Design Document

ECE 198 - Computer Engineering

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1.0 Introduction

1.1 Geographic Attributes

Manitoba experiences extreme winter conditions, which includes heavy snowfall, icy roads, and freezing temperatures. Navigating through these conditions can be especially difficult for the visually impaired without considering the lack of accessibility options. Due to poor accessibility and infrastructure in Manitoba, there exist fewer sidewalks, public transportation and other ways of getting around safely, especially for those who live in rural communities. These issues become so severe that those with similar issues as the visually impaired report being thrown off their wheelchairs and unable to go outside during the winter conditions [1].

1.2 Demographic Attributes

There is no specific demographic when discussing visually impaired people in Manitoba. However, the leading cause of visual impairment in Canada is a result of older age, socioeconomic status, geographic location, smoking, diabetes and other health issues [2].

1.3 Economic Attributes

Blind people face many economic challenges, such as lower income, limited employment opportunities, the cost of assistive devices, and transportation costs. As aforementioned, one of the most common traits associated with blind people is lower socioeconomic status [2]. This results from the limited job opportunities for the visually impaired and the high cost of assistive devices and transportation. A study observed an average of 11% decrease in workforce participation for those with mild and up to a 50% decrease for those with severe visual impairment. [3]. As a result, it becomes more difficult for the visually impaired to afford assistive devices and transportation costs.

1.4 Competitive Landscape

1.41 Service Dogs

Service dogs aid the visually impaired with mobility by guiding the owner around obstacles, being able to navigate busy streets, and can adapt to different environments and settings. They are trained in such a way that they are able to respond to commands and use their senses to alert and protect the owner from any dangers. However, there are shortcomings of service dogs, such as limitations due to lifespan and aging, leading to the retirement of the service dog and a replacement. Another shortcoming is the high initial cost due to the extensive training required and financial constraints from caring for the dog. Additionally, service dogs face many social barriers in public spaces due to a lack of understanding of the public, which is detrimental to the job of the service dog. [4]

1.42 White Canes

White canes are the most common assistive mobility device for the visually impaired as it provides tactile feedback. The tactile feedback allows visually impaired people to detect potential hazards and objects obstructing their path. The length of the cane allows for visually impaired people to be able to detect a wide range of surfaces and areas, making navigating much easier and safer for them. However, white canes do not provide much information and detail of the environment, and their effectiveness decreases in complex environments. Due to the length and space needed for those who use a white cane, it fails to work effectively with more obstacles and people around them. Additionally, the white cane cannot detect any hanging obstacles, causing a higher collision rate of 79% compared to other mobility aids. [5]

1.43 Electronic Mobility Pointers

Electronic mobility pointers assist visually impaired people by using technology and sensors to detect obstacles. Mobility pointers are lightweight and compact, allowing users to send a signal with the pointer and receive tactile or auditory feedback. These devices either use cameras or sensors to interpret their surroundings and aid visually impaired people in navigating their surroundings and obstacles up to 10 feet away. However, mobility pointers suffer problems from short battery life, high initial cost, and a training curve. These mobility pointers are advertised as small, lightweight and portable mobility guides that will easily aid the visually impaired in navigating complex surroundings. Nevertheless, due to its small design, the battery life is much shorter and comes at a higher cost ranging from $300-$3000. Additionally, studies show that it takes visually impaired people much longer to get comfortable with using mobility pointers compared to regular mobility aids [6].

1.5 Technical Requirements

1.51 Appropriate Volume Range

- The device must emit a warning sound when an object is detected, with a sound level ranging from a minimum of 65 decibels to a maximum of 80 decibels [4], and this sound will be generated by a small buzzer.

1.52 User Size Adjustability

- The device must be designed for attachment to the user's chest and must feature an adjustable mechanism to accommodate chest circumferences within the range of 75 cm to 130 cm [7].

1.53 Distinct Volume to Proximity

- The buzzer's volume should vary based on the user's distance from the detected object, ranging from 65 decibels at the minimum distance to 80 decibels when the object is closest [8].

1.54 User Comfortability

- The device must be comfortable for short-term and long-term wear, with a weight similar to current wearable health monitoring technology (30-60g) and dimensions not exceeding 12 cm by 12 cm (excluding the wearing mechanism) [9] [10].

1.55 Minimum Detection Distance

- The device's IR module must detect objects at a minimum distance of 0.8 meter, considering the average auditory reaction time (140-160 milliseconds) [11] and the average human walking speed (0.94 m/s to 1.34 m/s) [12].

1.56 Detection Rate

- The device must alert the user immediately upon detecting an object, with the buzzer sounding for at least 200 milliseconds (equivalent to the auditory reaction time) and continuing for the same duration even after the object is no longer obstructing the user's path.

1.57 Time Taken to Alert User

- The device needs to detect and alert the user within a range that allows them approximately 0.8 meters to respond to the object (0.60 to 0.85 seconds), considering the average walking speed and auditory reaction time and the STM32 MCU's processing speed of 84 MHz [13].

1.58 Material Makeup

- To ensure comfort, the material makeup of the wearing mechanism must align with standards in wearable health technologies, featuring air permeability, overall comfort/cushioning, and skin-friendly frictional properties. The material should support a heat flux from the body to the environment within the range of 90-120 W/m^2 [13], and a suitable material mix such as nylon/polyester will be employed to meet these criteria.

1.6 Safety Requirements

1.61 Power Consumption

- The device's design must not exceed power consumption of 30 Watts at any point during operation, encompassing all forms of energy usage.

1.62 Energy Capacitance

- The design must not store more than 500 millijoules (mJ) of energy at any given time, which includes all forms of energy.

2.0 Analysis

2.1 Design Documentation

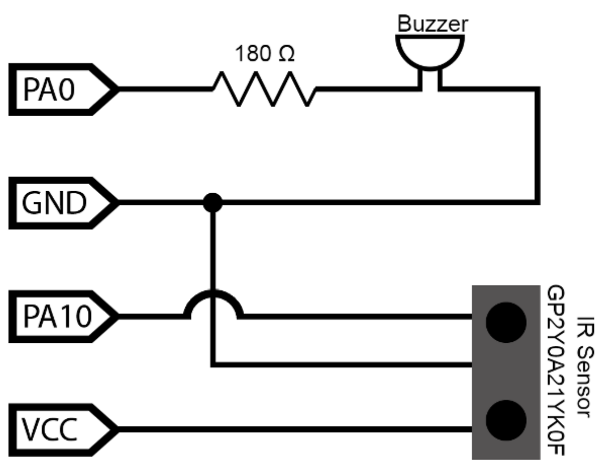
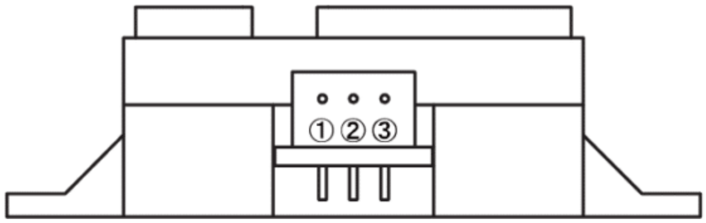


Fig. 1. Proximity Detector Circuit Diagram.



Connector signal

	signal name
①	Vo
②	GND
③	Vcc

Fig. 2. GP2Y0A21YK0F Connector Signals.

The GP2Y0A21YK0F sensor consists of an IR emitter and an IR receiver. The emitter emits an infrared signal, typically an infrared light beam, which is invisible to the human eye. When the sensing device receives an input, it will output a max of 3.3V. The sensor will be connected as a GPIO output on PA10 as seen in Fig. 1 and Fig. 3.

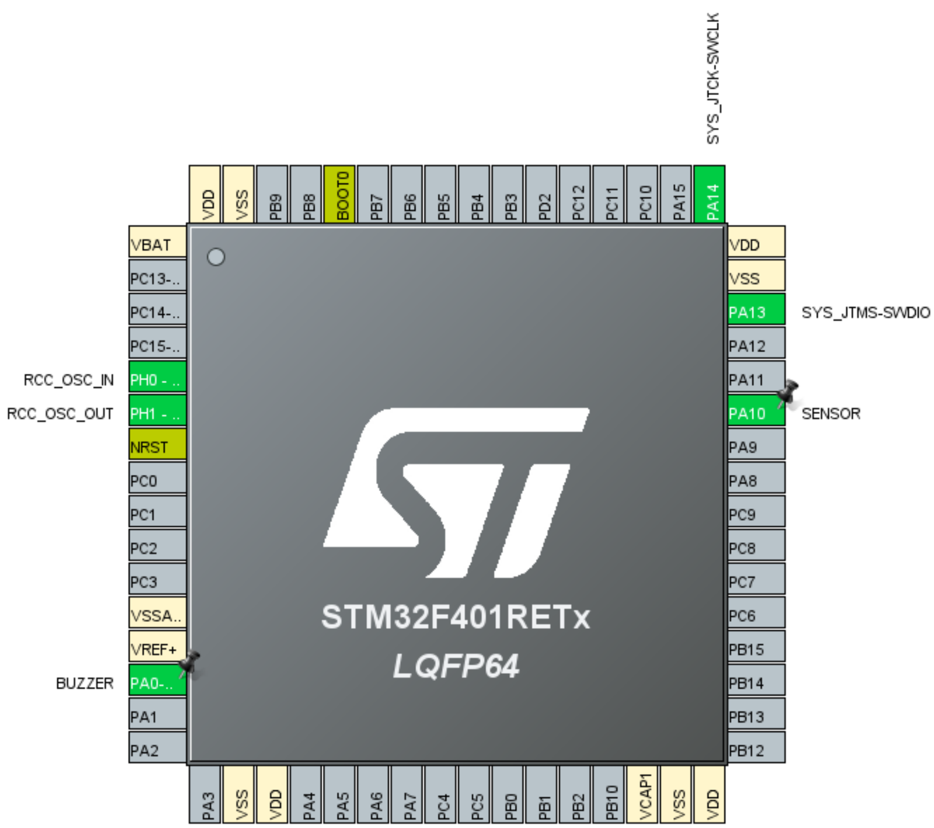


Fig. 3. STM32F401RETx Pins.

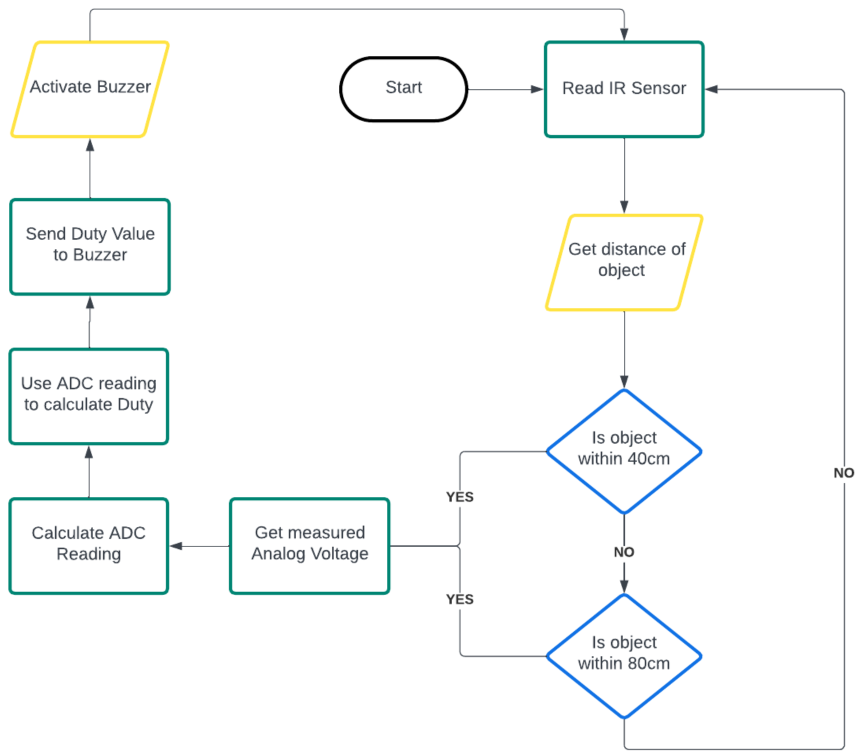


Fig. 4. Flowchart of the coding process of the proximity detector.

2.2 Scientific and Mathematical Principles

2.21 Signal Strength Calculation

- The first technical calculation of our design involves calculating the signal strength of our IR. This will then be used to generate a noise of appropriate volume depending on the user's distance from the object. As stated in our principles, the IR sensor we will use will return an analog voltage to its output, which we can then convert to a digital signal using an ADC (analog to digital convertor). The analog voltage output of the IR sensor changes depending on which IR sensor we use for the final design. For a typical IR sensor with a range of 10 - 80 cm (**GP2Y0A21YK0F IR Sensor),** the IR sensor will output 3V when an object is 10 cm away and 0.4V when the object is 80 cm away. To change this to a digital signal, we will use the following formula [14].

$$\frac{Resolution\ of\ the\ ADC}{System\ Voltage} = \frac{ADC\ Reading}{Analog\ Voltage\ Measured}$$

We will be using a 10 bit ADC for our design so the resolution of the ADC will be **1023 [14]**, and the system voltage of the STM32F401RE Nucleo Board is 3.3V [15].

Ex: Object that is 40cm away:

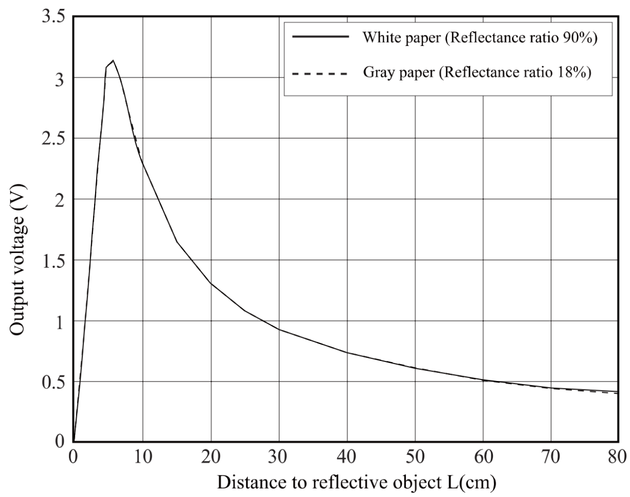


Fig. 4. Output voltage of sensor with respect to the object's distance [16].

$$\frac{1023}{3.3V} = \frac{ADC\ Reading}{0.8V}$$

$$ADC\ Reading = \frac{1023}{3.3V} * 0.8V$$

$$ADC\ Reading = 248$$

This value is representative of the average signal strength of the IR sensor and varies depending on the reflective surface.

2.22 Duty Calculation

- The second technical calculation of our design involves using the signal reading from the IR sensor to generate a duty value that we will pass into the piezo buzzer to generate a noise that varies depending on the object's distance to the user. (Closest = loudest noise, and so on). To do this, we will normalize the values of our digital signal from 0 and 1

[17], and convert those to a duty between 1 and 254. Using the previous example and formula [18]:

$$Duty = \frac{ADC\ Reading - Min}{Max - Min} * 254$$

$$Duty = \frac{248 - 128}{930 - 128} * 254$$

$$Duty = 39$$

128 is the minimum value that our ADC can return as obtained by the formula in Ex 1 (setting analog voltage measured to 0.4V) and 930 is the maximum value (setting analog voltage measured to 3V)

2.23 Ohm's Law

- It is necessary to select the correct resistance for our buzzer using Ohm's Law, which states that $V = IR$, where V is the voltage measured in volts (V), I is the current measured in amps (A), and R is resistance measured in ohms (Ω) [19]. This is essential for this project as it will clamp any positive-going voltage and correct the diode to clamp any negative-going voltage. This equation will be used for the resistor and for finding the proper diode. This principle is crucial to our project as it will ensure that no excess voltage is transferred to the MCU or other components from the system and to the user, as the buzzer will be a piezo buzzer.

3.0 Cost

3.1 Manufacturing Costs

Item	Quantity	Manufacturers (Company, Location)	Distributors (Distributor, Location)	Cost ($)
SHARP GP2Y0A710K0F IR distance sensor	1	SHARP (Japan)	Amazon (Canada)	13.99
STM32F401RE microcontroller	1	STMicroelectronics (Italy & France)	UWaterloo Store (Kitchener, Waterloo)	34.99

Assorted M/M Jumper Wires	10	DigiKey (United States)	RigidWare Waterloo (Kitchener, Waterloo)	1.50
100Ω Resistor	1	DigiKey (United States)	RigidWare Waterloo (Kitchener, Waterloo)	0.10
400 Point Breadboard	1	DigiKey (United States)	RigidWare Waterloo (Kitchener, Waterloo)	3.30
Buzzer	1	DigiKey (United States)	RigidWare Waterloo (Kitchener, Waterloo)	1.85
100cm of 4 Inch Wide Elastic Fabric	1	CISONE (United States)	Amazon (Canada)	20.96
Gorilla Super Glue Liquid	1	The Gorilla Glue Company (United States)	Amazon (Canada)	9.89

Total Cost ($): 86.58

3.2 Installation Guide

Wiring the Components

1. Place STM32F401RE microcontroller into the middle of the breadboard, wiring a **black wire to GND,** and a **red wire to 5V power supply**
2. Wire the GP2Y0A710K0F sensor, connecting the **yellow wire to PA10** on the STM32F401RE microcontroller, the black wire to GND, and the **red wire to 5V**
3. Wire the buzzer with the 100Ω resistor, connecting it to **PA0** and **GND**

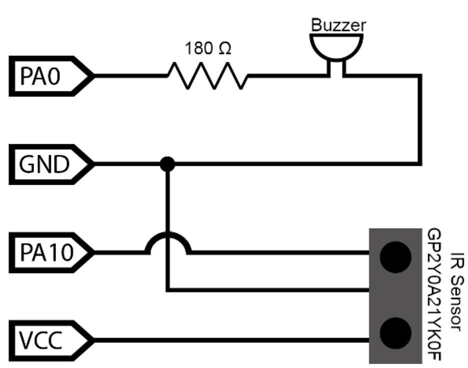


Fig. 1. Proximity Detector Circuit Diagram.

Coding the functionality

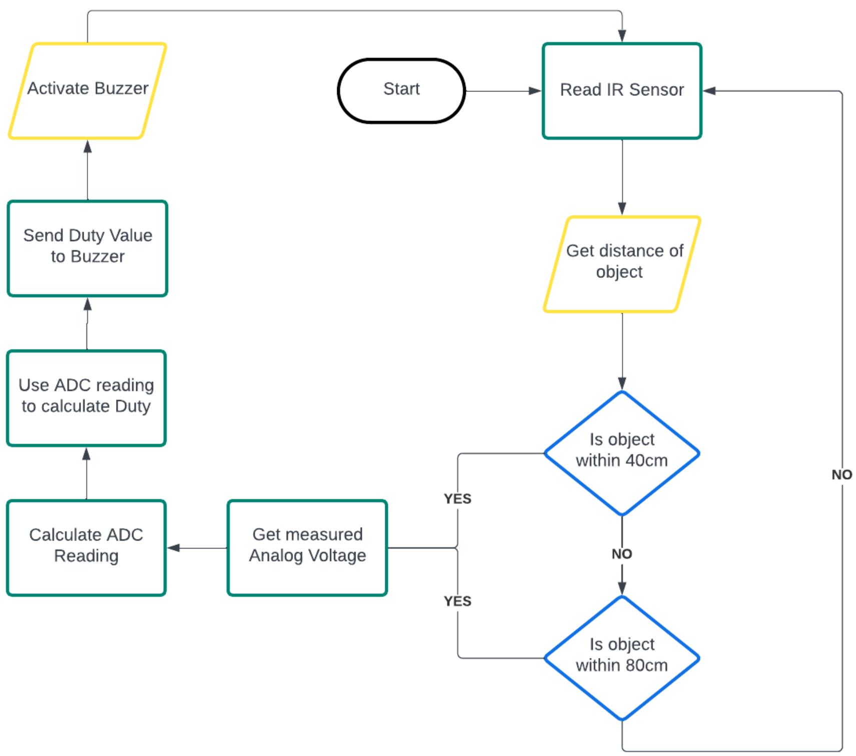


Fig. 4. Flowchart of the coding process of the proximity detector.

3.3 User Manual

Getting Started:

1. Putting on Device
    a. Secure the device around chest level
    b. Ensure the device fits well and does not slide, adjustments may be required to fit the user
2. Powering On
    a. Power the device with 5V using a bench supply
    b. The system will start initializing, indicated by the LED status when complete

Proximity Detection:

1. Detecting Obstacles
    a. Upon starting the device, the proximity detector will sense obstacles

    b. The proximity detector will detect obstacles from 10-80cm away
2. Determining Distance of Object
    a. The buzzer will start beeping louder as you get closer to an obstacle, reaching its maximum loudness when the obstacle is 40cm away

Turning Off:

1. Turn the power on the bench supply to 0V
2. Press the off button on the MCU to turn off the board
3. Remove the device from the chest

Safety Precautions:

1. Caution
    a. Avoid direct contact with the sensors and MCU to prevent damage to the components
    b. Keep the device away from water or extreme environmental conditions to minimize malfunctions

Troubleshooting:

1. Hardware Issues
    a. Ensure all power connections are secure and the power source is functioning
    b. Verify that the MCU is correctly connected and all wires are connected to the right pins (refer to the installation guide for pins)
2. Component Malfunctions
    a. Power off the system, waiting 30 seconds before turning the system on again
    b. If the problem persists, refer to the installation manual of the MCU for any potential programming or hardware issues

4.0 Risks

4.1 Energy Analysis

According to our safety requirements:

- The device's design must not exceed power consumption of **30 Watts** at any point during operation, encompassing all forms of energy usage.

- The design must not store more than **500 millijoules (mJ)** of energy at any given time, which includes all forms of energy.

4.11 Power Consumption

The STM32F401RET has baseline input voltage levels of **4.75 - 5.25V** when powered through an external power source and has a maximum allowed current of **500 mA** into the board through CN7 pin 6. Therefore, in the worst-case scenario, the MCU will draw a current of 500 mA at 5.25V [20], resulting in total power consumption of

$$W = VI$$

$$= (5.25\ \text{V})(0.5\ \text{A})$$

$$= \mathbf{2.625\ Watts\ at\ maximum\ load}$$

Through this analysis, we can see that the design meets the first safety requirement.

4.12 Energy Storage

The STM32F401RET has two main capacitors, E106 and C106, each with a capacitance of 10 µF (Microfarads) [20]. In addition, the PCB also has many other small capacitors in the 1-10 pF (Picofarads) range which are negligible in calculating the total energy storage of the design. To calculate the total energy stored in the design, we add up the total energy that can potentially be stored in each capacitor, with the formula [21]:

$$E = 0.5CV^2$$

Where E is the energy (Joules), C is the capacitance (Farads), and V is the voltage (Volts)

Let E = the energy stored in E106 and C106. The operating voltage of the STM32F401RET is 3.6V [20], and 10 µF is equal to 0.00001 F, So:

$$E = 2[0.5(0.00001)(3.6)^2]$$

$$= 0.0001296\ \text{J} = \mathbf{0.1296\ mJ}$$

Other forms of energy (mechanical or chemical) are not stored in our design and we only rely on the voltage regulation and capacitors on the PCB. Therefore we also meet the second safety requirement as we only store a total of 0.13 mJ of energy during operation.

4.2 Risk Analysis

To analyze the general risk from operating our device, we will consider the following conditions: using the design as intended, using the design incorrectly, not the design as intended, or the design malfunctioning

4.21 Operational Risk

Use of design	Intended	Not Intended	Incorrect
Safety	Becoming reliant on the device could cause safety issues with ground level objects. Although our design is for a demographic living in an area with flat terrain, it is possible for the terrain to have potholes, objects on the ground, etc.	Misusing the design intentionally, for example, modifying the IR sensor's beam component to output a higher wattage, laser, could be used to assault individuals (causing blindness or visual damage). Taking apart the device and modifying it could trigger a short circuit from the piezo buzzer if the resistors are altered. As a result, the device would stop working, and if used by the expected user, they could collide with objects.	Not turning the device on or wearing the device incorrectly would consequently cause the user to collide with objects
Environment	N/A	Misusing the design intentionally, for example, modifying the IR sensor's beam component to output	Not wearing the device incorrectly could cause the device to fall off, since our users are

		a higher wattage laser, could cause fires if the device is pointed at trees, grass, etc.	visually impaired, they might not notice this. As a result, the device would end up as litter in the environment and the various components (wires, fabrics, MCU) could cause damage to the environment

4.22 Design Malfunctions

Malfunction	**Consequence**
The IR Sensor malfunctions and does not detect an object	The user would collide with the object in front of them, suffering physical damage
The piezo buzzer does not go off, despite a detection	Since the user is visually impaired, they would not know there is an object infront of them and collide with it
The piezo buzzer goes off but does not stop when the object is no longer in front of the sensor	The user would not know where to go and would become increasingly disoriented, possibly causing themself injury when trying to move out of the way of the “object”

5.0 Testing and Validation

In the Needs Assessment section, we list the 5 following testable requirements for our design (although the other ones are testable, they require human testing).

5.1 Appropriate Volume Range

The device must emit a warning sound when an object is detected, with a sound level ranging from a minimum of 65 decibels to a maximum of 80 decibels [8], and this sound will be generated by a small buzzer.

5.2 Distinct Volume to Proximity

The buzzer's volume should vary based on the user's distance from the detected object, ranging from 65 decibels at the minimum distance to 80 decibels when the object is closest [8].

5.3 Minimum Detection Distance

The device's IR module must detect objects at a minimum distance of 0.8 meters, considering the average auditory reaction time (140-160 milliseconds) [11] and the average human walking speed (0.94 m/s to 1.34 m/s) [12].

5.4 Detection Rate

The device must alert the user immediately upon detecting an object, with the buzzer sounding for at least 200 milliseconds (equivalent to the auditory reaction time) and continue until the object no longer obstructs the user's path.

5.5 User Comfortability

The device must be comfortable for short-term and long-term wear, with a weight similar to current wearable health monitoring technology (30-60g) and dimensions not exceeding 12 cm by 12 cm (excluding the wearing mechanism) [9] [10].

Test Criteria	**Test Setup**	**Env Parameters**	**Test Inputs**	**Measurement Std**	**Pass Criteria**
Req 1. **Volume Range**	- Isolate the buzzer from the rest of the design to ensure that volume is not influenced by other components	- Ensure that there is minimal to no background noise before the test	- Provide a varying voltage to our buzzer that is inline with what is returned by the IR sensor	- The readings will be tested against audio that is at a standard volume (phone with a max DB speaker of 80 DB) - Audio recording software will be used to measure the	If the buzzer can successfully emit a sound that is at a minimum 65 DB and maximum 80 DB, then the test is passed, or else it is failed

				decibel output of the buzzer	
Req 2. **Varying Volume**	- The entire design must be used to test this requirement -Place an object with a high level of IR reflectiveness in front of the design -Set up various measurement markings beforehand in order to analyze the volume in relation to the distance from the object	- Ensure there is a minimal number of other reflective items in the direction of the sensor - Ensure that the object is at room temperature so that IR readings are not higher than what they are supposed to be	- Move the design to the different measurement markings in front of the object, starting at the closest distance, recording the volume of the buzzer at each distance	-The distance will be pre-measured by a measuring tape - The readings will be tested against audio that is at a standard volume (phone with a max DB speaker of 80 DB)	If the buzzer emits 80 DB at the closest range, and 65 DB at the farthest range, while continuously decreasing in volume at each distance after the initial, then the test is passed, or else it is failed.
Req 3. **Detection Range**	-Isolate the IR sensor from the rest of the components to ensure no other interference -Place an object 0.9 m away from the device and put measurement markings in 0.1 m	- Ensure there is a minimal number of other reflective items in the direction of the sensor - Ensure that the object is at room temperature so that IR readings are not higher than what	Start the with the device 0.9 m away from the object, moving it closer and closer until it reaches the 0.8 m threshold	-The distance will be pre-measured by a measuring tape -The distance will be recorded by multiple observers to ensure accurate readings	If the buzzer emits a noise as soon as the device reaches a distance of 0.8 m away from the object, the test is passed, or else it is failed.

	increments towards the device. These will be used to find the actual max distance if the test fails (for debugging)	they are supposed to be			
Req 4 **Alert time**	- The entire design must be used to test this requirement -Place an object with a high level of IR reflectiveness in front of the design -Set up a measurement marking of 0.9 m and 0.8 m from the device to the object	- Ensure there is a minimal number of other reflective items in the direction of the sensor - Ensure that the object is at room temperature so that IR readings are not higher than what they are supposed to be -Ensure that the room has minimal to no background noise	Start with the device 0.9 m away from the object, moving it closer and closer until 0.8 m where the buzzer emits a noise. Afterward, leave the device in front of the object for at least 1 second before moving it out of the way	The time it takes for the buzzer to emit a sound will be recorded using audio software that will be continuously recording right when the test starts up until when the test finishes. We can measure the time it takes for the buzzer to go off by analyzing the peaks in volume recorded by the software. The same strategy will be used for testing whether the buzzer goes off for at least 200 ms	If the buzzer emits a noise within 100 ms of the object being detected and continuously emits this noise until the object is moved out of the way, the test is passed, or else it is failed
Req 5.	The entire device, along	-Ensure that the room is	-Place the entire device	The housing compartment	If the entirety of

Comfort	with its housing and attachment method, must be used for this test.	not humid (moisture could expand the fabric)	onto a weight scale to measure the total weight of the device -Measure the housing compartment of the device with a measuring tape	will be measured with a measuring tape and the device's weight will be measured by a scale with 2 decimal digits of precision	the device weighs between 30-60g and the housing compartmen t measures 12 cm x 12 cm in width and length, then the test is passed, else it is failed

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