Design Document

ECE198 – group 24

Fall 2024

Client/Customer Definition:

- The customer base consists of the 12 distinct branches of libraries in the region of Waterloo [1].
- Our clients receive their funding from the Canadian government and look for cheap solutions, allowing the government to pool the rest of their funds into other internal improvements within Canada [2].
- Kitchener is the 10th-largest census metropolitan area in Canada, allowing our product to have a large impact population-wise [3].

As of right now, libraries within the region of Waterloo have no standardized method of controlling the noise levels within the public spaces, resulting in inconsistency as to the noise levels within the different branches. The noise levels are dictated solely by the inhabitants the libraries take, making variation impossible to avoid. With the implementation of our device, ideally, this noise variation will be able to be monitored and controlled, allowing for easier focus for the inhabitants [4]. This is one of the major reasons for going to the library, and it would result in less work for the librarians and/or inhabitants, who would have had to go out of their way to control the noise levels of the other inhabitants [5].

Competitive Landscapes:

- The designated noise-controlled areas in libraries, such as the University of Waterloo Dana Porter Library, help address the challenge of maintaining a quiet environment. However, these spaces are often limited and frequently full, making them an insufficient permanent solution. A noise-control device (like ours) could ensure acceptable noise levels are maintained throughout the entire building, rather than just in specific areas [6].

- Sound masking systems are a relatively new technology designed to make noises and conversations less audible, creating a quieter library environment. However, these systems require high-quality sound systems to work properly, making them costly. The cost of sound masking systems can range from 4 to 8 dollars per square foot, which is a lot more expensive compared to our library noise control device [7].

- One of the most traditional methods to reduce noise in libraries is by soundproofing walls and doors. However, given that libraries often have open-space designs, and it's impractical to build soundproof barriers around every table, noise from nearby conversations can still be heard. The most effective solution to these distractions is to remind visitors to keep their noise below a certain level. Our library noise control device can assist in creating a quieter environment by helping libraries and librarians maintain an atmosphere with fewer distractions for everyone for a much more affordable price [8].

Requirements:

O: Objective requirements
F: Functional requirements
C: Constraints

[F1] The output microcontroller(s) should be able to go through the signaling procedure within a reasonable delay (<u>1000ms or less</u>).

[F2] The output devices (lights or sound) should only activate when loud noise is detected over a prolonged period (<u>4 seconds</u>).

[F3] The device should be scalable so that other output devices can be added later. (Should come with <u>4 LEDs</u> as the output device, and users should be able to have the option to increase or extend the output device.)

[F4] Out of 10 tests, the device should perform all listed requirements at least <u>8</u> times.

[F5] The input microcontroller should be able to read decibel levels up to <u>5dB</u> of precision accurately.

[O1] The device should be as small as possible (Smaller = Better).

[O2] The device should be in a protective casing.

[O3] The communication between the two microcontrollers should be as fast as possible. (Faster = better)

[O4] If batteries are selected as the power source, the device should prioritize energy efficiency to reduce the amount of e-waste generated. (More efficient = better)

[O5] The infrared transmitter and receiver must be capable of maintaining communication over a distance of at least 2 meters [9]. (Longer range = better)

[C1] The device should not violate people's right to privacy.

[C2] The device should not consume more than 30 Watts of power.

[C3] The device should not contain more than 500 mJ of energy at any point in time (Assuming STM32 maximum voltage- 5V).

[C4] The device should not include any microcontroller other than the STM32F401RE.

Design:

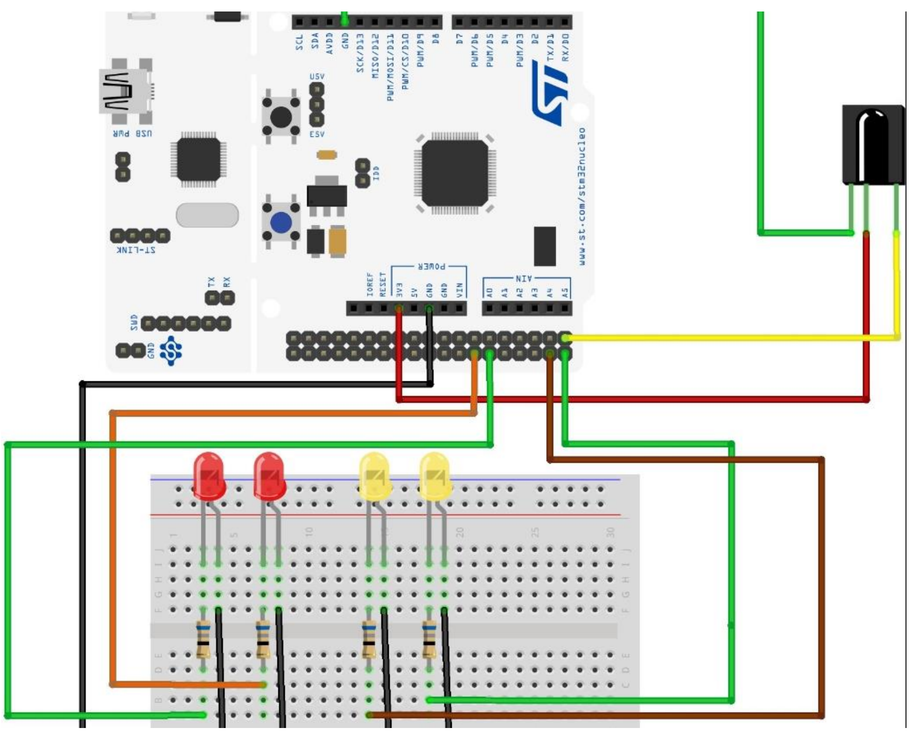


Diagram of the Receiver of the library noise-controller

The receiver-side of the library noise control device consists of 11 simple electronic components, and 12 jumper wires (these can later be replaced by onboard LEDs where no bread board is used.)

Here is a quick list of the components:

- STM32F401RE
- Breadboard
- Two Red LEDS (633nm)
- Two Yellow LEDs (592nm)
- Infrared Receiver
- 4 x 68 Ω resistors
- 12 jumper wires

The 4 LEDs are each connected to a GPIO pin in order to be controlled by the microcontroller, here is that mapping of the LEDs and their corresponding pin:

First Red LED -> PC15 – CN7

Second Red LED -> PC14-Cn7

First yellow LED -> PC3 – CN7

Second yellow LED -> PC2 – CN7

Each LED's cathode pin will be after a 68Ω resistor to stop the excessive current as shown in the diagram, and match our calculations based on Ohm's law, and Kirchhoff's law (For more detail please go to the analysis section). Note: although we calculated a resistor value of 50Ω, we went with a 68Ω resistor to have a safety buffer zone. All LEDs are powered via their respective GPIO pins, each supplying 3.3V. The ground pins of the LEDs are connected to the common ground rail on the breadboard, ensuring a consistent grounding scheme throughout the system.

The infrared receiver's supply voltage (Vs) is sourced from the STM32's 3.3V pin, with its ground connected to a ground pin on the STM32. The data output pin of the infrared receiver is connected to pin PC0 (CN7) on the STM32F4 board to receive digital signals.

*Please note that all these pin connections can be modified or changed at any time. However, the firmware (software) must be modified in order to compensate for the wiring changes.

The LEDs will turn on in the following sequence:

- Two yellow LEDs activate when the sound level is between 40 and 55 dB (Decibels).
- Two red LEDs and both yellow LEDs activate when the sound level exceeds 55 dB.

The receiver device satisfies all the requirements and constraints that deals with the receiver device:

1. The receiver will come with a minimum of 4 LEDs, and it's expandable as still have many other GPIO pins for other outputting purposes. Requirement [F3] is satisfied here.
2. The device does not incorporate energy storage elements like inductors or capacitors. Requirement [C3] is satisfied here.
3. The receiver device will at maximum use 0.25W of power (Assuming STM32 maximum voltage- 5V). Requirement [C2] is satisfied here. (See Energy Analysis for more details)
4. The design does not include any Arduino modules, or any other kind of micro controller. Requirement [C4] is satisfied here.

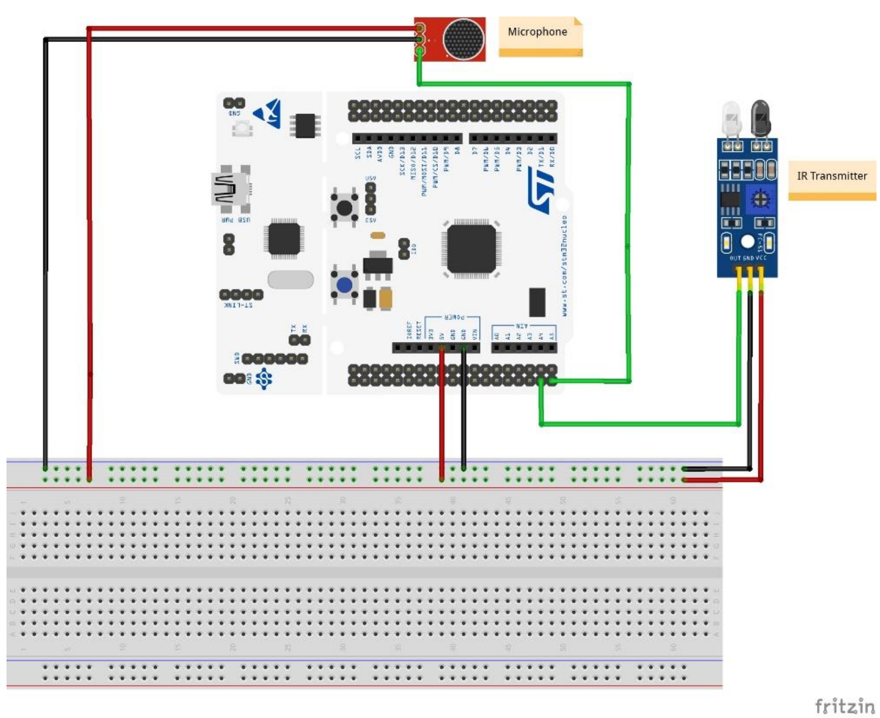


Diagram of the Transmitter(sender) of the library noise-controller

The transmitter-side of the library noise control device consists of 4 simple electronic components, and 8 jumper wires (these can later be replaced by onboard LEDs where no bread board is used.)

Here is a quick list of the components:

- STM32F401RE
- IR Transmitter Module
- Microphone
- Breadboard
- 8 Jumper wires

The microphone pin mapping is as follows:

VCC -> 5V on the STM32, however it will be supplied through the Breadboard positive rail as shown in the diagram.

GND-> GND on the STM32, however it will be supplied through the Breadboard ground rail as shown in the diagram.

AUD/AO -> PC3 (CN7) to provide the microcontroller with Analog data.

The IR Transmitter pin mapping is as follows:

VCC -> 5V on the STM32, however it will be supplied through the Breadboard positive rail as shown in the diagram.

GND-> GND on the STM32, however it will be supplied through the Breadboard ground rail as shown in the diagram.

OUT - > PC2 (CN7) to receive input from the microphone.

There will be no resistors or other components needed for this part of the device, since the voltage provided by the STM32 will be sufficient enough and will not damage any of the components.

The sender device will perform the following functions:

1. Continuously monitors the sound level using microphone module, converting the measured volume into a digital signal represented as an integer.

2. If the volume is between 40 and 55dB, the sender will signal the receiver via the IR transmitter, telling the receiver to activate the yellow LEDs.

3. If the volume exceeds 55dB, the sender will notify the receiver via the IR transmitter, telling the receiver to turn on both the red and yellow LEDs.

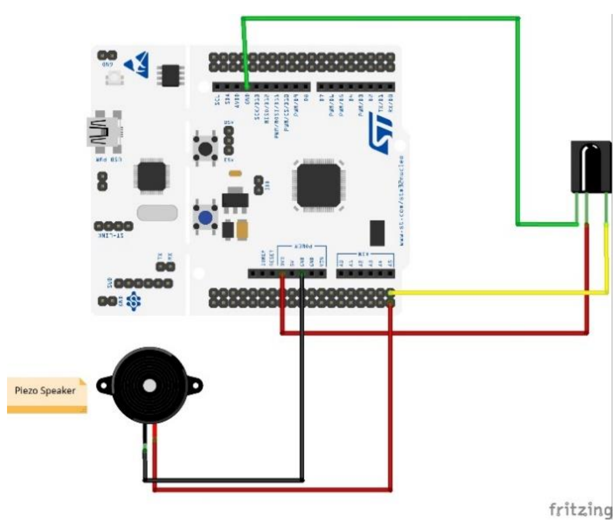
The sender device satisfies all the requirements and constraints that deals with the sender device:

1. The sender will not save any of the sound data in any format. Requirement [C1] is satisfied here.
2. The device does not incorporate energy storage elements like inductors or capacitors. Requirement [C3] is satisfied here.
3. The receiver device will at maximum use 0.25W of power. Requirement [C2] is satisfied here. (See Energy Analysis for more details)
4. The design does not include any Arduino modules, or any other kind of micro controller. Requirement [C4] is satisfied here.
5. The device will ensure that the sound level remains above the specified threshold for at least 4 seconds before sending a signal to the receiver, satisfying requirement [F5].
6. The receiver device will at maximum use 0.25W of power (Assuming STM32 maximum voltage- 5V). Requirement [C2] is satisfied here. (See Energy Analysis for more details.
7. The design does not include any Arduino modules, or any other kind of micro controller. Requirement [C4] is satisfied here.
8. The device will be capable of transmitting signals to the receiver over a minimum distance of 2 meters, fulfilling requirement [O5].
9. The sender device will be sensitive enough to distinguish between sound levels that differ by at least 5dB, meeting requirement [F5].
10. The device will ensure that the sound level remains above the specified threshold for at least 4 seconds before sending a signal to the receiver, satisfying requirement [F5].

A form of protective casing which could be used to protect the device from the surrounding environment, as well as contain all electronic components to protect them from potential external damage such as water is depicted below. While this casing will not be a part of the demonstration design, in the case of manufacturing/implementing the device, this casing would be added. It can easily be built via 3D printing, with the addition of 4 machine screws and a clear acrylic plate (to allow light to be emitted and received, and signals to be visible).

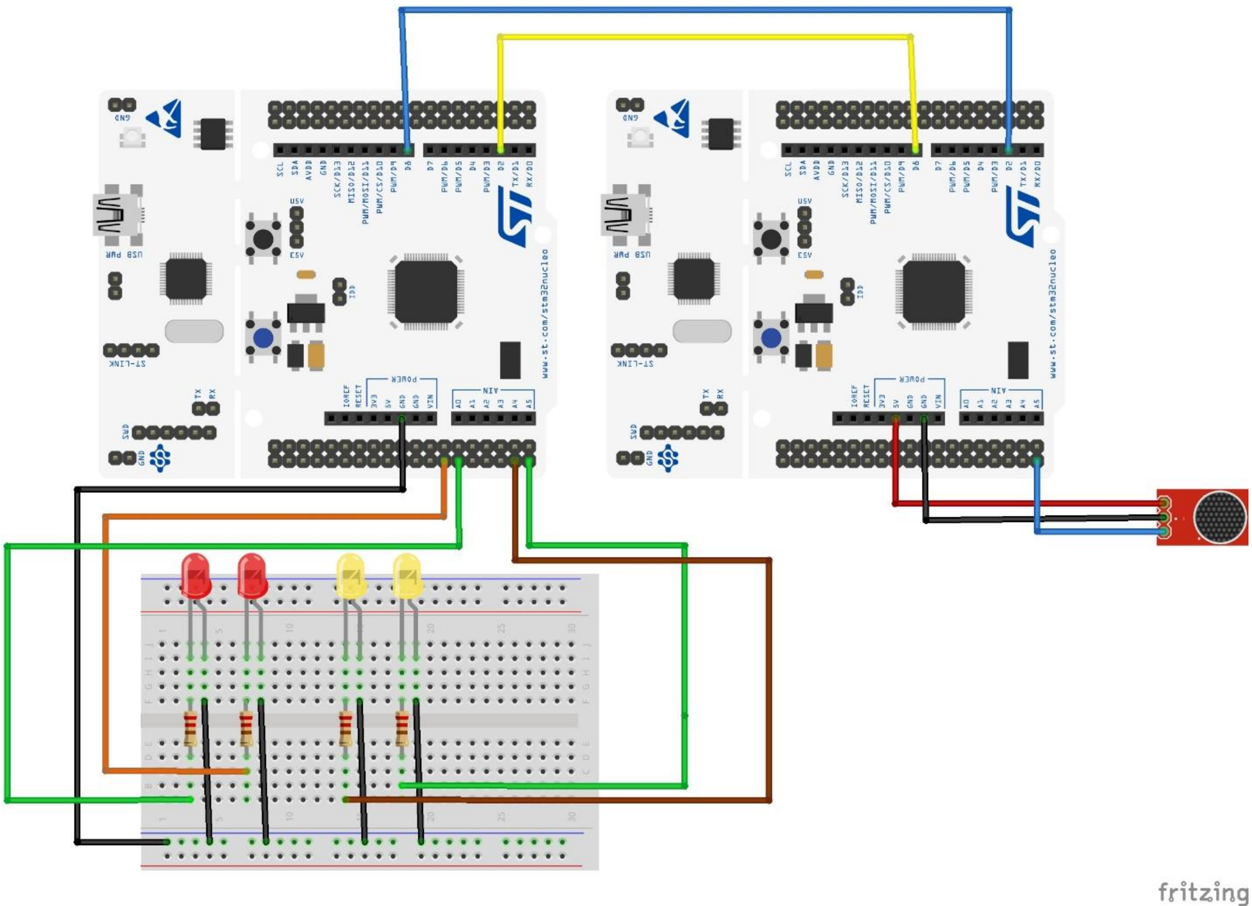
The design is comprised of a simple transparent box (note, the only plate which MUST be transparent is the largest, front facing plate fastened with the machine screws). The box has a hole on one side to allow for the power cable to pass through. The dimensions of the box are 140mmx166mmx40mm, large enough to fit all components in an organized manner. The casing can fit both the sender and receiver units, allowing for simple repairs.

Alternative Designs:



We considered designs that implemented noise-output devices to alert the inhabitants of the libraries that they were being too loud, however ruled it out due to this implementation causing more decoherence than desired.

As seen in the first diagram, the IR receiver communicates with the STM32 Microcontroller, which then sends a voltage to the Speaker, causing it to output some audio.



Different communication methods were also considered, such as using a traditional transmitter/receiver, rather than using IR technology.

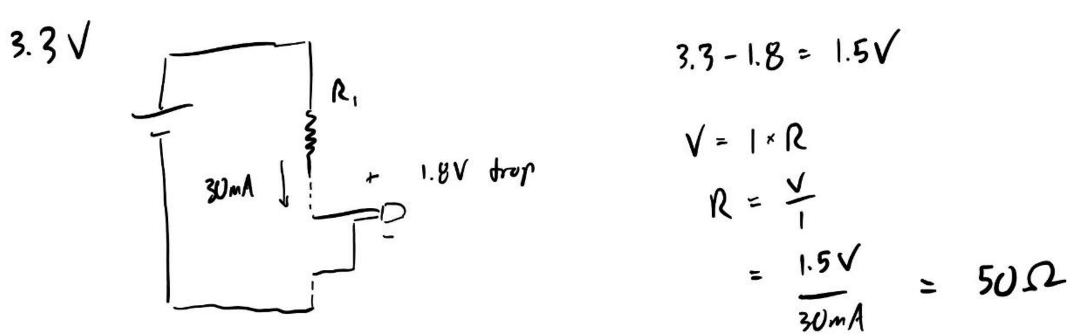
In the second diagram, we see that the two STM32 boards are connected directly by wire, rather than relying solely on other transmission/receiving techniques.

We went with our selected design due to its minimization of decoherence, consistency of communication, and the safety of its design. As we can see in the final diagrams, it uses a microphone to receive input, which is pushed to the STM32, sending the information to a transmitter. A receiver on the other STM32 can interpret the noise level and have voltages (numerical values needed here) set such that output LEDs visually indicate the noise level to the outside observer.

Technical Analysis

8.1 - Ohm's Law:

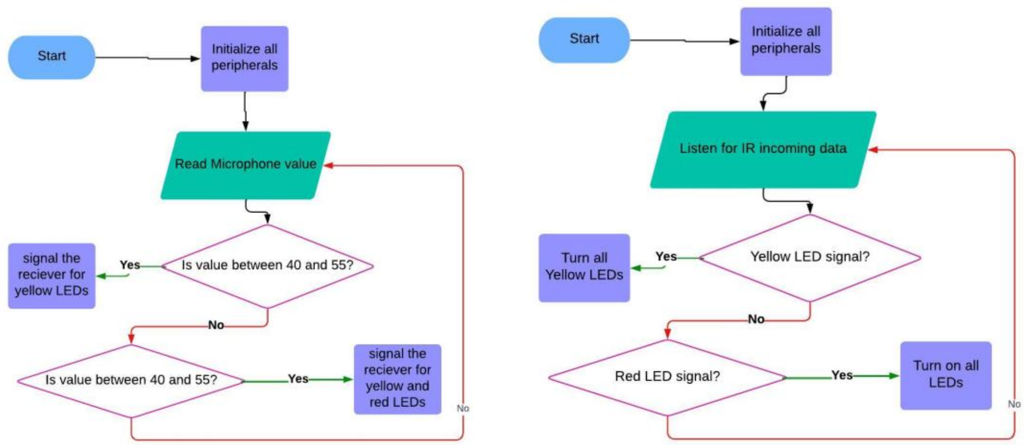
Ohm's law is a fundamental principle used in all electronic circuit boards including ours. This principle describes the relationship between voltage (V), current (I), and resistance (R) in an electrical circuit. It can be shown as V = I × R [10] . In our project, we will frequently use Ohm's Law to choose appropriate resistors for the LEDs and to calculate power consumption, ensuring it always remains below 30W. We aim to prevent our LEDs from overloading and ensure the current stays at 30mA to achieve optimal brightness and maintain safety, and Ohm's law will help us achieve this. In calculating for resistance, we used the 3.3 Volts from the GPIO pin, and accounted for the 1.8 Voltage drop from the LED to get a final 1.5 Total Voltage. Using the datasheets for our LEDs, we determined that a current of 30mA would be satisfactory, and rearranging for R, R = V/I, so 1.5V/30mA = 50Ω. Therefore, We will be using the next higher value for the resistors which will be a 68Ω resistor [13].



8.2 - HAL and LL Libraries:

The STM32 HAL (Hardware Abstraction Layer) library is a set of software functions provided by STMicroelectronics to simplify the development of applications for

STM32 microcontrollers. It abstracts the hardware details, allowing developers to interact with the microcontroller's peripherals (like GPIO, UART, SPI, and more) using high-level APIs. This Library will be used for all our software and firmware.



(On right: Receiver device logic. On left: Transmitter device logic. Flowcharts, mirroring code used in the STM32)

8.3 - Watt's Law:

Watt's law defines the relationship between power, voltage and current and states that the power in a circuit is a product of the voltage and the current. There are many practical applications of Watt's law, and the formula to calculate Watt's Law is P = IV. This law will allow us to test the device's maximum wattage, which was defined in the design requirements. The voltage from the power supply is 5V, and the current STM32 boards take is only 0.05A. Using P = VI, we get 5V * 0.05A = 0.25W [11].

$$5V \times 0.05A = 0.25W$$

This proves that STM32 by itself can never exceed 0.25W of power.

8.2 - Kirchhoff's Voltage Law:

Kirchhoff's Voltage Law states that the sum of all electrical voltages around any closed loop in a circuit is equal to zero. This means that the total voltage supplied in the loop is exactly balanced by the total voltage drops across the components in that loop . This law will help estimate how much voltage each component is taking. We are aiming for a voltage of 3.3V to ensure the LEDs operate as efficiently and sustainably as possible. Also, this law will help while choosing resistors for LEDs in combination with Ohm's law. Can be mathematized like: v1 + v2 + v3 + v4 = 0 where v represents the voltage taken in by each component. We use this law in accounting for the voltage drop across the LED and use the voltage of the GPIO pin minus that of the voltage drop across the LED in accounting for the ideal resistor value (3.3V - 1.8V = 1.5V) [12].

Cost:

Cost savings were achieved through the use of the STM32 microcontroller, which provided enough GPIO capabilities and integrated peripherals, avoiding the requirement for extra specialist ICs. The component selection was refined to incorporate just necessary elements such as LEDs, sensors, and IR modules, achieving functional requirements while reducing costs.

2 x STM Nucleo F401RE ordered online through Digi-Key Electronics:

- Free shipping
- Unit Cost: $19.92
- 13% tax: $5.18
- Total Unit Cost: $22.51
- Total Cost: $45.02
- https://www.digikey.ca/en/products/detail/stmicroelectronics/NUCLEO-F401RE/4695525

5 x 220 Ohm Resistor available online through Digi-Key Electronics:

- Unit Cost: $0.10
- 13% Tax: $0.07
- Total Unit Cost: $0.11
- Total Cost: $0.57
- https://www.digikey.ca/en/products/detail/stackpole-electronics-inc/CF14JT220R/1741346

3 x Yellow (592nm) LED available online through Digi-Key Electronics:

- Unit Cost: $0.23

- 13% Tax: $0.11
- Total Unit Cost: $0.26
- Total Cost: $0.78
- https://www.digikey.ca/en/products/detail/w%C3%BCrth-elektronik/151053YS04500/4490030

3 x Red (633nm) LED available online through Digi-Key Electronics:

- Unit Cost: $0.18
- 13% Tax: $0.07
- Total Unit Cost: $0.20
- Total Cost: $0.61
- https://www.digikey.ca/en/products/detail/w%C3%BCrth-elektronik/151033RS03000/4490003

7 x Jumper Wire (M to F) (20 pack) available online through Digi-Key Electronics:

- Unit Cost: $11.15
- 13% Tax: $1.45
- Total Unit Cost: $12.60
- Total Cost: $12.60
- https://www.digikey.ca/en/products/detail/digikey/DKS-20MF-10/17038796

13 x Jumper Wire (M to M) (20 pack) available online through Digi-Key Electronics:

- Unit Cost: $11.15
- 13% Tax: $1.45
- Total Unit Cost: $12.60
- Total Cost: $12.60
- https://www.digikey.ca/en/products/detail/digikey/DKS-20MM-10/17038782

1 x IR Remote Receiver available online through Digi-Key Electronics:

- Unit Cost: $1.29
- 13% Tax: $0.17
- Total Unit Cost: $1.46
- Total Cost: $1.46
- https://www.digikey.ca/en/products/detail/vishay-semiconductor-opto-division/TSOP34836/4074516

2 x Solderless Breadboard available online through Digi-Key Electronics:

- Unit Cost: $6.57

- 13% Tax: $1.71
- Total Unit Cost: $7.42
- Total Cost: $14.85
- https://www.digikey.ca/en/products/detail/twin-industries/TW-E40-1020/643111

1 x Microphone/breakout board available online through Digi-Key Electronics:

- Unit Cost: $7.50
- 13% Tax: $0.98
- Total Unit Cost: $8.48
- Total Cost: $8.48
- https://www.digikey.ca/en/products/detail/sparkfun-electronics/BOB-12758/6592307

1 x IR Emitter available online through Digi-Key Electronics:

- Unit Cost: $0.40
- 13% Tax: $0.05
- Total Unit Cost: $0.45
- Total Cost: $0.45
- https://www.digikey.ca/en/products/detail/excelitas-technologies/VTE1291-1H/5885863

2 x USB A Male to USB Mini B Male 5m available online through Digi-Key Electronics:

- Unit Cost: $6.33
- 13% Tax: $1.65
- Total Unit Cost: $7.16
- Total Cost: $14.31
- https://www.digikey.ca/en/products/detail/assmann-wsw-components/AK672M-2-5/930237

2 x DC converter available online through Digi-Key Electronics:

- Unit Cost: $7.89
- 13% Tax: $0.97
- Total Unit Cost: $8.92
- Total Cost: $7.89
- https://www.digikey.ca/en/products/detail/cui-inc/SWI5-5-N-I38/5287192

Total Cost Per System:

Total Cost: 106.34

Total Tax: 13.84

Net Cost: $120.18

Manufacturer : STMicroelectronics

Headquarters: Chemin du Champ-des-Filles 39, 1228 Plan-les-Ouates, Switzerland.

Canadian Branch: 350 Burnhamthorpe Rd W, Missis**sa**uga, Ontario, Canada.

Vendor: Digi-Key Electronics

Headquarters: 701 Brooks Avenue South, Thief River Falls, Minnesota, USA.

Canadian Distribution Website: digikey.ca

Installation Manual :

Requirements for the installation of the device:

- An uninterrupted horizontal pathway greater than or equal to 2 meters which can be travelled by the IR signal. It is best if this pathway cannot be acutely interrupted by patrons or staff walking by.
- 2 standard 120V power outlets, 1 located within 5 meters of each end of the pathway.

Installation Steps:

1. Choose a monitoring point: a high-traffic location in the library intended for silent use.
2. Securely mount the sender unit within 2 meters of the monitoring point and connect the power cable to the available outlet. Ensure the IR emitter is pointing in the intended direction of the receiver unit.
3. Choose a display point: a location 2 or more meters from the sender unit which is easily visible from the monitoring point.
4. Securely mount the receiver unit at the display point, ensuring it aligns vertically with and points its IR receiver at the sender module. Ensure the indicator LED lights are visible from the monitoring area. Connect the power cable to the available outlet.

User Guide :

This device is intended to monitor the noise level (volume in dB) of a specific area of a library, and indicate via light display when the noise level is over the threshold of 40 dB for a period greater than or equal to 4 seconds.

The user should follow the installation manual in order to set up the device.

Upon powering the device, the sender unit will repeatedly monitor the noise level and transmit signaling procedures to the receiver device via an Infrared LED. Similarly, upon receiving power, the receiver unit will constantly check for IR signals and attempt to process the results in order to illuminate the signaling yellow/red LED lights. Successful powering of the device is indicated by the illumination of the LED light embedded in the main STM32-F401RE board in each unit.

The user should cut power to or unplug the device when in prolonged periods without use in order to conserve energy.

The user should indicate to patrons of the library via signage or other methods the intended meaning of the display LED lights. Yellow should be indicative of an uncomfortable volume and suggest to patrons to lower their volume. Red should be indicative of an unacceptable volume, demanding that patrons lower their volume. For extra efficacy in the decrease of noise levels in the library, upon passing by units, library staff should monitor the light signals in order to know when to intervene:

If the light is yellow, politely suggest that the guilty party lowers their volume.

If the light is red, give the guilty party a warning, and reinforce the importance of lowering their volume. If they consistently reach a red level after being warned, the user should remove the guilty party from the silent environment.

If no indication LED lights are activated, it can be determined that the noise level is acceptable. The only light activated in this case should be the status light of the main STM32 F401RE board in each unit.

Energy Analysis:

The STM32F4 series boards are all 5 volts tolerant, and operate on 5V, therefore a 5-volt DC adapter should be used with the two boards, if they are going to be powered directly from an outlet to the USB mini-B port which is our preferred method. Please ensure that the adapter is DC and supplies stable 5V signals. It's important to note that STM32 microcontrollers internally operate at 3.3V [13]. In summary, the adapter should have specifications such as: Input: 100V-240V, 200mA; Output: 5.0V DC, 1A. Please note that this adapter is CSA and FCC approved, and can be used in North America with no additional certifications, and training required (Link to product available through the cost section).

- This device will have no significant energy storage due to the absence of components like capacitors, and inductors which are usually associated with non-negligible energy storage. There are no capacitors or inductors present in the LED, or sensors that are used as the peripherals of this device [13]. Since the operating power of our circuits is very low, heat energy storage is also not a concern [14].
- According to the facts presented in the point above, this device will have no significant energy storage in any form, and since the voltage applies by the power supply is 5V and the current that STM32 boards take is only 0.05A [16], this project will use 0.25 Watts of power at the most. Here is a mathematical demonstration using Watt's law [11]:

$$P = V \times I$$

Power = voltage X current

5V x 0.05A = 0.25 W

Risks and Hazards:

- If LEDs are used as an output device, caution should be taken as LEDs can cause light pollution, which negatively affects wildlife, and could be harmful for photosensitive individuals. In this case, adjust the brightness when necessary [17].

- Since this device uses an Infra-red transmitter and a receiver, it may interfere with other IR controlled devices if the user doesn't use the product correctly, and in this case other methods of communication could be used for communication between the two microcontrollers [18].

- The device can operate using either battery power or a direct USB cable, requiring an input voltage of approximately 3 to 5 volts. Incorrect voltage or unstable power supply can lead to malfunction, overheating, or permanent damage to internal components. Use recommended power sources to avoid fluctuation and ensure device stability.

- The device's protective design, including its casing, is crucial for safe a operation. Damage such as cracks in the casing or loose/exposed wires can compromise the device's functionality, and short circuits, electric shock, or fire hazards. This poses a significant risk to users and the environment around the device.

- Since this device has the capability of being powered by batteries, it can harm the environment due to toxic chemicals like lead and mercury, which can leak into soil and water. If the chosen power source for the device are batteries, it is recommended to use rechargeable batteries to reduce the e-waste generated.

Testing and Validation :

Repeating the tests 5 times and having them be successful 4 times will be our benchmark. All tests assume the devices have access to power from the wall through an adapter that is CSA approved.

Length procedure:

The device should be able to receive signals from a minimum of 2 meters away. To test this, one member will stand 2 meters away from the LED output device with the microphone input device in hand and emit some readable noise into the microphone. When at least one LED lights up, this test is considered complete.

Signaling procedure:

The device should be able to be activated when given an input of sound over a period of time greater than or equal to 4 seconds, in order to pass the test. To test this, one member of our team will stand 2 or more meters away from the LED output device and emit a consistent sound for more than 4 seconds into the microphone input device. The sound should be in the decibel range of detection for the device, defined above.

Precision procedure:

When given an input of sound over a prolonged period of time greater than or equal to 4 seconds, it should be able to distinguish decibel levels with a margin of error of 5dB. To test this, one member of our team will emit a consistent sound into the microphone input device, steadily increasing the decibel level of the sound emitted, and noting when the LED sensors change. An accurate decibel level reader will be used as a control group for the read values, ensuring accuracy. To pass this test, when comparing the LED output to the decibel level reader, they should be within 5dB of each other.

Power procedure:

The device should never exceed 30 Watts of power. To test this, while the device is actively receiving input through the microphone, we find the maximum voltage and current of the device by using a multimeter, then multiply them using Watt's Law to get the power, in Watts, of the device. Calculations less than 30W will signify a pass of this test.

Energy procedure:

The device should never exceed 500mJ of energy used. To test this, we collect the data from the previous "Power procedure," and multiply this by the time period that elapsed while testing the device. Any calculation less than 500mJ will signify a pass of this test.

Sources:

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[3] "List of census metropolitan areas and Agglomerations in Canada," Wikipedia, https://en.wikipedia.org/wiki/List_of_census_metropolitan_areas_and_agglomerations_in_Canada (accessed Oct. 29, 2024).

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