CaneTech

March 28, 2017

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University Burnaby
British Columbia V5A 1S6

RE: ENSC 405W/440 Design Specification for **Mobility Cane Improvement – The NavCane**

Dear Dr. Rawicz,

The following design specifications for the NavCane has been prepared by CaneTech as a course requirement for ENSC 405W/440W. The goal of our capstone project is to provide an upgrade to the functionality of current mobility canes by allowing for the detection and avoidance of obstacles from a greater distance, effectively extending the reach of the standard cane. The NavCane will give the visually impaired the freedom and independence to travel with greater confidence, even while alone.

Through proximity detection, the NavCane will provide the user with the ability to avoid obstacles that would not be noticed using a conventional cane. The NavCane will communicate to the user using haptic feedback, to indicate locations of objects outside the range of a conventional mobility cane and overhangs that a conventional cane would not detect. To specifically achieve our listed goal, we have outlined a set of required functionalities in our former document. For the sake of reference, we have listed these in the appendix.

This design specification document will discuss the specific design of our product, showing exactly how our system will meet the requirements proposed in our functional specification. We will project the design into the proposed stages of development over the remaining time of our eight-month project. Enclosed is the technical descriptions of our general system design and specifics of each separate module in our project. In addition, a separate appendix that outlines the design of our user interface and test plan for our product is included.

I would like to thank you for your time and efforts. Please feel free to reach out with any questions or concerns regarding our project to our Chief Communication Officer Ryanpreet Sihota by email or phone at rsihota@sfu.ca or 778-908-2545.

Sincerely, Ishika Luthra

Ishika Luthra

CEO
CaneTech

Enclosure: Design Specifications for the NavCane

CaneTech

DesignSpecification

The NavCane©

An improved mobility cane for the visually impaired

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Abstract

For the visually impaired, independent navigation in unfamiliar and changing environments can be a challenge. This can limit them to a few learned paths and restrict their freedom to travel to unknown locations. At NavCane we aim to tackle this problem with our improved mobility cane as a solution, giving our users the confidence to be independent.

Typical mobility canes only help to identify obstacles they make physical contact with, so a user's area of perception is limited to the length of the cane. Standard mobility canes also cannot assist the user in detecting low overhangs, leaving the individual vulnerable to head injuries should they travel below a low hanging obstacle. These are the two primary areas of inadequacy we hope to address with our product. At CaneTech, we believe that it is possible to update the antiquated standard cane, using the technology of today to provide a more fulfilling solution to independent navigation for the visually impaired.

Our solution has two parts. First, we will upgrade the classic mobility cane to have proximity sensors that have a greater detection range than physical contact. This will eliminate the need for the user to contact an obstacle with their cane to avoid it. The proximity sensors will be able to detect upcoming obstacles at a distance, as well as provide warning for low overhangs. Second, through the use of haptic feedback, we will convey information regarding hazards in an intuitive manner.

This paper will discuss our design details for the NavCane and how its functionality will be realized. The information presented throughout the document will be in reference to the requirements specified in our previous report. Through this design specification we will describe our overall system design, followed by our mechanical design, haptic feedback, and obstacle avoidance modules. Also included in this document is two appendices that describe our planned product validation testing and user interface design. It is our hope that this document fully realizes and elucidates the product we are trying to build.

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Acronyms:

API - Application Program Interface
UI - User Interface
IMU - Inertial Measurement Unit
CDBA - Canadian Deaf Blind Association
ERM - Eccentric Rotating Mass
*GPIO - General Purpose Input Ou*tput
SMPS - Switching-mode Power Supply
PCB - Printed Circuit Board
SMT - Surface Mount Technology
LIPO - Lithium Polymer
PLA – Ploylatic Acid
PWM - Pulse Width Modulation

1 Introduction

It can be difficult for someone who is visually impaired to travel outside of the environment they are familiar with. Using technology to extend the sensory access of an individual opens doors for more independent travel. The current mobility cane gives the user feedback regarding nearby obstacles and surface texture, through hindrances that come in contact with the cane or surfaces that vibrate the cane. However, the mobility cane has shortcomings in certain areas: obstacles outside of the range of the cane and low overhangs are not detected, making exploration of new areas and buildings difficult and potentially dangerous. The restriction of only being able to detect obstacles within the range of the cane also limits the user’s walking speed, as there is a minimum time needed to react to hazards. Increasing this range of detection will give the user more time to react to obstacles, increasing their speed of travel. This will also improve their ability to explore new areas independently, as they can gather information from the environment faster and more efficiently. We believe that our product, the NavCane, can solve these problems.

An obstacle detection system will be the core of our system. An array of proximity sensors will be used to detect overhanging objects or obstacles in the user’s path. To relay this information in a meaningful way to a user, we are going to utilize a haptic feedback system built into the handle. Together these two systems will work in tandem to steer the user away from obstacles without a requirement for the cane to come in physical contact with the obstacle.

In general, the purpose of this paper is to specify at a technical level exactly how we are going to achieve our proposed solution. The requirement specifications paper that preceded this document gave an overview of what criteria each system would have to meet. This document discusses our design, as well as justifies how it meets the requirements outlined. The table of requirement specifications can be found in Appendix III. We will confirm that our design is in fact a solution to the outlined problem, and explain how we made our design decisions.

It is important to note that this paper is going to be specifying our design in reference to the proposed stages of our project. Our project is planned to span eight months, and as such, different features are expected to be implemented at different stages of design. There are also some proposed features that are dependent on the results of the next few stages in development. These features are being considered for our final product, but are not necessarily going to be included.

We will start with a description of the overall system. In this section, we will discuss the components that make up our system, their relevance to the system, and how we plan to realize them. Essentially, we are going to be describing our overall vision for this project and its various stages. We also discuss a few proposed features we would like to implement, should we have time, to provide a more feature-rich product.

Next, we will discuss the mechanical design of this project. The NavCane is going to need to be designed to house our sensors, actuators, and internal electronics, and also maintain its integrity in the face of unexpected forces that it might be subject to in daily use. The ergonomic design of the handle must be considered, as it is important that it is comfortable for the user and encourages use with the appropriate orientation. This section also discusses design specifics such as thermal dissipation, manufacturability, and component protection.

Next, we will describe the design of the obstacle detection system, discussing the system design, sensor coverage, and high level descriptions of the algorithms that will be used. This is arguably the most complex feature in our design, and its reliability will be the core of what makes our project useful. We will describe our considerations and decisions that have resulted in the current state of our continually evolving design.

After this, the haptic feedback design is going to be discussed. This is a very important topic as it is our main method of communication with the user. Aside from technical considerations such as power and cost, the ergonomics and overall 'feel' has to be considered. A design we have dubbed the 'thumb toggle' is our chosen design after testing several haptic feedback methods. We will be discussing this and more in this section.

Next we will discuss the potential indoor navigation feature of our product. This is an optional feature, and is still very much in the conceptual state of development. Indoor navigation is by no means part of the bedrock functionality of the NavCane at this stage, and our design would be still be considered a solution to our targeted problem without these features.

Finally, the appendix is attached to the end of this document. This includes the test plan appendix that outlines tests we have chosen to demonstrate the capability of our design. The second is the user interface (UI) design, in which we talk about the specific considerations we made in developing our product regarding the user interface.

2 Overall System Design

The NavCane is a modified mobility cane for the visually impaired. Users will be able to navigate using the NavCane in the same way they would with a typical mobility cane, but will also be able to benefit from the cane suggesting movement direction to avoid obstacles and warning them of upcoming overhangs and low ceilings.

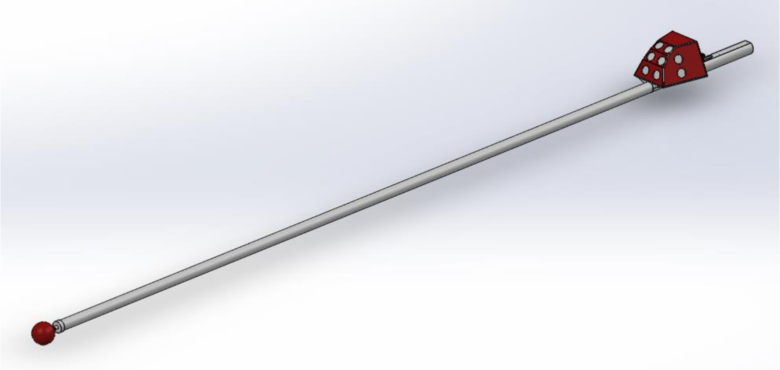

Figure 1: Conceptual model of the NavCane

As a modified mobility cane, the product will be a varied size depending on user with sensors, actuators, electronics, and battery located near the handle as to limit the torque needed to lift the end of the cane off the ground. As mobility cane users are used to a golf club-style grip, the handle itself will be as minimalistic as possible while still encouraging proper orientation of the cane (as improper orientation may result in the sensors facing the wrong way). The user's thumb will sit in a small recess in the handle in the cane, mounted on a servo motor. Direction suggestions will be indicated to the user through changes in orientation of this recess, and alerts will be indicated via a few vibration patterns in the handle of the cane.

Figure 2: Mock-up of thumb toggle

The internals of the NavCane, in its current form, consists of three sub-systems. The first is the data collection system, responsible for measuring the environment. The second is the information processing sub-system, which converts the raw data from the sensors to useful navigation information fed into haptic feedback, that the NavCane will use to steer the user away from obstacles. Finally, the feedback sub-system uses that information to indicate to the user a safe direction to travel and/or alert them of upcoming hazards like overhangs.

The first sub-system, data collection, consists of an IMU and an array of five ultrasonic sensors. These ultrasonic sensors are arranged to collect data from the right and left of the cane, from a few metres in front of the cane, and from a short distance ahead of the user at head height. As the user sweeps the cane back and forth in front of them, these sensors will capture a simple representation of the obstacles in the near vicinity of the user.

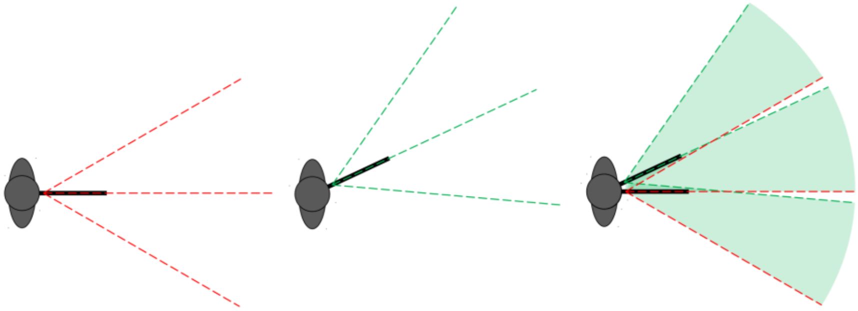

Figure 3: Field of view of sweeping NavCane

The IMU provides accurate relative orientation data, which is combined with the distance measurements from the ultrasonic sensor array to produce several points in space where objects have been detected. These points will be saved and used in combination with recently collected points for a short time. This allows the generation of a reasonably information-rich point cloud with a small number of sensors. Using only gyroscopic data we can very accurately account for the user rotating the cane from the left to the right, but it is more difficult to account for forward motion. Without any compensation for linear motion, data points become invalid after a short time and must not be used. Methods of linear compensation will be addressed in the following four months.

The second sub-system is data processing. This system will be focused on manipulating the point cloud provided by the data collection system. First, the point cloud will be processed to find surfaces of objects. This will be a constant operation, as new points will be continuously added and old points will expire. Next, a path finding algorithm will find the easiest and safest path to follow, in the general direction of travel, that avoids all calculated faces with some radius of avoidance.

There are also several features that we would ideally implement in the next four months. However, there is some question of increasing the complexity of our project too far, so these features are being kept as potential additions for later on in the project. The features all revolve around smartphone connectivity. The first and most important feature is to have the option for audio alerts, to satisfy **R7.8-PROD**. A user can get more information from the NavCane from descriptive audio than from the minimal haptic feedback on the cane itself. The user would connect their phone to the cane via Bluetooth (to satisfy **R7.5-PROT** and **R7.10-PROT**), and a custom app on the smartphone would receive signals from the cane and announce them to the user. This would be advantageous for situations where there is no easy way to notify the user through haptic feedback, like a dead end, or for less urgent alerts like warnings of uncertain objects to the side.

Another feature that smartphone connectivity would allow us to accomplish is customization. To meet **R7.7-PROT**, an app could have customizable parameters like how close objects must be before an alert is sent or how subtle the vibration alerts are for power users. This wouldn’t be a requirement for using the cane, so it wouldn’t restrict our audience, but would allow more advanced users some control.

One last feature smartphone connectivity would allow is indoor navigation. IndoorAtlas is a service that provides accurate indoor positioning without requiring installation of any hardware in a building. Any building, once mapped out, can be navigated using the IndoorAtlas API. Integration with this system would allow users of the NavCane that have a smartphone with an internet connection will be able to utilize increased positional accuracy and indoor navigation of public buildings.

3 Electrical

Proof of Concept

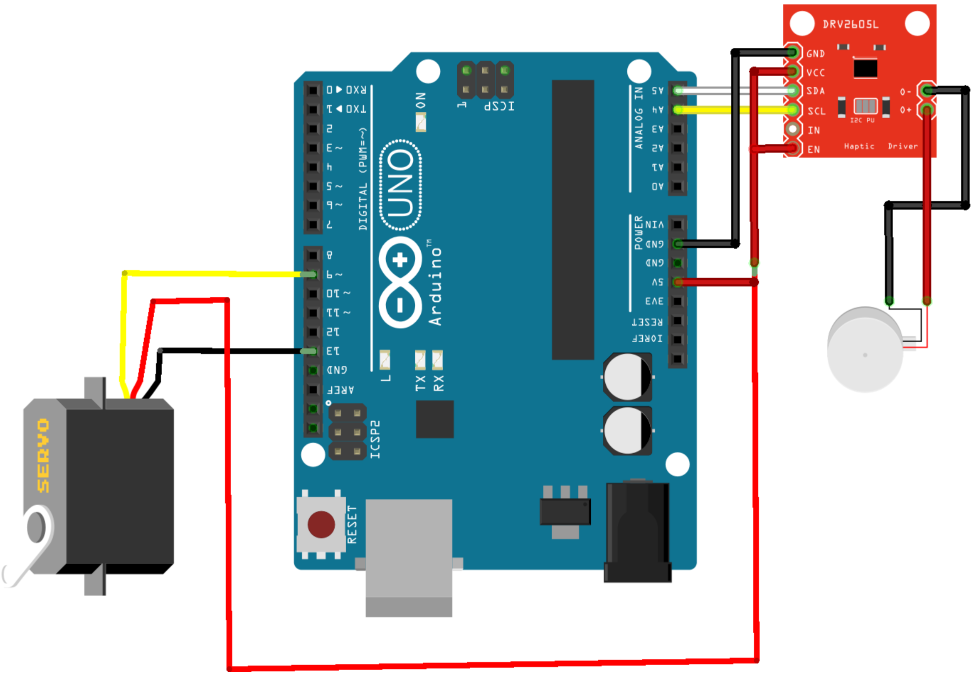

Figure 4: Haptic Feedback Circuit

The circuit diagram in the figure 4 is for the haptic feedback system. This system consists of a servo motor for primary feedback and an ERM motor for secondary vibrational feedback. The servo motor is controlled using a PWM signal from the micro-controller. The ERM motor uses a Texas Instruments' DRV2605L Haptic Motor Driver, which is connected to the microcontroller via the I^2C bus. The driver provides the use of different vibration patterns which would be used to relay urgent information like upcoming overhangs or low battery warnings to the user. The driver chip also has an enable pin which could be used to disable the driver when not in use and thus help in preserving the battery. This system allows **R5.2-POCT** to be met.

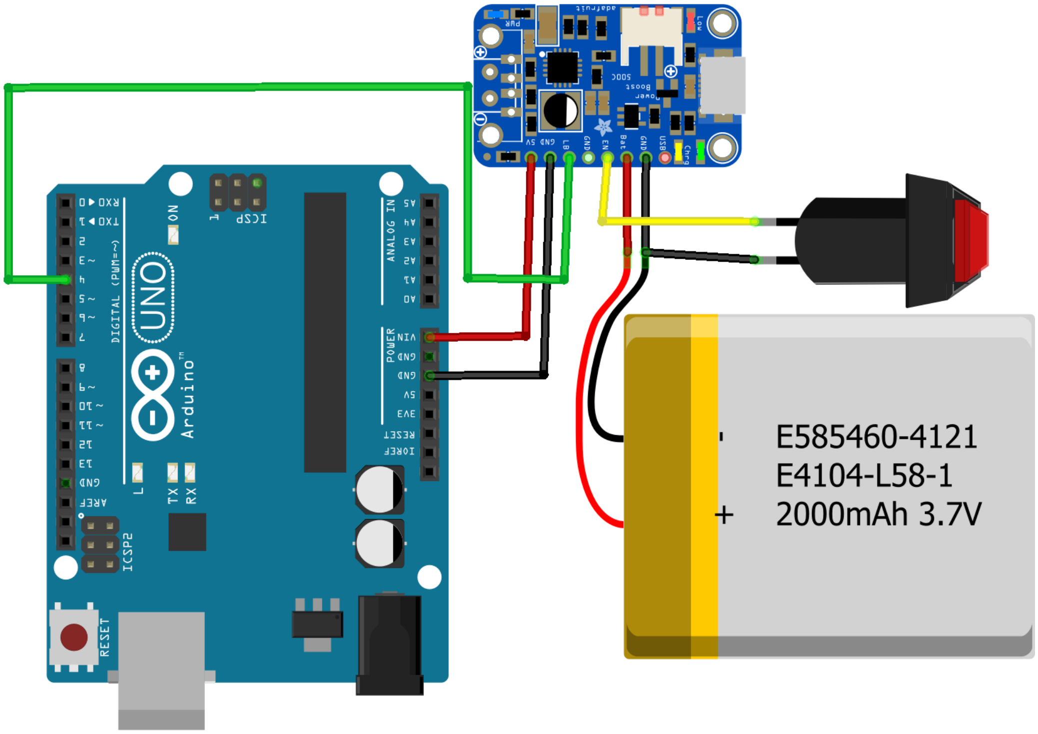

Figure 5: Power Management Circuit

The circuit diagram in the figure 5 is for the power management of the system. The cane is powered by a Li-ion battery which is rated for 3.7V (operating range is between 3-4.2V) and has a capacity of 2000mAh. The cane will also feature a micro-USB port which allows the user to easily charge the inbuilt battery by using any commonly found USB chargers. The charging circuitry utilizes a Microchip's MCP 73831-Miniature Single Cell, Fully Integrated Li-Ion, Li-Polymer Charge Management Controller. The charge controller is set to regulate the charging voltage at 4.2V and maintain a charge current of 500mA according to the battery specifications. The circuit also includes a Texas Instrument's TPS61090-Synchronous Boost Converter with 2A Switch. This SMPS has a 96% conversion efficiency and has been chosen as it works over the entire battery range. It has also has been designed to regulate the output voltage. This will power the micro-controller and other circuits at 5V. The chip also has a low battery comparator which sends a signal to the microcontroller when the battery is below 3.2V, so that the user can be warned. The enable pin of the chip is connected to a on/off switch provided on the cane which shuts down the output when the switch is triggered by the user. This system will allow **R3.7-PROT**, **R3.8-PROT**, **R5.3 -PROT**, **R5.4-PROT** and **R5.7-PROD** to be met.

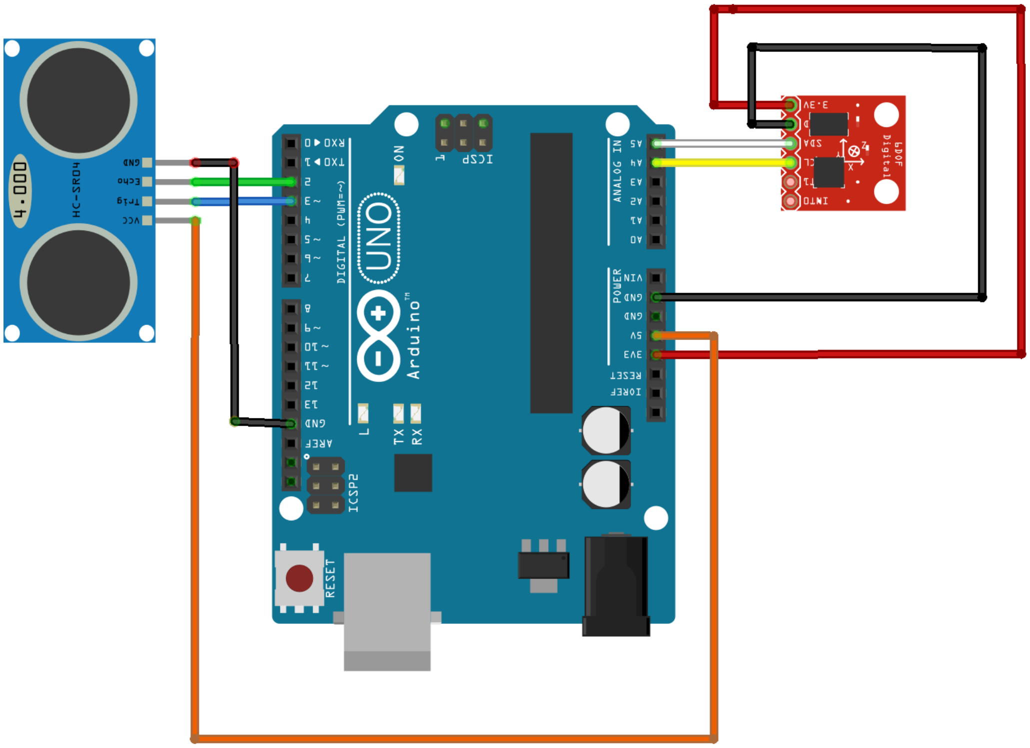

Figure 6: Obstacle Detection Circuit

The circuit diagram in the figure 6 is for the proximity detection system. The cane utilizes a total of five HC-SR04 Ultrasonic sensors. The micro-controller triggers the sensor by providing a pulse at the trigger pin, which makes the transmitter in the sensor emit an ultrasonic wave at 40kHz. The receiver waits for the reflected wave and then sends a signal back to the micro-controller using its echo pin. Based on the time difference between the transmitted and received pulse, the distance between sensor and objects can be determined. The proximity algorithm also uses an IMU (Inertial Measurement Unit) which has 9 DOF (Degrees of Freedom). The IMU is connected to the micro-controller using the I^2C bus.

Prototype

Our design will utilize an Intel Edison as our microprocessor. It contains a dual core processor clocked at 400 MHz and a microcontroller unit clocked at 100 MHz, which should be able to satisfy **R7.4-PROT**. The Intel Edison also includes built-in Wi-Fi and Bluetooth support which would be helpful if the android application/indoor navigation system is implemented in the future. The Edison will be used to control the hardware circuits and to process the data collected. The breakout boards for the Edison would be used for debugging purposes as they make it easier to connect to the Edison’s 70 pin Hirose connector. The base block would be used to access the serial console port, and the ethernet-over-USB port would be used to program the Edison. The GPIO block makes some of the GPIO pins easily accessible and can be easily placed on a breadboard. The Edison works on 1.8V logic but the GPIO board consists of a logic translator chip which gives us the ability to work with 3.3V logic level. The I^2C block gives us access to the I^2C bus of the Edison which can be used to connect the different I^2C enabled devices.

The final design would include all the parts mounted on a PCB (Printed Circuit Board). SMT (Surface Mount Technology) parts would be used to ensure smaller footprints, making it easier to install the circuit on the cane.

Power saving features would be implemented. The user would be warned when the battery reaches 15% capacity and when the battery further drops to 5% the cane would be switched over to function in power saving mode. This mode would keep only certain emergency functions active like warning the user of overhang. The user would also be alerted before the battery completely runs out of power and all the functionalities of the cane need to be switched off. If the user forgets to switch off the cane when not in use, the cane would be switched over to sleep mode which would help in conserving the battery. This would further contribute to meeting **R3.7-PROT**.

Thermal simulations would be performed on the cane using industry leading software by Mentor Graphics called FloTHERM XT. Proper techniques would be utilized to ensure that the heat is dissipated reducing any discomfort to the user.

4 Mechanical Design

During the exploration of the obstacle detection and avoidance system, a number of options were considered. We could have built a handheld device with the intention of replacing the mobility cane, but that would mean users would have to entirely abandon their cane navigation skills and rely solely on our obstacle detection system. This drastically steepens the learning curve of our product, and leaves the user with nothing in the case of system failure or power loss. Our general philosophy is that we want users to navigate with the cane as they are used to doing, supplemented with feedback from our system. We are adding to the information gathered by the cane, rather then replacing it. In addition, having a physical cane means the user would have a backup method of navigation to rely on should our system fail.

We considered designing our system to be attachable to any pre-existing cane, but this leads to some severe issues. Accommodation for the variance in cane types would have made our overall system more complicated and less reliable, as we struggled to find consistent parameters in our design with which to base our detection algorithms. A removable product would also likely be heavier then a cane with built in hardware, as we would require an additional mounting apparatus. Creating a full cane also comes with the added advantage of being able to house electronics in the interior of the cane, making the product smaller and distributing weight more evenly. In the long run, the additional time and cost that would be incurred by designing an all-in-one cane was justified by the weight, size, and complexity improvements gained. We made the decision to design an entire cane so we could house our haptic feedback and proximity detection equipment inside.

We subdivided the mechanical design of the NavCane into 3 sections. The first is the handle design, which accommodates the haptic feedback system and battery. The next section of the cane is the sensor box. This will hold all the sensors and the microcontroller. It needs to be designed so that it isn't too large and unwieldy. The last section is the cane itself, which is fairly standard. For this part, reference will be taken from the materials and dimensions of standard mobility canes on the market today.

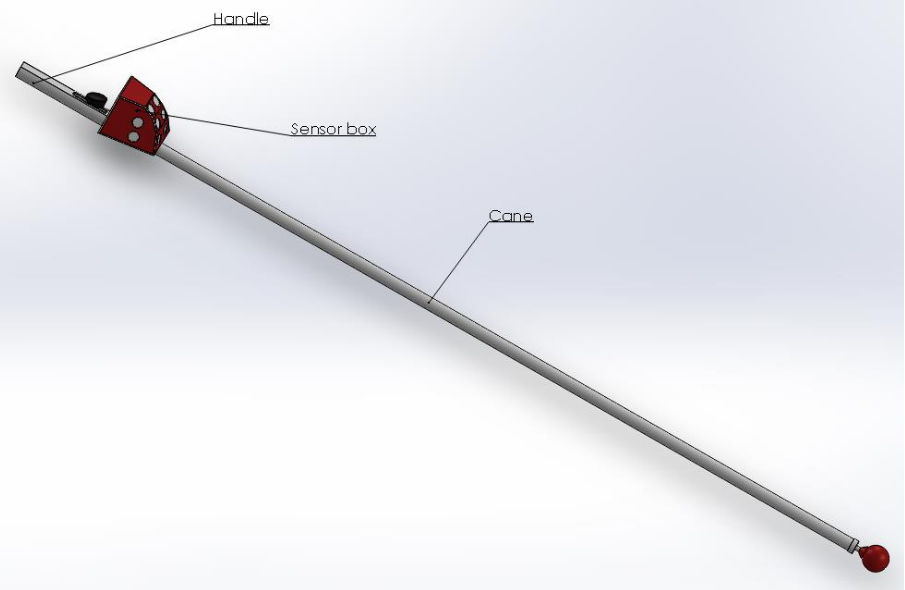

Figure 7: High level mechanical system

One thing to note before exploring the specifics is that all this design work primarily concerns our prototype. The POC stage is planned to physically realize only the haptic feedback and proximity features. It is our intention that this section will primarily cover the post-POC design.

Handle:

The handle has multiple purposes. In general, it is the point at which the user grasps the cane and physically holds it. As this is intended to be the user's sole point of contact with the cane, it is naturally where the haptic feedback system is to be located. This requires that the haptic feedback system be embedded in the cane, and that the handle be built to promote a grasp in which the user can directly interface with the haptic system while holding the cane. In addition, the handle will also house the battery. The reasoning for this is that we wanted the center of mass to be as close to the users grasp as possible. A center of mass close to the handle will make the cane more manoeuvrable, as the user does not have an as much of a moment of inertia to overcome [1].

To fit all this equipment in the handle we came up with the rough layout diagram as shown below:

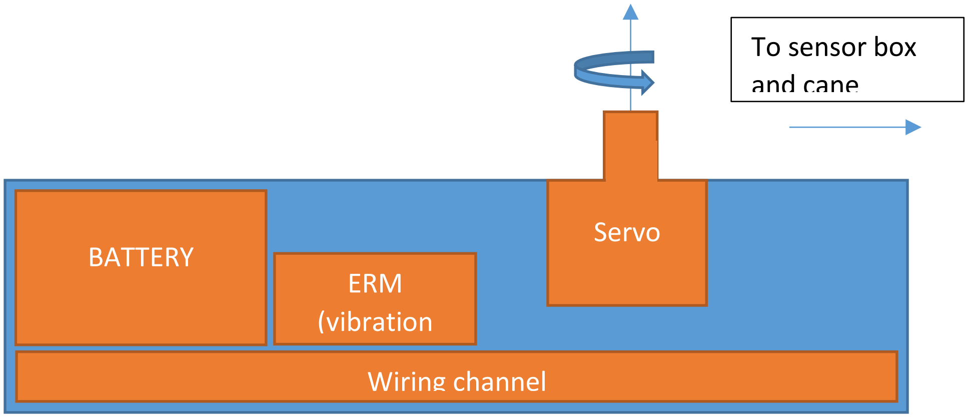

Figure 8: Handle equipment placement

The center of the handle will be hollowed out to allow for the placement of hardware inside. As was previously mentioned, the battery is to be placed in the back of the cane to shift the center of mass back, as it the heaviest component we have to accommodate. We also want the handle to accommodate wiring so a little bit of extra space will have to be allocated for this. In addition to this we also want to mount our vibration motor inside the cane close to where the palm would be so that the user can feel it the best. There is going to be a hole in the handle that we can use to place the servo. This hole design can be seen in greater detail in the diagram below.

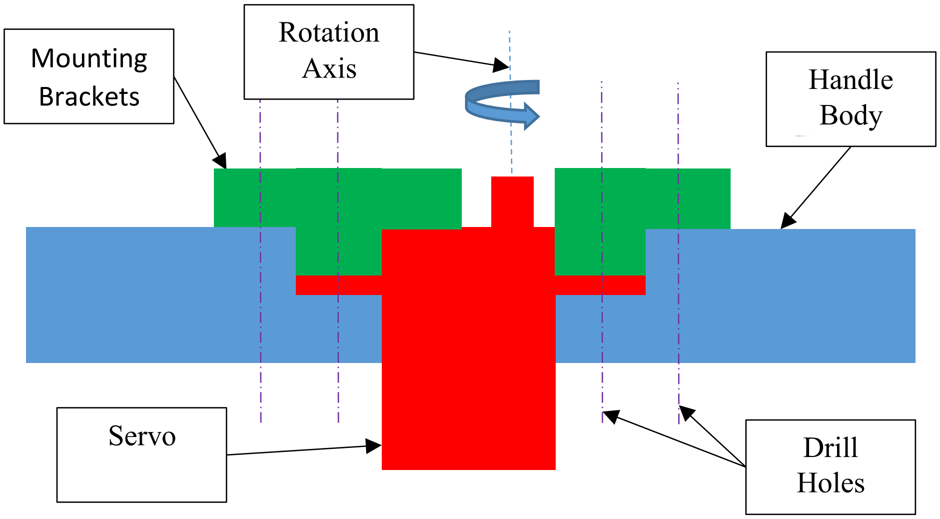

Figure 9: Hole diagram

These mounting brackets would allow us to tighten the assembly very easily. As such this would make the opening in the handle body more resistant to water. We need to prevent the exposure of electronics to water as we can expect the cane to be used in rainy conditions, and this kind of mounting system would help us achieve that.

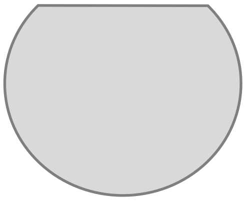

Figure 10: Handle Shape

For the handle shape itself, we referenced the most common design of mobility canes. They are semi-circular with a flat side as seen in the diagram above. Discussing with an Orientation and Mobility Specialist we were informed that typically the visually impaired are taught to grasp the cane with their thumb on the flat side, called a ‘thumb press’ grip. There are alternative grips such as the ‘pencil grip,’ but in Canada the thumb press grip is by far the most popular way of holding a mobility cane. Both grips can be seen in Figure 11 below. This is what inspired the placement of the haptic toggle on the flat side, as this would seem intuitive to someone who is used to using a mobility cane.

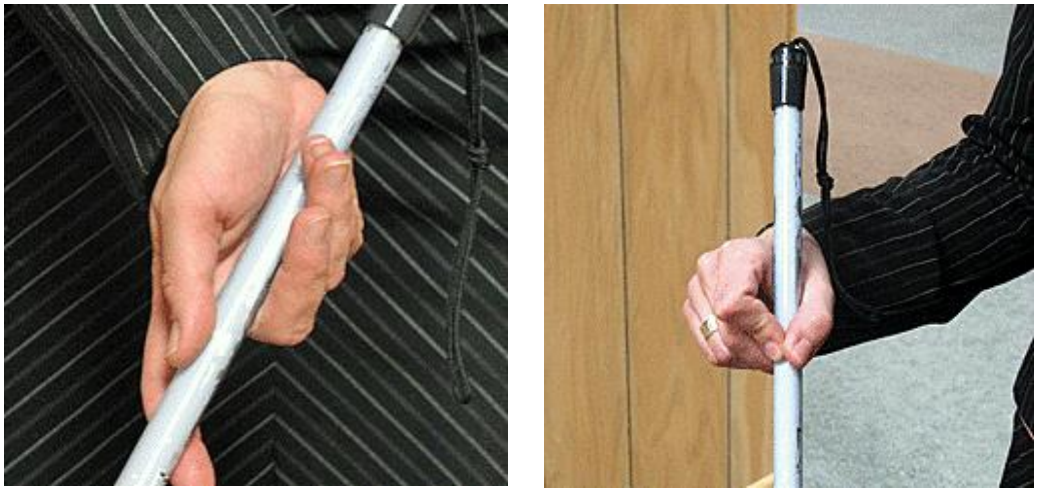

Figure 11: Handle grip (thumb press on left and pencil grip on right) [2]

The material we intend to use for the handle body and mounting brackets is aluminum. Aluminum is relatively light and will suffice for maintaining the structural integrity of the cane body. In addition it will help to dissipate heat generated from the battery, ERM, and servo contained within the body, since aluminum has very good thermal transfer properties. For comfort and grip, we intend to place a rubber liner on the body. This will make the handle more comfortable to hold for extended periods of time.

For the dimensions of the handle we are planning a diameter of about 26mm for the circular shape of the handle (with a slice of the circle taken away to make a flat face) and a length of 15cm. The current radius was chosen so that it was small as possible while containing the equipment in a structurally sound way. This was done to reduce weight and not vary from the regular handle of a mobility cane too much (for familiarity reasons). Now the length was chosen to be 15 cm as felt like a good length. The average palm size for males is 84mm and females is 74 mm [2]. Assuming the more popular 'thumb press' grip described above and the average male palm size we have 66mm for the thumb to stretch out. This is more then needed but will accommodate outlier hand sizes without adding too much extra weight.

$$\begin{aligned} &weight\ of\ handle\ (rough\ calculation) \\ &\qquad = 0.9g\ (erm) + 46g\ (battery) + \ 9g\ (microservo) + \ 112g\ (aluminum\ case) \end{aligned}$$

The force we expected on the handle will come from two sources. The first is gravity - the weight of the handle was very roughly estimated to come out to 168 grams, which would be the contribution of the handle to the total weight the user would be carrying. The second applied force would be the grip of the user itself. We believe that the aluminum body will be sufficient to prevent the user from crushing the handle.

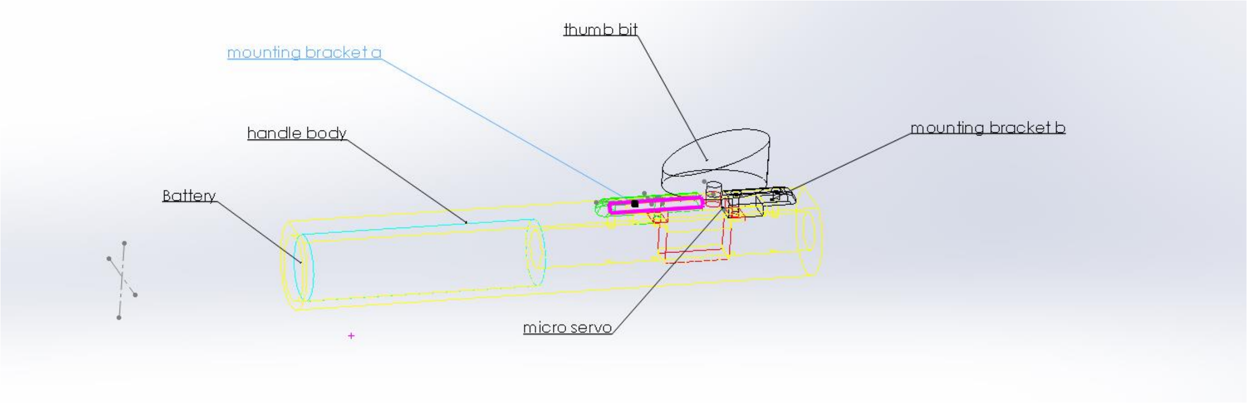

Figure 12: Handle model view A

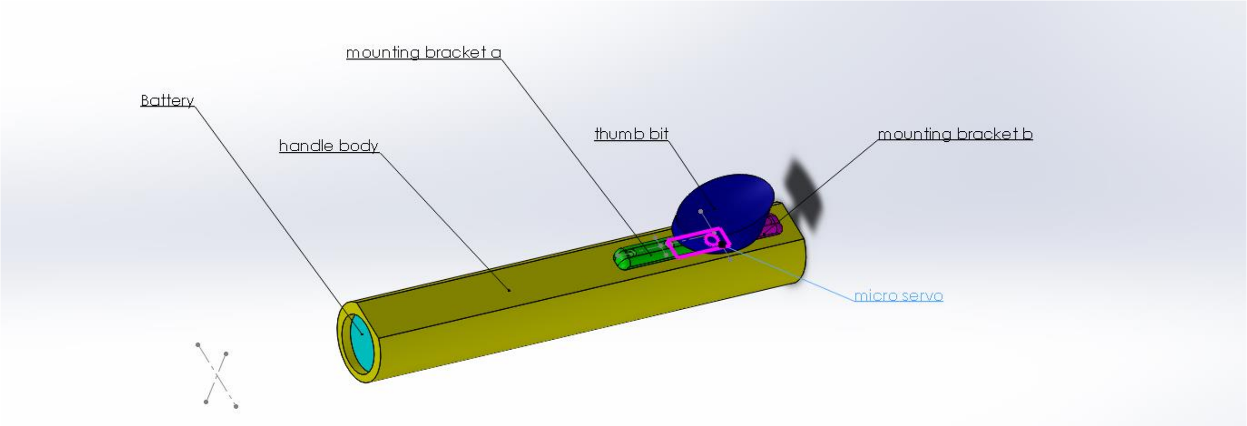

Figure 13: Handle model view B

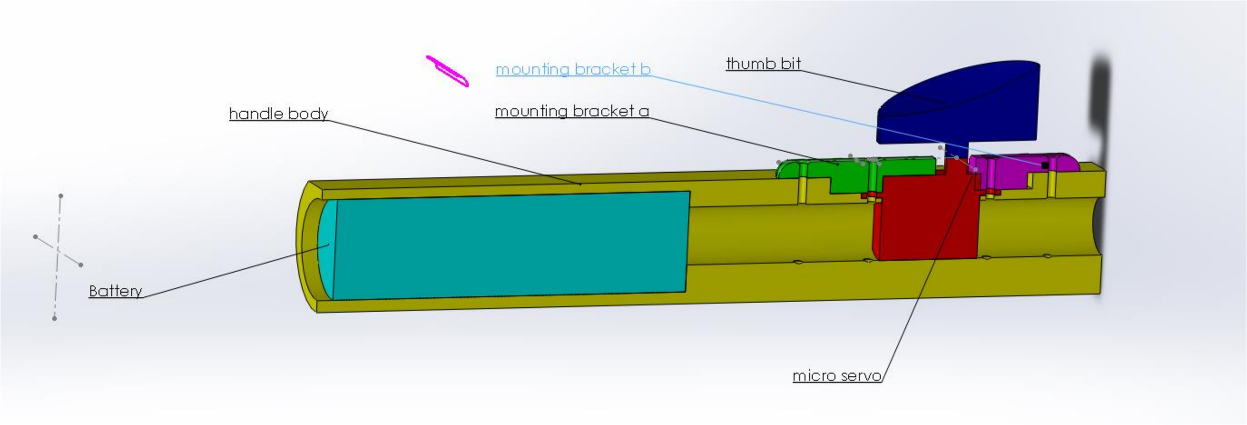

Figure 14: Handle model view C

The figure above shows a model we created for the cane handle. It is worth mentioning that this is a rough model to be used in simulation and to illustrate what our handle prototype is conceptually going to be. As such, it is subject to revisions in the coming months.

Sensor Box:

The topics that will be covered throughout this section will be as follows: structural design, mounting, and simulation results. Within these topics, a more in-depth discussion and analysis will occur which will show the justification of our design in regards to the sensor box. The purpose of the sensors box is to house most of the electronics so that easy access is possible, while still providing a clean, dry, and thermally optimal environment. Its other purpose is to contain the ultra-sonic sensors in a very particular arrangement. For every user, the sensor box orientation must also be consistent within a small variation, even with users of different sizes and canes of different lengths, in order for our sensor array to cover the appropriate area. For more information about sensor angles and justification refer to Obstacle Detection Design.

Within the sensors box there will be five ultrasonic sensors, one inertia measurement unit (IMU), one Intel Edison, an ERM motor driver, one Lithium Polymer(LiPo) battery, a battery management chip, and a charging circuit. Each of these components takes up varying amount of space; therefore, the structural design must be able to appropriately contain all of the components while keeping in mind properties such as thermal dissipation, waterproofness, material choice, and vibration isolation.

The sensor box had to meet requirements that were previously made, within the requirement specifications paper, such as **R3.12 – PROD**, **R6.4-PROD**, and **R6.5-PROD**. Requirement **R3.12-PROD** touches on the fact that, in today's world, we as engineers need to design with the environment in mind, and therefore adopt the cradle-to-cradle design philosophy. With this is mind, our sensors box material will either be PLA or Aluminium. PLA, "corn plastic, is made with Midwestern corn … Its production releases fewer toxic substances than making petroleum plastic and uses less energy, spewing an estimated two-thirds less greenhouse gasses. Corn plastic can also be composted, incinerated or recycled, its manufacturer says, offering "the most alternatives" of any plastic to landfilling." [4] Aluminium is also considered to be extremely recyclable, and therefore by choosing one or the other for the prototype will result in an optimal material in regards to environmental awareness. Requirement **R6.4-PROD** says that the sensors box will be impact resistant, the isometric figure of the sensor box below shows multiple different angled faces, each of which will have one ultrasonic sensor flush to on the inside. These faces play two important roles: one is that each face represents the specific angle each sensor is angled at, and the other role is that if the cane were to fall and the sensor box was to take a direct hit, the force on the box will be deflected rather than absorbed as a straight on impact.

The following calculation gives the weight of the sensors box to be 138g. This calculation was done with the volume of the box being 110.31 cm^3 (from solid works model) and the material used being PLA plastic. The weight of five ultrasonic sensors and the Edison added an extra 50g to make the total weight of the sensor box with housed components to be 188g.

$$weight\ of\ sensor\ box\ (rough\ calculation) = 138g\ (box) + 50g\ (sensors + edison)$$

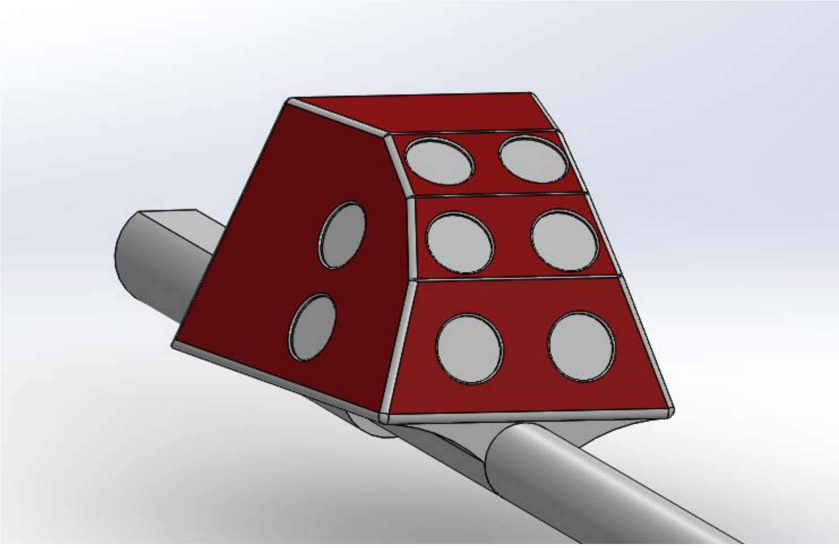

Figure 15: Isometric view of sensor box

Requirement **R6.5-PROD** says that the sensors box will be waterproof. This is essential as most of the canes electronics will be housed within it. We plan to achieve waterproofing by form fitting the lid to the box, while placing a gasket in between the lid and the box. By tapping a thread forming stainless steel screw with a rubber washing into a flange within the body, at all four corner within the main sensor box body, this should implement a waterproof seal.

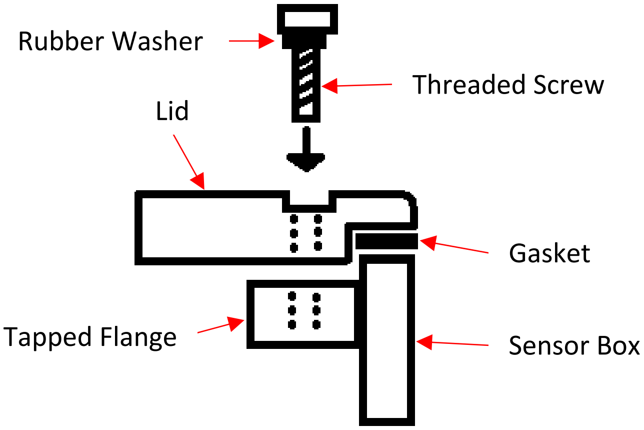

Figure 16: Exploded side view of waterproof lid

As seen by the picture above, the threaded screw with a rubber washer will fit into the counter sunk drilled out hole, which will then be tightly threaded into the tapped flange. As the threaded screw becomes more tightly screwed in, the gasket in between the sensor box and the lid will be compressed, effectively creating a watertight seal. The sensor box will most likely be made of PLA, which will act as more of a thermal insulator because the thermal conductivity coefficient of PLA is 0.13 W/m-K [5]. Therefore, the need for a proper heat dissipation process is evident. All components that generate heat will have thermal pads attached to the pre-made PCB’s, and the thermal pads will then attach to a very thin aluminium plate. These thermal pads will transfer heat from the component to the aluminium plate, while acting as an electrical isolator to prevent the components shorting through the aluminium plate. The thin aluminium plate will then be welded to an aluminium stud which will fit into a bored hole through the bottom of the sensor box, facing the cane shaft. We will use silicone to seal the bored hole that the aluminum stud will fit through, then on the end of the stud that is outside of the sensor box, small fins will be implemented so that natural convection can take place. Therefore, to summarize the heat transfer path, the heat will be generated from the component, travel to the thin aluminium plate via the thermal pads, continue through the aluminium stud down to the fins, and finally be dissipated. A potential hiccup with this design is that the efficiency of heat transfer relies on the temperature difference between the thin aluminium plate and the end of the aluminium shaft with the fins. That being said, if the temperature difference at the given time is not sufficient, the thin aluminium plate will dissipate the heat by spreading it over a larger surface area. For reference please see figure below.

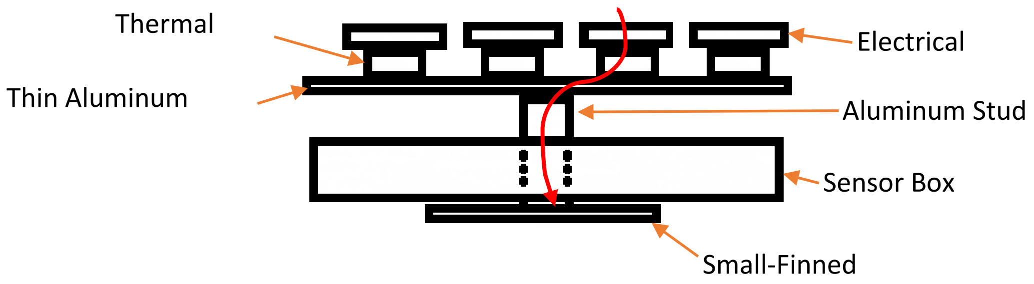

Figure 17: Side view of heat transfer path

Vibration is a complex phenomenon, one that impacts materials in many ways. How vibration impacts a particular material can be measured in what is called the tan delta. The tan delta “quantifies the way in which a material absorbs and disperses energy.” The higher the tan delta of a material the greater the dampening coefficient it presents [4]. In general, vibration isolation throughout the majority of the cane is not needed. Vibration isolation does become very important wherever the IMU resides inside the sensor box. Since the IMU measures acceleration data as well as rotational data, any impact the NavCane goes through will spike the IMU’s output data, especially without any sort of software filtering or mechanical dampening. Therefore, on the mechanical side, a need for dampening is prevalent. Since this level of detail within the NavCane has not been implemented yet, like all the solutions listed within this section, we would need to test what type of dampening would work best. The first and most likely solutions is using a low-density foam epoxied to the thin aluminium sheet. This would be a cost effective, light, and efficient solution. Another possibility is to use a spring, but mounting the spring while inserting foam into the core would be quite challenging, and potentially not very helpful in our case. Therefore, the most likely candidate is low density foam. Upon testing if we find that the foam is not performing, we can buy a different density foam and try again.

The sensor box protects the components within from water, vibration, and heat, while also keeping the hardware in an enclosed environment that prolongs component life. To summarize design choices with respect to waterproofing, heat dissipation, and vibration isolation respectively, the following techniques were used: waterproofing through using techniques such as using gaskets and sealed screws, heat dissipation via surface area and temperature differentials, and vibrational isolation using low density foam.

Cane:

For the staff portion of the NavCane we are going to take influence from current mobility canes out on the market. From our research, we have found the shaft of most mobility canes to be roughly ¾ inch in diameter. The material can vary from aluminum to carbon fibre. For the sake of our prototype design, our material will be aluminum, as this is cheaper and easier to work on. Also, we will be assuming a non-collapsible solid shaft for at least our prototype. This will reduce complexity and cost. Our final product will likely be offering different length to accommodate people of different heights. For the sake of demonstration, our aluminum shaft will roughly be 1.2m long. This, of course, may be subject to change as we further develop our algorithms and may need the user hold the cane in a more specific position. Lastly, the shaft will be hollow and roughly weigh about 282 grams (1.2m of ¾ inch aluminum tubing with 1/16 inch thickness).

Overall Assembly:

In totality, assuming about 50g for miscellaneous weight using the previous derived weights, our system should weigh about 688g. we did an analysis using SolidWorks and our center of gravity is 500 mm from the butt of the cane directly within the center of the shaft. This is not ideal as you typically want the center of mass at the handle, but this is normally where the center of mass is for a standard mobility cane. To improve the location of the center of mass we would have to either add more overall weight to the cane at the handle butt or try to redistribute the current weight. Unfortunately, adding weight would may not improve the maneuverability as while the distance of the mass to the handle is reduced the mass increases so the moment of inertia would likely remain same. Regarding a redistribution of current weight, this would prove difficult to do greater then we already have without risking the structural integrity of the stick and the functionality of the stick.

For the prototype, it is expected that between the handle and the sensor box there is going to be a conduit to pass wiring between the hollow handle chamber and the interior of the sensor box. The way the handle will attach to the cane is by a mortise style joint. The cane shaft will be one piece and will require no special handling. The large sphere near the tip will connect to the shaft by having a tapped hole within the sphere, and the male threaded side will be on the tip of the cane shaft. The sensor box will require no construction as it will be 3D printed, and will be mounted to the cane shaft via a custom mount.

5 Indoor Navigation Design

The indoor navigation feature is a future consideration that will utilize a smart phone application and the indoor mapping capabilities of an application API called IndoorAtlas. This feature will help the users of the NavCane navigate in buildings that may not be familiar to them. It will have pre-mapped locations such as bathrooms, reception desks, elevators, etc. that the haptic feedback will be able to guide the user to. The smart phone application will take audio input from the user and provide them with directional feedback through the NavCane to guide them to the desired location using the IndoorAtlas API. IndoorAtlas is a company that has created a software which takes advantages of sensors in smartphones to measure fluctuations in the Earth's magnetic field around the building due to its structure. This magnetic field data as well as data from other sensors in smartphones such as GPS, accelerometers and gyroscopes are then used to create a map of the building. Once the building has been mapped it is available to all users of the application of API. We will use this API within our application to provide directional data to our user is two ways: through Bluetooth connection to the haptic feedback module, audio feedback from the smartphone, or a combination of both. Again, this feature is a consideration for the future and is not planned to be implemented yet.

6 Obstacle Detection Design

The NavCane detects objects through an array of five ultrasonic sensors just below the handle of the cane:

Sensor 1 – Angled upwards to detect low overhands that the user is in danger of hitting their head on

Sensor 2 – Angled downwards to detect objects below waist level

Sensor 3 – Oriented straight ahead of the user to detect oncoming walls and obstacles from a distance

Sensor 4 and 5 – Pointed to the left and right to detect lateral walls and objects

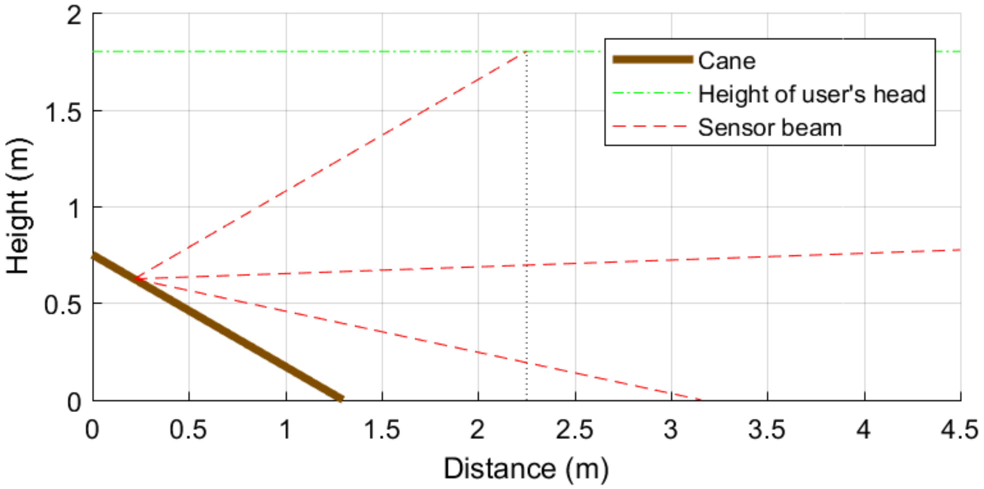

Figure 18: Vertical sensor angles at rest

Mobility canes are typically fitted to be the same height as the user's armpit when stood on end. These canes are held with the handle of the cane roughly at half that height, near the waist of the user. This results in an estimated 30° angle of the cane with respect to the ground, and a reach of roughly 1.25m. We assume our sensors to be 25cm from the end of the handle. Our top sensor will be mounted at an angle of 60° with respect to the cane, giving an estimated angle of 30° above the horizontal at rest. This angle will intersect with objects at the height of the user's head roughly between 1.75m and 2.25m in front of the user at rest, depending on the object's height. This will give them a few seconds of warning for overhangs, even at a reasonable pace. Our lower sensor will be mounted at an angle of 18° with respect to the cane, giving an estimated angle of 12° below the horizontal at rest, and intersecting with the ground at a distance of about 3m in front of the user. This will intersect with any short obstacles in front of the user with enough distance to send a warning, to satisfy **R3.4-POCT**. The third sensor will be mounted at an angle of 32° with respect to the cane, giving a slight angle of 2° above the horizontal at rest. This sensor will be primarily for detecting taller obstacles like walls at the maximum distance of the ultrasonic sensors, which was found to be about 4m in testing. This will allow the NavCane to satisfy **R3.2-POCT**. The positive angle with respect to the horizontal has the benefit of removing the possibility of intersecting with the ground. This will reduce error, as any measurement detected can be considered as an obstacle to avoid (ignoring the possibility of false positives).

It is worth noting that some users tap the cane side to side as they walk, with an approximate lift angle of 10° above the rest position, giving the cane a variation between 30°-40° above the horizontal as the user walks. This will change the angle each sensor makes with the horizontal, which has been taken into account. At a lift angle of 10°, the top sensor will detect overhanging obstacles at the height of the user's head at distances between 1m and 1.5m from the user. This is still enough distance that a warning can alert the user before walking into the obstacle, satisfying **R3.5-POCT**. The lower sensor partly takes on the role of the middle sensor, detecting slightly shorter obstacles up to the full range of the sensor. The middle sensor still detects taller obstacles at the full range of the sensor.

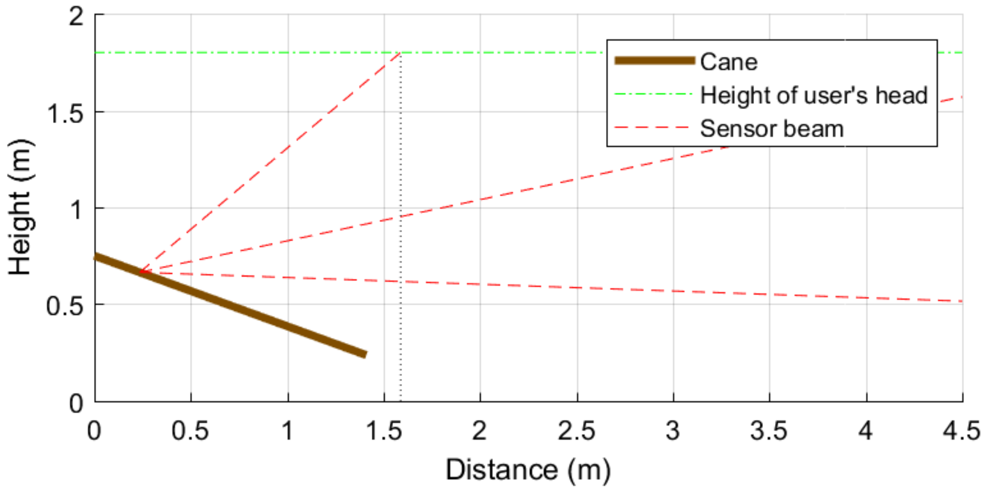

Figure 19: Vertical sensor angles with the cane lifted by 10°

The varying of the cane's angle actually works to the NavCane's advantage, providing more area coverage with the same five sensors. The same effect is present in the horizontal dimension, resulting from the side-to-side sweeping motion of the cane typical of almost every mobility cane user. This sweeping motion moves the tip of the cane across the user's path, usually between the width of the user's shoulders. With a cane length of 1.5m at a downwards angle of 30° below the horizontal, this works out to about a 15° sweep from right to left. Coupled with sensor angles of 30° to the left and right of the NavCane (at a vertical angle of 32° with respect to the cane), the resulting field of view across the entire sweep is about 90°. The area covered by this sweep is shown in the figure below:

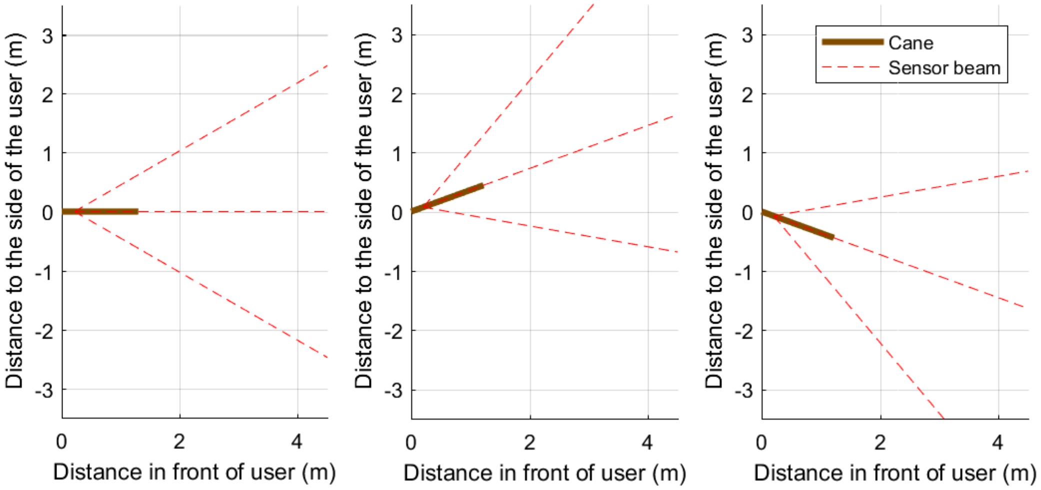

Figure 20: Horizontal sensor angles with the cane sweeping 15°

In accordance with R7.1-POCT and R7.2-POCT, data will be continuously collected and feedback will be continuously updated. For every measurement tick, each sensor returns a distance. If the cane doesn't move, it is trivial to map these distance measurements to points in space. However, with a moving cane, the sensors alone cannot acquire a valid history of detection points, and can only provide instantaneous feedback. Without saving sensor data for use in the next few seconds, the NavCane will only have 5 points in space to work off of, all collected in a single instant of time. This would severely limit the complexity and quality of our obstacle avoidance algorithm, as the NavCane can no longer use sweeping motion to increase coverage area. Additionally, this kind of naïve sensor algorithm can result in severe issues when the user sweeps the cane back and forth. An easy example is a hallway: if the cane is pointing straight ahead the cane will tell the user to go straight, but as the user sweeps the cane to the right, it will tell the user to go left avoiding the wall on their right, and as the user sweeps the cane to the left, it will tell the user to go right avoiding the wall of the left. It is fairly obvious that the 'correct' instruction in this case would be for the user to continue straight, so this method fails in this very common and simple situation, causing the user to move in a weaving motion as they walk:

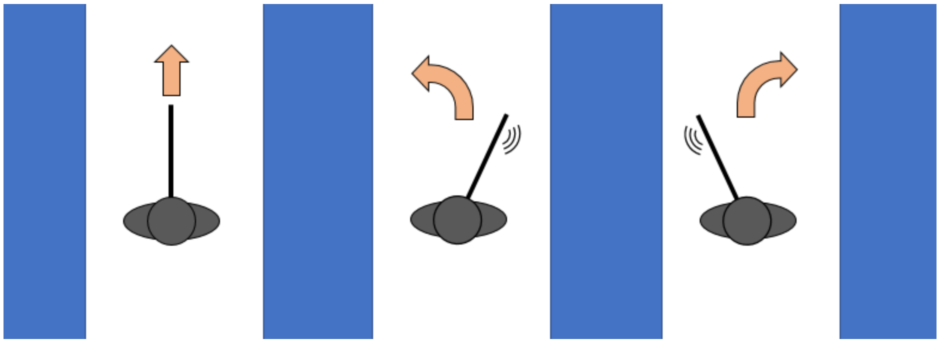

Figure 21: Naïve sensor algorithm problem

To correct for this, the NavCane will use the gyroscope of an inertial measurement unit (IMU) to provide orientation information. This orientation can be combined with the sensor measurements to obtain a point cloud of detection points in world space. These point clouds can then be processed to find faces and objects, which can then be avoided, satisfying **R3.4-POCT**.

Although this is a much better algorithm, it doesn't take linear motion into account. The point cloud obtained would be technically invalid as soon as the user moves, but would serve as a decent approximation for small changes in position and time. Therefore, this algorithm will work if points in the point cloud 'expire' after a short amount of time. As long as the points are valid for a long enough time to collect a dense enough point cloud to infer objects, this algorithm will work. After acquiring the points, the time period of validity of a point is estimated to be about 0.5s, which may not be long enough to avoid the failure case demonstrated in Figure 21.

One way to increase the validity of the time points is by assuming a constant forward velocity of the user, where the forward direction is assumed to be the center of the angle of sweep of the cane. Ignoring the obvious failing case where the user is stationary, this will provide much better results than the previous algorithm. The movement speed of users of the NavCane will not vary by a significant amount, and the valid time period of points would be increased from approximately 0.5s to closer to 2s. This increased time is much better for the user, but is still limited by errors in the estimation of the speed and direction of the motion of the user.

A further increase in positioning accuracy could potentially be found through use of the linear accelerometer readings of the IMU. Dead reckoning using an accelerometer is theoretically possible, but in the discrete world the double integration required to obtain position rapidly accumulates error, propagating through the integrations. Further research and testing of the accelerometer could result in a method of using the accelerometer to provide clues to changes in the user's velocity (to counter the issue of stationary users with the previous algorithm), or even positional data with a robust enough filtering algorithm.

7 Haptic Feedback Design

Haptic feedback is a critical component of our design, as it will guide the user to navigate safely around obstacles. Haptic feedback consists of forces or vibrations applied to a user [4]. Our design uses a blend of these methods to give the user information about their surroundings such that they can travel independently without risk of collisions or injuries. Haptic feedback will be the principal mode of communication with our users, so its flawless implementation is paramount. Audio queues were considered, but those who are visually impaired gain clues from their environment using sounds in their proximity. By using haptic feedback, we avoid interfering with the auditory information provided from the user's surroundings. Constant audio cues can also distract the user from focusing on the feedback that a basic mobility cane provides them. It was also important to take into consideration that those who are visually impaired can distinguish more detail with their hands than the average person because they are very sensitive in their fingertips [5].

The NavCane solely uses haptic feedback to provide our users with information to keep them safe and navigate their environment. Our design goals are to create very simple and easy to understand signals that will minimize the time before a new user can effectively use the NavCane **(R3.3 – POCT)**. We wanted to minimize any possible learning curve by implementing intuitive feedback mechanisms to prevent errors with feedback interpretation **(R3.10 – PROT)**. During the design process, we wanted to maintain a delicate balance, making sure that we gave the user enough information so that they were safe, but were not bombarded with too much information. By not overloading our user with information we can make sure that a user will be comfortable in using the NavCane for extended periods of time.

The first step in designing an intuitive system was to decide if it was better to indicate to the user if there was an obstacle in their way, or to simply suggest a direction to move away from the obstacle. Meeting with an Orientation and Mobility Specialist, we learned that allowing the NavCane to guide the user around an obstruction was more instinctive. It was also important to ensure that the algorithm used to interface with the haptic feedback was robust and would not steer the user away from one obstacle into the path of another. For example, the NavCane should not direct the user into an obstacle while helping them avoid another. Extensive testing of different scenarios using our various sensors and proximity detection algorithm will confirm NavCane's abilities to navigate safely.

To provide the user with directional feedback as well as warn them of upcoming hindrances, four basic models were built and tested. The development process was done in an iterative manner: designing, developing and testing in repetitive cycles until we were satisfied with our models. We wanted to successfully build a very rough version of each of our designs so we could meet the Orientation and Mobility specialist and receive feedback regarding what model would work best.

The first design we dubbed the 'Rotary Disk,' and was a disk that would sit vertically under the users thumb and be connected to a stepper motor. It would rotate right and left to guide the user around obstacles, using the duration and speed of rotation to indicate the magnitude or importance of the turn. This model was comparatively quite large and heavy due to the stepper motor, and had the potential to be uncomfortable when used for extended periods of time. The rotating disk would provide constant friction to the users thumb and the weight of the motor may bear strain on their wrists. On the other hand, it was a mechanically simple design and was easy to decipher which way it wanted the user to progress (right or left and at what angle).

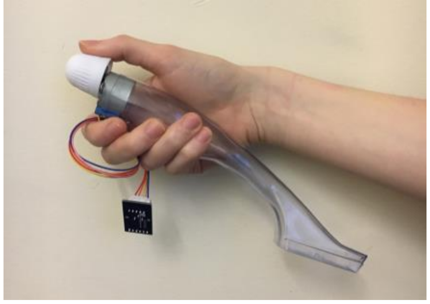

Figure 22: Rotary disk haptic feedback model

The second design was named 'Triple Point Vibration,' and used three vibration motors sitting under the users thumb; one vibrator was placed at the tip of the thumb, and the other two were placed on either side. The concept was to have different combinations of the three vibrators to be activated to indicate the direction in which the user should proceed. The benefits of this design were the potential customization and combinations for vibration patterns and its non-intrusive approach. Due to the simplicity and size of motors, it would be very easy to fit this into a standard cane without increasing weight or diameter by a lot. However, there was a major concern regarding variation of thumb size and positioning on the cane, possibly preventing the user from being able to distinguish which part of their thumb was being stimulated.

The third design, the 'Vibration Pad,' were similar to the Triple Point Vibration model in that it used only vibration. The Vibration Pad model was designed to counter the issue with the small surface area of the thumb. By placing vibration motors inside the cane itself, on the right and left side, we could direct the user around obstacles by vibrating either the right or left side of their hand. Using nothing but different strengths of vibration limited our ability to tell the user specific magnitude of turn to safely navigate themselves around obstructions. This model also proved to be difficult for users to tell direction when only provided with a short pulse. The mapping of strength of vibration to the magnitude of turn would be difficult to teach, and is relative person to person

The 'Thumb Toggle,' our final model, was the design we decided to proceed with in our proof of concept and prototype stages of production. By attaching an spherical recess to a servo motor we could move the users thumb with a specific rotation to guide them around obstacles. This design allowed the user to know exactly how much they should alter their course of path and when it was clear to return to their current course. It also does not make the user change their grip from the standard cane grip, which allows us to have accurate orientation of the cane and its sensors (**R3.11-PROT & R4.10-PROT**). The feedback we gained from discussing all our designs with the Mobility Specialist was that the Thumb Toggle was non-intrusive and would be comfortable to use for extended durations. Its physical movement of the user's thumb gave the most well defined feedback with few ambiguities.

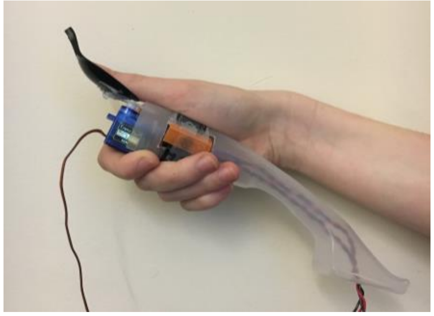

Figure 23: Vibration pad (orange pad) and thumb toggle (black spoon) haptic feedback models

Because the safety of the user is vital in our product, we wanted to add another method of communication with the user to warn the user of immediate dangers. This includes obstacles that the sensors have picked up until the obstruction is very close to the user, or low overhangs in the path of the user. Appropriate limits on latency of haptic feedback will ensure that the user is never put in danger, preventing injuries and falls. Since the servo motor can only rotate right or left we can only move the users thumb right or left, and we do not have any way to tell them to stop moving. To tackle this we have added vibrating motors into the handle of the stick along with the Thumb Toggle to alert the user to stop moving in case of an emergency situation where their safety is compromised. Using a strong, pulsing vibration we will inform the user in this rare, but important corner case.

In the POC model we mounted the scoop portion of a spoon to the end of the servomotor to demo a rough version of what we want to use. By moving the users thumb right or left by specific displacements we can give them the feedback for how far they need to turn to avoid the obstacle in their path. For example, a large movement of the "Thumb Toggle" to the right will indicate that the user should turn sharply to their right, avoiding an obstacle on their left.

In the Prototype and production stages we aim to 3D print a more ergonomically designed "Thumb

Toggle" that will be more comfortable to hold and will not alter the "natural" grip of a cane user. The toggle will be better molded to match the shape of user's thumbs. We will also be using a micro servo motor with ERM Vibrators to design a system that will be smaller in size and lighter weight to better fit in a standard cane handle.

8 Conclusion

We want our users to be more independent and confident in their abilities to travel in new areas; by providing them with our safe and effective device we believe we can improve the lives of those who are visually impaired. Our hope is that by designing an ergonomic product with intuitive feedback features we can enhance the current mobility cane and urge users to switch to the NavCane. Our cost effective solution will allow people in different economic situations to use the NavCane. Users will be able to detect obstacles earlier, which reduces the chances of collisions because they will have more time to react.

Our thoughtfully built mechanical system will allow the NavCane to be light in weight and small in size, two very important features for extended use of our product. The overall mechanical system will house the sensors, actuators and internal electronics with an ergonomic design that correctly orients the cane. The obstacle detection system is designed with a well-tested and robust algorithm that will provide our users with reliable obstacle detection to keep them safe. The "Thumb Toggle", our haptic feedback module, was built such that it communicates with our users in a non-intrusive, effective way making sure the user is not overloaded with information. Our discussion of the future proposed features shows that we at CaneTech are here to create always-evolving designs to meet our users needs. We always want our users to feel comfortable and relaxed, knowing that our products at CaneTech will always provide them with reliability, affordability, user friendliness, and simple learning curves.These factors are paramount for our passionately, broadly skilled team and by following our design specifications and thoroughly testing our product we aim to deliver on our success factor.

References

[1] W. K. William S.Marras, Inteventions, controlls, and applications int occupational ergonomics: The Occupational Ergonomics Handbook, Second Edition, CRC Press , 2006.

[2] National Federation of the Blind, "https://nfb.org/," [Online]. Available: https://nfb.org/images/nfb/publications/fr/fr27/2/Open-Palm-open.gif. [Accessed 3 29 2017].

[3] theaveragebody.com, "Average Hand," [Online]. Available: http://www.theaveragebody.com/average_hand_size.php. [Accessed 27 3 2017].

[4] wikipedia, "https://en.wikipedia.org/wiki/Haptic_technology," [Online]. Available: https://en.wikipedia.org/wiki/Haptic_technology. [Accessed 29 3 2017].

[5] ScienceDaily, "https://www.sciencedaily.com/releases/2012/05/120508152002.htm," [Online]. Available: https://www.sciencedaily.com/releases/2012/05/120508152002.htm. [Accessed 29 3 2017].

[6] M. Sjoredsma, "Human Factors Usability," 2017, p. 90.

[7] D. A. Norman, The design of everyday things, New York: Doubleday, 1990.

[8] CSA Group, "AN/CSA-C22.2 NO. 61508-1:17 - Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements (Adopted IEC 61508-1:2010, second edition, 2010-04, with Canadian deviations)," CSA, Mississauga, 2017.

[9] doc.aldebaran, "http://doc.aldebaran.com," [Online]. Available: http://doc.aldebaran.com/2-1/family/robots/joints_robot.html. [Accessed 29 3 2017].

I Test Plan Appendix

Users of the NavCane will be relying on it to provide important feedback so it must be a robust system, where the chances of failure are small. As users will be entrusting the device to give them the information they need to move safely and effectively in various situations. Because of this there is an inherent potential for risk or injury should our product fail. Taking this into account, it is essential that our test plan conclusively verify that our product works as promised.

Table 1: NavCane Tests

Test Case	Expected Results	Pass/Fail (Comments)
Mechanical System		
The NavCane is used for 8 hours.	The NavCane is used for approx. 8 hours without causing discomfort to the user. The temperature of the handle never rises above 45 degrees Celsius over time	
The user picks up the NavCane for the first time.	The ergonomic design discourages improper orientation of the NavCane. The sensors will point in the correct directions	
The user drops the NavCane from a height of 2m.	The sensors and electrical integrity of the cane is not compromised, product is resistance to the impact	
The NavCane is used in rain for 5 hours.	Standard cane functionality is not impacted	
The NavCane is used in snow for 5 hours.	Standard cane functionality is not impacted	
A user is able to use the device as a standard mobility cane with the cane turned off	Standard cane functionality is not impacted	
A user is presented with 3 vibration patterns in the cane	The user can distinguish the vibrations	
Electrical System		
The NavCane is continuously used for 9 hours.	The NavCane battery supplies power for a full day's usage	
The servomotor is stalled for 5 minutes	The device still works and there is no permanent damage	
The NavCane is used with full functionality.	No electrical shock occurs to user	
The NavCane is plugged into a wall and charged for longer than necessary.	Over charging is dealt with by proper charging circuit implementation and will not damage the battery	
Hardware System		
An obstacle 10 cm wide object is placed within 3 meters of the sensors, between a 90-degree field of view from center of cane.	Proximity sensors are able to detect objects in this range	
Software System		

Sensors find an obstacle in their field of view.	Proximity data is collected and collated in real time and haptic system is driven efficiently and accurately within	
The cane is moved in a consistent sweeping pattern. With various objects placed in the 3 meter range	Objects in this range are detected and mapped. Avoidance path calculated and haptic system appropriately driven. All this occurs with 1millisecond of sensor detection	
The cane is moved in a non-consistent sweeping pattern. With various objects placed in the 3 meter range	Objects in this range are detected and mapped. Avoidance path calculated and haptic system appropriately driven. All this occurs with 1 millisecond of sensor detection	
The cane is moved in a consistent sweeping pattern while moving forward with consistent speed. With various objects placed in the 3 meter range in the path traversed	Objects in this range are detected and mapped. Avoidance path calculated and haptic system appropriately driven. All this occurs with 1millisecond of sensor detection	
The cane is moved in a consistent sweeping pattern while moving forward with non-consistent speed. With various objects placed in the 3 meter range in the path traversed	Objects in this range are detected and mapped. Avoidance path calculated and haptic system appropriately driven. All this occurs with 1millisecond of sensor detection	
The cane is moved in a non-consistent sweeping pattern while moving forward with non-consistent speed. With various objects placed in the 3 meter range in the path traversed	Objects in this range are detected and mapped. Avoidance path calculated and haptic system appropriately driven. All this occurs with 1 millisecond of sensor detection	
The cane is moved in a consistent sweeping pattern while moving forward with consistent speed. Towards a dead end.	Dead end Situation is detected and haptic system driven within 1 millisecond of detection from sensor.	
An overhang is approached with the cane	Overhang is detected and haptic system driven within 1 millisecond of detection from sensor	
User chooses to connect the NavCane to the optional App.	The app and NavCane are easy to connect, advanced customization options are available and it has an audio interface	
Haptic System		
An overhang is approached	A vibration pattern is sent and the user can recognize it in enough time to prevent a collision.	
The user approaches a dead end	A vibration pattern is sent and the user can recognize it in enough time to prevent a collision	
The battery gets low in power	A vibration pattern is sent and the user can recognize it	

The cane is turned on	A vibration pattern is sent and the user can recognize it	
The cane is turned off	A vibration pattern is sent and the user can recognize it	
An obstacle approaches from the right	The toggle is steered to the left and user recognizes to do so in enough time to prevent a collision	
An obstacle approaches from the left	The toggle is steered to the right and user recognizes to do so in enough time to prevent a collision	
An obstacle approaches from 12 o'clock	The toggle is steered to the right or left and the user recognizes to do so	
A series of obstacles are approached	The toggle is steered through the obstacles and user recognizes to do so in enough time to prevent a collision	
The user places hand on the thumb toggle and the thumb toggle moves left and right in a test pattern	The servo is able to move left and right under the pressure of the users thumb without stalling.	

II UI Appendix

The NavCane's user interface (UI) design is extremely important as it is the channel through which the cane provides information to the user. The NavCane will be used to guide the user past obstacles, and any difficulties with interpretation of the information provided can result in collision or navigation to a dangerous area. A simple and easy UI will help prevent these types of issues and maintain the safety of the user, while allowing them to easily access the information collected by the NavCane. The NavCane will be designed such that the fundamental use of the NavCane as a mobility cane is not impacted. This will allow the user to receive information from the NavCane as a regular mobility cane and as a smart system.

The NavCane needs to be easy to learn and understand while being comfortable for long hours of use. A steep learning curve will push a potential user to use a regular mobility cane instead of putting in the effort to adapt to ours. Difficultly learning could make a user feel stupid and leave them feeling frustrated which would result in negative feelings towards our product. Designing such that the NavCane can be adopted quickly will make a user more likely to try our product. The next focus is to make the information provided from the cane intuitive. If our system is easy to understand, the number of decisions the user needs to make is minimized, which results in more effective use of the NavCane. Successful use of our product will result in more information provided to the user than a regular mobility cane, which will make them more likely to continue using our product. Lastly, standard mobility canes can be used for several hours of the day without tiring the user, so feeling uncomfortable holding the NavCane for a long duration will encourage them to go back to using a simpler cane. The NavCane needs to be comfortable so that after long hours of use the user will be not frustrated with our product.

To achieve this definition of a good UI design, our potential users were analyzed and the features of the NavCane were considered in the seven stages of UI design. Understanding the abilities, limitations and knowledge of our users is a key factor in designing a good UI. With information about the user and their experiences with similar products and situations, decisions regarding what is more intuitive to the user can be made. It also gives insight into any areas that the user may struggle with, which can be more heavily considered during the design process. In a high-level description, the seven stages of UI design consider the product's learnability characteristics, as well as errors the user could be prone to and how to avoid them. This process helps achieve a good UI design because it takes into consideration multiple avenues that could lead to error and misunderstanding. Applying this process to all the features of our product will make using the NavCane a simpler and more effective process.

Once the analysis of the users and the product have been completed, usability testing is used to gain further insight into the UI of the product. Usability testing is broken down into two methods, analytical and empirical. Analytical usability tests consist of the in-house tests conducted by the design team, whereas empirical usability tests are performed on potential users to receive their feedback. Both methods are crucial to addressing the reliability and simplicity of our product.

In this appendix, the UI design of our product will be presented. This begins with the analysis of our users and application of the seven stages of UI design on the features of the NavCane, after which engineering standards that apply to the NavCane UI will be explained. Lastly, details regarding the analytical and empirical usability testing will then be discussed.

II.1 User Analysis

Users of the NavCane will be visually impaired and can range in experience with mobility canes, so it is crucial that our product's UI design takes this into consideration. The degree of impairment of our users will range from complete blindness to slight loss of sight and could even include hearing loss. The percentage of the visually impaired that have complete loss of sight is quite small, as we were told by a Mobility Specialist, which means most of the NavCane's users will have lower degree of impairment. The experience with mobility canes will also vary with our users, as some will have years of experience with mobility canes, and others none. The users of our product will range in ability and experience, but our UI design has considered these variations such that learning and using the NavCane is intuitive and simple.

An important demographic to consider is Mobility Specialists, since they teach the visually impaired how to properly and safely navigate using a mobility cane. Mobility Specialists need to be able to understand how to use the NavCane If they are to teach others how to use it. After speaking to a Mobility Specialist, we learned that when recommending products to their students they take into consideration the functionality, cost and learning curve associated with it. Therefore, keeping Mobility Specialists in mind will make it more likely for them to recommend the NavCane to their students.

Visual impairment of our users means that the design of our product's UI should focus on physical and/or audio feedback during its use. As such, our product must not rely on any kind of visual interface, as this would make the product difficult or impossible to use.

Experienced mobility cane users will be more competent with their ability to navigate which makes it important to maintain the functionality of a regular mobility cane in the NavCane. If the UI of our product varies drastically from a regular mobility cane, a veteran cane user will feel like their experience is rendered useless which can deter them from using our product. This is because having to learn something new can create a barrier especially when there is a comfortable alternative; therefore, the NavCane's UI needs to be consistent with that of a regular cane so that this barrier can be avoided. When giving information to an experienced cane user the NavCane needs to easily trusted and reliable. This is because a veteran cane user will be used to relying only on their own abilities, and giving them information that is hard to understand or inaccurate will quickly lead to a loss of trust in the product. Therefore, our product's UI needs to not interfere with the information that is obtained from a regular mobility cane while making sure the information relayed to the user is reliable.

Overall, our users taken into consideration in the UI design all have some degree of visual impairment, with ranging experience with a mobility cane. We also considered Mobility Specialists since they work very closely with the visually impaired, teaching them how to use mobility canes so that they can navigate safely while travelling.

II.2 Technical Analysis

In this section, the features of our product that interface with users will be analyzed using the seven elements of UI interaction to further develop NavCane's UI design. This seven-layer model consists of the following factors [3]:

1.) **Discoverability**: is it possible to discover what actions are possible and the current state of the device.
2.) **Feedback**: full and continuous information about the results of actions and the current state of the project.

3.) **Conceptual Model**: the design project all information needed to create a good conceptual model of the system, leading to the understanding and a feeling of control.
4.) **Affordances**: the proper affordances exist to make the desired action possible.
5.) **Signifiers**: effective use of signifiers ensure discoverability and that the feedback is well communicated and intelligible.
6.) **Mappings**: the relationship between controls and their actions follows principles of good mapping enhanced as much as possible through spatial layout and temporal contiguity.
7.) **Constraints**: Providing physical, logical, semantic, and cultural constraints guides actions and ease interpretation.

With these factors defined we will now analyze the features interfacing to the user: haptic feedback, handle design and phone application.

Haptic Feedback:

Our haptic feedback feature will be directly communicating to our users and was greatly considered during our UI design so that it would be easy to learn and understand. In terms of discoverability, the user needs to be able to understand the directional information given to them simply by the feel of it. We decided that a simple recess that the thumb of our user could sit in, placed where the thumb normally would be positioned, would provide a consistent location of the user's thumb to focus tactile feedback. Next, we needed to consider how the feedback from this feature would be communicated so that the user can formulate a good mental map of their surroundings. We feel that the decision to rotate the thumb recess, along with vibration alerts, gives the users good intuition of where they need to move and an idea of the state of the cane. This is because the rotation can easily emphasize the degree and direction in which one needs to move to avoid obstacles, as the user simply needs to walk in the direction their thumb is pointing. The vibration alert can give a good indication of the cane's state since it can be used to inform the user of low battery, and can also alert the user of a close obstacle. These signals can be differentiated through the vibration pattern used. However, we need to be careful not to overload the user with too many vibration patterns, so we only allowed for a few of them to be used and to differentiate them as much as possible. There are also some constraints on the thumb recess, as it isn't common in the mobility cane market. The most important problem is that users are not used to having to have their thumb in a position on the cane. To help minimize this constraint we placed the feedback module where mobility specialists train their students to place their thumb.

Handle:

The UI design of the handle is substantial due to how often the user will be interacting with it. We need the NavCane's handle to be comfortable, recognizable and moulded in such a way that the proper orientation is intuitive. The handle of the cane needs to be similar enough to that of a regular mobility cane so that when the user picks up the cane there is some signifier that it is mobility cane. The handle also needs to be comfortable since mobility canes are used for extended hours of the day. To address this issue we studied the design of mobility canes on the market and found that most were slender and had a flat face on the handle. We incorporated the flat edge on our handle to help our users position the orientation of the cane; a lot of mobility canes in today's markets do the same to show the user where their thumb should go. This orientation is very important to our product since the sensor box will be placed on one side of it. The design of the NavCane's handle had additional constraints to consider in terms of size and weight. Mobility cane handles tend to be small and light so that they don't irritate the user after long hours of use. Because of this, we made it a priority to keep our handle design as light and small as possible. Another factor that was considered was the on/off switch. The switch needs to be an indicator to our user of the state of the cane and cannot be a simple switch with no indication as to if the NavCane is on or off. We plan to have a push button that sticks out when the cane is off and is flush when the cane is on. We will place it on the handle so that it is easy for our user to find.

Mobile Application:

As one of our potential future features the NavCane smartphone application needs to consider its user's experience, so that it is simple and intuitive. One feature that must be implemented if we plan to create this application is audio input and feedback so the user can use the app without the need of vision. This is an obvious necessity since our market is the visually impaired, and without it the user would not be able to use the app effectively or at all. Some of our users might not be comfortable with technology, but still may want to use our app to take advantages of its uses with the NavCane. Because of this, when designing the UI, we need to keep the menu and options simple and provide feedback to the user as to any decisions that impact their experience with the NavCane. Doing so will make the users experience with our app simpler and ultimately more useful.

Overall, we feel we that applying the seven-layer model of UI design on our product provided a new angle to the UI design, and as a result the user's experience will be greatly improved. As a secondary measure to provide information about the three UI features discussed above, we will add a UI section in our user manual so that the information can be reached if needed. We feel that our product will be easy to learn while providing enough information to be useful to the user.

II.3 Engineering Standards

The NavCane UI design will incorporate appropriate engineering standards. The following table shows the engineering standards that were considered:

Table 2: UI Engineering Standards

Engineering Standards	
Number	**Description**
CAN/CSA-C22.2 NO. 61508-1:17 -	Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements (Adopted IEC 61508-1:2010, second edition, 2010-04, with Canadian deviations) [5]
ISO 13854:1996	Safety of machinery -- Minimum gaps to avoid crushing of parts of the human body [9]
ISO 9241-920:2009	Ergonomics of human-system interaction -- Part 920: Guidance on tactile and haptic interactions [10]

The electrical safety is important to our UI design since the handle will have electronics within it and a sensors box with wiring very close to it. Failing to take this into consideration could lead to our users shocking themselves and getting hurt. To avoid this, we will maintain the standards set with electronic safety. To continue the topic of safety, the mechanical standard of avoiding gaps so that our user cannot catch any parts of their body in them was also considered for our product. This is because if there are any gaps in the handle our users could potentially get their hands caught which could lead to injury or discomfort. We will remove or minimize all gaps to meet this engineering standard. The last engineering standard considered for our product was the Guidance on Tactile and Haptic Interactions; this standard is important for our haptic feedback unit. Following this standard will help make our haptic feedback more intuitive so that the user will be able to follow directions more accurately and safely.

II.4 Usability Testing

Usability testing will discuss two types of testing, analytical and empirical. Analytical testing is done by the designers and creators of the product. Empirical testing greatly involves the users input, which can be done through experiments, questionnaires, and observations [6]. Both types of testing are necessary for a product to be properly designed so that it can succeed in the market, assuming there is a demand for the product. When discussing usability testing, the following metrics will be used to help define and rate our UIs: learnability, efficiency, memorability, errors, and satisfaction. Learnability speaks to the learning curve the user will first undergo, efficiency is how productive the user will be once they learn how to use the product, memorability is how easily the user can remember the UI once it has been learned, errors look into how likely errors are and if the user can recover from the error states, and satisfaction is how enjoyable the UI is. This section will further discuss both analytical and empirical testing with respect to our product, the NavCane.

The NavCane features go through continuous analytical testing, whether it’s testing grip sizes for the handle, thumb placement for haptic feedback, or location of the sensor box to insure the best cane stability and weight distribution. The following sections will give a description of how both testing methods were applied on the features of the NavCane.

Analytical Usability Testing

Haptic Feedback

Haptic feedback in conjunction with proximity sensing is arguably the most important feature of the cane. If the user cannot understand the information the cane is relaying, then from a user’s standpoint, the NavCane is not worth the extra money when compared to a conventional cane. To avoid this issue, we at CaneTech designed four possible implementations of a haptic feedback system. The four possibilities, discussed below, are triple point vibration, rotating wheel, vibration pad, and thumb toggle.

Triple Point Vibration

Triple point vibration was tested using three ERM (eccentric rotating mass) motors that were mounted on the back of depressible silicon so that when a user’s thumb was placed down into the depressible silicone, the three ERM’s were on the left, right, and tip of the thumb. The team felt that this method of feedback was not ideal. The triple point vibration module did not seem very efficient because the user would have to interpret three different vibrations on all sides of the thumb, and then react based on that information. If a product is to be efficient, then needing time to think about what the information is trying to relay is out of the question. We at CaneTech also found this UI to be error prone due to the proximity of all the ERMs. It was extremely easy to mix up which motor was vibrating. Due to these reasons the triple point vibration was no longer an option.

Rotating Wheel

The next type of feedback considered was the rotating wheel. Taking the hollow handle of a dish scrubber, we placed a small DC motor inside with the shaft sticking out, and mounted a small plastic wheel concentrically on the shaft. This type of feedback was easy to interpret, the learnability was excellent, it was easy to remember, and the error rate tested throughout the group was low. However, the satisfaction when testing was also reasonably low. The satisfaction was low because of the continuous friction between the wheel and the tester's thumb, which has the risk of a user potentially getting skin irritation if used for a prolonged amount of time. CaneTech decided to test this haptic feedback model further through empirical testing, which will be discussed later.

Vibration Pad

Next to discuss is the vibration pad model. Using the same dish scrubber handle previously mentioned, we cut out rectangles on either side where the tips of your fingers and your palm would normally rest. Then, by placing pads that protruded out of the handle to make contact with the user's hand, along with ERMs attached to the inside of these pads, we were able to convey direction through vibrating either the left or right pads. Testing this particular UI was quite difficult without proper vibration isolation and dampening materials, which practically rendered testing this UI useless. With the model used, there was hardly any difference in feel between the left and right ERM vibrating as the entire structure would vibrate regardless of which motor was vibrating. As a result the learnability was low, errors were likely with a good chance not to recover, and the satisfaction then was also low. Once again, this UI had to be further tested via empirical usability methods, which will be discussed later.

Thumb Toggle

The final system to test was the thumb toggle. Once again, using the same dish scrubber handle previously mentioned, a servo motor was placed out the backend opposite to the scrubber side. A plastic spoon head was attached to the servo in a location that the user could comfortably rest their thumb in. The spoon then could achieve yaw rotation, as seen below.

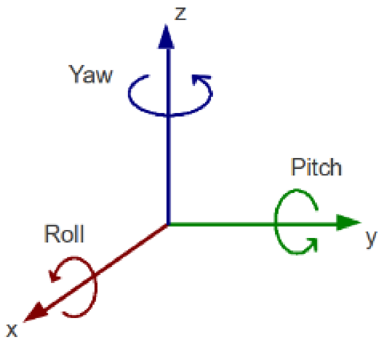

Figure 24: Cartesian diagram [4]

When placing their thumb in the spoon head while it rotated, the NavCane team found this extremely informative and easy to interpret as the spoon changed orientation from left to right. This model's simplicity and quick and easy learning curve propelled this UI to the top of our four potential haptic feedback systems. The shape of the spoon made it very unlikely to incur errors in interpretation, satisfaction was high, memorability was effortless, and the efficiency, due to the previously mentioned metrics, was also high. Once again, to determine what feedback system was to be implemented, empirical testing methods would also be needed, as our product, NavCane, will not be market worthy if empirical usability testing methods are not used as well.

Handle

If you do not have a handle on the UI of the product you wish to put out into the market, your product will not achieve success. Seriously, a handle is really important. The way CaneTech tested multiple types of handles analytically was to discuss and brainstorm handles that are used in different areas that work well and are comfortable (CaneTech was not able to create multiple models, as neither the resources nor the tools were available). Handles to draw inspiration from that were brought up were joysticks, gaming controllers, and golf clubs.

Joystick

Joysticks are particularly interesting, as they are heavily reliant on comfort and easy usability. Memorability can be an issue if the user is overloaded with buttons, but satisfaction, as we discussed, is generally high because of the sheer comfort. Joysticks can also be ambidextrous, and usually used ribbed finger placements so that it is obvious to the user where to place his or her hand. The major problem with joysticks in regards to our application, is that joystick handles are usually curved. In our application this would not be good, because direction can become less inherent if the handle is bent downwards or upwards rather than being aligned with the cane. What NavCane took away from the joy stick was the importance of being able to use a handle ambidextrously.

Gaming Controller

Gaming controllers have gone through vigorous UI testing, and therefore are a great resource to draw inspiration from. It is helpful to analyze how the designers went about the seven stages of design. By running through and brainstorming ideas on how to design a controller, valuable information was learned, especially when considering discoverability and mapping. With respect to discoverability, if a controller has a steep learning curve, the system runs into severe risk of pushing away potential consumers. This is because beginner to moderate gamers just wish to play video games, and do not want the extra task of having to learn how to use the controller before he or she can play a game. Mapping is also important, because if the button layout is not well placed then the experience of playing a game can be ruined. What NavCane took away from this discussion was the importance of mapping and keeping the learning curve to a minimum.

Golf Club Handles

Golf club handles are very simple, comfortable, and yet extremely informative by having the ‘front’ facing side flat, this lets the user know intuitively what the orientation of the intended grip is supposed to be. Although generally there is no specific hand placement scheme on a golf club handle, the flat sides guide the user to orient the club correctly. The take-away from the golf club handle was that simplicity can be very informative, and that information can be conveyed through something as modest as a side of the handle being flat.

Analytical testing as a preliminary testing method is the obvious first step, as it is cheap, fast, and very easily repeatable. But as previously mentioned, a product that is not tested with user feedback is one that will not succeed in the market because it lacks the design feedback that is most needed.

Empirical Usability Testing

Although analytical testing is necessary, the determining factor of whether a product will succeed or not comes from the feedback received by the target market. Here at NavCane, we have been in very frequent constructive dialogue with The Canadian Def Blind Association, CDBA, which has given us the tools to enable our design in a simple yet effective manner. Topics that will be discussed further will be first broken down into POC stage, and Prototype Stage, then as sub topics we will discuss the dialogue between CaneTech and the CDBA, the meeting that took place between NavCane and the mobility specialist, and future meetings between both organizations; furthermore, an in-depth look will go into how these meetings are and will be conducted, the sequences of these meetings, and the results we at NavCane took away, and can take away to better our product.

POC Meetings

Before starting this project, a channel of communication was set in place to reassure that our product, NavCane, is a product that is in need, and will tackle issues that need solving. Once we received this reassurance, we found ourselves diving into possible realizations, hence the design process began. Now that CaneTech is well into the design phase, our empirical testing methods generally consist of constructive interactions, keeping logs within our journals of the meetings we have had, as well as over the phone meetings where we essentially execute a questionnaire. A part of our design process is to log every question we have while designing our proof of concept. What this enables us to do is before each meeting with the CDBA, we pool our questions, and rank them based on priority so that we can come into the meeting well prepared with good questions to ask. This strategy we find ensures a good questionnaire session, and shows the CDBA we have thought of meaningful questions. Our meetings are usually quite informal, and therefore do not require entering and exiting surveys, or conventual empirical testing sequence methods. We find that if we log our questions throughout the design process, have meetings that flow well and are clear and concise, while keeping logs of the results of our meetings, we at CaneTech will finish with a fantastic product in which we will be proud of.

The meeting that took place between CaneTech and the mobility specialist was crucial in regards to the information that we received, but before discussing what this information was we will outline how the meeting proceeded. The empirical testing methods we decided to use was mainly constructive interaction, as well as observing the mobility specialist reactions to each different situation we presented while keeping log within our journals. Constructive interaction was achieved by presenting the mobility specialist with a multitude of different haptic feedback modules (which can be found in figures 22 and 23) and then proceeded to ask him a full range of questions as he moves from one module to the next. These questions ranged from comfort level to more technical questions such as does this module relay the proper information. While keeping logs of his verbal and physical responses, we were able to run through our pre-determined questions as well as our improvised questions that were constructed from these previously mentioned responses. As said above in our meetings over the phone, we have not yet implemented empirical testing sequencing methods because we feel that will be in the latter four month during the Prototype Stage. The results, or measures, gathered from this particular meeting was very crucial to some of CaneTech's design decisions, such as which haptic feedback module is best suited for the visually impaired, which issues should be tackled by our cane, and lastly ensuring our cane does not overload the user with information and to much complexity. Face to face meetings are an absolute must if we want to ensure a well-designed product, therefore many more types of these meetings will be had later on when in the Prototype Stage of our product.

Prototype Meetings

In the next four months, our meetings will continue to work in the same way, but the need for exploratory experiments will become much more prevalent. This implies that our empirical testing methods will continue on the same path, but an additional type of testing method will be added as previously mentioned. With this new method, we will need to design a very in-depth and detailed sequence that will enable us to extract as much information as possible, in an efficient and timely manner. Before proceeding into how we would design our experiments, we need to define and analyze potential user errors. The NavCane will be designed to minimize two particular types of user errors: slips and mistakes. A slip is defined as an unconscious error made by an experienced individual, who has performed a task many times. A mistake is a conscious error made by someone through lack of knowledge and/or experience. NavCane will be able to minimize both these errors at the same time through its very simple and intuitive interface.

By creating a flat side on the handle where the haptic feedback device resides, the NavCane will feel familiar to prior users of standard mobility canes, and as such will promote proper orientation. If there was not a flat side on the handle, proper orientation would not be obvious. Once the users hand is in the correct position with his or her thumb on the thumb toggle, all the user has to do is interpret the direction the NavCane is telling them to go. By rotating an elliptical recess under the thumb, it is extremely evident which direction of travel is being suggested to the user.

Knowing that we designed with the intention of minimizing slips and mistakes, we envision multiple experiments that will put our design to the test. These experiments would be conducted as follows: one participant would be allowed to enter a room, where they will be asked to pick up the NavCane, perform designed tasks before and after being instructed in the use of the NavCane, and then answer questions about their experiences. The slips and/or mistakes that occur in these trials will allow us to learn is how intuitive our handle is, whether the learning curve is gentle enough, if the NavCane meets our product goals, what the NavCane currently is doing well, and potentially much more. These types of meetings/experiments will allow CaneTech to propel its product into the final design with confidence that we are making a safe and well designed product.

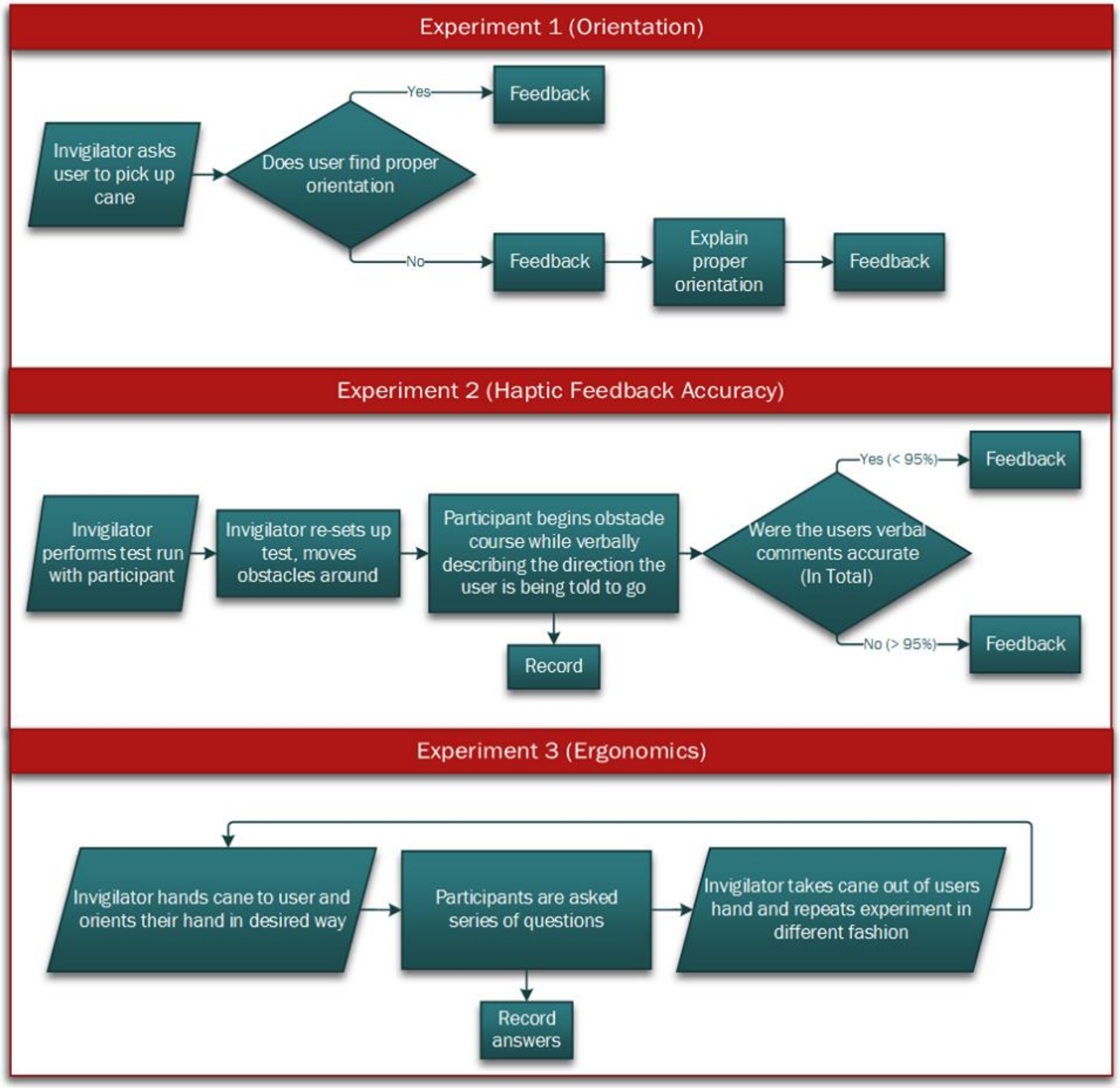

Figure 25: Prototype experimentation flowchart

Our final design of the NavCane should be able to demonstrate in these ergonomic experiments that it is intuitive, reliable, and that users are comfortable with using the product. All three experiments would have overlapping questions, an example of which would be in regards to comfort. The first experiment exploits the users first contact with the cane and how intuitive the handle and haptic feedback orientation is to the user. The second experiment allows the user to get a feel for the cane and how it works as they walk through the designed course. Lastly, the third experiment focuses in on how the cane feels to the user, in regards to weight, feedback felt through the cane tip, comfort level, handle size, etc. This high-level overview of the experiments would need to undergo further investigation into whether we are extracting the most information possible in the time given with each participant, but for now CaneTech believes these experiments will suffice in constructing a great, useable product.

II.5 Conclusion

Many factors make or break a product, and UI is a significant one. User interface designs are extremely situationally dependent, and may need to be complex or simplistic to convey the appropriate data. In this case, CaneTech needed to implement a very simple yet effective UI that would allow for intuitive use of the NavCane. To achieve this type of implementation, we discussed and designed the user interface while keeping the seven stages of UI design in mind. Once the foundation of the UI design and implementation were constructed and documented, we employed other methods such as analytical and empirical testing methods. Analytical testing methods allowed us to build-up and construct workable models to let test subjects experiment with. Once these models were constructed, meeting up with a Mobility Specialist from CDBA allowed us to employ empirical testing methods. Out of the two methods previously mentioned, we believe that empirical testing methods, if done correctly, can be significantly more important than analytical methods. Implementation of both these testing methods will provide vital information that will be used to create a simplistic and effective UI.

III Requirement Specifications Reference Appendix

In the requirement specification document, all functional requirements follow the following coding scheme:

$$\left[\boldsymbol{R}[\boldsymbol{section\ number}].[\boldsymbol{subsection\ number}]-[\boldsymbol{Stage\ Code}]\right]$$

The section number corresponds to the particular section the requirement aligns to while the subsection number corresponds to the different requirements within a section. The stage code corresponds to the stage of development at which the requirement is expected to be met. The tables below provide a legend of all the possible codes for the stage code and section number components of our coding scheme.

Table 3: Stage Code Explanation

STAGE CODE	***explanation***
POCT	proof of concept
PROT	prototype
PROD	Hypothetical production model

Table 4: Section Descriptions

SECTION#	***explanation***
3	General requirements
4	Hardware requirements
5	Electrical requirements
6	Mechanical requirements
7	Software requirements

Codes:

Table 5: Requirement Specs

Requirement ID	Requirement Description
R3.1-PROD	The system will cost no more than $300.00
R3.2-POCT	The system will allow users to navigate situations while warning them of obstacles in their path within 3 meters of the sensor.
R3.3-POCT	The warning signs sent to the user will be deployed in a non-intrusive way using haptic feedback.
R3.4-POCT	The system will guide the user around obstacles at ground level, to steer them a safe distance away.
R3.5-POCT	Feedback for upcoming obstacles will be provided given enough time to prevent collisions or falls.
R3.6-PROD	The system will be constructed using waterproof equipment allowing for use in all weather circumstances.
R3.7-PROT	The battery life of the system will be long enough for the user to go safely through the day while operating the NavCane; approx. 9 hours.
R3.8-PROT	The device must use only rechargeable batteries for a power source
R3.9-PROT	The weight of the system will not bear strain on the users' wrists or arms.
R3.10-PROT	The use of the NavCane will be very intuitive, allowing people of all ages to learn and use its functionality.
R3.11-PROT	The ergonomic design will make sure it is comfortable for users and sure that the cane is used in the proper orientation (with sensors pointing in the correct directions).
R3.12-PROD	All materials used in the mechanical enclosure must be non-toxic
R3.13-PROD	All electronics solder in the NavCane should be lead free
R4.1-POCT	Proximity sensors should be able to detect objects in the range of 3m

R4.2-POCT	Objects as wide as 10 cm should be detected
R4.3 -PROT	Processor capabilities ensure real time processing to give user sufficient response time
R4.4-PROT	Each RFID tag should be able to map at least 10 m radius around it.
R4.5-PROT	Low power mode and sleep mode should be implemented to ensure longer run time on battery
R5.1-POCT	Easy access interchangeable fuses for motor circuit
R5.2-POCT	Precise motor control
R5.3 -PROT	Processor will have proper circuit protection
R5.4-PROT	Battery must supply power for a day’s usage
R5.10-PROT	Wiring code will be upheld
R5.6-PROT	No injury will occur due to electrical failure
R5.7-PROD	Ensure over charging is dealt with by proper charging circuit implementation
R6.1-PROT	Product is light and easy to manipulate
R6.2-PROT	Use does not cause discomfort over long periods of time
R6.3-PROT	Standard cane functionality is not impacted
R6.4-PROD	Product is impact resistant
R6.5-PROD	Product is water resistant
R6.6-POCT	Feedback does not overload senses or distract user
R6.7-POCT	Feedback is easily distinguishable from environmental noise
R6.8-PROT	Feedback does not cause discomfort over log periods of time
R6.9-POCT	Product is easy to learn how to use
R6.10-PROT	Ergonomics discourage improper orientation
R6.11-PROT	Sensors are protected
R6.12-PROT	Product can easily be disabled, but can not be accidentally turned off
R7.1-POCT	Proximity data is collected and collated in real time
R7.2-POCT	User feedback is continuously calculated
R7.3-POCT	Motors are driven efficiently and accurately
R7.4-PROT	No sensor or actuator is subject to CPU starvation unless non-critical

R7.5-PROT	On-board processor can communicate with the user’s smartphone
R7.6-PROT	On-board processor can communicate with RFID beacons
R7.7-PROT	App is easy to use to customize experience
R7.8-PROD	App has audio interface for the visually impaired
R7.9-PROT	Advanced customization options are available for advanced users
R7.10-PROT	App and cane are easy to connect