GLASSES FOR THE BLIND

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Abstract

Smart Glasses for the Blind is a supplemental mobility tool for visually impaired people and is used in conjunction with existing white canes. This device will provide users with additional information about the location of obstacles above the waist level that a walking cane normally would not detect, such as tree branches. The device also has a wearable armband that communicates with the glasses to provide haptic feedback to the user about the obstacles that are detected. This document outlines the results of this design project.

Contents

1. Introduction

1.1 Updated Problem Statement

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 is to mitigate accidents occurring outdoors due to unfamiliar obstacles at head level for blind people while providing an intuitive user experience. In particular, the target demographic is wealthy blind people who can afford technological devices to aid in their everyday lives.

1.2 Updated Solution

Currently, visually impaired people use mobility tools to get a better understanding of the world around them and avoid obstacles in their path. One such tool that is often used is the white cane. 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. Companies such as BAWA and WeWALK have developed technology-assisted white canes which are able to provide additional feedback for these potential hazards above waist level, and Team 18 in Spring 2019 created a project, OptiCane, which was a variation of these technological canes and used inbuilt LIDAR and a wearable 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.

Our team created a solution which focuses on providing information about obstructions in a user’s path in an intuitive manner and consists of two subsystems: a glasses sensor subsystem (sensor subsystem) which houses a 3D ultrasonic sensor and an armband haptic feedback subsystem (feedback subsystem). The sensor subsystem maps the space that the user is facing onto a 2D grid. Obstacles that are detected send a signal back for the specific grid space that they are located in. The glasses then use Bluetooth to communicate with the feedback subsystem. The feedback subsystem is made up of vibration motors in a grid which activate based on the data from the sensor subsystem to let users know within which grid block in front of them objects have been detected. This design fulfills the problems visually impaired people have by providing them with a more accurate and tangible picture of what obstructions lie in their path which serves to help mitigate potential accidents in their everyday lives.

Comparisons with OptiCane

The design outlined above is a fundamentally different solution from previously implemented devices such as OptiCane. First, instead of LIDAR, Smart Glasses for the Blind uses ultrasonic sensors. LIDAR does not work well at high sun angles and reflections since laser pulses depend on the principle of reflection. [5] 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]. [6] Our 3-D ultrasonic sensor has a FOV of 140 [degrees]. [7]

In addition, this design has a more streamlined, unintrusive feedback system. OptiCane used a wearable bracelet which would communicate information sent from the cane in the form of different patterns and intensities of vibrations. 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. [8] Due to this, our vibration design in the feedback subsystem 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.

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

Finally, the location of the sensor subsystem of this design is different from existing ones which improves upon the consistency of the device. When using a cane, blind users 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 as seen in Figure 1.

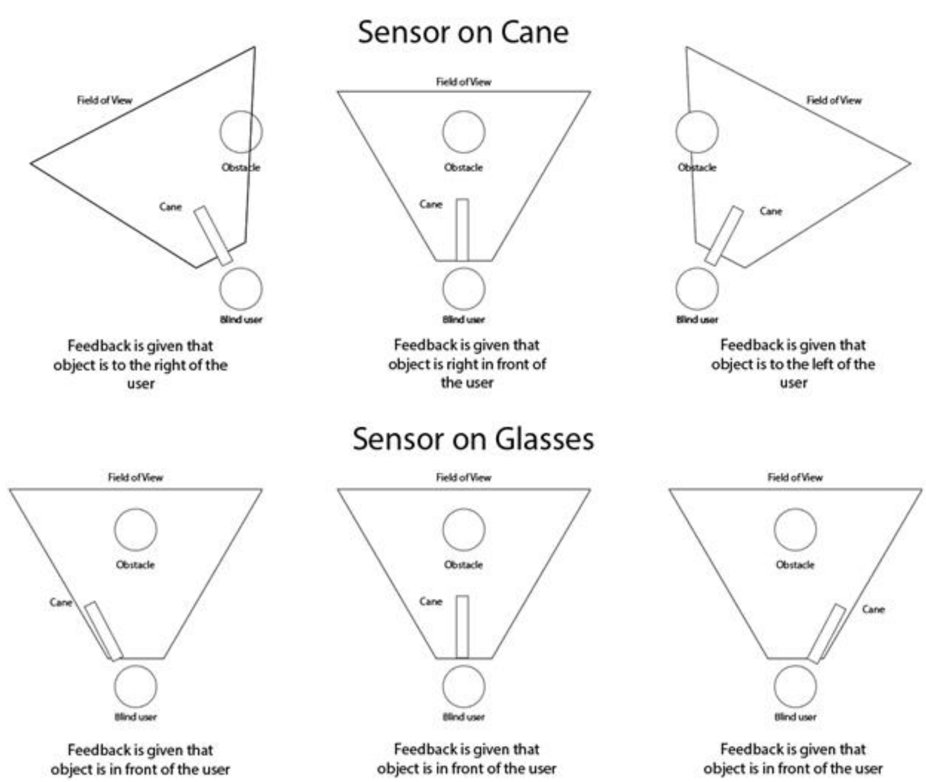


Figure 1: Feedback Based on Sensor and Obstacle Location

1.3 High-Level Requirements

- The sensor will be able to detect obstacles ± 25 [cm] of actual position when users are walking on sidewalks outdoors that appear within a 2x4 [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 grid-like 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]

1.4 Visual Aid

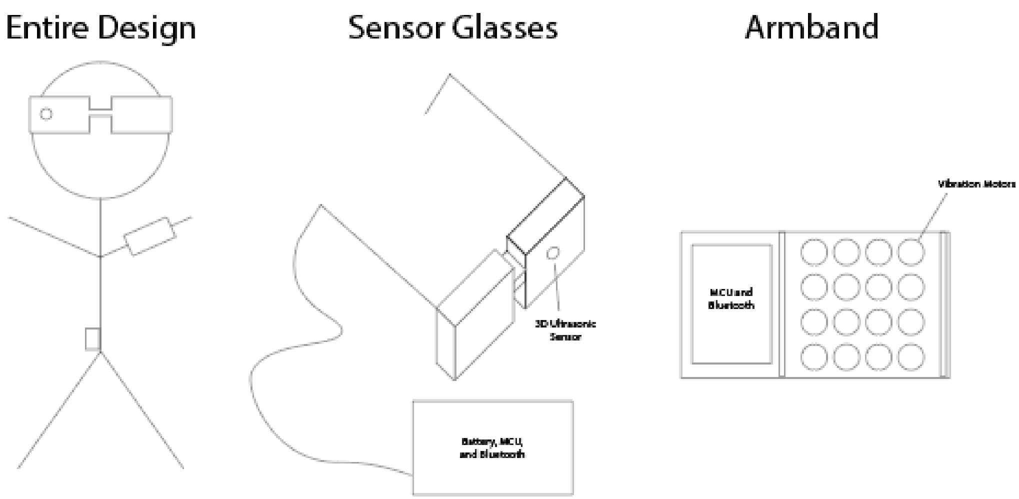


Figure 2: Visual Representation of the Glasses Subsystem and the Feedback Subsystem

This design consists of a sensor 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 feedback subsystem made up of 16 vibration motors to let the user know where obstructions are.

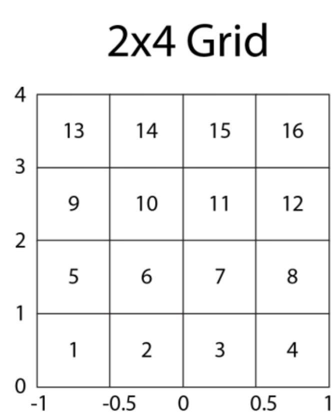


Figure 3: Reference 2x4 Grid

The grid is 2x4 [m] and the layout can be seen in Figure 3. The exact methodology will be discussed in the respective subsystems.

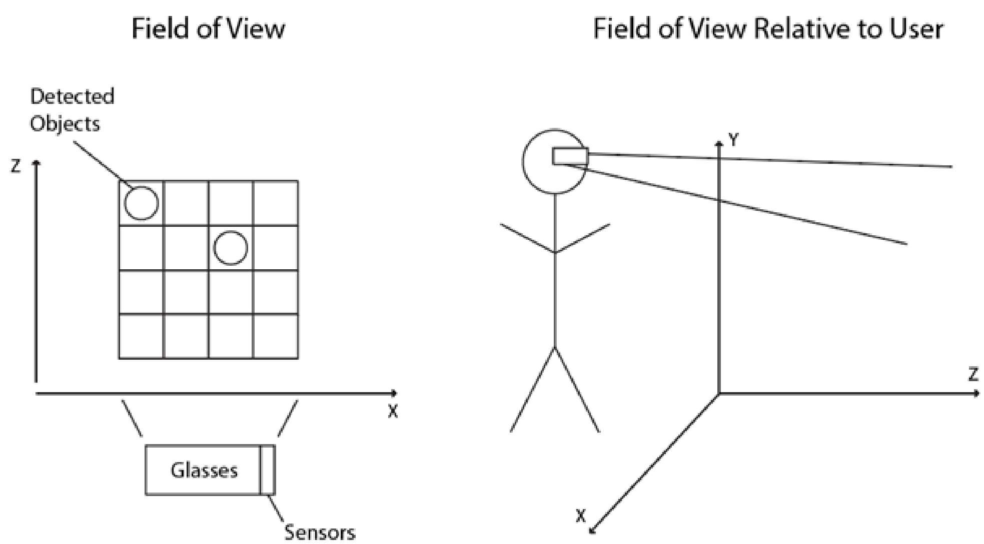


Figure 4: Detailed Visual Representation of the Glasses Subsystem

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 as seen in Figure 4. 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.

1.4 Block Diagram

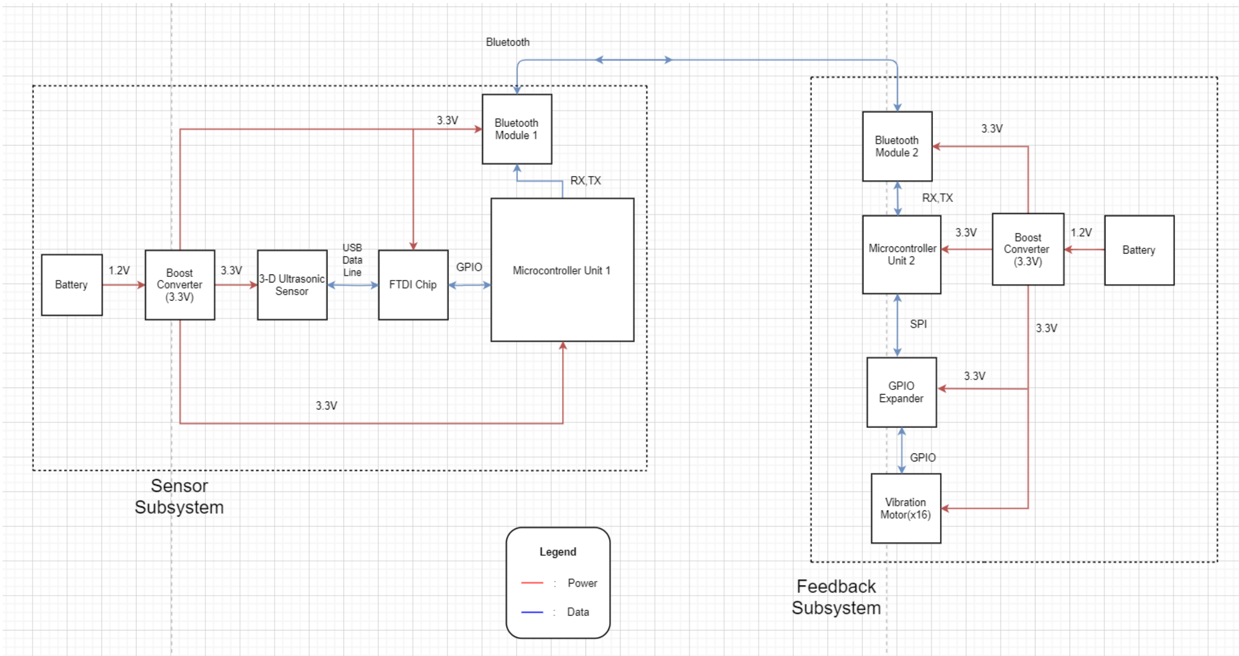


Figure 5: Block Diagram of Glasses for the Blind

The block diagram has 2 subsystems as seen in Figure 5. The first subsystem is the sensor subsystem which 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 the users determine where the obstacles are located.

2. Second Project Implementation

2.1 Implementation Details and Analysis

2.1.1 Power Calculations

We are using two AA rechargeable batteries to power each module, resulting in a total of four AA batteries. One AA battery has a power storage of 2500 [mAh]. Therefore, the total power for each module is 5000 [mAh].

$$Time[h] = \frac{TotalPower[mAh]}{PowerConsumption[mA]} \qquad Eq1$$

Sensor Subsystem

The components that consume power in this module are the microcontroller (ATmega328P), Bluetooth module (RYB080I_lite), FTDI chip (768-1007-1-ND), and 3D ultrasonic sensor (TS3 3D Ultrasonic Sensor). The microcontroller and the Bluetooth module consume 1.5 [mA]. The FTDI chip consumes 15 [mA]. The 3D ultrasonic sensor consumes 200 [mA].

The total power consumption is the sum of all the components' power consumption, which ends up being 218 [mA].

Using Eq 1, we get a time of 22.94 [h].

Feedback Subsystem

The components that consume power in this module are the microcontroller (ATmega328P), Bluetooth module (RYB080I_lite), GPIO Expander (MCP23S17), and vibration motors (ROB-08449-ND). The microcontroller and the Bluetooth module consume 1.5 [mA]. The GPIO Expander consumes 1 [µA]. The vibration motors each consumes 60 [mA]. We will calculate for an average of four vibration motors constantly running assuming normal sidewalk densities in suburbia. This will make the total power consumption of the motors to be 240 [mA].

The total power consumption is the sum of all the components' power consumption, which ends up being 243.001 [mA].

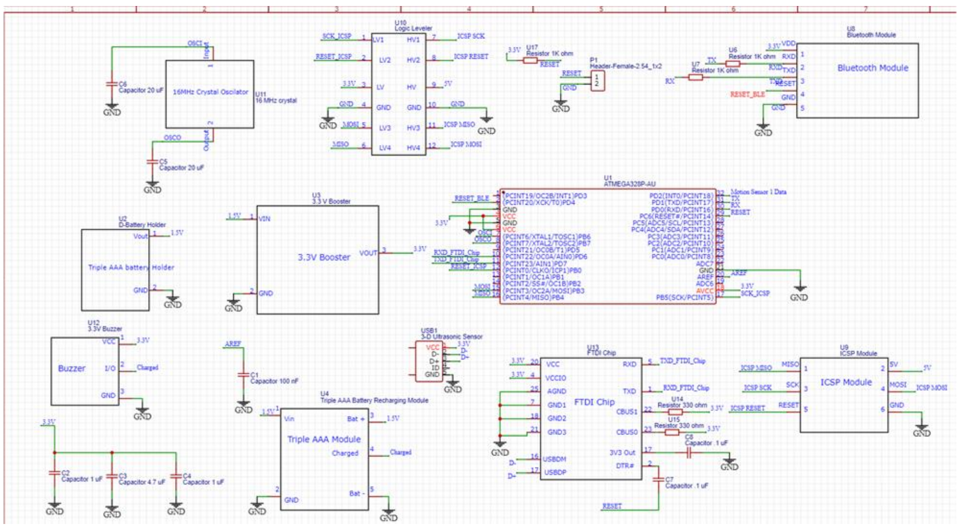
Using Eq 1, we get a time of 20.58 [h].

Conclusion

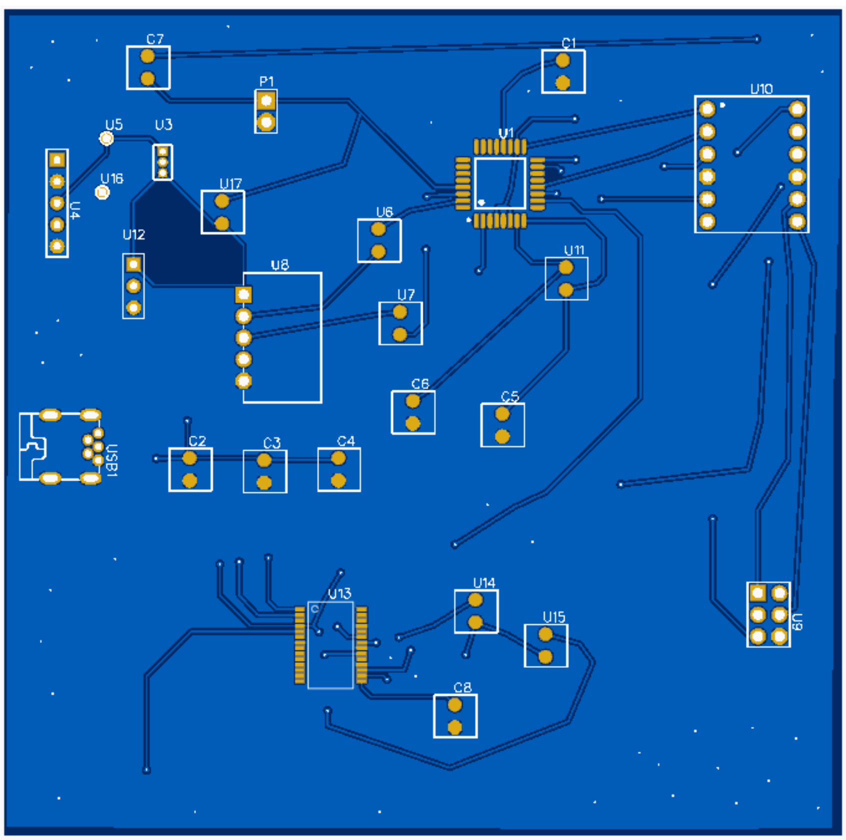
As seen in the previous two subsections, the sensor subsystem can last for around 23 hours and the feedback subsystem is able to last around 20 hours. As a result, we can see that both the sensor subsystem and the feedback subsystem are able to last at least 12 hours.

2.1.2 PCB Design

For implementation, we also completed all the schematics and PCBs for the sensor and feedback subsystems. Explanations for design choices are provided below.



(a) Schematic



(b) PCB

Figure 6: Sensor Subsystem Schematic (a) and PCB (b)

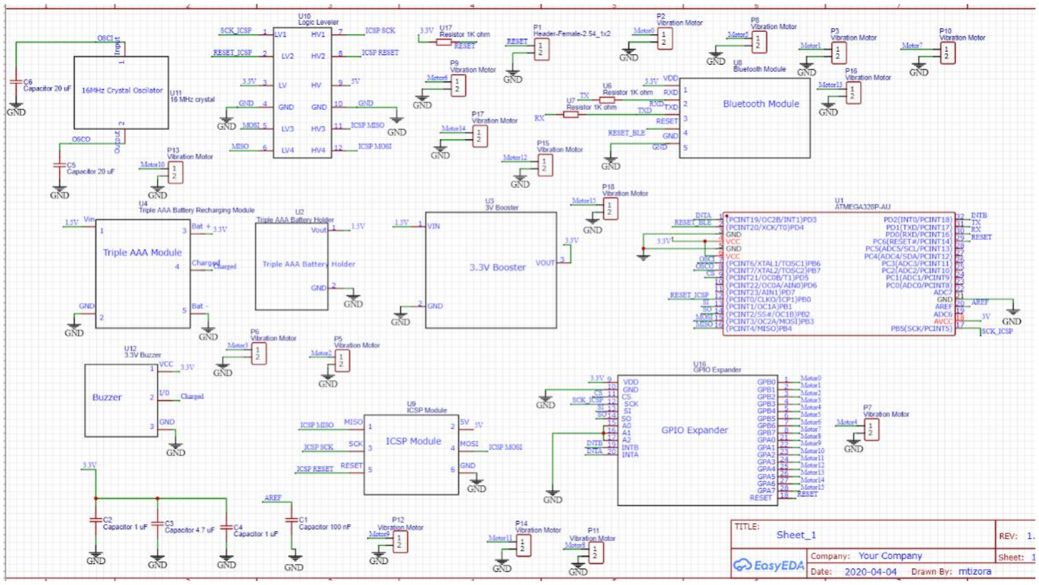
This is the sensor subsystem schematic, which is shown in Figure 6a. The schematic was done using EasyEDA. We used the sensor subsystem schematic to design the PCB, which is shown in Figure 6b. The dimensions of the sensor subsystem PCB are 98.68 x 96.52 [mm]. We used those dimensions for the PCB because we needed to make sure that we had a size less than 100 x 100 [mm] for the hip holder.

We used a two-layer PCB and flooded both the top and bottom layer with copper. We stitched the two planes together using vias to adequately ground the PCB. To program the MCU on the sensor subsystem PCB, we will use ICSP (In Circuit Serial Programming). The ICSP header (U9) is on the PCB. The ICSP flashes code to the microcontroller through SPI (Serial Peripheral Interface). The reason we went with this method to program the board is that we wanted less of a debug hassle versus using an USB to upload code to the microcontroller. The ICSP works at 5 [V] so we use a logic leveler (U10) to step down the voltage going into the microcontroller to 3.3 [V].

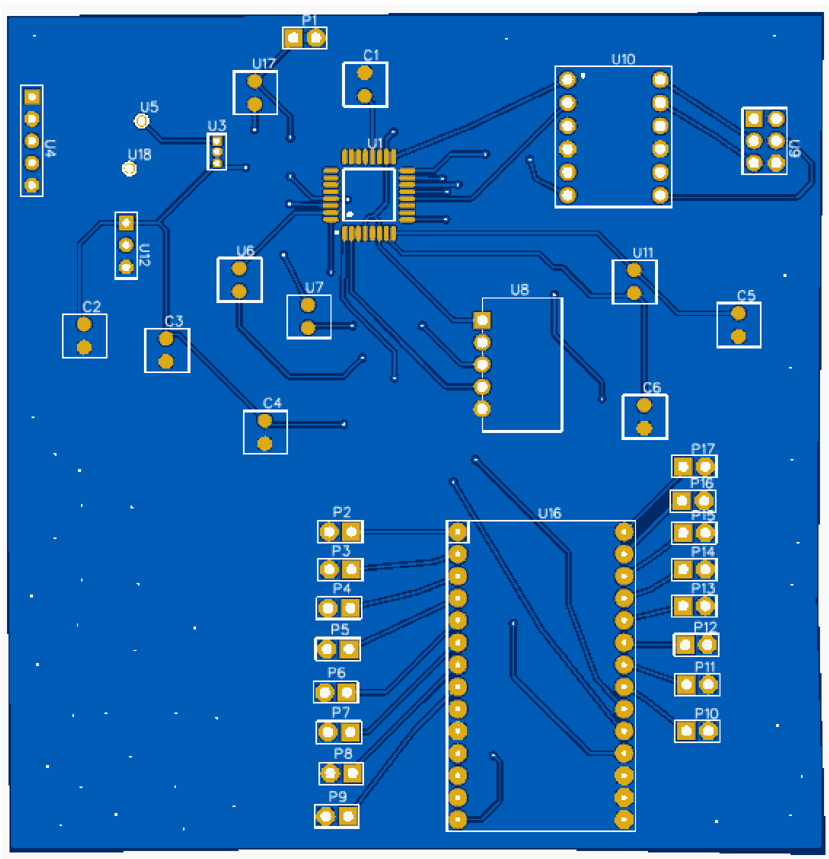
We placed the microcontroller (U1) in the upper middle of the board. The reason we placed it there is because a lot of the connections go through the microcontroller, so we wanted it to be more in the center. The USB on the sensor subsystem board is for the 3-D ultrasonic sensor. We placed it on the edge of the board because we wanted the USB to be easily accessible.

We connect the positive terminal of the AAA battery to test point U5 and the negative terminal of the AAA battery to test point U18. The boost converter (U3) is located right next to the battery. The reason it is placed there is because we wanted to step up the voltage coming directly from the battery to power the rest of the board. The charging module (U4) for the feedback subsystem PCB to the upper left side of the PCB. We put it there to make connecting the PCB to the charger easier for the users. From the charging module we connect the output line that goes high when the battery is fully charged to the buzzer (U12) on the PCB. We do not want the device to overcharge, and since the users cannot see we will use the buzzer to alert them when they can remove the sensor subsystem PCB from the charger.

To translate the USB signals from the 3-D ultrasonic sensor to serial inputs to the microcontroller we use an FTDI chip U13. We have a 16 [MHz] crystal (U11). This crystal sets the clock for the microcontroller. P1 is the Reset Header. If the two header pins are shorted together, the microcontroller will reset. We placed it at the top edge of the board because we wanted it to be easier for the users to access. We use Bluetooth to send location data to the feedback subsystem. The Bluetooth module (U8) is in the middle of the PCB. We wanted the Bluetooth module closer to the microcontroller which it shares many connections with.



(a) Schematic



(b) PCB

Figure 7: Feedback Subsystem Schematic (a) and PCB (b)

This is the feedback subsystem schematic, which is shown in Figure 7a. The schematic was done using EasyEDA. We used the feedback subsystem schematic to design the PCB, which is shown in Figure 7b. The dimensions of feedback subsystem PCB are 93.85 x 96.65 [mm]. We used those dimensions for the PCB because we needed to make sure that we had a size less than 100 x 100 [mm] for the armband.

We used a two-layer PCB and flooded both the top and bottom layer with copper. We stitched the two planes together using vias to adequately ground the PCB. To program the MCU on the feedback subsystem PCB, we will use ICSP (In Circuit Serial Programming). The ICSP header (U9) on the PCB. The ICSP uploads code to the microcontroller through SPI (Serial Peripheral Interface). The ICSP works at 5 [V] so we use a logic leveler (U10) to step down the voltage going into the microcontroller to 3.3 [V].

The reason we went with this method to program the board is that we wanted less of a debug hassle versus using an USB to upload code to the microcontroller. We placed the microcontroller (U1) in the upper middle of the board. The reason we placed it there is because a lot of the connections go through the microcontroller, so we wanted it to be more in the center. We placed the motors (P2-P-17) at the bottom of the board, so that we could wire them to the vibration motors on the armband.

We connect the positive terminal of the AAA battery to the connection point (U5) and the negative terminal of the AAA battery to the connection point (U18). The boost converter (U3) is located right next to the battery. The reason it is placed there is because we wanted to step up the voltage coming directly from the battery to power the rest of the board. The charging module (U4) for the feedback subsystem PCB to the upper left side of the PCB. We put it there to make connecting the PCB to the charger easier for the users. From the charging module we connect the output line that goes high when the battery is fully charged to the buzzer (U12) on the PCB. We do not want the device to overcharge, and since the users are blind, we will use the buzzer to alert them when they can remove the sensor subsystem PCB from the charger.

We have a 16 [MHz] crystal (U11). This crystal sets the clock for the microcontroller. P1 is the Reset Header. If the two header pins are shorted together, the microcontroller will reset. We placed it at the top edge of the board because we wanted it to be easier for the users to access. We use Bluetooth to receive location data from the sensor subsystem. The Bluetooth module (U8) is in the middle of the PCB. We wanted the Bluetooth module closer to the microcontroller which it shares many connections with.

2.1.3 Sensor Algorithm Design

The 3D ultrasonic sensor returns the coordinates of objects detected in its field of view which are then mapped to the grid. This grid data is then output by the sensor subsystem and sent to the feedback subsystem. We only wrote the pseudocode as the sensors had not arrived and the Bluetooth and Arduino modules used were left at our apartments on campus. The pseudocode detailing the procedure for this process is outlined below. However, for sampling and retrieving data from the Toposens sensor, we analyzed the GitHub documentation for the sensor. [9] In addition, for outlining the connection between the HC-05 Bluetooth units, a tutorial on Arduino and HC-05 provided by How to Mechatronics was followed with supplementary information of Bluetooth usage from a Bluetooth information guide provided by Sparkfun. [10][11]

Pseudocode

```
Create a 4x4 2D array called Data that stores the sensor subsystem output to the feedback subsystem
Initialize Data values to false
Read in output from Toposens 3D ultrasonic sensor
For each coordinate outputted by the sensor
        i = Mapped coordinate to its location in Data
        Data[i] = true
Send Data through Bluetooth to the feedback subsystem
For all i in Data
        If Data[i] is true
                Send positive signal to vibrate corresponding vibration motor
```

2.1.4 Future Modeling

As we do not have all the components for implementation, we have created a detailed test scenario for the actual devices. This test scenario will aim to gather data from the sensor subsystem that will be compared against the true data specified in the scenario.

All tests will be done both indoors and outdoors to determine the effects of different light conditions on the sensor subsystem's outputs in both controlled and uncontrolled light environments. For the outdoor tests, we will test over the course of a week at three different times each day: once in the morning, afternoon, and evening. We will use a light sensor module to measure the lumens outdoors for each time of testing. For the indoor tests, we will test in a room with controlled lighting and test at 3 different lumen levels commonly produced by artificial light: 400, 500, and 600 [lumens]. [12]

In addition, we will test for 1, 2, 3, 4, and 5 obstacles within the field of view at any given point in time. There will be 5 set configurations for each number of obstacles in which they are placed in the field of view that will serve as the standard for testing. For all tests, members of the project group will be wearing the device. The heights of group members will be recorded and referenced in the results.

Test 1

For a basic test, the sensor will be in a stationary position. This test will simulate a stationary position of the user and serve as a baseline for the device with the least number of variables. The true data distances from the test subjects will be compared with the sensor data output.

Test 2

This test will control for movement and simulate walking while using the device and will introduce an additional variable of velocity. For this test, we will control the velocity of test subjects to 2, 3, 4, and 5 [mph] as the walking speed of the average person is 3-4 [mph]. [13] The distances to the test subjects of objects will be calculated by accounting for the starting location of the test subjects, time, and given velocities. The true data calculated distances will be compared with the sensor data output.

Test Conclusions

The tests will provide a check to make sure that the sensor subsystem is performing within adequate tolerances which will be defined as within ± 25 [cm] of the true location as specified in the high-level requirements.

3. Second Project Conclusions

3.1 Implementation Summary

For the implementation phase, Makomborero was able to successfully create the schematics and PCB for both subsystems. This is key for future steps in completing the project as it will form the core of the device. In addition, Samuel did calculations for the lifespan of the device on one battery charge, and the system was found to far exceed the high-level requirement of lasting at least 12 hours. Finally, Cary completed the pseudocode for the software algorithm as well as an in-depth testing procedure which are necessary for ensuring the functionality of the device in meeting the goals for allowing visually impaired users avoid obstacles in their path.

3.2 Unknowns, Uncertainties, Testing Needed

A large part of development is currently unable to be completed due to the Covid-19 situation. The main problems faced in testing were the short notice in needing to implement the design as the 3D ultrasonic sensor and vibration motors were not able to arrive on time. As these are at the core of the design, we were unable to do rigorous testing on the components. However, the PCBs and schematics were all created, and calculations were done on the expected outputs from each of the subsystems. These calculations would need to be tested against with the actual components. The exact procedure for testing is outlined in Section 2.1.4.

3.3 Ethics and Safety

In terms of safety and ethics we have identified a few potential problems. The first one is moisture. The users of the 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 the 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. [14] In order to protect against moisture we plan to apply a PCB varnish on the board to protect against moisture. The second concern we have for the project is the location of the PCB. The device is a wearable so there is a possibility that the 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 the circuit will have adequate grounding. We also plan to add a metal casing to the PCB as additional ESD protection.

Another concern that we have with the project is the Bluetooth communication between the sensor subsystem and the feedback subsystem. Bluetooth communication is not very secure, and it is possible that someone with malicious intent could hack the Bluetooth device and give the users false information which could cause them injury. To ensure we follow ACM's General Ethics Principles we plan to make the Bluetooth network more secure. We will add a pairing between the 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. [15]

The 3rd concern that we have with the project is that we are using NiMh batteries which are hazardous materials. If the batteries are ingested, inhaled, or contact the user's skin or eyes it can cause harm to the users. [16] We plan to counter this by enclosing the sensor subsystem and feedback subsystem in metal casings so that the batteries will be harder to access for the users. There are also dangers associated with the project due to both the sensor subsystem PCB and feedback subsystem PCB being rechargeable. If the NiMh batteries are overcharged it could cause heat damage or even high-pressure rupture to the batteries. [16] To combat this we plan to attach a buzzer to the device that sounds when the battery is fully charged, so that the user will know when to disconnect the PCBs from the charger. The recharging module also has overcharging protection that will stop charging the batteries if they are fully charged. [17]

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

3.4 Project Improvements

With an additional year to complete the project, improvements regarding the comfort and usability of the design would be made.

3.4.1 Replace Vibration Motors with Pneumatic Actuators and Microfluidic Air Channels.

This was part of the original design. However, we decided that it was outside of the scope of this project due to time constraints. Companies developing haptic feedback gloves for virtual reality, such as HaptX, use pneumatic actuators and microfluidic air channels to produce highly realistic touch sensations. [18] Pneumatic actuators take up less space than vibration motors and can therefore be implemented in high density; as a result, the feedback subsystem would provide a higher resolution grid as an output and would give users a better sense of obstacles in their path. In addition, pneumatic actuators would be applying a constant force, which is less distracting than the constant vibration of the vibration motors.

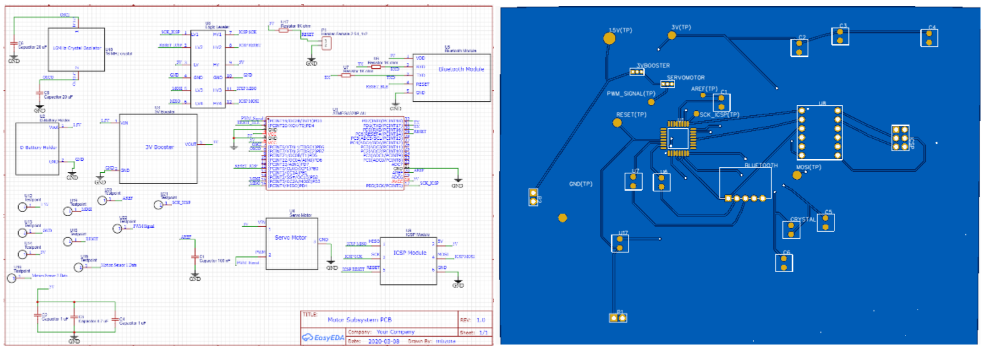
3.4.2 Refine the Algorithm for Sensor Outputs

With the implementation of pneumatic actuators, we could refine the algorithm for reading feedback from the sensor subsystem. Currently, the output from the sensor subsystem is a 4x4 grid that provides estimations of the location of the object. However, the estimations are not pinpoint. The current algorithm is also unable to take into full account the range of accuracy of the sensor. It is partly dependent on the user interpreting the results and knowing that the object might be on the edge of one of the blocks detected. With the pneumatic actuators, we could provide a more accurate and precise picture, so the user would not have to worry that the object is not in the block. it is said to be in. Instead of returning a rough estimate of the location of the object, we can include the range of accuracy so that the device will return the entire zone of where the object could possibly be in.

3.4.3 Adjust Weights of Glasses to be More Balanced and Comfortable for the User

In the current design, there was no focus placed on the balance of the sensor unit on the user’s head, because the main goal was prototyping a solution that will effectively detect obstacles in the path of visually impaired users. However, with more time, we believe the comfort of the headset to be an important aspect. We would do calculations for the total weight of the sensor subsystem and how to better distribute it to rest on a user’s head more comfortably.

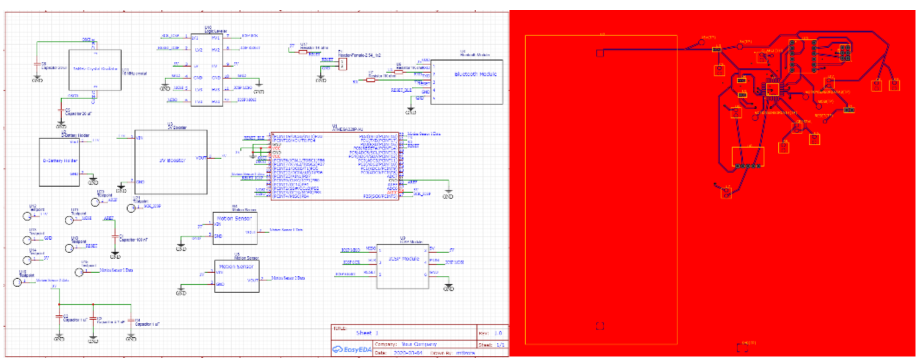
4. Progress Made on First Project



(a) Schematic (b) PCB

Figure 8: First Project Motor Subsystem Schematic (a) and PCB (b)

This is the First Project Motor Subsystem (FPMS) schematic, which is shown in Figure 8a. The schematic was done using EasyEDA. We used the FPMS schematic to design the PCB, which is shown in Figure 8b. The dimensions of the FPMS PCB are 97.9 x 98.32 [mm]. We chose these dimensions because we needed the PCB to be less than 100 x 100 [mm]. We programmed the board using ICSP and we used a logic leveler to step down the 5 [V] coming from the ICSP to 3 [V] that the microcontroller runs on. We use a 16 [MHz] crystal to set the clock for the microcontroller. The light switch motor data connects to the microcontroller through a GPIO pin. We controlled the direction the motor rotates to flip the switch using Pulse Width Modulation (PWM). The Bluetooth module on the FPMS receives information from the First Project Sensor Subsystem, which indicates when the FPMS needs to rotate the motors that control the light switch.



(a) Schematic (b) PCB

Figure 9: First Project Sensor Subsystem Schematic (a) and PCB (b)

This is the First Project Sensor Subsystem (FPSS) schematic, which is shown in Figure 8a. The schematic was done using EasyEDA. We used the FPSS schematic to design the PCB, which is shown in Figure 8b. The dimensions of the FPSS PCB are 94.3 x 99.5 [mm]. We chose the dimensions because we needed the PCB to be less than 100 x 100 [mm] for the design. We program the board using ICSP and we use a logic leveler to step down the 5 [V] coming from the ICSP to 3 [V] that the microcontroller runs on. We use a 16 [MHz] crystal to set the clock for the microcontroller. The motion sensor data connects to the microcontroller through a GPIO pin that goes high when motion has been detected. The Bluetooth module on the FPSS communicates with both the phone application and the First Project Motor Subsystem.

5. References

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