Design Document

ECE 198

Fall 2024

Section 3

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Needs

Customer Definition:

Severe vision impairment hinders daily life for most suffering from it. A survey conducted by Statistics Canada found that almost 3% of Canadians aged 15 years and older [1] (~750,000 people) reported having a seeing disability that limited their daily activities. According to the data from the 2012 Canadian Survey on Disability (CSD), 5.8% of the people in this group (~43,500 people) reported legal blindness [1]. According to the Eye Physicians and Surgeons of Ontario, if a visual impairment limits vision to 20/200 (one-tenth of normal vision), then the person is considered legally blind [2]. This does not mean that they are completely blind, but their lack of clear vision certainly has an impact on their life. Living with this condition makes many day to day tasks like reading, writing, and navigation more difficult or downright impossible without external assistance or devices, this problem is amplified immensely for people residing in large cities as people and potential obstacles are way more densely packed than a rural setting. Currently, we mainly rely on the white cane to assist the blind with navigation. However, the traditional cane comes with the downside of being limited by its physical length. Typically, the longest cane length someone uses is 4 inches less than their height [3]. This means that using the average height of an adult male, their longest cane would be about 165cm. However, using a HC-SR04 ultrasonic sensor, their possible detection range increases dramatically (2 cm - 400 cm range) [6]. Integrating ultrasonic sensors into glasses and canes can allow the user to detect obstacles at a greater distance and thus provide early warnings. This is a substantial improvement over traditional white canes, which can only detect objects upon physical contact. From an economic perspective, Statistics Canada reports that among those aged 16 years and older, persons with disabilities earn 21.4% less than those without disabilities [43]. This income disparity highlights the importance of making assistive technology more affordable for individuals with disabilities.

Competitive Landscape

1. Traditional White Cane
    a. By far the most widely used assistive device for people with visual impairments [7], it allows users to detect obstacles through tactile feedback (through the cane physically making contact with objects), in order to guide the user through objects in their path. The traditional white cane is relatively affordable, making it widely accessible to the population.
    b. Shortcomings:
        i. The traditional cane's physical length is a limit to its detection range [7]
        ii. It does not detect objects above waist height or provide any warnings as a potential obstacle gets closer
        iii. It may be difficult to maneuver around in densely packed areas with a full-length cane
2. Guide Dogs
    a. Guide dogs can navigate through various terrains, avoid obstacles, and adapt to changes in the environment [8]. They are effective for daily travel, especially in complex environments and sometimes help owners feel more secure in new and unfamiliar environments [9].
    b. Shortcomings:
        i. Training guide dogs is both costly and time-consuming
        ii. Guide dogs also require maintenance and care, which adds additional work and cost [9].
        iii. Accessibility is limited by the availability of trained dogs and waiting lists
3. Accessible Public Transportation Systems
    a. Some cities and towns have designed accessible public transportation systems with features like audio announcements and tactile maps [10]

b. Shortcomings:
    i. Many cities have not invested in making public transport more accessible and many others still lack features specifically for visually impaired passengers
    ii. While audio announcements can be useful, navigating a busy and crowded station may still pose a challenge

Requirement Specification

The device should be able to detect objects which are at least 0.5m away. Given that the average walking speed of an adult ranges up to around 1.8 meters per second[11], and the average human reaction time is around 0.25 seconds}, an appropriate distance buffer is 0.45m (1.8m/2 · 0.25m/s) which we have rounded up to 0.5m. This will ensure that, once alerted, users will be able to react to objects before collisions occur.

Our device should emit a sound of at least 60dB and at most 70dB to alert the user. Conversations generally occur at a sound of 60dB[12], so this will ensure that our device is heard but does not disturb the surroundings. Exposure to sound above 70dB is not good for hearing, hence our upper limit is 70dB.

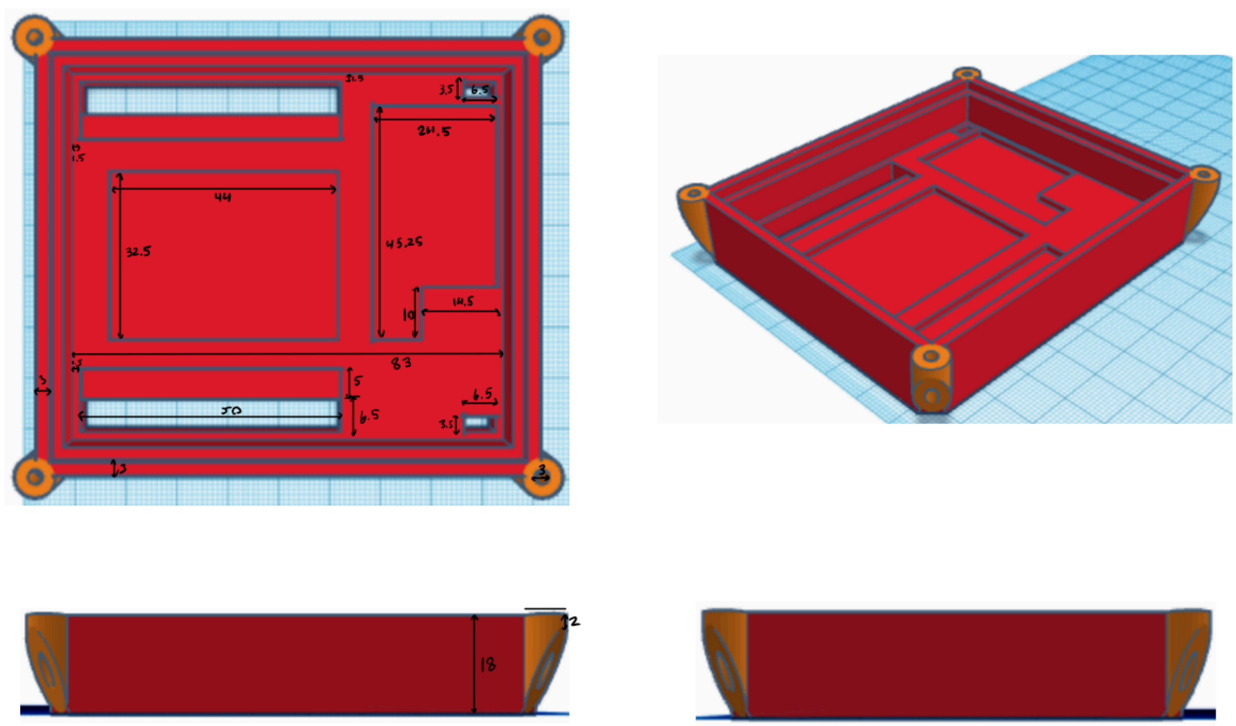
Our device's battery should be able to last the user for 30 minutes before the battery needs to be changed. Given that the average person walks for around 2 miles (or 3,200m), and the average walking speed of a person is 1.8m/s, the average person walks for around 30 minutes every day (3200m / 1.8(m/s) = 1778s = 30min)

Touch is an effective method of getting attention[13], so we will be vibrating a motor to alert the user when objects are on a collision course. It should vibrate at a higher frequency as objects come closer to the user to indicate the level of required attention. The vibrating motor should be able to cover a wide range of frequencies and the lowest and highest frequencies should differ by at least 50Hz.

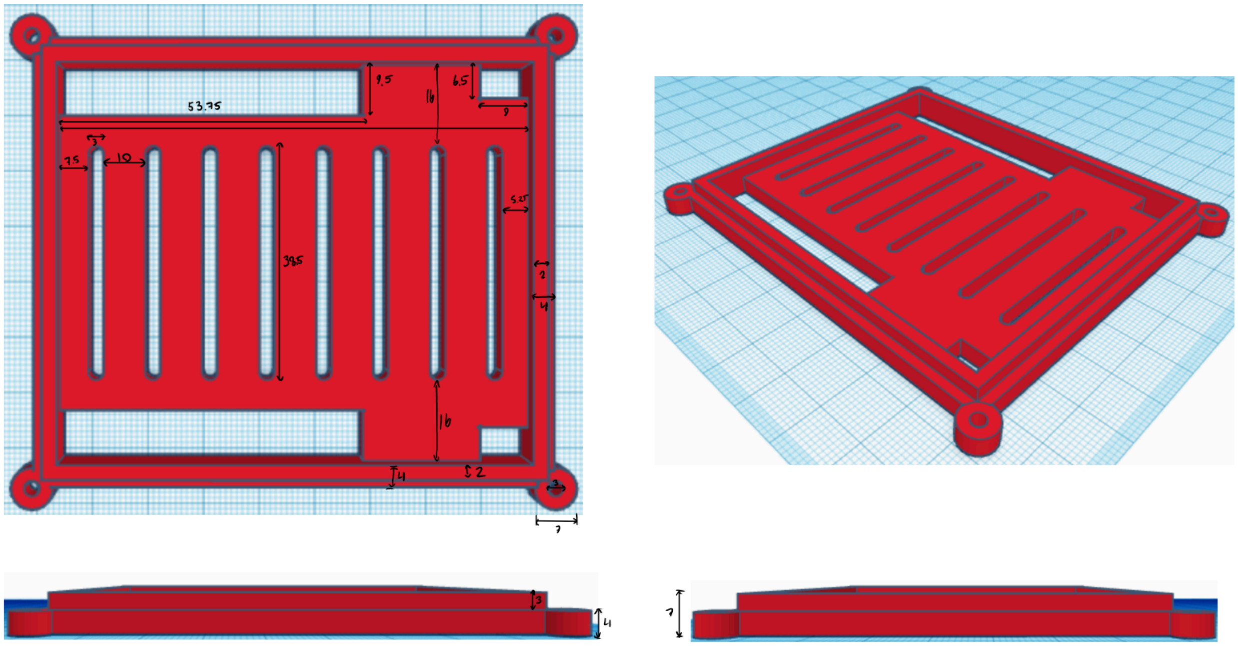
Since the device is to be used outdoors, it should be operational between temperatures of -20 to 40 degrees celsius; the typical temperature range in Canada of a large city like Toronto [40].

Analysis

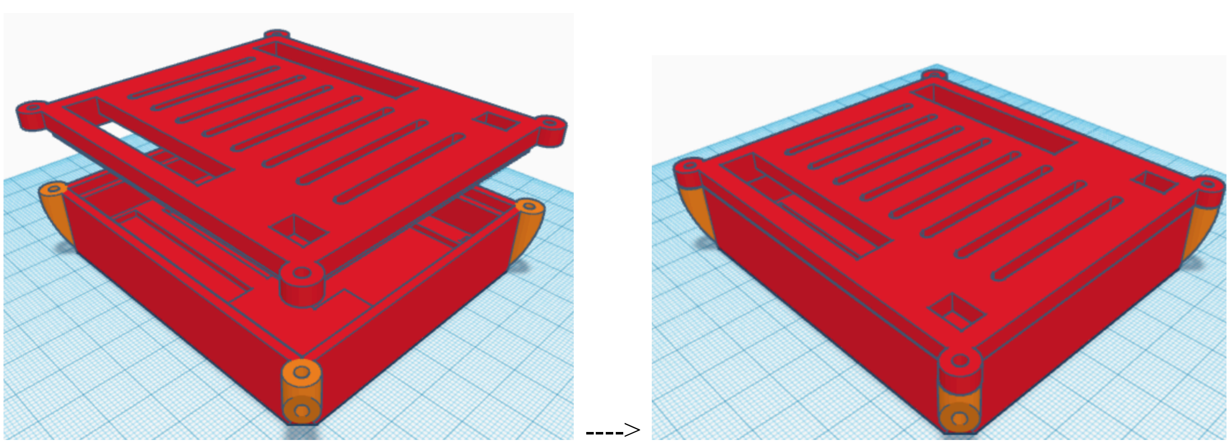
Design



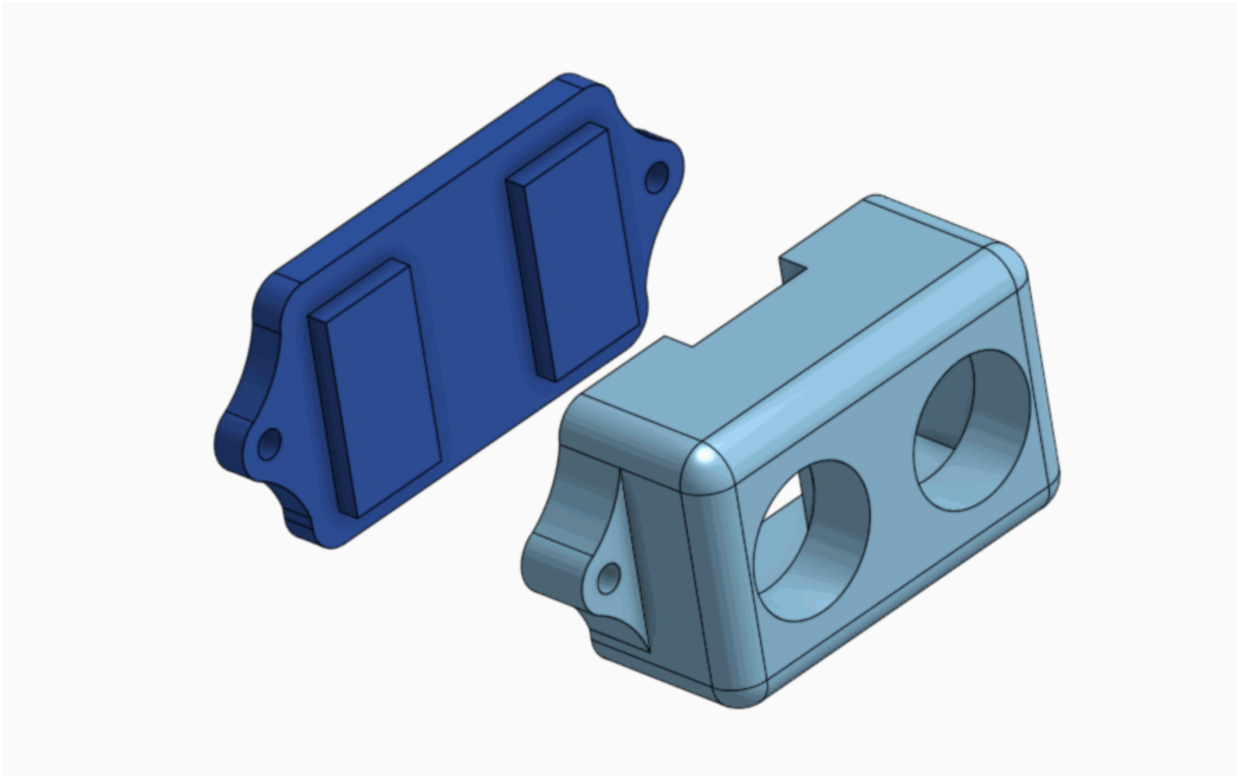
The above diagram shows the top, isometric, front, and right views for the STM 32 nucleo board case 3D model. Units are all in millimeters. The dimensions for the design were gathered by measuring the physical STM32 Nucleo board.



The above diagram shows the top, isometric, front, and right views for the STM 32 nucleo board case lid 3D model. Units are all in millimeters. The STM32 Nucleo boards will both be placed into the cases with the lids snapped on and attached, and secured to the cane and the glasses respectively (see the user guide for more details). Note that this model has the necessary holes to allow for access to the STM32 board's pins, so all of the necessary components are secured and protected, but also accessible, as well as holes to allow for air-flow and full access to the STM32.



The above diagram shows how the lid fits onto the case.

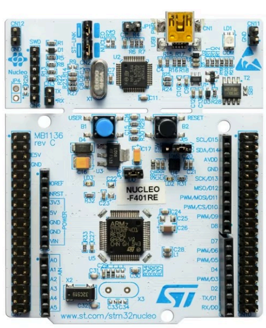


This is the final drawing for the ultrasonic sensor, and it was borrowed from Nuno on Printables [39], so dimensions and additional views are unavailable. Once the ultrasonic sensor is in the case, it will be secured with screws, and the other components will be secured in the same manner (see the user guide for more details).

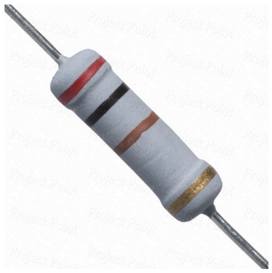
See the User Guide for more information on how all the components work together.

Components:

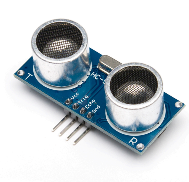
- STM32-F401RE Board (x2)



- 200Ω resistor (x2)

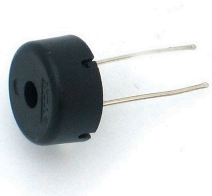


- HC-SR04 Ultrasonic Distance Sensor (x2)

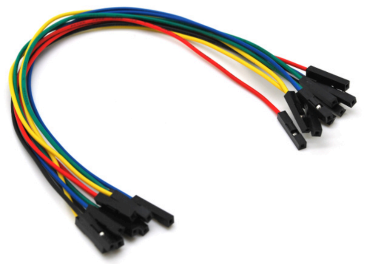


- ABS 3D printed case
- Vibrating Mini Motor Disc (x2)

- Piezo Buzzer - PS1240

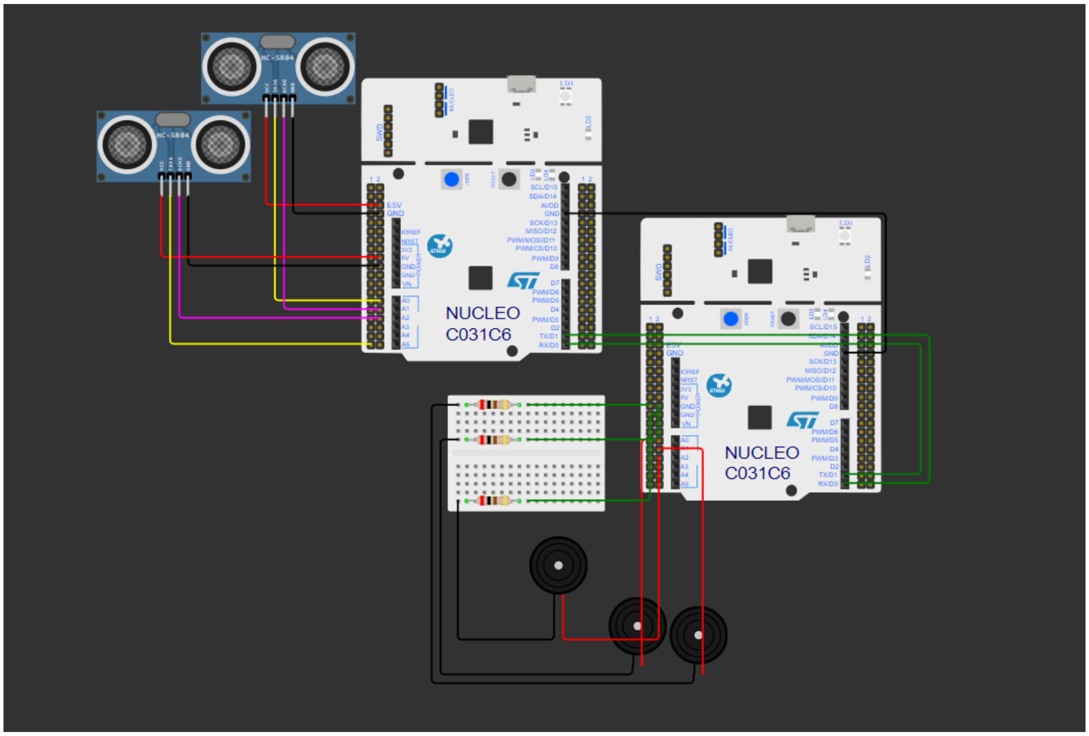


- Female to female jumper wires (x8)



- Male to male jumper wires (x6)
- Male to female jumper wires (x6)
- Foldable Cane
- Sunglasses
- 9V Battery

Board Wiring



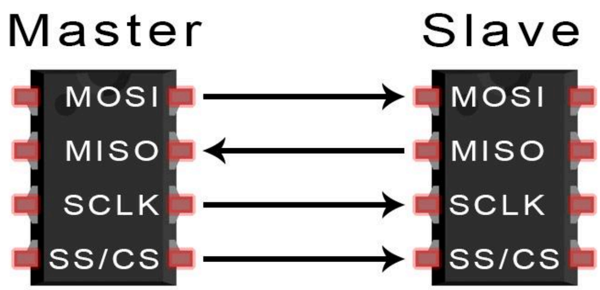
Wiring Diagram

One STM32 Board will be responsible for input, and the other will be responsible for the output. For input, there are the distance sensors, and for the outputs, there are the buzzers and vibrators. They will be transferring information using the Universal Asynchronous Transmitter-Receiver protocol (UART). This can be done by connecting the Transmitter (TX) pin on the STM32 which collects sensor data to the Receiver (RX) pin on the STM32 which provides tactile feedback to the user (Half Duplex UART). The ground pins of the two STM32s will also be connected to provide a reference voltage. This approach has many advantages compared to potential alternatives [14]:

- Simple Implementation: Only two wires are needed for half-duplex UART communication
- Ease of Debugging: UART is a widely used protocol and thus easy to debug
- Low Power Requirement: UART communication is efficient and doesn't require much power, which is ideal for portable systems that may need to operate on battery power.

This will be elaborated upon more in the Technical Analysis.

An alternative method of communication we considered was the Serial Peripheral Interface (SPI) protocol. This approach follows a master-slave architecture and uses four logic signals: Chip select (CS), Serial clock (SCLK), Master out slave in (MOSI), Master in slave out (MISO) [15].



We decided to stick to UART due to its easier implementation.

I2C, also known as Inter-Integrated Circuit, is another method of communication protocol that could be used between STM-32s. It is a communication protocol where multiple masters control the input and output between the multiple slaves. Masters are the devices that organize the communication between the systems classified as slaves. As a result, devices are synchronized to efficiently receive and send out data. I2C is usually faster with speeds of up to 3.4 MHz; however, its circuit complexity is greater and data can only be sent in one direction at a time [45]. In addition, UART has typical data transfer rates of 115200 bps which is ideal for our scenario where moderate data must be communicated between the STM-32s [46].

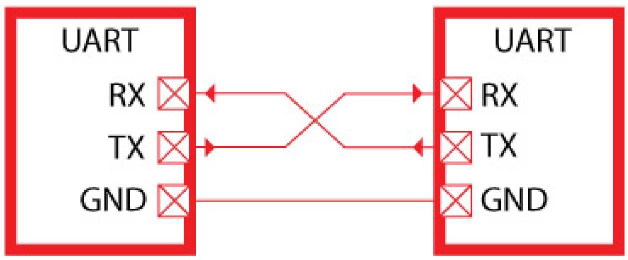
Another alternative method of communication is bluetooth or wifi. This would reduce the need for wiring and physical connections. However, wired connection is generally faster with speeds between 10 Mbps to 100 Gbps, compared to the max 10 Gbps in wireless connections [44]. Additionally, wired connections are much more secure over wireless, increasing security and liability. However, as wireless connections continue to develop, it will certainly be considered as a future update.

Technical Analysis

Application of Principles in the Project

UART Communication Standard and Data Transfer Rate

As stated before, the UART protocol will be used to implement single duplex communication between the two STM32 Nucleo boards. One STM32 board, which collects data from the HC-SR04 ultrasonic sensors, transmits distance readings to a second STM32 board.



This second board uses the received data to determine the vibration intensity, alerting the user to nearby obstacles.

The HC-SR04 sensor has a measurement range of 2 cm to 400 cm and an ultrasonic frequency of 40 kHz. Given that sound travels at approximately 343 m/s in air [17], the maximum time for the sensor to receive an echo from a 400 cm object is about:

$$time = \frac{2 * distance}{Speed\ of\ sound} = \frac{2 * 4.0m}{343m/s} = 0.023s = 23ms$$

The minimum time for the sensor to receive an echo from a 2 cm object is about:

$$time = \frac{2 * distance}{Speed\ of\ sound} = \frac{2 * 0.004m}{343m/s} = 2.3 * 10^{-5}s = 0.023ms$$

Obviously, this transfer rate is unrealistic, thus we can refer to the HC-SR04's distance measurement frequency of 40Hz [6] to determine our UART baud rate. The total data rate from the two sensors would thus be 40Hz * 2 = 80Hz.

Each UART frame typically consists of

- 1 start bit
- 8 data bits
- 1 stop bit

For a total of 10 bits per byte of data [18]

To send 2 bytes for each distance measurement (reasonable since the range is relatively small at 2 - 400cm), the overhead for two bytes of data would be:

$$Total\ bits\ per\ second\ = \frac{80\ measurements}{second} * \frac{20\ bits}{measurements} = 1600\ bits\ /\ second$$

A baud rate of 2400 bps would hypothetically be sufficient but not very generous for our purposes. Thus, in order to avoid potential data loss and bottlenecks due to timing issues the UART baud rate will be configured at 9600 bps to be on the very safe side.

Determining the intensity of the buzzer with respect to the distance from the object:
If we want the vibration strength to gradually increase as the cane approaches an object, we can implement a transformed inverse function that slowly increases the voltage output to the vibrating motor disc:

$$V = k / (d + c)$$

V is voltage

k is a constant that determines the speed of the increase

d is distance

c is another constant that offsets the curve

Assuming we want the voltage output to be 3 volts at 0.5m and 5 volts at 0.2m, we can solve for k and c to determine the equation for the curve:

Eq1: $3V = k \div (0.5m + c)$

$3V\ (0.5m + c) = k$

Eq 2: $5V = k \div (0.2m + c)$

$5V(0.2m + c) = k$

Divide Equation 2 by Equation 1:

$$(3V(0.5m + c)) \div ((5V(0.2m + c)) = 1$$

$$1.5\ mV + 3Vc = 1\ mV + 5Vc$$

$c = 0.25$

Substitute c into eq 1:

$3V(0.5(0.25) + 0.524) = k$

$2.25 = k$

$$\rightarrow V = 2.25 / (d + 0.25)$$

Using Pulse Width Modulation:

Because the voltage outputs are constant, to output a voltage within the range of 0 V and 5 V we will need to implement Pulse Width Modulation [36].

We decided that our Pulse Width Modulation calculations would follow a linear curve, because there was no need for any other curve. This means that to calculate the duty cycle, we can use the linear equation [35]:

$duty\ cycle\ (\%) = (\frac{5-0}{100\%-0\%})x + 0$

$duty\ cycle\ (\%) = 5x$

This equation is done using the linear equation of a line, $y = mx + b$, where $m = \frac{\Delta y}{\Delta x}$. Since at 5V, there is a 100% duty cycle, and at 0V, there is a 0% duty cycle, we are able to come up with the above equation.

Determining buffer distance:

Given that the average walking speed of an adult ranges up to around 1.8 meters per second [13], and the average human reaction time is around 0.25 seconds, we can use basic kinematic equations when acceleration is constant to calculate the buffer distance.

$$(v\, x\, t = d) -> 1.8\, m/s^2\ x\, 0.25\, s = 0.45m.$$

0.45m is the distance for an average walker to be able to react in time before colliding with the object. By ensuring the buzzer activates at 0.5m, it ensures that the user is given enough time to prevent themselves from hitting the obstruction.

Determining battery capacity:

Using the basic kinematic equation and the average walking speed, we can calculate the minimum battery capacity. For instance, given that the average person walks for around 2 miles (or 3,200m), and the average walking speed of a person is 1.8m/s [13], we can estimate that the average person walks for 30 minutes everyday

$$(d\,/\,v\ =\ t)\ \ {-}{>}\ \ (\,3,200m\,/\,1.8m/s\ =\ 30\,min)\ .$$

Hence, we want to ensure that the cane will last at least 30 minutes.

$$Battery\ Life\ (hours)\ >\ Battery\ \ Capacity\ (mAh)\ \div\ Current\ Consumption\ (mA)$$

$$Battery\ Life\ \ (hours)\ \times\ Current\ Consumption\ (mA)\ \ >\ Battery\ Capacity\ (mAh)$$

$$0.5\ hours\ \ \times\ 185\ mA\ (calculated\ in\ the\ energy\ analysis)\ >\ 92.5\ mAh$$

Therefore, the minimum battery capacity to be used on this system is 92.5mAh to ensure it will function over 30 minutes.

Costs

Manufacturing and Implementation Costs

Material List:

1. STM32-F401RE Board [20]
   a. Manufacturer: STMicroelectronics, Geneva, Switzerland
   b. Vendor: STMicroelectronics
   c. Cost: 18.83 CAD
2. HC-SR04 Ultrasonic Sonar Distance Sensor [19]

    a. Manufacturer: Adafruit Industries LLC, New York City, USA
    b. Vendor: Digikey
    c. Cost: 6.11 CAD

3. Vibrating Mini Motor Disc [21]
    a. Manufacturer: Adafruit Industries LLC, New York City, USA
    b. Vendor: Digikey
    c. Cost: 2.83 CAD
4. PS1240 Piezo Buzzer [25]
    a. Manufacturer: TDK Corporation, Tokyo, Japan
    b. Vendor: Digikey
    c. Cost: 0.94 CAD
5. 200Ω resistor [24]
    a. Manufacturer: Stackpole Electronics Inc, Raleigh, North Carolina, USA
    b. Vendor: Digikey
    c. Cost: 0.16 CAD
6. Jumper Wire - Various [23]
    a. Manufacturer: Bud Industries, Willoughby, Ohio, USA5
    b. Vendor: Digikey
    c. Cost: 15.39 CAD
7. Mini Breadboard [22]
    a. Manufacturer: Seeed Technology Co., Ltd, Shenzhen, China
    b. Vendor: Digikey
    c. Cost: 4.57 CAD
8. 9V Battery [38]
    a. Manufacturer: Energizer Holdings, Inc., St. Louis, Missouri, USA
    b. Vendor: Walmart.ca

    c. Cost: 3.98 CAD
9. ABS Case (64g) [48]
    a. Manufacturer: 3D printer at UWaterloo, Waterloo, Ontario, Canada
    b. Cost: 0.18 CAD
10. Foldable Cane [50]
    a. Manufacturer: J&D Tech, Nesconset, New York, USA
    b. Vendor: Walmart.com
    c. Cost: 12.51 CAD

Risks

Energy Analysis

Reference Standard:

Components have been checked and ensured that they are running at the recommended voltages. For instance, the STM-32 will be operating between 1.8V and 3.3V, as recommended in its user guide [26].

- STM-32 STM32-F401RE Board [26]
    - Operating Voltage
        - 1.8V - 3.3V
    - Operating Current
        - 10-20 mA
- PS1240 Piezo Buzzer [27]
    - Operating Voltage
        - 3V
    - Operating Current
        - 10 mA
- HC-SR04 Ultrasonic Sonar Distance Sensor [34]
    - Operating Voltage

        - 5V
    - Operating Current
        - 15 mA
- 2 x Vibrating Mini Motor Disc [28]
    - Operating Voltage
        - 2V to 5V
    - Operating Current (Per Motor Disc)
        - 40mA to 100 mA
- Copper Wiring will be used due to its effective conductivity, low cost, and little resistance.
- $Average\ Operating\ Current\ for\ Motor\ Disc\ (mA)\ =\ (40mA\ +\ 100mA)/2\ \times\ 2\ =\ 140mA$
- $Total\ Operating\ Current\ (mA)\ =\ 20mA\ +\ 10mA\ +\ 15mA\ +\ 140mA$

  =185 mA which satisfies the requirements in the user guide for the STM-32 [26]
- $Maximum\ Voltage\ Component\ =\ Total\ Operating\ Voltage\ (V)\ =\ 5V$

  The total operating voltage should never be above the 5V requirement that we disclosed, which this passes.
- **Quantifying Maximum Total Energy Stored:** These numbers were used to calculate the minimum battery capacity in the applied principles above
- Analysis of Energy Storage:
    - Chemical: In the 9V batteries that will supply power
    - Electrical: Store in the STM-32's components [26]
    - Mechanical Energy: Created in the vibrating motors

Risk Analysis

Battery Disposal:

Environmental/ Safety Consequences:

Commonly, users may choose to use a 9 V lithium battery to power the STM-32. Disposal and production of these lithium batteries are environmentally damaging. Specifically, lithium mining is known to cause environmental degradation, habitat loss, water pollution, and health concerns. In addition, incorrect disposal of batteries may cause toxic chemicals to escape, causing additional health risk and pollution [29].

Mitigations:

In the manual, we will emphasize the use of sodium ion batteries or other alternatives that are more environmentally friendly [41]. Moreover, instructions to dispose of lithium batteries will be provided. Specifically, it will include dropping the battery at local drop-off depots instead of recycling bins and other general garbage systems [30].

Environmental Interference:

Environmental/ Safety Consequences:

Rain or fog potentially causes false reading and activation.

It may hinder the ultrasonic sensor's ability to detect nearby objects, leaving the user vulnerable to collision [42].

Heavy rain may entirely cause the cane to either malfunction or entirely cause the system to not function at all.

Extreme temperatures may damage internal components also causing possible malfunctions

Mitigations:

Require electrical compartments to be fully sealed

Use an epoxy spray to provide a waterproof coating [34]

Include limitations in the manual that describes it should only be used within temperatures of -20 to 35 degrees celsius and when there is no fog [31]

Internal temperatures Above 85 degrees celsius:

Environmental/ Safety Consequences:

The internal STM-32 is rated to function in temperatures between -40 to 85 degrees celsius. If outside these ranges, the STM-32 may stop functioning permanently or create a fire hazard [32].

Mitigations:

The user guide will be clear that the cane should only function in temperatures of -20 to 35 degrees celsius.

Incorrect Use Of The Cane:

Environmental/ Safety Consequences:

Due to conflicts, misunderstandings, or extreme circumstances where the user may intend to inflict harm on others, they may use the cane as a weapon. However, this is clearly not the intent of the cane.

Mitigations:

The cane's structure is required to be fully entirely smooth, ensuring there is not rough or sharp edges that could inflict potential harm

The manual will be strict and clear that the cane should not be used in any case to harm others. Any occurrences where the cane is used as a weapon will not be our liability.

Battery Depletion:

Environmental/ Safety Consequences:

Power consumption from sensors and motors will deplete the battery and it is possible that the cane will lose power during usage. The average 9V battery capacity is 600 mAh [37].

$Battery\ \ Capacity\ (mAh)\ \ \div\ \ Current\ Consumption\ (mA)\ \ =\ \ Battery\ Life\ (hours)$

$600\ mAh\ /\ 185mA\ \ =\ \ 3h$

The user should replace the battery ever after 3 hours of use.

Mitigations:

Our device's battery should be able to last the user for at least 30 minutes as stated in the requirements. In addition, the cane can still function even without the additional features.

Inadequate Feedback:

Causes:

If the user is in a loud environment (>60 decibels) or wearing thick hand wear, it is possible that the alert may not be felt or heard [33].

Mitigation:

Thorough testing and tuning will be done to ensure that as stated in the requirements, the device should emit a sound of at least 60dB and at most 70dB to alert the user. A safety feature where the cane vibrates at higher frequencies as objects approach will be included. In addition, the manual states that the cane should be used in an environment that is below 70dB and thick (>¼ inch) should not be worn.

Testing and Validation:

- **Objective:** Ensure the ultrasonic sensor is accurately recording distances form objects

  Test Setup:

  Place objects at ranges of 0.25m, 0.5m, 1m, 1.5m, and at different angles

  Test Inputs:

  Repeat with different common objects that one may encounter everyday: Chairs, poles, boxes, tables, a moving object that could simulate a pet or person…

  Environmental Parameters:

  The test will be done indoors to ensure consistency during the tests.

  Quantifiable Measurement Standard:

  A tape will be placed at the listed range (using a ruler) above from the front of the object. The recorded data from the ultrasonic sensor will be then compared to analyze its accuracy.

  Pass/ Fail Criteria:

If the results are within +-5 centimeters it has passed the test.

- **Objective**: Test all feedback functions are properly function and that device can be heard in different noise environments

  Test Setup:

  When less than 0.5m away from the object, the devices should emit a noise and vibrations to effectively alert the user

  Test Inputs:

  Change surrounding noise levels using a speaker and phone to simulate different scenarios. For instance, in a normal conversation, decibel levels range from 40-60 as sounds above 70 dB can damage hearing over time [33]. We can simulate these variables with a decibel meter.

  Gloves will be tested to analyze the buzzer's effectiveness.

  Environmental Parameters:

  The test will be done indoors to ensure consistency during the tests. Noise level will vary depending on the test input.

  Quantifiable Measurement Standard:

  A decibel meter will be used to ensure the test inputs (speaker and phone) are producing similar noise levels to realistic scenarios (store, restaurant…)

  Fail/ Pass Criteria:

  Ensure all vibration motors and buzzers are functioning properly. Even in conditions where it is above 60 decibels, alerts can still be heard and vibrations can be felt.

- **Objective:** Ensure there is minimal delay between the feedback activation and the detection of an object

  Test Setup:

  Using a camera in slow motion, measure how long the cane takes to provide feedback once passed a specific deadzone from an object (0.5m).

Test Inputs:

Vary the speed that the cane approaches the object (+-0.5m/s).

Environmental Parameters:

The test will be done indoors to ensure consistency during the tests.

Quantifiable Measurement Standard:

A ruler will be used to measure the distance from the object.

Using the slow-mo feature on modern phones, the playbacks will allow us to accurately capture and average the time for the cane to provide feedback after it has passed the marked distance from the object.

Pass/ Fail Criteria:

If the delay is less than 0.25s as required, then it will allow sufficient time and distance for an average user to react. Hence, it passes the test.

- **Objective:** Ensure the battery functions as required.

  Test Setup:

  The cane will be placed onto a chair that will simulate a human user. The chair will move forward and back, continuously crossing the threshold before the feedback is activated. This allows us to control the frequency the cane is activated.

  Test Inputs:

  Because the battery life will depend on the frequency that feedback is activated, separate tests will consist of 10, 20, 30 activation cycles

  Quantifiable Measurement Standard:

  The cane will be connected to a power bank that displays the battery capacity out of 100 percent. $Percentage\ Lost\ x\ Capacity\ of\ Power\ Bank\ /\ Time\ (s)$ will provide an estimate of the power consumption

  Environmental Parameters:

The test will be done indoors to avoid environmental variables. Temperature will be approximately 23 degrees celsius.

Pass/ Fail:

If the power consumption in 30 minutes is less than a 9 V battery then it has passed the test.

- **Objective:** Temperature test

  Test Setup:

  In a small room (i.e a dorm room), the temperature will be changed, where the effectiveness of others tests are analyzed.

  Test Inputs:

  Trials will be conducted at temperatures of -20, 0, 10, 20, and 35 degrees celsius using a heater or cooler.

  Environmental Parameters:

  The test will be done indoors to avoid environmental variables such as wind that could affect the temperature of the cane.

  Quantifiable Measurement Standard:

  A thermometer will be used to measure the indoor temperature.

  Other instruments such as a ruler, slow-mo camera, and power bank may be used as this final test consists of the other trials

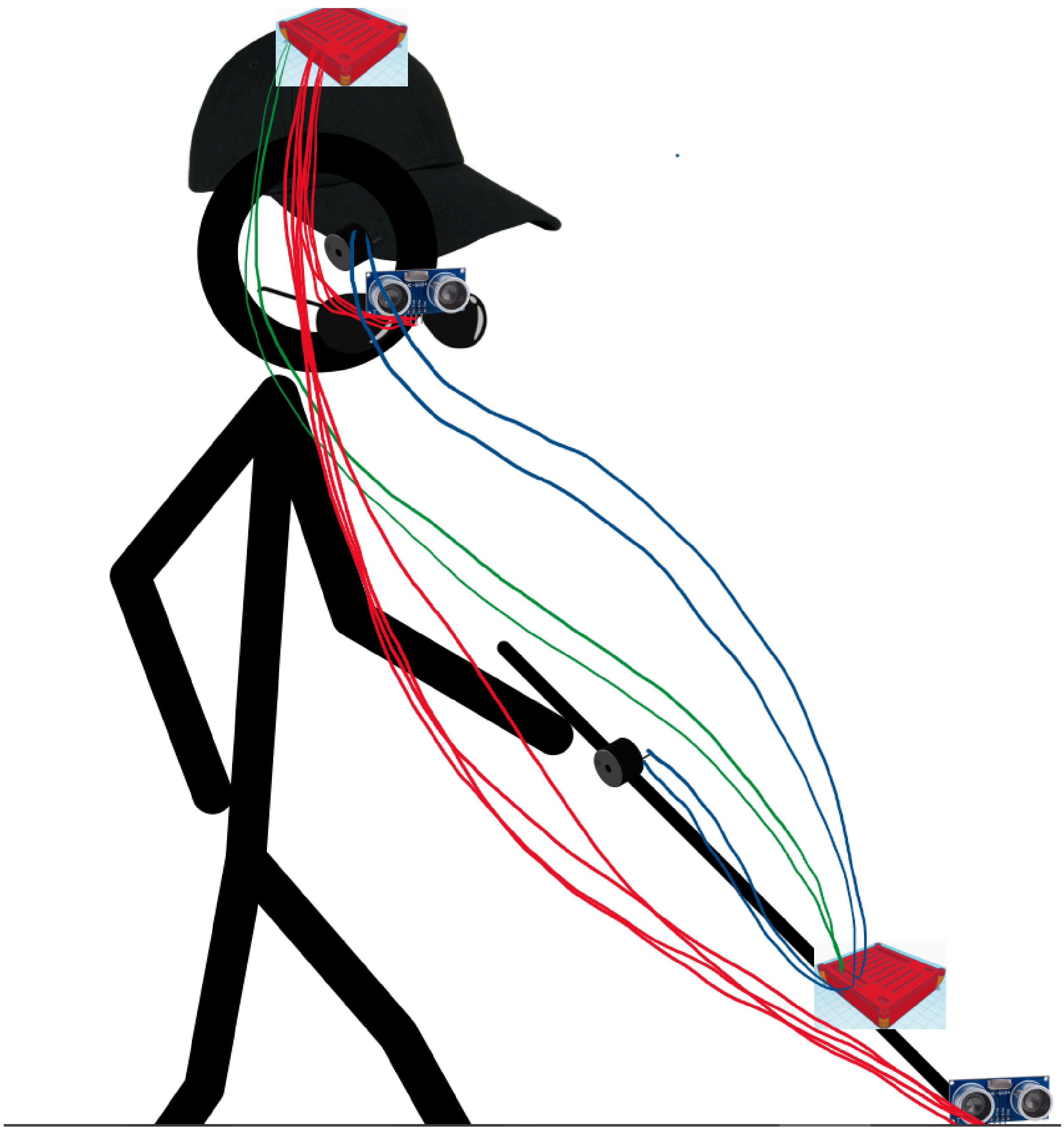
  Pass/ Fail:

  After performing the previous tests, we will have data that we can compare to. If the results are consistent (+- 5 percent deviation) and continue to meet the functional requirements listed previously, the system passes the test.

User Guide

Instructions:

1. Insert STM32 Boards, ensuring that the boards fit well in the case
2. Use string to close the STM32 case and attach to hat
3. Use electrical tape to secure HC-SR04 sensor and cases to the Glasses and Cane.
4. Connect components: With the case's access holes, connect the required components using jumper wires (HC-SR04s to $STM32_1$, $STM32_1$ to $STM32_2$, Motors and buzzer to $STM32_2$).
5. Power and Testing: After all components are connected, power the STM32 boards on to ensure they are receiving power and operating as expected. Test the ultrasonic sensors, motors, and buzzer with a nearby wall to confirm they are functioning properly
6. Maintenance: Periodically check the case and connection points (Hat and Cane) to ensure they remain secure, especially if the product is being used in various environments.
   - The case can be opened if adjustments or replacements are necessary.



See the above diagram for a high-level representation of how all the components connect together.

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