THE PENNSYLVANIA STATE UNIVERSITY
MILLENNIUM SCHOLARS PROGRAM

DEPARTMENT OF INFORMATION SCIENCES AND TECHNOLOGIES

DEVELOPMENT OF HAPTIC NAVIGATION DEVICE TO ASSIST INDIVIDUALS WITH VISUAL IMPAIRMENTS

STUDENT NAME ZION EMANUEL
SPRING 2019

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Information Sciences and Technology: Design and Development

Reviewed and approved* by the following:

John Carroll
Distinguished Professor of Information Sciences and Technology
Thesis Supervisor

* Signatures are on file in the Millennium Scholars Program office.

ABSTRACT

It is known that people with visual impairments (PVI) traverse their environment in ways that are much different from sighted individuals. In most cases PVI have to use external devices such as a cane or a service animal to support them. While these devices do prove to be effective and grant the PVI a certain level of independence, they can be bulky and difficult to manage at times. Large devices like these also stigmatize PVI as individuals who are in constant need help or assistance, overall lowering their sense of independence. This study explores the design and production of a haptic feedback device that will be used by PVI to navigate common areas, mainly grocery stores. There are two main forms of navigation that are facilitated by the device; Body navigation, assisting the user by guiding them around obstacles; Hand Navigation, Guiding the user's dominant hand to a specific item they want to pick up. The device is composed of an Arduino Nano Microcontroller, a Bluetooth module, and several vibration motors attached to a bracelet. The vibrations motors activated externally by a smartphone to signal that an obstacle is nearby or the direction in which the users had should be moved depending on the situation. Several pilot experiments show that haptic information can be effective for navigating individuals around obstacles as well as guiding a user's hand to a specific item. With refinement and a sturdier design, this haptic feedback device can assist PVI with navigation in their daily life while also promoting their independence.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

According to the World Health Organization's "Global data on Visual Impairments 2010" [5], It is estimated that nearly 285 million individuals live with a visual impairment. Of this population, an estimate of 39 million from this group live with total blindness while around 246 million people have low vision. It is commonly known that these visually impaired individuals need some sort of assistance in order to traverse their environments. Some of the most commonly used support systems/devices include the white cane and the guide dog. It is also common to see PVIs relying on others to help them safely get where the need to go.

The white cane does a good job at detecting obstacles and tripping hazards that may be dangerous to a PVI. It also can signal to the PVI very important locations that they are approaching including the entrance to a crosswalk or the edge of a railing/building. The canes are long and lightweight making them easy to use and very efficient at giving the user the information they need for navigation. The next popular option that PVIs have for navigation assistance is the guide dog. These dogs are service animals that have received specific training necessary to assist PVIs. They help guide the user around obstacles and hazards while also locating points of interests including entrances to buildings or stairs. The PVI, however has full control of guidance and simply has to let their service dog know where they desire to go. Another option that PVIs have at their disposal for assistance with navigation is to use the help of a sighted person to guide them to their destination. This option may be one of the easiest since the user is able to directly communicate with someone else who can give descriptions of an environment and notice possible hazards. The PVIs converses with the other individual who in turn, lets the PVI know of their surroundings and can easily lead them through a safe route to where they need to be. This is very effective in areas that the PVI is not entirely familiar with or in locations that constantly have a large quantity of people commuting.

All of these options prove to be effective and some individuals may prefer one over another depending on the circumstances. However, there are a few details regarding PVI's that these options do not entirely support. The two issues that I will discuss today include notion of independence and the social stigma of visually impaired individuals. Independence, or the state of being independent, can be defined as not depending or contingent upon something else for existence, operation etc. This is an immense issue in the world of a PVIs because they want to be seen as people who do not need to rely on others in order to get buy in life. PVIs do not want to be at the mercy of other individuals for simple tasks such as getting around the house. This is not to say that there is a lack of trust that PVIs have for others, but it can be seen as demeaning and even dehumanizing if visually impaired individuals need several external support systems to accomplish something that sighted individuals can do completely on their own. An excerpt from *ICT Results* States that "Activities that the sighted take for granted, such as going for a walk in the park or trying out a new restaurant, becomes an odyssey for the visually impaired, particularly when they do not already know the route by heart" [1]. Support options regarding sighted individuals does the opposite and expresses a PVI's dependence on someone else.

When attempting to build a device to support PVIs, we must also examine the stigma that PVIs face on a day to day basis. Blind and visually impaired individuals want to be treated just like any other sighted person in the world. They do not want to be pitied or look down upon because of their disability. An account from a PVI on an article on Perkin's School for the blind states the following: “People treat me differently,” she said. “Some people will yell at me, thinking I can’t hear them. Some people will speak slower or ask where my assistant is. They think I’m incapable”.[4] From this statement we can see that some PVIs are treated differently in certain situations that can be considered degrading and hurtful. This stigma comes people noticing the visible signs that a person is visually impaired (i.e. white cane and service animals).

The purpose of this study is to create a small, minimalist device that could safely and effectively navigate a PVI where they need to be. The design of the device must be compact so that the wearer would not have an increased social stigma of a PVI. Chapter two of this paper will examine current solutions to this issue that PVIs face and will compare some design choices made during these devices’ production with this study’s device design. Chapter 3 will discuss in detail the production of the device along with any challenges that were faced along the way. In chapter 4 we will examine the resulting prototype as well as its effectiveness in navigating users. Lastly, in Chapter 5 we will relate our solution to the beginning problem statement determine if the problem has been solved. This chapter will also mention future work for the study and recommendations to make the device more effective for the user.

Chapter 2

Literature Review

There have been many different technological advancements for assistive technology for PVIs. Some of these devices are tailored to specific events like obstacle detection for skiing and snowboarding while others are considered to be more general and can be utilized in a variety of different scenarios. For the purpose of this paper, we will focus on wearable devices with the main purposes of navigating users to a specified location while detecting/avoiding obstacles that could pose as threats for visually impaired individuals. We will also take a look at some studies that provide navigation assistance for the user's hand, making the selection and grasping of a specified object easier. Several studies [2] [3] utilize a glove that the PVI wears and receives information (either haptic or auditory) from to effectively navigate their surroundings. This section will analyze some of these prototypes and see how they meet the two criteria of being efficient enough to successfully navigate a user through an environment and be small enough to handle easily as well as reduce the social stigma of being a PVI. First, we will look at previous studies that created haptic devices with the goal of body navigation, and then we will transition to other works focused on hand navigation, or guidance of a specific body part that will fulfill a certain task.

Body Navigation

The haptic feedback glove devices provide a good solution to the previously mention problem. All of the necessary equipment is generally located on the glove in an organized layout, allowing the user to use their hand for other tasks while being navigated. One study [2] uses beacons around environment along with one on the PVI's hand to triangulate obstacles in the path of the user. One of the issues with this study however, was that the signals of the beacons were not strong enough to cover a wide distance efficiently. Also, there were buttons on the device that users could use to declare the directions in which they wanted to walk. Sometimes users would accidentally press the buttons on the device and alter the path that was initial set out for them.

When designing my study, the main goal was to create a device that could easily navigate its user through an environment. However, I was also very interested in the compact size of the device mentioned in the previous study. I wanted the device to be small enough where it would not draw too much attention to its wearer while still housing all of the necessary components to fulfill its main goal. Although I did not want to include the beacon and triangulation system from the experiment, the study gave me a good start for finding a relative size of the device that I would make.

Another study [3] proposes a solution that utilizes a glove that provides both haptic and audio feedback. The device also utilizes an ultrasonic sensor that can detect obstacles within a certain distance. Depending on the distance of the obstacle a specific vibration pattern or sound is relayed to user notifying them to take the appropriate action. Due the Arduino Uno, speaker and GPS located on the back of the glove, the size of the device is rather large and bulky which may take away from its practicality. The study does state that the usage of a smaller microcontroller than the Arduino Uno could be helpful for reducing the size of the device. From this, I researched several Arduino and Raspberry Pi Microcontrollers and decided to use the Arduino Nano due to its small size and simplicity.

Hand Navigation

While there are ample studies that show the creation of a device to be used for body navigation, there are fewer studies that focus on hand navigation of a PVI. One study [6] uses a hand brace as a base and contains a vibration motor that is directly in contact with the user's skin. Through the use of an Android application, the motor will vibrate signaling the user to rotate their wrist to a specific angle. Results of the experiment declared that it is not possible to precisely rotate a person's wrist without being able to actually see the degree of rotation. This study interested me because although the type and direction of the hand movement was not the same as my study, it still gave a great deal of information regarding precision and hand navigation. Findings from this study gave insight for some of the different challenges that would arise from this navigation method and also became the main influences for the hand navigation portion of my experiment.

Chapter 3

Methods

When building the device, two important criteria were that it be comfortable on the user's body and it would allow the user to keep their hands free to perform other tasks. The glove-based devices provided a good framework for the general size of this study's device. However, they left the user with a bulky block on their hand that was either unsightly or easily damaged. That said, we wanted to create a device that was small enough to remain comfortable for the wearer while still being able to house its necessary components. We decided to use a Wizard of Oz study where obstacle detection and the necessary feedback are controlled by an external individual with an android smartphone application connected to the device through Bluetooth. This way we could reduce space needed on the device for sensory technologies and focus solely on the bracelet's navigation abilities.

Materials

We decided to use a Velcro bracelet for the base because of its simplicity and comfortability. For the microcontroller, with the task facilitating all of the connections of the device we used an Arduino Nano. The Nano has similar functionalities to the Arduino Uno used in other studies but its smaller size works better with the simplistic design of the device. To connect the device to the to a smartphone, we used an HC-05 Bluetooth module. Through the use of an application created by MIT's App Inventor software, the device will be able to receive commands from the application as input and output the specified haptic signal. The haptic signal would be conveyed using four small vibration motor disks placed at four locations on the bracelet. A portable power bank was connected to the Arduino Nano with a micro USB cord. Again, to minimize space, the power bank was placed in the user's pocket and not on the actual device. Lastly a breadboard and jumper wires were used to connect each of the components to the Arduino Nano.

Device Creation

After acquiring all of the necessary materials, we could begin with the production of the device. I first started with the smartphone application seen in Figure 1. This application contains four buttons which will connect to the four vibration motors on the bracelet (Top, Bottom, Left, Right). The next task before the team was to create the software for the Arduino Nano. We utilized public code posted from the YouTube Channel "Electronoobs" and modified it to work with our device instead of the devices described in his video. The software was programmed with the following requirements in mind: When the user presses one of the four buttons on the Android application, the app will send a corresponding letter to the Arduino Nano. Depending on the letter that the Arduino Nano has received, one of the 4 vibration motors will vibrate for exactly 500 milliseconds, signaling the user to move their hand or body, depending on the situation, to a corresponding direction.

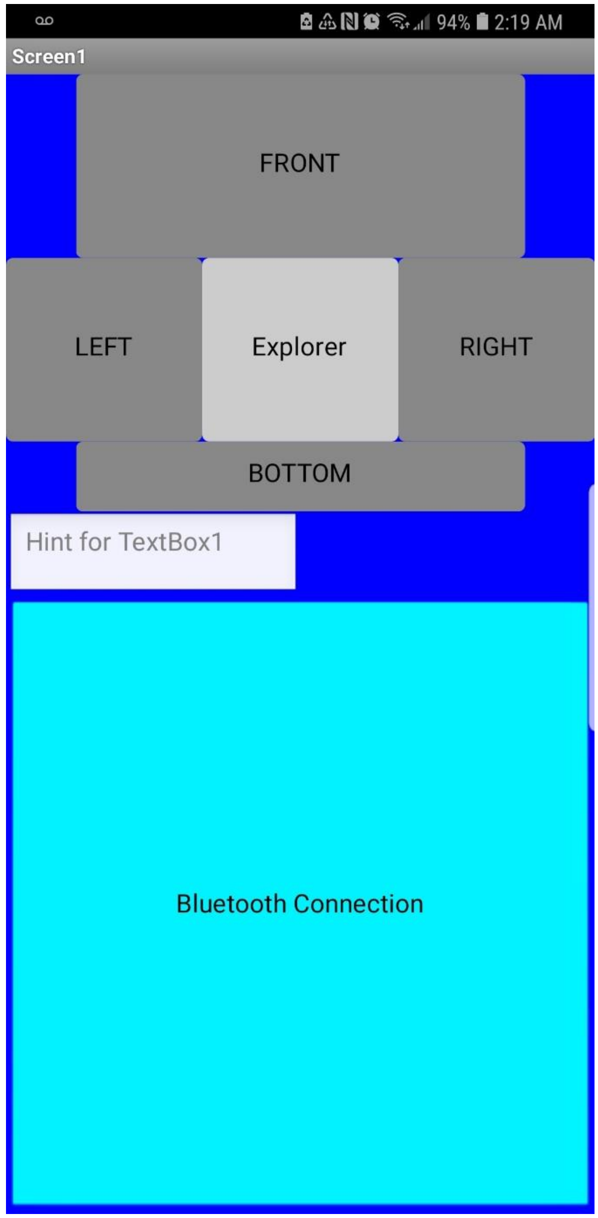

Figure 1. Android Application for Controlling Device Vibrations

Once the Arduino software was completed, we placed the Arduino Nano and Bluetooth module on the breadboard and connected them with several jumper wires. One of our challenges was finding a sufficient Bluetooth module for the device. The first of the three modules that was purchased overheated and began to melt some of its circuit when supplied with power. The second module worked efficiently with the Android application for a short period of time before it began to malfunction and eventual stop receiving and transmitting signals altogether. Luckily the third Bluetooth module that was purchased has continuously been able to send and receive signals without any issues. After confirming that the microcontroller and Bluetooth module were fully functional and testing the smartphone connection using LED Lights, we connected the vibration motors to the Arduino Nano and fixed them to the bracelet. We were now ready to begin testing. The first prototype of the device can be seen in Figure 2.

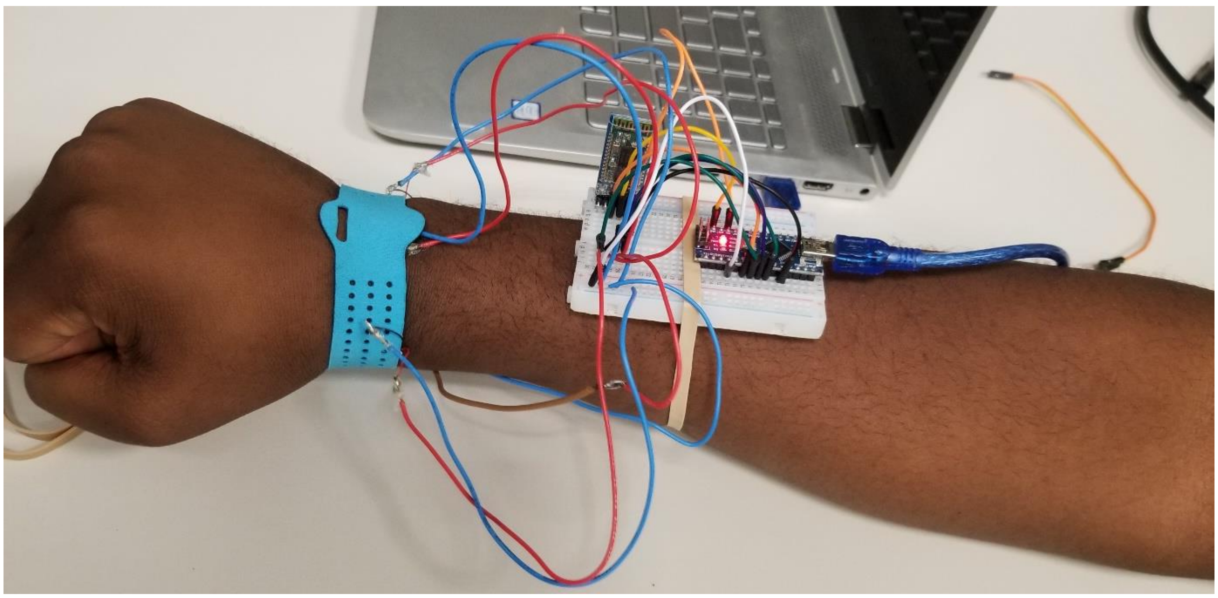

Figure 2. First Prototype of Haptic Feedback Device (Vibration motors located under bracelet)

Pilot Experiments

The initial pilot experiments went as follows: A blind-folded lab member will wear the bracelet on one wrist while holding a smartphone in the other hand. For the sake of these experiments, this user would be called the pilot. Another lab member located, in a different room than the pilot, will use a video call (Google Hangouts was used most frequently for our study) to call the pilot and view their surrounding environment. This individual will be called the agent. The agent will also use the Android application to send signals to the device causing it to vibrate, letting the user know where to walk. Table 1 shows the first vibration-action mapping we used for our experiments.

Vibration pattern	Pilot Action
1 Vibration on right side	Take a step to the right
1 Vibration on left side	Take a step to the left
2 Vibrations on bottom	Stop
2 Vibrations on top	Go/ Begin Walking

Table 1. First Set of Vibration to Pilot Action Mappings

The goal of the experiment was for the agent to successfully navigate the pilot to the end of the lab space where there is a mock grocery store "aisle". Upon reaching this aisle, the agent must then navigate the pilot's hand to pick up a specific item located somewhere on the shelf. Besides the haptic information the pilot receives, the agent also provides some verbal information regarding the pilot's surroundings such as descriptions of nearby obstacles. Obstacles included tables, chairs and other lab members. These obstacles were placed in random locations throughout the environment after each experiment to prevent pilots from relying on memory to navigate themselves. From these first experiments, we have gained significant data that has been used to improve the efficiency of the device. The information gained and revisions made will be explained more in the next chapter.

Chapter 4

Results

The pilot experiments gave the team plenty of helpful information regarding the device's response time, precision, durability and other attributes. We noticed that application was very responsive with the device as the time it took for the vibration motors to activate after pressing a button on the application was nearly instantaneous. Increasing the distance between the pilot and agent does tend to delay this response time. There were also issues involving durability of the device. Sometimes when the pilot moved their hands to a certain position, the wires connecting the vibration motors to the device would become disconnected and the experiment had to be restarted. To remedy this, we used stronger sturdier jumper wires and affixed them to the vibration motors with tape.

One of the main revisions that we made to our project was the vibration mapping pattern. Our first vibration to agent action mapping uses the vibrations to direct the pilot through a safe route avoiding obstacles to reach their destination. This vibration pattern was not to efficient due to the pilots not being able to gauge how far they should move in one direction. For example, if the pilot received a vibration signal on the left side of the bracelet, they would be unsure weather the step they took would be enough to move around the obstacle. Eventually the pilot would be able to maneuver around the obstacle but a decent amount of time would (around 20 seconds per obstacle) would be wasted. We decided to change the vibration mapping pattern to the one shown in Table 2. This vibration mapping pattern proved to be more effective because it gave the pilot a better sense of where the obstacles in the environment were. Having a vibration mapping pattern that focuses on obstacle detection allows the pilot to formulate their own route to safely navigate the environment instead of relying solely on the agent, thus shaving time off of each completed experiment.

Vibration Pattern	Description
1 Vibration on right side	There is an obstacle to your right
1 Vibration on left side	There is an obstacle to your left
2 Vibrations on bottom	Stop
2 Vibrations on top	Go/ Begin walking
1 Vibration on top	There is an obstacle directly in front of you

Table 2. Revised Vibration Mapping Pattern

There were fewer issues regarding the hand navigation to the desired item located on the aisle shelf. Once the pilot has reached the shelf, they were asked to place their dominant hand out in front of the camera of the smartphone they are holding. the agent then utilizes the Android application to navigate the pilot's hand to a specific item to be picked up. 1 vibration in any of the 4 locations on the device tells the pilot to move their hand slightly in that direction. Once the pilot's hand is directly in front of the desired object, 2 vibrations on the top motor signify that the user can reach forward and grab the item, thus completing the experiment. Once positioned in the aisle, pilots were able to efficiently use the vibration signals to find the desired object within a relatively short amount of time. No major changes were made to this section of the experiments.

The experiments were performed with several different lab members acting as pilots, each with varying wrists sizes. Having to move the vibration motors around the bracelet so that they are located exactly on the top, bottom, left and right sides of the wrist became an arduous task. Several wires continuously disconnected from their sockets and vibration motors during the transfer of the device from one lab member to another. This gave us the notion that we should make changes to the wristband that would make it easily adjustable for the varying wrists sizes of its users. We applied a strip of Velcro to the wristband and smaller opposing strips of Velcro to the vibration motors. This way the motors could be easily affixed onto the bracelet at their designated locations without having wires disconnecting from the device or its motors.

The addition of Velcro onto the bracelet also made the vibrations feel more separated from each other. Previously, there were instances where the pilot would receive a vibration signal and not be able to discern where on the bracelet it originated from, causing collisions and confusion. The Velcro strips hold the vibrations motors firmly on the wrist and keep them in constant contact with the skin allowing the user to better differentiate between each of the motors. We also decided to reduce the time of the vibration from 500 milliseconds to 200 milliseconds. This way the vibrations would be less intense and less irritating on the pilot’s skin.

Chapter 5

Conclusion

After making the necessary revisions from the pilot experiments, the device addresses two of the three initial problems it was created to solve. The first of which is body navigation. The device can effectively navigate its user through an environment with several obstacles without collision. By changing the vibration mapping pattern from a user guidance design to an obstacle detection design, pilots are able to get a better understanding of their surroundings and traverse their environment quicker. Secondly, hand navigation and selection of a specific object is also possible through the use of the haptic device. Pilots can easily interpret the vibration signals and move their hand accordingly so that it is placed in front of the desired object. This device is smaller and more compact than some of the other devices that were mentioned in the chapter 2. However, it is still bulky and requires a small brick shaped breadboard to be placed on the back of the pilot's wrist. That said, the device currently does not meet the third requirement of reducing stigmatization of its wearer.

One of the most prominent issues that still persists is the delicacy of the device. As the pilot is being navigated, there are times where wires will fall out of the device causing minor issues for the experiments. Future work on the device would include making the bracelet and its components sturdier so that it can withstand average arm movement. We also plan to replace the breadboard with a thinner apparatus for connecting all of the device's components. This way, the device will be able to reduce the stigma placed on PVIs with its sleek and minimalistic appearance. Once a smaller, sturdier prototype had been created, we will begin more rigorous testing to further improve the device's effectiveness. Figure 3 shows the current version of the prototype after some of the changes mentioned above were completed.

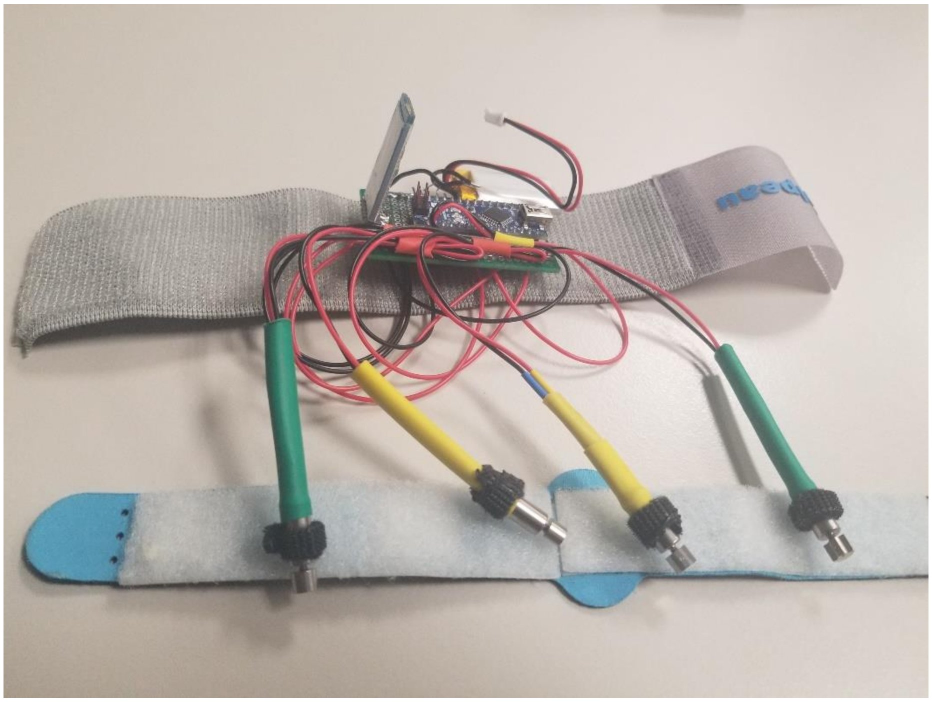

Figure 3. Current Prototype of Haptic Device

BIBLIOGRAPHY

[1] ICT Results. "Enabling The Blind To Find Their Way." ScienceDaily. ScienceDaily, 27 October 2008. <www.sciencedaily.com/releases/2008/10/081024084738.htm>.

[2] A. Keyes, M. D'Souza and A. Postula, "Navigation for the blind using a wireless sensor haptic glove," *2015 4th Mediterranean Conference on Embedded Computing (MECO)*, Budva, 2015, pp. 361-364. doi: 10.1109/MECO.2015.7181944

[3] S. T. H. Rizvi, M. J. Asif and H. Ashfaq, "Visual impairment aid using haptic and sound feedback," *2017 International Conference on Communication, Computing and Digital Systems (C-CODE)*, Islamabad, 2017, pp. 175-178. doi: 10.1109/C-CODE.2017.7918924

[4] Hackett, Alex. “We're Blind, Not Invisible.” *Perkins School for the Blind*, www.perkins.org/stories/were-blind-not-invisible.

[5] “Global Data on Visual Impairment.” *World Health Organization*, World Health Organization, 8 Dec. 2017, www.who.int/blindness/publications/globaldata/en/.

[6] K. Aqeel *et al*., "Skin stroking haptic feedback glove for assisting blinds in navigation," *2017 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Macau, 2017, pp. 177-182. doi: 10.1109/ROBIO.2017.8324414

ACADEMIC VITA

Academic Vita of Zion Emanuel
zion.indigo@gmail.com

Education: Pennsylvania State University
Major(s) and Minor(s):
Major- B.S Information Sciences and Technologies
Minor- Chinese Language
Thesis Title:
Development of Haptic Navigation Device to Assist Individuals with Visual Impairments
Thesis Supervisor: John Carroll

Work Experience
Date: Spring 2019
Title: IST 140 – Introduction to Java Programming Learning Assistant
Description: Tutor and learning coach for the Course IST 140
Institution/Company (including location): Pennsylvania State University
Supervisor's Name: James Farrugia

Grants Received: 3M Research Grant

Community Service Involvement: BluePrint Peer Mentorship Program

International Education (including service-learning abroad):

Summer 2017: Impact of Culture on engineering in China

Language Proficiency: English