GLASSES FOR THE BLIND

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Contents

1. Introduction

1.1 Objective

There are many groups of people in the world today who are faced with accessibility issues every day in their lives. According to the World Health Organization (WHO), 285 million people in the world are visually impaired of whom 39 million are blind. [1] For blind people in particular, unfamiliar obstacles in their path present a hazard for which accidents and injuries can occur. In a study carried out by the University of California, Santa Cruz, 86% of accidents occur outdoors due to branches, poles, and signs which are closer to head level. [2]

For this project, the goal will be to mitigate accidents occurring outdoors due to unfamiliar obstacles at head level for blind people. The target demographic that will be the focus is wealthier blind people who can afford technological devices to aid in their everyday lives. The design will implement a glasses sensor subsystem which will house a 3D ultrasonic sensor and a feedback subsystem which will provide greater understanding of the world to blind users. Our product will map the space where the user is facing onto a 2D grid to determine if obstructions above the waist level are present in certain zones of the grid. It will then communicate with a haptic feedback device that will use actuators in a grid to let users know within which grid block in front of them the object has been detected.

1.2 Background

Currently, blind people will often use white canes as a mobility tool to get a better understanding of the world around them. This tool can be effective for providing feedback about obstacles at the ground level. However, obstacles above waist level such as tree branches often go unnoticed. Technology-assisted white canes which have been developed by companies such as BAWA and WeWALK are able to provide additional feedback for these potential hazards above waist level, and a project done by Team 18 in Spring 2019, OptiCane, was a variation of these technological canes which used LIDAR and a vibration bracelet to provide blind users with information about their environment. [3][4] However, these technological canes tend to provide superfluous features and only use imprecise vibrations for feedback.

The design proposed in this document will be a fundamentally different solution. Instead of providing a technology-assisted white cane, a supplementary wearable system to white canes will be created. This system is designed with the goal of providing blind users a more accurate and tangible picture of what obstructions lie in their path ahead and will consist of a glasses sensor system and an arm sleeve feedback system.

1.3 Physical Design

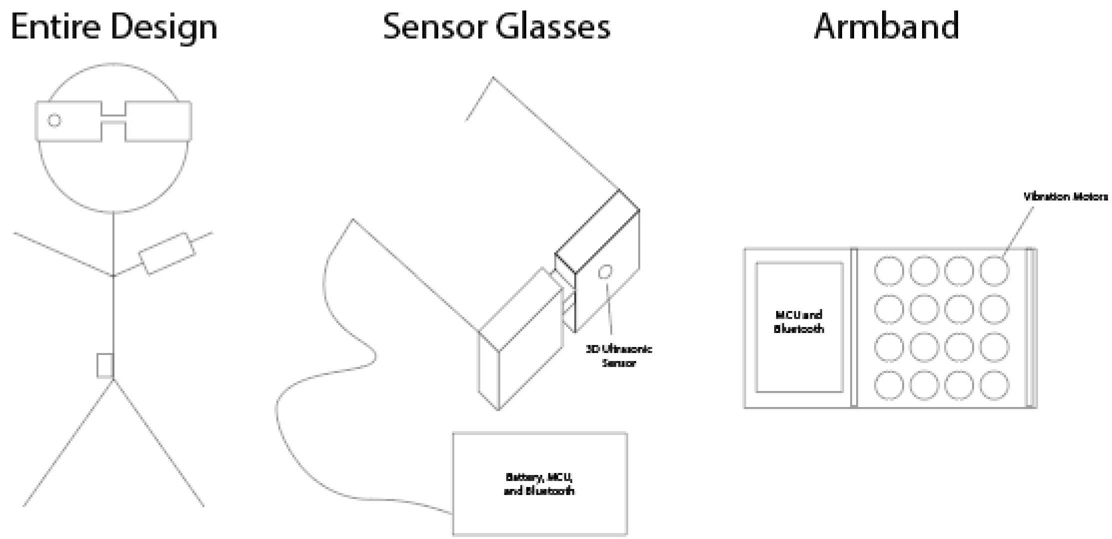

Figure 1: Physical Design of the Glasses Subsystem and the Feedback Subsystem

This design consists of a sensor glasses subsystem which houses a 3D ultrasonic sensor that will detect potential obstructions in a blind person's path. This unit has a wire which is connected to a unit that houses the MCU, power supply, and Bluetooth. There is a separate armband feedback subsystem made up of 16 vibration motors to let the user know where obstructions are. The exact methodology will be discussed in the respective subsystems.

1.4 High Level Requirements

- The sensor will be able to detect obstacles within 30 [cm] of accuracy when users are walking on sidewalks outdoors that appear within a 4x4 [m] space in front of the user in the x and z orientation, where the x axis is left-right and the z axis is depth.
- The haptic feedback will be able to provide the users with detailed and non-intrusive information about obstacles in the space in front of them through a wearable armband.
- The device must be able to last the larger part of the day, at least 12 [hr]

2. Design

2.1 Block Diagram

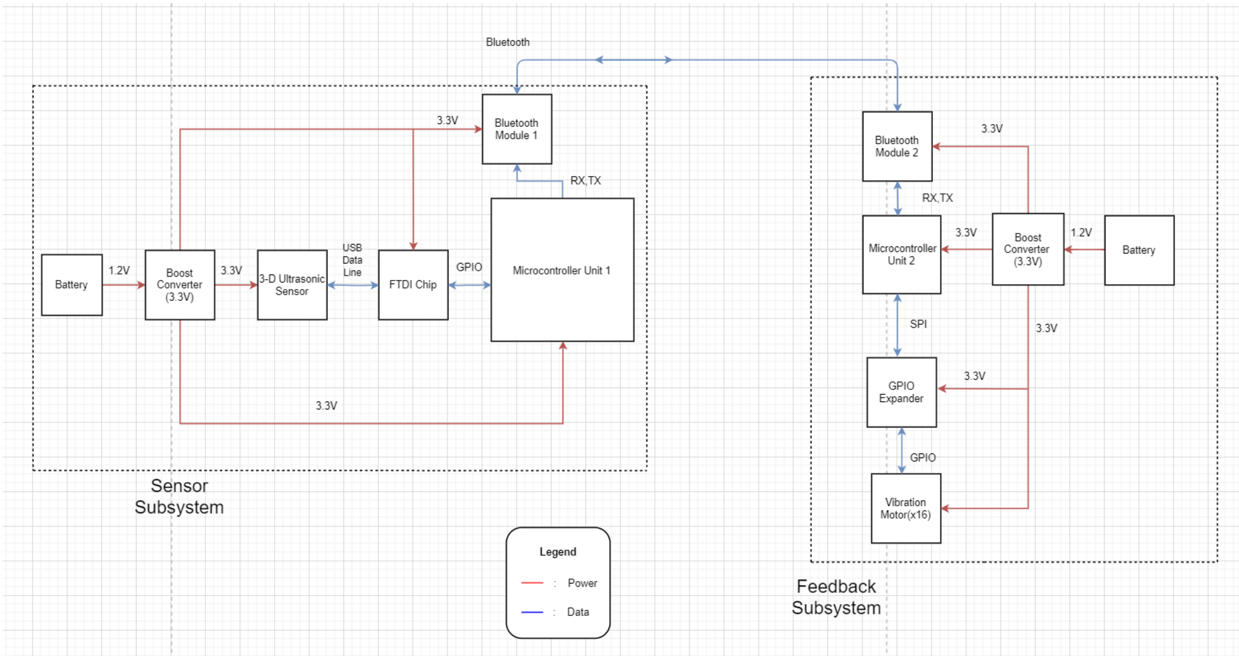

Figure 2: Block Diagram of Glasses for the Blind

Our block diagram has 2 subsystems. The first subsystem is the sensor subsystem. This subsystem houses a 3-D ultrasonic sensor that maps obstacles in the outside world. Data from the 3-D ultrasonic sensor is communicated over USB B to an FTDI Chip, which converts that USB signal to an input into the microcontroller. The microcontroller then sends that information to the feedback subsystem via the Bluetooth module. The feedback subsystem is responsible for controlling the vibration motors that will help our users determine where the obstacles are located as explained in the “Physical Design” section.

2.2 Sensor Subsystem

The purpose of the sensor subsystem is to detect obstacles in the surrounding area using the Topsens 3-D ultrasonic sensor (TS3). The 3-D ultrasonic sensor works by sending out an ultrasonic pulse. That pulse is reflected by surrounding objects. Based on the time the reflected pulse takes to make it back to the sensor the origins of the reflected ultrasonic pulse are calculated as 3-D coordinates. The 3-D ultrasonic sensor transmits location data through USB. Before the location data gets to Microcontroller 1, it first must go through an FTDI chip, which will translate the USB data into serial inputs for Microcontroller 1. Once Microcontroller 1 receives the location data, it sends the data to Bluetooth Module 1, which transmits the data to the Feedback Subsystem.

Requirements	Verification
1. 3-D Ultrasonic Sensor must be able to detect objects from 1-3 [ft] away and have a field of view of 140 [degrees] and have an accuracy of ± 10 [degrees]. 2. Microcontroller 1 must be able to process data from the 3-D ultrasonic sensor and then send that data to the Bluetooth Module 1 3. The Bluetooth Module 1 must be able to connect to Bluetooth Module 2 at a distance of 1-3 [ft]. 4. System must be able to operate at 3.3V with a tolerance of ± 5%, and last 12 [hr].	1. 3-D Ultrasonic Sensor Verification a. We will connect our 3-D ultrasonic sensor through USB to our PC, to display sensor readings. b. We will place objects within 1-3 [ft] at different angles from the sensor, to see if the sensor can detect the objects. 2. Microcontroller 1 Verification a. Connect the 3-D ultrasonic sensor to the USB connector on the sensor subsystem PCB. b. Run a test script that will display the serial communication line between Microcontroller 1 and the 3-D ultrasonic sensor. c. Write a test script which will display the serial communication line between Microcontroller 1 and Bluetooth Module 1 to make sure Microcontroller 1 is transmitting the 3-D ultrasonic sensor data to Bluetooth Module 1. If Microcontroller 1 and 3-D Ultrasonic Sensor are properly communicating over Bluetooth the test message should be displayed in the serial communication window which will be displayed on the PC. 3. Bluetooth Module Data Transmission a. We will verify this requirement by writing a script that will send test messages between our Bluetooth modules which will be separated by 3 [ft]. If Bluetooth Module 1 and Bluetooth Module 2 are properly communicating over Bluetooth, the test message should be displayed in the serial communication window which will be displayed on the PC. 4. Power Verification a. To verify that our system is working at 3.3 [V] with a tolerance of ±5%, we will use a voltmeter to measure the voltage at each of

	the components and make sure they all run at 3.3 [V] with a tolerance of ±5%. b. To verify that our system lasts for 12 [hr], we will first make sure our sensor subsystem PCB is fully charged. We will then write a test script which will display the sensor data processed by the microcontroller. We will allow it to run for 12 [hr] and verify that at the end of the 12 [hr] microcontroller is still reading in sensor data.

Visual Depiction of Glasses Module Output

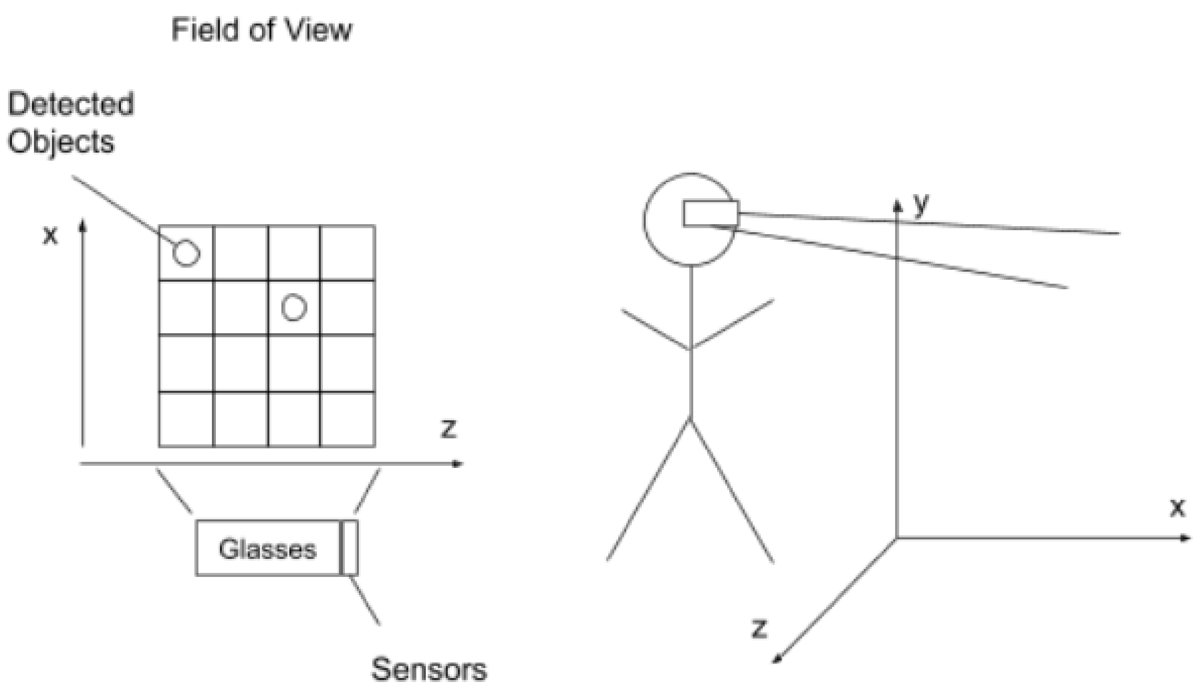

Figure 3: Visual Representation of the Glasses Subsystem

The 3D ultrasonic sensor in the glasses will return the coordinates of obstacles detected and map them to the corresponding space in the xz grid. This information will then be sent to the feedback subsystem which will be a 2D grid of vibration motors. When an object is detected in the grid space, the same grid will vibrate on the user's arm, effectively mapping the space in front of the blind person into a tangible 2D grid to provide greater understanding of the obstacles in front of them. Here, the y coordinate is not considered, as this design is to be used in conjunction with white canes. White canes can detect hazards below the waist, so this design only needs to focus on those above the waist. The accuracy from this design will allow users to see objects approaching as they move closer on the grid and will be able to evade them when they get close.

Schematic for Sensor Subsystem

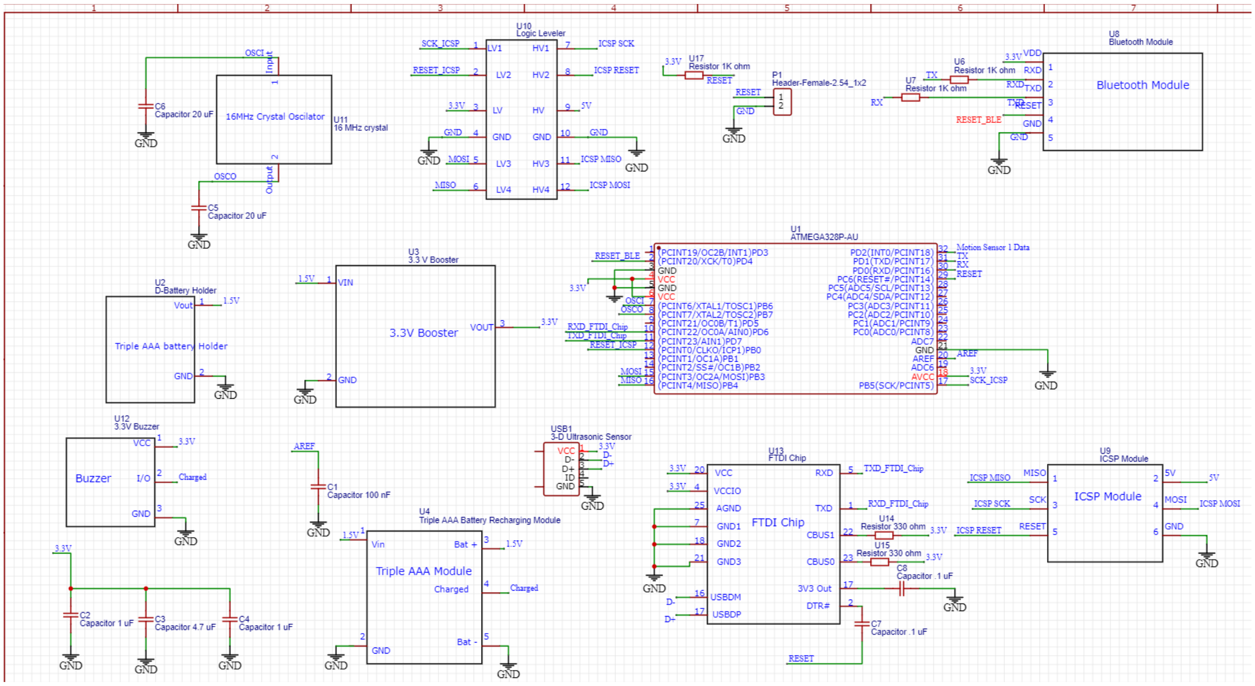

Figure 4: Sensor Subsystem Schematic

2.3 Feedback Subsystem

The purpose of the feedback subsystem is to use the location data sent from the Sensor Subsystem to control the vibration motors in a way that conveys the location of obstacles to the user, in this case by reflecting a grid. Bluetooth Module 2 first receives location data from Bluetooth Module 1 located on the Sensor Subsystem. Bluetooth Module 2 will then transmit that data to Microcontroller 2. Microcontroller 2 uses the location data to control the vibration motors to alert our users where obstacles are located.

Requirements	**Verification**
1. Bluetooth Module 2 must be able to connect to Bluetooth Module 1 at a distance of 1 - 3 [ft], and it must also be able to send location data to Microcontroller 2. 2. Microcontroller 2 must be able to process information from Bluetooth Module 2	1. Bluetooth Module 2 Verification a. Will write a test script that will send test messages between Bluetooth Module 2 and Microcontroller 2. If Bluetooth Module 2 and Microcontroller 2 are properly communicating over Bluetooth the test message should be displayed in the serial communication window which will be displayed on the PC. 2. Microcontroller 2 Verification

and control the vibration motors. 3. System must be able to operate at 3.3 [V] with a tolerance of ± 5%, and last 12 [hr].	a. Write a test script that will display on the PC the serial communication line between Microcontroller 2 and Bluetooth Module 2 to verify that they are able to communicate with each other. If Microcontroller 2 and Bluetooth Module 2 are properly communicating over Bluetooth the test message should be displayed in the serial communication window which will be displayed on the PC. b. Write a test script that will vibrate the vibration motors depending on the 3-D ultrasonic sensor data to verify that Microcontroller 2 is able to control the vibration motors. 3. Power Verification a. To verify that our system is working at 3.3[V] with a tolerance of ±5%, we will use a voltmeter to measure the voltage at each of the components and make sure they all run at 3.3 [V] with a tolerance of ±5%. b. To verify that our feedback subsystem lasts for at least 12 [hr], we will first make sure our feedback subsystem PCB is fully charged. We will then write a test script which will randomly vibrate a certain motor every 20 [s]. We will allow it to run for 12 [hr] and verify that at the end of the 12 [hr] microcontroller is still able to randomly vibrate motors.

Schematic for Feedback Subsystem

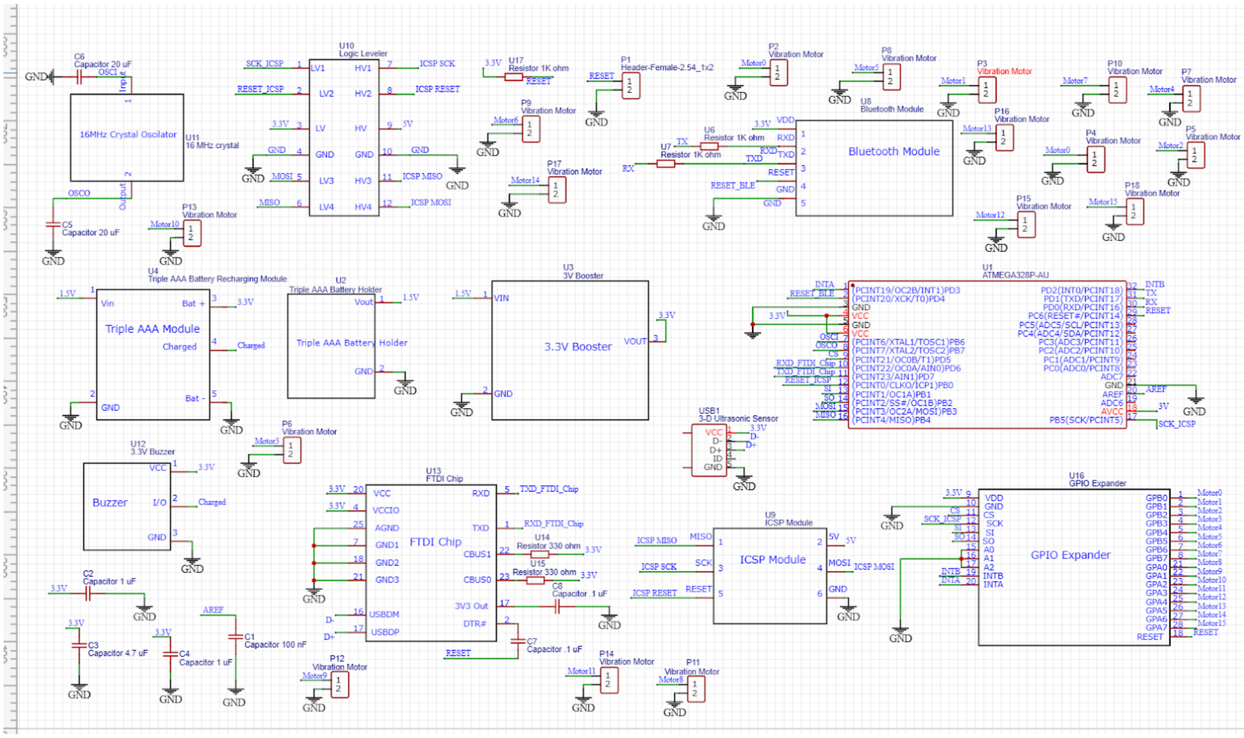

Figure 5: Feedback Subsystem Schematic

2.4 Tolerance Analysis

The greatest area of uncertainty for this project is the use of the 3D ultrasonic sensor and mapping its outputs to a 4x4 [m] grid. From the datasheet of the TS3 sensor, the range accuracy is plus-minus 4%. This means that a block in the grid has the potential of misactivations, to be activated even when the obstacle exists on the edge of an adjacent block instead of inside the activated block. The goal of this tolerance analysis is to confirm that the flexibility of the design will be able to deal with potential inaccurate outputs from the TS3 sensor. In order to do this, the focus of the calculations was on the worst-case scenarios of misactivations. This was done by calculating the borders of blocks in the grid with the 4% range accuracy to demonstrate that even with any inaccurate readings, the design is still able to provide the necessary information to blind users to avoid obstacles in their path. For this design, all objects being detected are greater than 7.5 [cm] in length as that is the standardized target that is used to get the values in the datasheet.

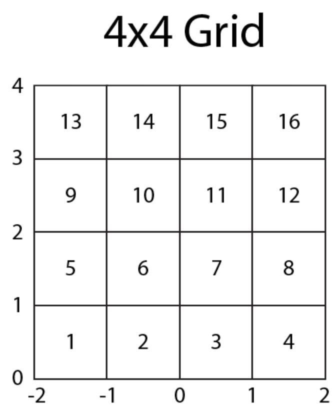

Figure 6: Reference 4x4 Grid for Tolerance Analysis

Reference

Corner 1 = Bottom left corner of the block
Corner 2 = Bottom right corner of the block
Corner 3 = Top left corner of the block
Corner 4 = Top right corner of the block

Block #4

Corner 1: $\sqrt{(1^2+0^2)}=1$ [m]
Corner 2: $\sqrt{(2^2+0^2)}=2$ [m]
Corner 3: $\sqrt{(1^2+1^2)}=1.414$ [m]
Corner 4: $\sqrt{(1^2+2^2)}=2.236$ [m]
Taking 4% error into account:
New Corner 1 = 1 * 0.04 = 0.04 [m]
New Corner 2 = 2 * 0.04 = 0.08 [m]
New Corner 3 = 1.414 * 0.04 = 0.0566 [m]
New Corner 4 = 2.236 * 0.04 = 0.08944 [m]
Taking the highest distance for each side of the block will result in Figure 7.

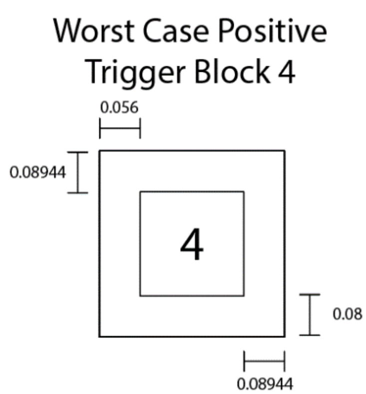

Figure 7: Worst Case Positive Trigger for Block #4

Block #3

Corner 1: $\sqrt{(0^2+0^2)}=0$ [m]
Corner 2: $\sqrt{(1^2+0^2)}=1$ [m]
Corner 3: $\sqrt{(0^2+1^2)}=1$ [m]
Corner 4: $\sqrt{(1^2+1^2)}=1.414$ [m]
Taking 4% error into account:
New Corner 1 = 0 * 0.04 = 0 [m]
New Corner 2 = 1 * 0.04 = 0.04 [m]
New Corner 3 = 1 * 0.04 = 0.04 [m]
New Corner 4 = 1.414 * 0.04 = 0.0566 [m]
Taking the highest distance for each side of the block will result in Figure 8.

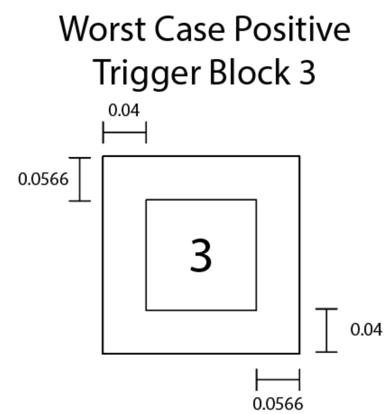

Figure 7: Worst Case Positive Trigger for Block #3

Block #15

Corner 1: $\sqrt{(3^2+0^2)}=3$ [m]
Corner 2: $\sqrt{(3^2+1^2)}=3.16$ [m]
Corner 3: $\sqrt{(0^2+4^2)}=4$ [m]
Corner 4: $\sqrt{(4^2+1^2)}=4.12$ [m]
Taking 4% error into account:
New Corner 1 = 3 * 0.04 = 0.12 [m]
New Corner 2 = 3.16 * 0.04 = 0.1264 [m]
New Corner 3 = 4 * 0.04 = 0.16 [m]
New Corner 4 = 4.12 * 0.04 = 0.1648 [m]
Taking the highest distance for each side of the block will result in Figure 9.

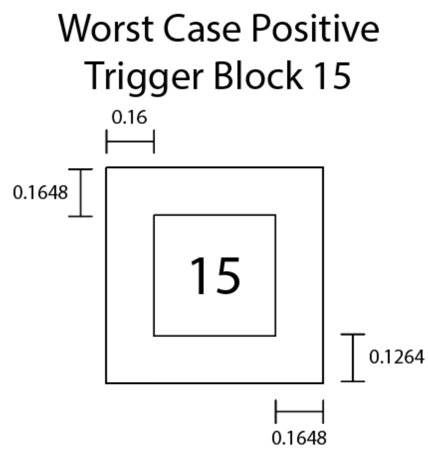

Figure 9: Worst Case Positive Trigger for Block #15

Block #16

Corner 1: $\sqrt{(3^2+1^2)}$=3.16 [m]
Corner 2: $\sqrt{(3^2+2^2)}$=3.61 [m]
Corner 3: $\sqrt{(4^2+1^2)}$=4.12 [m]
Corner 4: $\sqrt{(4^2+2^2)}$=4.47 [m]
Taking 4% error into account:
New Corner 1 = 3.16 * 0.04 = 0.1264 [m]
New Corner 2 = 3.61 * 0.04 = 0.1444 [m]
New Corner 3 = 4.12 * 0.04 = 0.1648 [m]
New Corner 4 = 4.47 * 0.04 = 0.1788 [m]
Taking the highest distance for each side of the block will result in Figure 10.

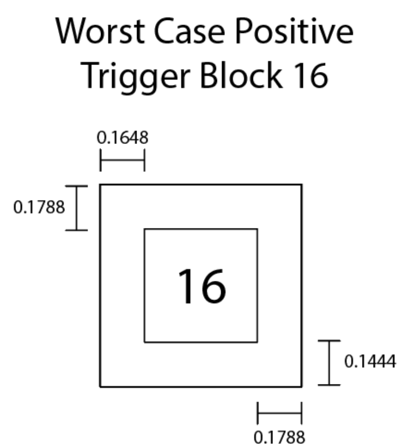

Figure 10: Worst Case Positive Trigger for Block #16

Refresh Rate

Another concern that comes with our project is the refresh rate. We must make sure that our sensor can read and transfer data at a much faster speed than the average walking speed. The average walking speed we selected was 1.43 [m/s]. We are using 1.43 [m/s] as an extreme scenario because it is the fastest average walking speed. [12] The scan rate of our sensor is 28 [Hz]. The scan velocity of our sensor is 28 [Hz] * 1 [m] which is 28[m/s]. The scan velocity is much greater than the average velocity of our user. We also must consider the data transfer rates of the 3-D ultrasonic sensor which is 9 kB/s and our system which is 9.6 kB/s. Since the sensor is only outputting an x, y, z coordinates the data amount is small enough that the data transfer will not have a huge impact on the refresh rate.

Conclusion

As can be seen from the above calculations, the farthest away the actual obstacle can be from the edge of a misactivated block is 0.1788 [m]. This means that the worst-case scenario for a misactivation is for an object's actual location to be one fifth of the way into a neighboring block from the activated block's edge. This is an acceptable variation from inaccuracies due to the sensor as it still provides blind people with the information needed to avoid the obstacle. For example, if Block 16 is activated, even with a misactivation, as long as the user is at least 0.2 [m] away from the edges of Block 16, they will completely avoid the object. To make sure individuals are aware of potential misactivations, a tutorial would be included with the product that would tell users to avoid the activated block as well as edges of that block.

In addition, the sensor is more inaccurate the farther away the obstacle. However, as the obstacle gets closer, its resolution will be clearer to the sensor and there will be less misactivations. This means that the misactivations will not be as significant when the obstacle is close. For example, in Block 3, misactivations are at most 6cm outside the activated block. In addition, since the refresh rate is significantly faster than the average walking speed of a human, this design will not be constrained by the refresh rate.

3. Project Differences

3.1 Overview

The original project was one done by Team 18 in Spring 2019, OptiCane. Opticane was a technological walking cane for the blind that used LIDAR sensors built into the cane and a vibration bracelet to provide blind users feedback about obstacles in their environment. Our design will be a modular solution using a 3D ultrasonic sensor and a vibration array to provide users with more precise feedback than the previous project while offering greater flexibility with its modular design.

As blind walking canes are mainly used for outdoor travel, ultrasonic sensors provide greater reliability than the LIDAR sensors used by the previous group. The reason being, LIDAR sensors are sensitive to varying light environments which makes them inconsistent during outdoor use while the ultrasonic sensors are not affected by this. In addition, we chose to move the sensor unit from a module on the cane to wearable glasses instead. The reason being, when researching the needs of blind users and their usage of existing technological canes, a major complaint was that the feedback provided by the cane was too disorganized. [13] This is due to how walking canes are used in a sweeping motion. The sweeping motion made it more difficult to really understand where the obstacles were in the user's path. Our glasses module will not have this problem as it will be independent of the cane.

For our wearable feedback array, our design is similar to the other group’s bracelet as it is a wearable armband. However, we chose to implement a grid instead of varying vibrations to show how far and the general direction of where the obstacles are. The other group used different vibration intensities to give feedback on distance and different vibration patterns to say which sensor was detecting the objects. However, all these different vibration patterns and intensities can be distracting to the user and would require them to constantly monitor the bracelet to understand the environment around them. Our solution is simpler. It uses a 4x4 array to show exactly in which block objects exist in front of the user without them having to think about the vibrations to determine the location.

The design proposed in this document is a fundamentally different solution. Instead of providing a technology-assisted white cane, a supplementary wearable system to white canes will be created. This system is designed with the goal of providing blind users a more accurate and tangible picture of what obstructions lie in their path ahead and will consist of a glasses sensor system and an arm sleeve feedback system.

3.2 Analysis

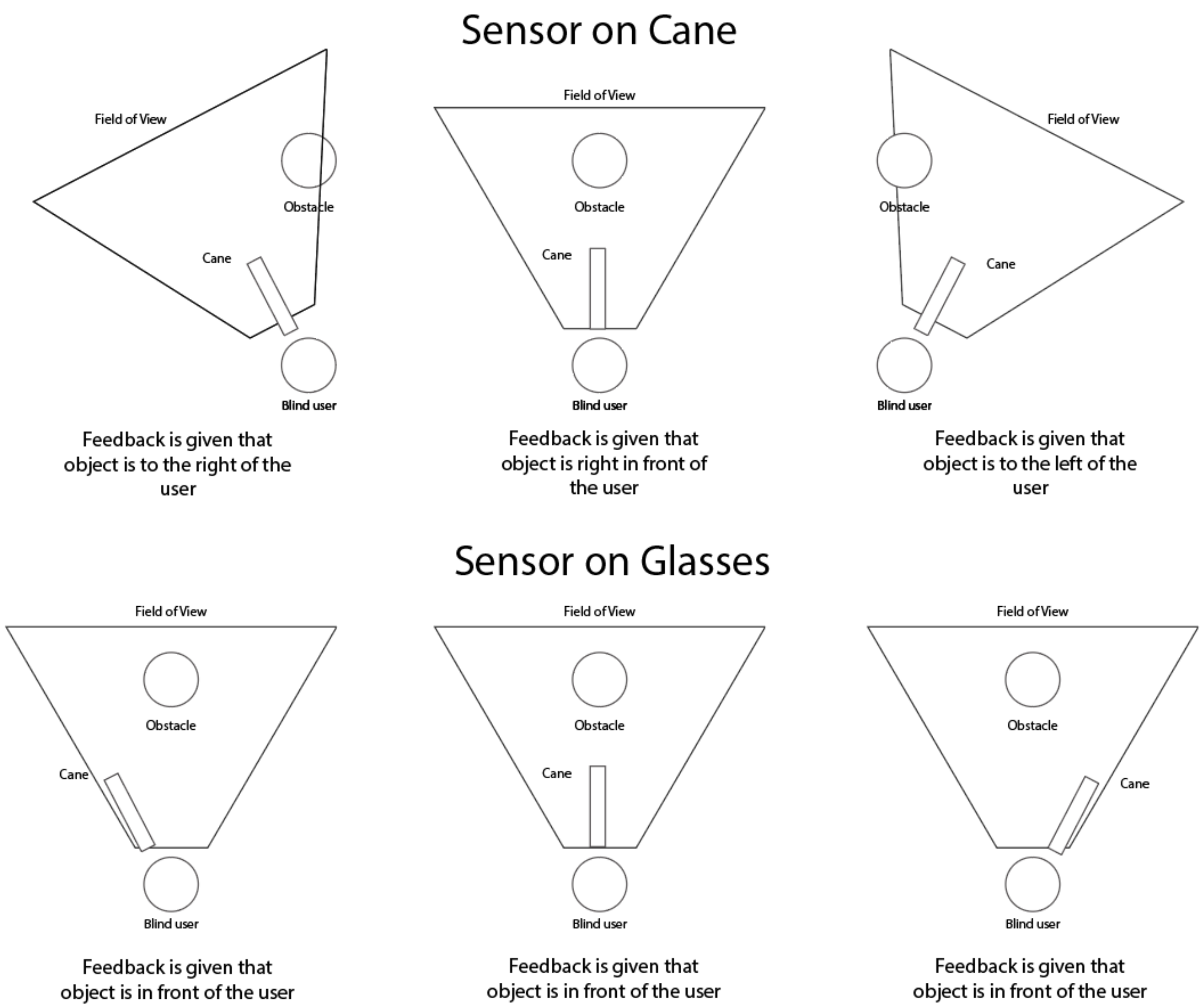

Figure 11: Feedback Based on Sensor and Obstacle Location

When using a cane, blind user's sweep the cane back and forth in front of them. In the previous group's design, the sensor was attached to the cane which meant that at varying times during the sweep, the feedback provided would say that the object is in different locations in relation to the center which is a fundamental flaw in the design. In our design, by moving the sensor to the glasses, the feedback provided is a lot more consistent as the sensor is not located on a constantly moving device.

In addition, the previous group used LIDAR sensors while we are using ultrasonic. LIDAR does not work well at high sun angles and reflections since laser pulses depend on the principle of reflection. [14] This means that LIDAR is not suited for outdoor environments where its performance can be greatly undermined by the sun's rays. In contrast to this, ultrasonic sensors are unaffected by light conditions and would be preferable to LIDAR for this scenario. Furthermore, the LIDAR sensor used by the previous group had only a field of view (FOV) of 25 [degrees]. [9] Our 3-D ultrasonic sensor has a FOV of 140 [degrees]. [10]

More so, our design is also modular and can be used in conjunction with current walking canes blind people have. The previous group, on the other hand, required replacing the walking cane with their solution.

Finally, the previous project uses vibration patterns to tell a blind person how far and in which orientation obstacles are in front of them. This requires constant monitoring by the user. This results in blind users needing to constantly multitask as they go about their day by monitoring the vibrations and thinking about what objects are detected through patterns. In a research study published by Springer Science, it was found that multitasking takes more time to complete tasks than singular tasks and with less accuracy. [11] Due to this, our vibration design limits the amount of multitasking required by blind users. It provides direct feedback on the location of obstacles in a user's path without the user needing to think about different patterns and intensities to get the location of the object.

4. Cost and Schedule

4.1 Cost

Part	Units	Cost Per Unit	Total Cost
Part #: ATmega328p Manufacturer: Microchip Description: Microcontroller	2	$2.01	$4.02
Part #: 768-1007-1-ND Manufacturer: Future Technology Devices International Ltd Description: FTDI Chip	1	$4.50	$4.50
Part #: TS3 3D Ultrasonic Sensor Manufacturer: Toposens Description: #D Ultrasonic Sensor	1	$320.00	$320.00
Part #: DD0606SA_3V3 Manufacturer: Eletechsup Description: Boost Converter	2	$1.89	$3.78
Part #: NIUP11TA Manufacturer: Eletechsup Description: Battery Charger Module	2	$3.00	$6.00
Part #: ROB-08449-ND Manufacturer: SparkFun Electronics Description: Vibration Motor	16	$2.15	$34.40
Part #: MCP23S17 Manufacturer: Microchip Description: GPIO Expander	1	$1.26	$1.26
Part #: Xinrubhbod27ckzy Manufacturer: Akozon Description: Beep Alarm Sensor Module	1	$10.18	$10.18
Part #: AAA NiMH Battery (4 count) Manufacturer: Duracell Description: AAA Rechargeable Batteries	1	$10.93	$10.93
Part #: RYB080I_lite Manufacturer: REYAX Description: Bluetooth Module	2	$5.80	$11.60

Part #: BC2AAAL-ND Manufacturer: Digikey Description: AAA Battery Holder	2	$1.15	$2.30
Total Cost of Parts			**$408.97**
Total Cost of Labor = $50 * 2.5 * 13 hours per week * 16 weeks * 3 people			$ 78,000
Grand Total Cost			**$78,408.97**

4.2 Schedule

Week	**Cary**	**Sam**	**Makombo**
1	Design Document	Design Document	Design Document
2	Work on getting both Bluetooth modules to communicate with each other	CAD metal casings for sensor subsystem, and begin building a feedback subsystem forearm band prototype	Design PCB's
3	Make sure the 3-D ultrasonic sensor works by connecting it through USB to our PC to display sensor readings.	Prototype Feedback armband which will house the feedback subsystem	Verify PCBs and finalize first PCB order
4	Finish testing 3-D ultrasonic sensor and make sure that microcontroller can process information from 3-D ultrasonic sensor	Finish feedback subsystem armband prototype and begin unit testing	Rework PCB
5	Make sure that 3-D ultrasonic data can be communicated over Bluetooth to the feedback subsystem	Verify, test, and debug feedback subsystem armband and make sure microcontroller can control the vibration motors	Solder components onto PCB

6	Combine project components and test and debug	Combine project components and test and debug	Combine project components and test and debug
7	Testing and Debugging	Testing and Debugging	Testing and Debugging
8	Mock Demo, Debugging	Mock Demo, Debugging	Mock Demo, Debugging
9	Demo & Presentation	Demo & Presentation	Demo & Presentation

5. Ethics and Safety

In terms of safety and ethics we have identified a few potential problems. The first one is moisture. The users of our device may be outside on a sunny day, and due to the heat, they may begin to sweat. This sweat could potentially land on the PCB or there could be cases where our users accidently spill liquid on the PCB. The problem with moisture is that it corrodes copper traces, causes short circuits, and damage to components on the PCB. [5] In order to protect against moisture we plan to apply a PCB varnish on our board to protect against moisture. The second concern we have for our project is the location of the PCB. Our device is a wearable so there is a possibility that our users could damage the PCB because of electrostatic discharge (ESD). To prevent ESD we plan to use proper grounding techniques. We will use 2 ground layers and stitch them together with vias so that our circuit will have adequate grounding. We also plan to add a metal casing to our PCB as additional ESD protection.

Another concern that we have with our project is the Bluetooth communication between our sensor subsystem and our feedback subsystem. Bluetooth communication is not very secure, and it is possible that someone with malicious intent could hack the Bluetooth device and give our users false information which could cause them injury. To ensure we follow ACM's General Ethics Principles we plan to make our Bluetooth network more secure. We will add a pairing between our feedback and sensor subsystems by utilizing the BLE's security mode. This service level security will allow for authentication, encryption, and authorization of data to be sent between subsystems. [6]

The 3rd concern that we have with our projects is that we are using NiMh batteries which are hazardous materials. If our batteries are ingested, inhaled, or make contact with our users' skin or eyes it can cause harm to our users. [7] We plan to counter this by enclosing our sensor subsystem and feedback subsystem in metal casings so that the batteries will be harder to access for our users. There are also dangers associated with our project due to both of our sensor subsystem PCB and feedback subsystem being rechargeable. If our NiMh batteries are overcharged it could cause heat damage or even high-pressure rupture to our batteries. [7] To combat this we plan to attach a buzzer to our device that sounds when the battery is fully charged, so that our user will know when to disconnect our PCBs from the charger. Our recharging module also has overcharging protection that will stop charging the batteries if they are fully charged. [8]

The final concern that we have is device failure. If our device is not functioning properly it could give our users wrong directions on where potential obstacles are located, which could cause them serious injury. To prevent this, we plan to put our device through intensive testing and make sure that it can operate reliably in many different scenarios. An additional protection that we have is that our product is not intended to be used on its own, but in conjunction with the cane. The cane will detect objects on the ground while our product focuses on obstacles that are at waist level, so if our device does fail our users will still be able to rely on their cane.

6. References

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