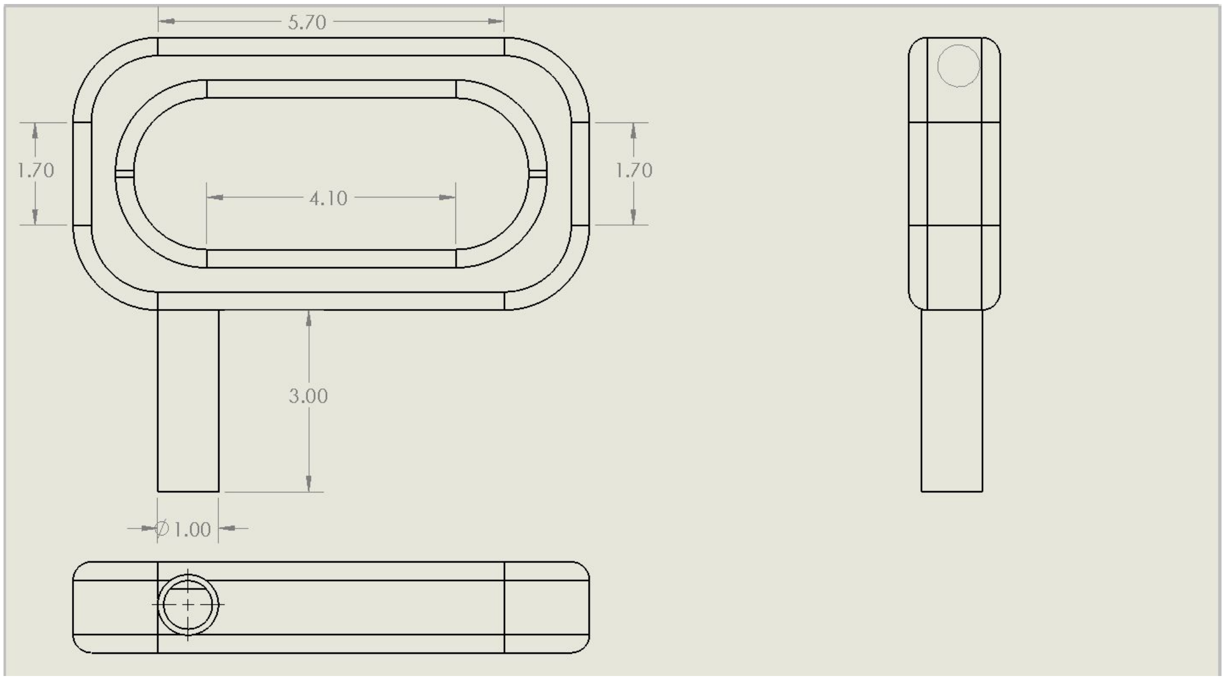


Figure 4.2.1.1 - *Ergonomic Handle Model 1.0*

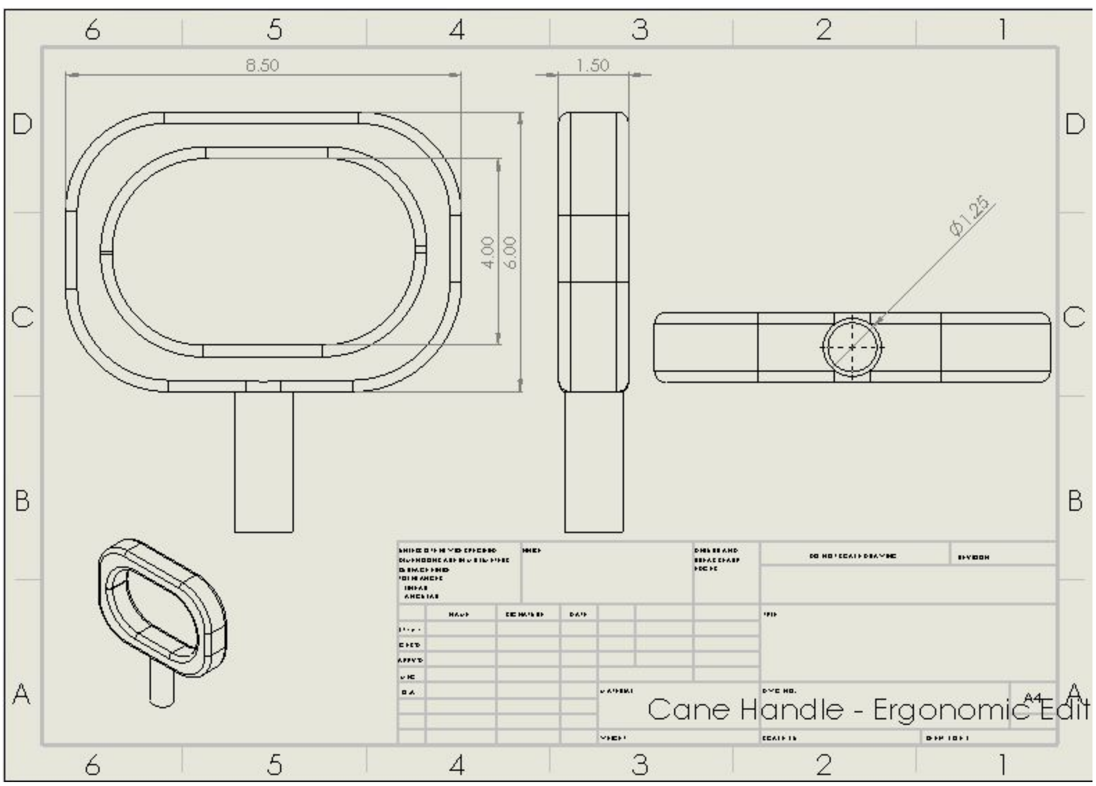


Figure 4.2.1.2 - *Ergonomic Handle Model 2.0*

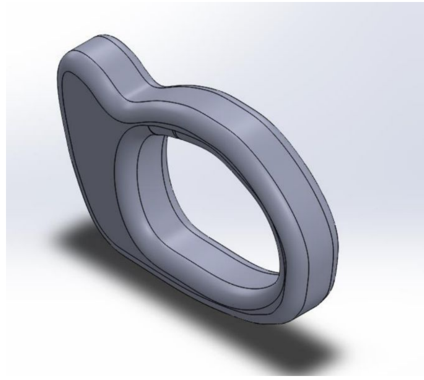


Figure 4.2.1.3 - *Ergonomic Handle Model 3.0*

The ergonomic handle design, shown in Fig. 4.2.1.1, offers more space and versatility than a traditional one-handed cane. Further, it offers a more modern and aesthetically pleasing design than the two-handed design. This design also offers additional space in which to integrate the electrical sensors and components, and as such has the capability of having more sensors, electrical components, and functionality as a benefit of the additional space provided within the hollow handle. Finally, should the patient want to rest both hands on the cane, they could use the lower portion of the handle as a secondary handle, or rest both hands on the top portion of the handle. A human factors approach will be taken to place all electrical components, sensors, and other interfaces within the handle and base of the cane in an intuitive manner for the user.

The second handle design shown in Fig 4.2.1.2 is a different version of the ergonomic handle design. In this handle design, the handle of the cane attaches to the base in the center, which enables the cane to be more symmetrically balanced. Further, the handle itself is slightly larger to allow for even more space for electrical components, to make the handle easier to grip, and to more easily enable the user to use both hands on the cane for additional support.

The third handle design shown in Fig 4.2.1.3 is the final design for the ergonomic handle. This handle design incorporates the loop and all of the benefits associated with the loop design, while implementing a curve to allow the cane to be more comfortable in the patient's hand. Each of the ergonomic handle designs were created using SolidWorks 3D modeling software.

4.2.2 - Two-Handed Design

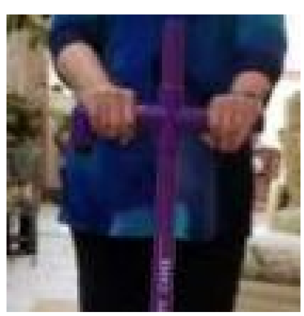


Figure 4.2.2.1 *Previous two-handed design of MightyCane operated by volunteer Julie.*

The primary advantage of the two-handed design was that its handle allowed for very particular use of the cane. The user could operate the cane by swinging its base in front of their body and then stabilize by creating a tripod with their feet. This additional, centrally forward point of contact with the ground allowed for operation by patients that had difficulty using single-handed canes. The disadvantages is that many patients were reluctant to switch to MightyCane when asked as they were too used to their single handed canes. In other words, even with the possible advantage of 'tripod' operation, patients and current cane users are reluctant to operate this previous design due to its unique shape and size.

4.2.3 - Single Handed Design

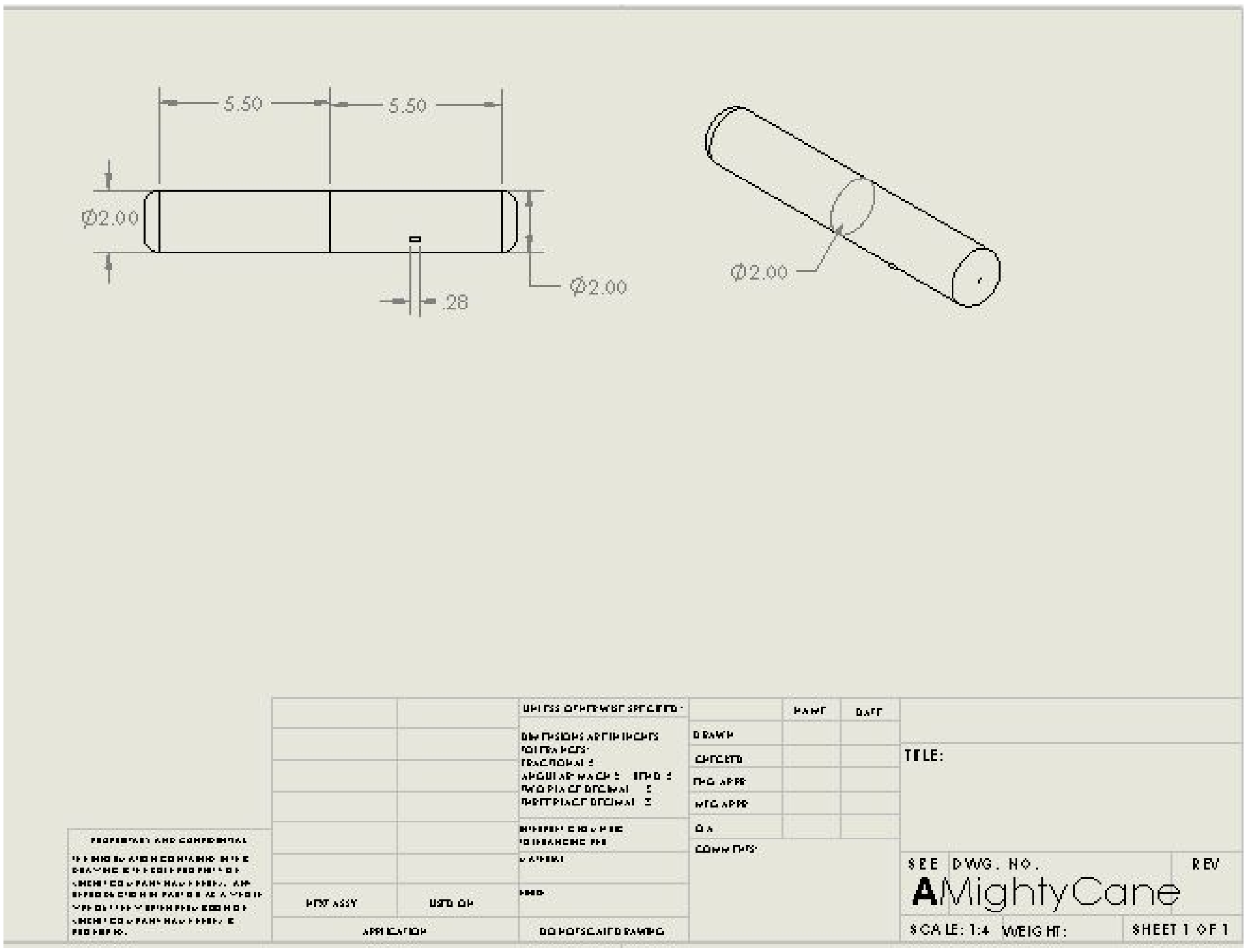


Figure 4.2.3.1- *Single Handed Design*

The single handed design, shown in Fig. 4.2.3.1, is a user friendly design for individuals with arthritis. The use of a single handed cane helps them go on about their daily activities by helping to improve their mobility. The collapsable component embedded in the cane opens up to provide an additional handle to provide the user with additional support and stability if they so desire. The cane will be made out of aluminium since it is easy to manipulate, and cheaper than alternative materials, such as carbon fiber. Further, aluminium is relatively light weight, and having a hollow aluminium design will provide the necessary strength and stability without being too heavy for the patient to comfortably operate. Similar to the other designs, there will be room to include the vibrational unit, sensors, and the electrical components.

4.3 - Thermotherapy

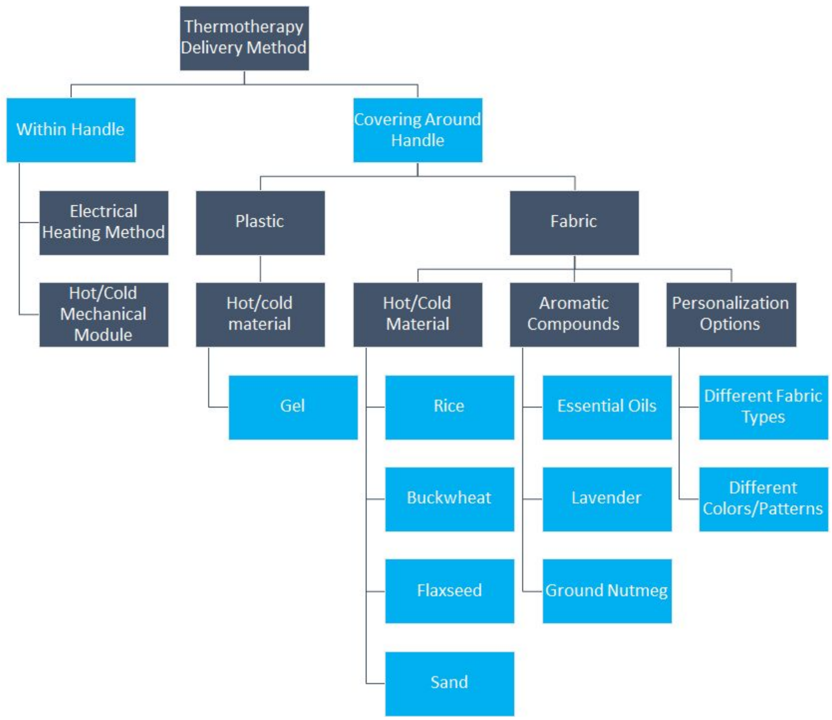


Figure 4.3.1 - *Thermotherapy Function/Means Tree*

Thermotherapy is the application of warm and cool temperatures to afflicted areas in order to provide pain relief [19]. As a part of the treatment options for osteoarthritis, thermotherapy offers relief from swollen and stiff joints. In order to optimize the cane design for patients with osteoarthritis, the cane should implement a method for patients to use thermotherapy to soothe their stiff and swollen joints. However, there is not a current consensus on whether heat or cold is more effective in relieving the pain [20]. As a result, it is important to provide the patient with the option to apply either method, or a combination, as a part of their osteoarthritis treatment. Therefore, both the cane materials and the materials used to provide the thermotherapy need to be able to withstand and provide both heat and cold therapy.

While the heat and cold therapy delivery method could be housed within the cane as either an electrical component for the heater, or as a mechanical module to be placed within the handle as desired, this is not the optimal way of delivering thermotherapy to the patient. The placement of a module within the handle that has been either heated or cooled to a desired temperature could prove difficult, especially for patients with limited joint mobility resulting from osteoarthritis. Additionally, such a module would limit space within the handle to house other electrical components, and the temperatures exerted by the module could potentially harm the electrical components and sensors housed within the cane handle. As a result, the thermotherapy will be delivered using an external unit.

The external unit will be in the form of a hot/cold pack, that is able to either be placed into a freezer or heated using a microwave, and can be placed around the outside of the handle using velcro straps. This hot/cold pack will be made out of a soft fabric to increase patient comfort while using thermotherapy. The fabric will help maintain the temperature at a comfortable level, as opposed to an alternative material such as plastic, which has the potentiality of getting too hot or cold, and would require a fabric covering to protect the patient from extreme temperatures. Further, the patient will be able to individualize their care by choosing the fabric material, color, and pattern, as well as adding aromatic compounds such as lavender or essential oils. One benefit of this is that lavender is helpful in the treatment of anxiety, depression, and is often able to improve mood [21].

The material contained within the hot/cold pack would be grain based in order to allow for the use of aromatic compounds and avoid the potentiality of gel spilling onto the electrical components of the cane should the hot/cold pack break. Some potential grains to be used include rice, wheat, buckwheat, and flaxseed[22,23]. Studies need to be done to determine which material is best suited for use in the hot/cold pack. These studies will include measuring the temperatures attained while freezing and heating, and the length of time the materials maintained their temperature.

4.4 - Sensors and Electrical Components

The sensors and electrical components included in the design of these canes are a heart rate monitor, vibration motors, Lithium Ion Polymer (LiPol) batteries, White LED, Arduino Uno board, and a Piezo buzzer. The heart rate monitor is DigiKey's model number MAXREFDES117# and will require 2-5.5V for operation. When paired with the Arduino, data of the user's heart rate and pulse oximetry will be visible on a computer by a process of photoplethysmography, or PPG. A process where one portion shines a green LED and another portion detects how much light reflects back. Upon more blood flow, green light adsorption increases thus allowing for relations to be made upon which required blood information is estimated [24]. The vibrational motors will be 5-10 mini vibration motor discs purchased from AdaFruit (product ID 1201). The disc dimensions are a 10 mm diameter and height of 2.7 mm. The weight of each motor disc is 0.9 grams with an operating voltage of 2-5 V with a current draw of 40-100 mA respectively and 11000 rpm at 5V. The vibration motor discs will be placed in the handle for closer contact with the hand than if they were located in the lower part of the shaft. The flashlight will be made using the cool white 1W LED from AdaFruit (product ID 518)

and at 3V the light will draw ~200 mA current. The piezo-buzzer will serve as an alert for when the user may ever be in distress and operates at 2-5 V with a current draw of less than 100 mA when operating at around 3V. The buzzers prospective location is currently below the handle as close proximity to the users hand is not required for its alerting operation. Last but not least, these will all be wired to an Arduino Uno with which power will be supplied by 2-3 LiPol rechargeable batteries, each of dimensions 1.4 by 0.6 by 0.3 inches and weight of 8.2 g. The nominal voltage of each of these batteries is 3.7 V with an output of 400mAh, sufficient to drive all of the above components within their operating levels.
It should also be noted that all of the components are physically capable of being housed within the cane for maximum appeal and smooth aesthetic.

4.5 - Alternative Design Considerations

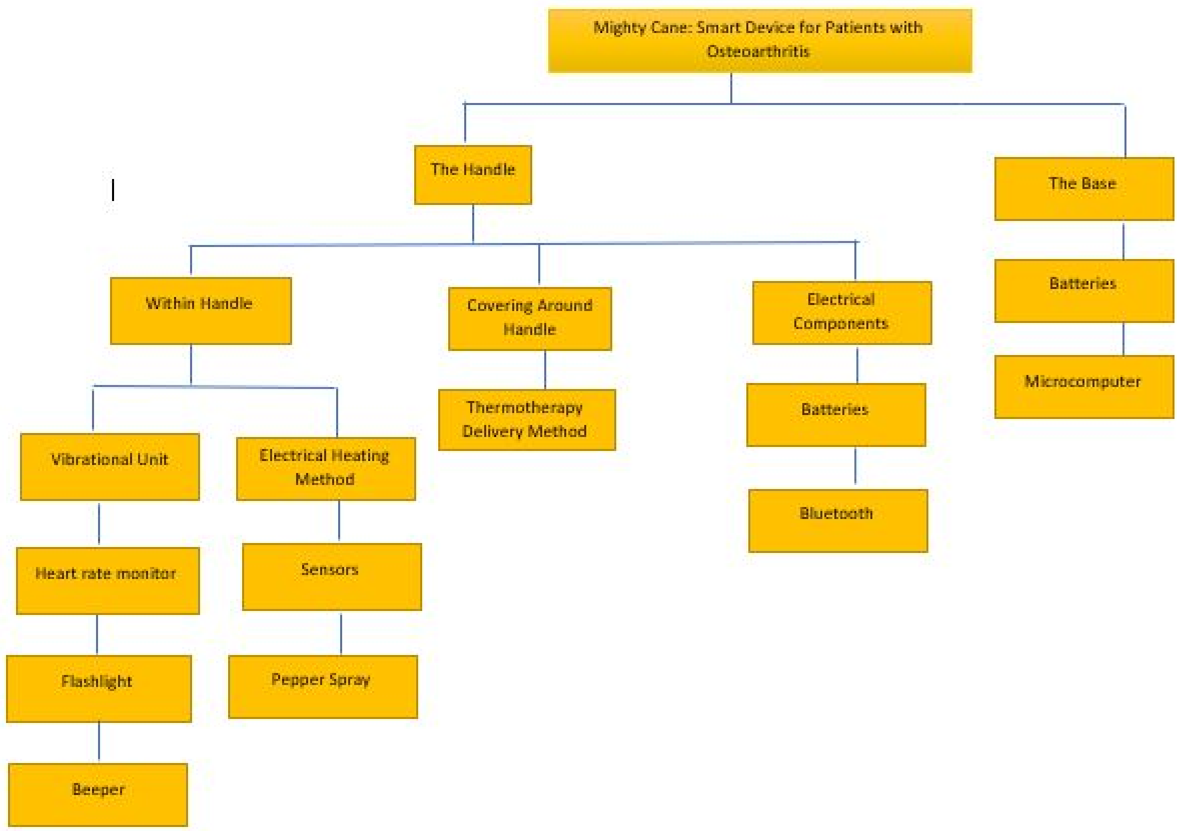


Figure 4.5.1 - *Therawalks Function/Means Tree*

All of the canes provide the same function. They are all able to house the necessary components to aid in patient care and relief from pain caused by arthritis, while simultaneously improving patient mobility. Fig. 4.5.1 is an outline of the components that will likely be included in the cane. Taking the design requirements into account, the cane we chose as our optimal design is the ergonomic handed cane, described above in section 4.2.1. The two-handed design was not chosen due to lack of its aesthetic appeal. Users would likely choose a cane that is visually appealing over one that is not, regardless of the benefits the less appealing design may have. Also, the material used for the two-handed cane is PVC (Polyvinyl chloride). However, it was decided that aluminum would be a better material since it is relatively cheap, easy to manipulate, and has better thermal conductivity than PVC.

Another design that was not chosen is the single-handed cane. If the user wants support, it would be inconvenient to have to press a button in order to receive that. Further, such a task may be difficult to accomplish for the user population we are focusing on, as osteoarthritis may cause such a task to be painful. It would be better if the support is already provided with the cane without the user having to do any additional “work”. The optimal design was chosen since, unlike the other two designs, it is aesthetically pleasing and provides immediate additional support for the user by using the lower portion of the handle. The hollow handle provides more room to fit the components that will be beneficial for the user, such as the heart-rate sensor and vibrational components.

Furthermore, in our design, we included an adjustable base instead of the non-adjustable one. A universal cane would not be ideal, as it would not be beneficial for patients whose height differs from that of the height the cane was designed for. Also, a non-adjustable base can be painful and cause imbalance for the user, since they are not able to adjust the height to their preferences. While the cane can be cut to size to fit each user, this is not ideal in creating an affordable cane, as each cane would have to be custom-made for the patient. Adjustable canes allow the perfect match for the height of the user while maintaining a cost-effective approach.

4.6 - Optimal Design

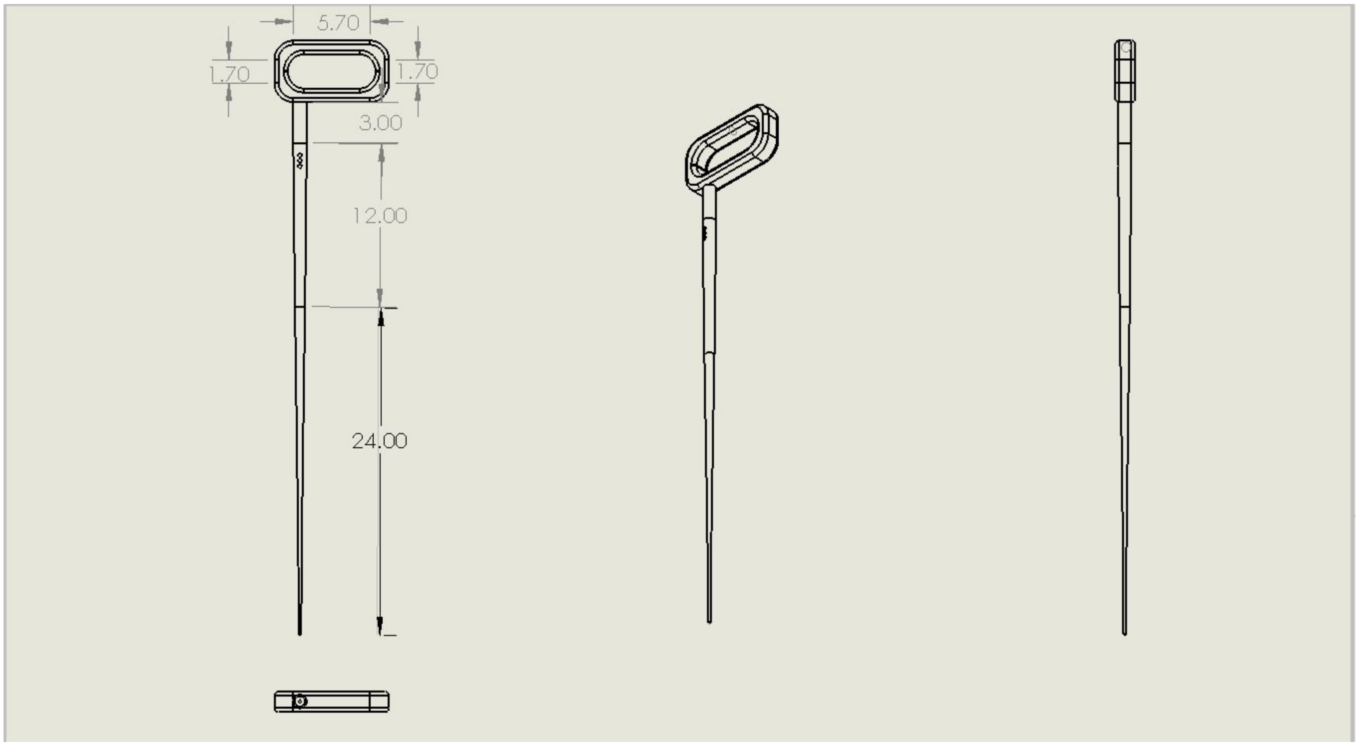


Figure 4.6.1: *Optimal Design: Implementing the ergonomic handle in accordance with the adjustable base. The Ergonomic Handle 1.0, 2.0, or 3.0 can be implemented here.*

Chapter 5: Data Collection

5.1 - Electronics

5.1.1 - Heating Pad

The electronic equipment was placed parallel to and powered by 7.4 V LiPol battery supply. The heating pad purchased from Adafruit (Product ID: 1481) consumes the battery supply within five minutes of continuous use necessitating a more practical thermal insert for regular operation of Therwalk.

5.1.2 - PulseSensor

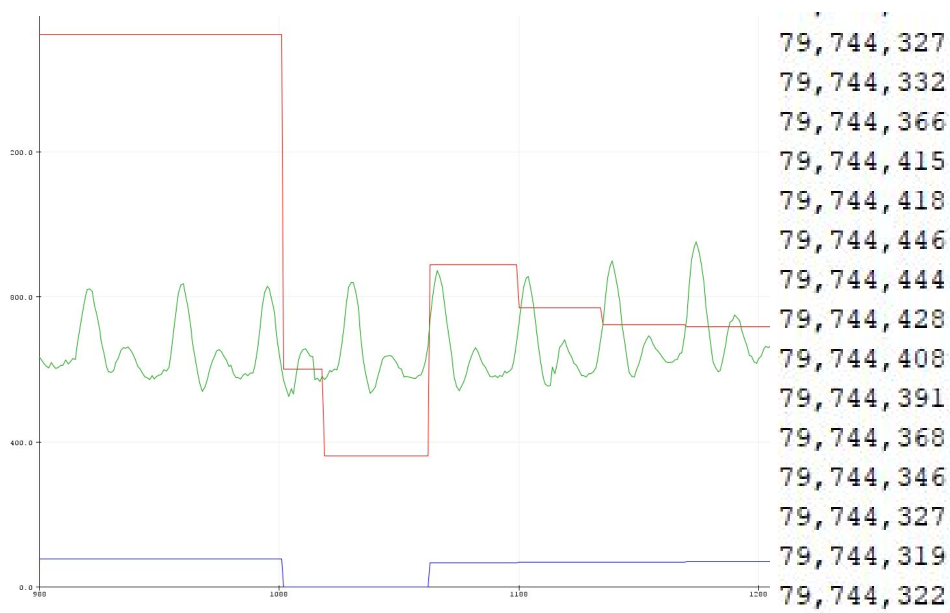


Figure 5.1.2.1 *The abscissa represents time in milliseconds. The ordinate on the left is the plot of BPM, beats per minute (blue), IBI, interbeat interval in milliseconds (red), and pulse wave data in milliVolts (green) on serial plotter. On the right is the BPM, IBI and pulse wave data displayed from left to right on the serial monitor.*

This is the output from the pulse sensor attached to the cane in figure 4.1.1.1 working on PPG technology. The output currently is manipulated by arduino and shown on a computer. This will be transferred to an LCD screen attached to the cane.

5.1.3 - Flashlight

Figure 5.1.3.1 - *Flashlight flipped over with a quarter for scale*

Testing of the flashlight shows that it operates at 2-4.5V with greater lumosity as higher voltage is applied. It amplifies 90 lumens in a 140 degree pattern which is close to 30,000 millicandela compared to the typical value of 20 millicandela of flashlights this size. At its max it's extremely bright so a potentiometer switch can be used for customized lumosity. It's been tested using a 3.7V LiPol battery for 20 minutes of max intensity when the battery is fully charged.

5.1.4 - Battery

The power supply used was two 3.7 LiPol batteries connected in series where the electrical equipment was either placed in parallel to one or both of the batteries. A larger power supply with longer battery life will be required for extended operation time of the electronics.

5.2 - Mechanical Design

Prototyping and testing the mechanical design involves creating a handle and base. The handle was 3D printed to allow for testing and mounting of the electrical components before a final model is created. The base was created using aluminum tubing, a spring, and a rubber stopper. This allows for testing of the cane at various heights, and the accommodation of a range of heights for the cane.

5.2.1 - Handle

The handle was created using Solidworks, and 3D printed with PLA as shown in Fig.5.2.1.1. The electrical components will be incorporated into the handle, and used for testing.

Figure 5.2.1.1 - *The 3D printed handle. Ergonomic model 2.0*

5.2.2 - Base

The base is made of aluminum and is able to be adjusted to accommodate a range of different heights. The telescopic design works by having two hollow aluminum tubes nested within each other. The inner tube has the spring, shown in Fig 5.2.2.2, which is able to lock into any of the holes drilled into the outer tube. This allows for a stable locking of the base at the preferred height. Having hollow aluminum tubing reduces the weight of the cane and allows for room to incorporate the electrical components if necessary. The hollow aluminum is shown in Fig 5.2.2.4. The base also has a rubber stopper on the end to minimize slipping of the cane while it is in use. The range of heights the base allows are from 44.5-57.4 cm.

Figure 5.2.2.1 - *Aluminum Base*

Figure 5.2.2.2 - *Adjustable Component of the Base*

Figure 5.2.2.3 - *Rubber End of Base*

Figure 5.2.2.4 - *Hollow Tubing*

Chapter 6: Discussion

6.1 - Economics

Therawalk is made out of aluminum, which is cheap and easy to manipulate. The cane is affordable, reusable, durable, and includes padded hand grips to provide comfort at the handles. Therawalk provides security, mobility, independence, and balance to individuals with Osteoarthritis. It influences the economy of everyday living by providing mobility and stability to those who need extra assistance.

6.2 - Environmental Impact

Therawalk will have a positive environmental impact due to the use of rechargeable batteries. Rechargeable batteries can be reused and recharged many times, which produces less waste. These batteries use less energy, more efficient than replacing and making new batteries.

6.3 - Societal Influence

Patients with Osteoarthritis hands cause joint pain, swelling, and stiffness that affects the ability to grasp and hold objects. Therawalk is a lightweight cane that reduces pain, and improves function in patient hands. The components incorporated inside the cane such as the vibrating motor alleviate the pain in the hands. The cane reduces the pressure in the joint, and increases ambulatory.

6.4 - Political Ramifications

There is an increase in the number of Osteoarthritis, companies have designed different walking-assistance devices for the disease. Therawalk is a user-friendly device with components embedded in the handle that alleviate pain and discomfort in the joints of the patients. Many individuals with the disease would purchase the device that allows them to complete simple physical activities. Walkers and canes are top competitors in the global market, Therawalk would not be beneficial to those within the U.S., but outside as well.

6.5 - Ethical Concern

Therawalk improves the quality of life for patients with Osteoarthritis. It enables them to perform simple tasks, improve mobility, and promote independence. The component inside of the handle, such as the vibrating motor is a tool patients use to reduce hand pain with a touch of a button. The handle is lightweight, which makes it easier for the patient to maneuver around.

6.6 - Health and Safety Issues

Analysis on the cane will need to be done in the future to determine the maximum load that it will be able to handle to determine a safe weight range for the patients operating the cane. Due to the situation with COVID-19, such analysis was not able to be conducted during the 2019-2020 school year. Further, clear instructions need to be given to the patients to ensure safe operation of the vibration feature embedded in the cane handle. While a certain amount of vibration is therapeutic and will help with the pain caused by arthritis, too much can be potentially harmful and have the opposite effect intended for the patient. Further, the same will be true when the thermotherapy component is added as well. Instructions will need to be provided to prevent any harmful effects from having prolonged exposure to vibration, heat, and/or cold.

6.7 - Manufacturability

The cane was designed with manufacturability in mind. While again, progress on the cane design was halted due to COVID-19, the hollow handle design enables for easy assembly of the internal electrical components. Further, having the design of the handle be in two halves enables for easy maintenance and replacement of any broken or faulty parts.

6.8 - Sustainability

The sustainability of Therawalk comes with the use of rechargeable batteries, along with the reusable and long-lasting aluminum material. By having the batteries be rechargeable, the impact on the environment is minimized as the user of Therawalk will not have to use disposable batteries.

Chapter 7: Final Design and Validation

7.1 - Final Design Components

The final design for Therawalk is broken up into three portions. First, is the final design for the mechanical portion of the handle. Second, the electrical components of the handle are considered. Finally, the final design for the base is described.

7.1.1 - Final Design Handle: Mechanic

The final handle design for Therawalk is the Ergonomic Design 3.0. This design will be manufactured and assembled in two halves, which will allow for both the easy assembly of the electrical components, and easy maintenance should any be required in the future.

7.1.2 - Final Design Handle: Electric

The final electric design for Therawalk is a circuit composed of an Arduino Nano, an Arduino booster, a powerful motor, and a transistor. The wires would be sautered and placed inside of the cane handle as shown in the figure below.

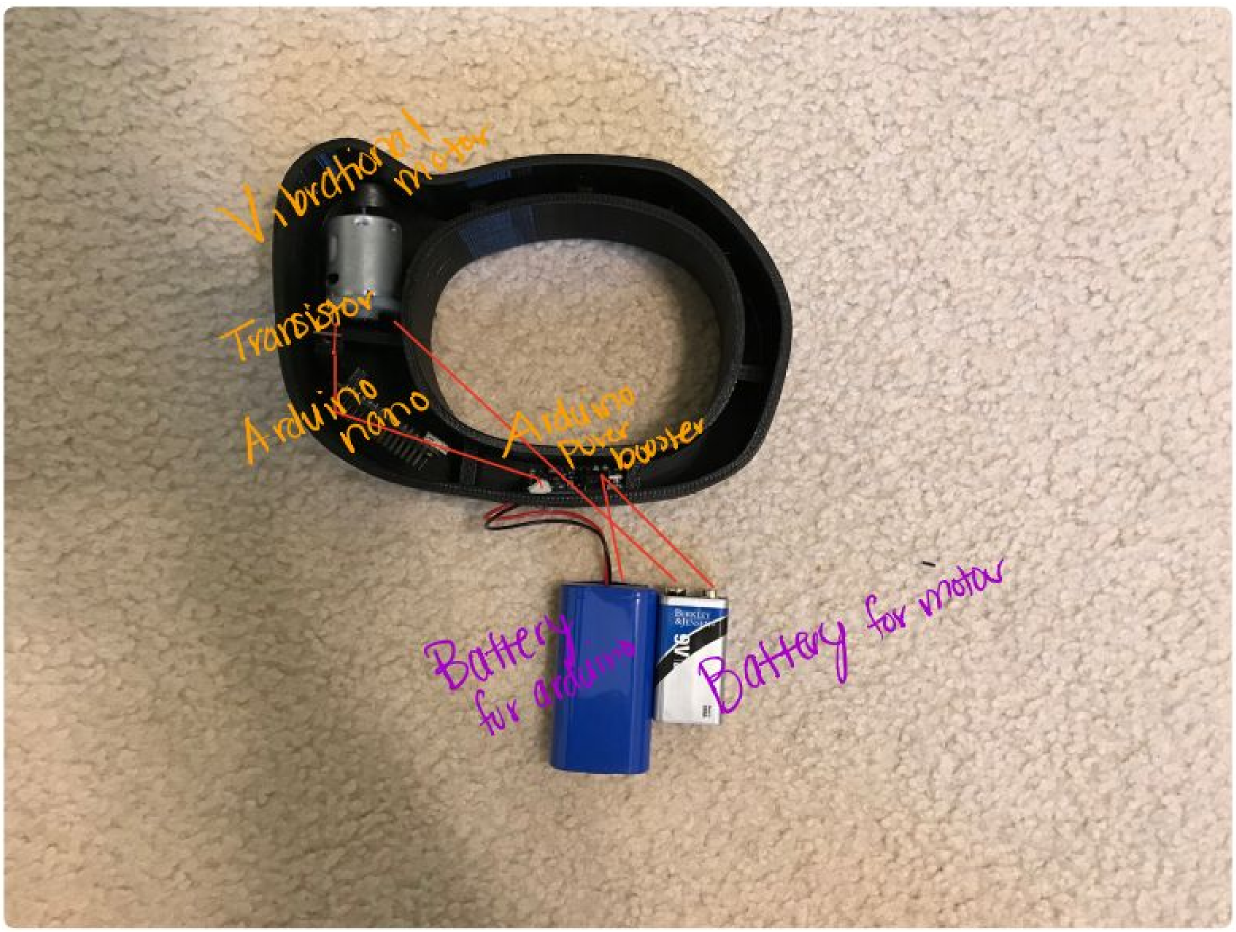


Figure 7.1.2.1 - *Components fitted inside of handle*

7.1.3 - Final Design Base

The final base design would have been redesigned the week after Spring Break, but due to COVID-19, it has been saved for future work. The base would have included a battery connecting the handle to the base and including different ranges to accommodate patient heights.

Chapter 8: Conclusion and Recommendations

8.1 - Future work: Handle Design

The handle was redesigned to house the electrical components and to provide a comfortable cane for the patients. Future work of the handle design includes incorporating other components such as a heating pad rather than the subject using a cloth to put over the handle. As more components are added into the cane, the handle design will be readjusted. Readjusting the design provides room for the other components. Further readjustment will be required if there is too much weight located in the handle as further components are added, as too much weight in the handle will be uncomfortable for the user.

8.2 - Future Work: Base Design

Future work on the base will focus on expanding the range that the cane is able to adjust to. Currently, the base only has a range of 44.5 to 57.4 cm. This range is insufficient to accommodate for the range of patient heights that Therawalk aims to provide for, specifically for shorter individuals. Further, the full assembly of the cane has been saved for future work due to the COVID-19 outbreak in the beginning of 2020. As a result, additional components such as screws may need to be added to facilitate full cane assembly. Furthermore, as additional components are added to the cane handle, such as the thermotherapy component, some of the electrical design may need to be housed in the base, resulting in further design alterations.

8.3 - Future Work: Electric Components and Design

Future work on the electrical components will primarily focus on allowing the user to easily change between vibrational and thermotherapy settings. This will be done using an app in which the settings can be altered and the battery life of the Therawalk cane would be displayed. This will be connected via bluetooth from the Therawalk device to their mobile phone.

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