Hearing Damage Detector and Alarm System

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Design Document
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1 Introduction

1.1 Problem

Middle and high school musicians can be subjected to harmful levels of noise on a daily basis between rehearsals, practice sessions, and performances. Cheap and effective hearing protection is available, but many students neglect using it until they start noticing the effects of their hearing damage years later. Even without considering hearing loss, long-term hearing damage can disturb the normal "balance between excitation and inhibition in the central auditory system" that can last several times longer than the time required to cause the damage [1].

1.2 Solution

Our solution is a device that provides live feedback to musicians about their noise exposure in an attempt to encourage more regular use of existing hearing protection equipment.

Our solution accomplishes this feedback through our LED system. Tentatively, LEDs corresponding to safe (green), potentially dangerous (yellow), and dangerous (red) indicate both instant danger and daily exposure danger by a static color and a flashing color. These LEDs, along with a more detailed csv report outputted using a USB connection, will be controlled/outputted by our microcontroller, which in turn is fed by our microphone subsystem. The microcontroller should be able to distinguish frequencies, especially those pertinent to humans, as well as the sound pressure level (SPL) at a given moment, instantaneous, and over a certain period, integrated. Our microphone subsystem feeds our microcontroller subsystem through the use of a microphone tuned to the human ear and a pre-amp circuit to prepare the raw data from the microphone. Last, all of these subsystems should be powered by a 3.3 V USB connection. Thus, our system should be powered by USB connection, able to read relevant sound from the environment, convey both instantaneous and daily exposure danger through LEDs, and give a detailed report through USB connection and a software program to aid musicians in combating dangerous sound.

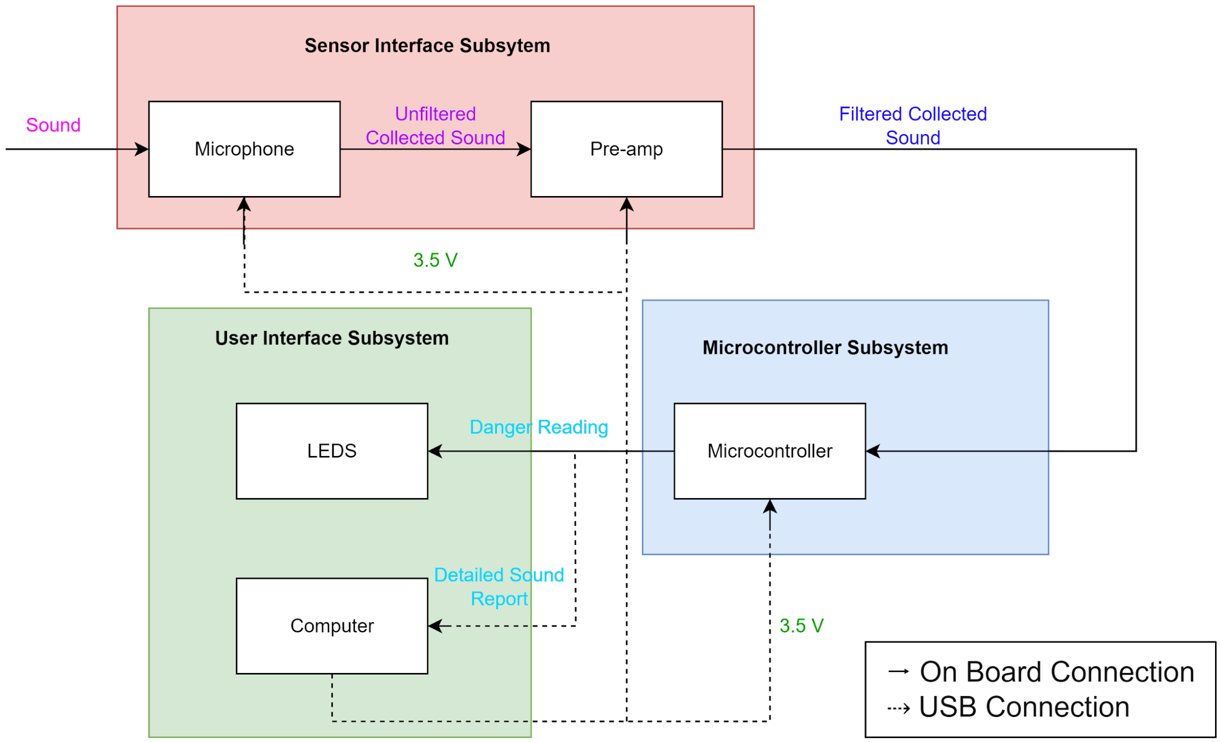
1.3 Visual Aid

1.4 High-Level Requirements

1. The device needs to be able take signals from a microphone and accurately calculate SPL from the data. The data transferred to the microcontroller should be correct without noticeable noise as defined in the requirements and verification section of the sensor interface.
2. The microcontroller needs to be able to convert the filtered sound data from our sensor interface to meaningful LED and sound report outputs compared to a simple oscilloscope reading.
3. The device needs to be able to display instantaneous and integrated SPL data in the form of lit-up LEDs. These LEDs should accurately convey instantaneous SPL within reasonable tolerance range and integrated SPL exposure as given by the requirements and verification section below.
4. The device needs to be able to upload recorded SPL data to a computer to perform the integration and generate a report. This report should include frequencies primarily that the human ear can listen to as well as the instantaneous and integrated SPL over the period the device was active. The report should be consistent with raw oscilloscope readings within a 5% tolerance.

2 Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 Subsystem 1 — Sensor Interface (Microphone)

To capture the sound pressure levels, we'll need a microphone that is omni-directional, responsive to the frequencies that the human ear is responsive to (about 20Hz-20kHz), and has a suitably high signal-to-noise ratio (~60dB or above). One microphone that fits these criteria is the TOM-1537L-HD-LW100-B-R. Accompanying this microphone will be a pre-amp circuit to filter out DC noise and prepare readings to be used by the microcontroller.

This subsystem will take in outside sound data, filter out noise, and output useful sound data for the microcontroller to use. This subsystem is essential for our goal of accurately and quickly providing information about the environmental noise and any possible health concerns.

Requirements	**Verification**
1. Sensor interface output sufficiently outputs frequencies between 20 Hz-20kHz without noticeable noise as defined in the verification step.	1. Use an oscilloscope to measure the interface output in a quiet room. 2. Maximize the gain (G=2000 V/V=66.02 dB) on the preamp and record the noise of the room.

	3. Reduce the gain by 20 dB and make another recording. 4. Verify that the first recording is either as noisy or less noisy than the second [2].

2.2.2 Subsystem 2 — Microcontroller Unit

Our microcontroller will need to be able to take input data from the microphone interface and turn it into useful information for the user in order to indicate possible sound hazards

There are two types of feedback we would like to be able to provide: 1 - instantaneous SPL readings in dB and 2 - integrated SPL over time (also called “sound exposure”) to gauge potential hearing damage accumulated over a session. A potential MCU to use for our device is the ATMega4808, which contains a 10-bit analog-to-digital converter and 48 kB of RAM.

Although a future version of this device could be powered by a rechargeable lithium-ion battery for the sake of portability. Due to time and scope limitations of the course, we will be powering this device via USB.

Requirements	**Verification**
1. Instantaneous and SPL readings are correct within a 5% dB margin of error.	1. Feed either mock sound data or data from the sound interface if it has been verified to the microcontroller interface and to oscilloscope directly. 2. Measure the output of the microcontroller interface using the same oscilloscope. 3. Compare outputs, verify that microcontroller interface does not vary more than 5% dB from the direct oscilloscope output.

2.2.3 Subsystem 3 — User Interface

To present live feedback on instantaneous SPL, the device could feature a series of LEDS that light up in response to recorded dB. They should range from green for safe sound levels up to red for potentially dangerous sound levels. Statically, for instantaneous exposure, green should indicate from 0 dB to 90 dB, the limit of safe exposure according to OSHA [3]. Yellow should indicate from 90 dB to 105 dB, or the maximum noise level OSHA limits for a 1 hour period. Last, red should denote anything above 105 dB, when 1 hour of exposure is too much. Flashing should occur if the integrated SPL exposure limit is breached.

We use and define our LEDs to be easily discernible at glance and relevant to our problem, i.e., to musicians. Since 1 hour intervals are fairly common for structures like middle and high school bands, we would like to warn if the exposure for a 1 hour period is too high.

To present a report of sound exposure over the course of a session, we will plan to pull the data from the device onto a computer (just like the computers that would be located in a practice room or classroom) and perform the necessary integration operation there to conserve system resources. This operation will produce a report detailing the amount of sound exposure and what hearing damage it has the potential to cause.

Requirements	**Verification**
1. LED readings accurately convey instantaneous SPL within a 2 dB range.	1. Input 5 dB values via a simulated input for the green range: 86 dB, 88 dB, 90 dB, 92 dB, and 94 dB. 2. Verify that at most, 86-92 dB readings show up as green. 3. Repeat procedure for yellow, i.e., 101-109 dB with 2 dB intervals for yellow and verify 107 dB as the largest dB value accepted for yellow. 4. For red, repeat the procedure starting from 105-111 dB with 2 dB intervals. Verify that the lowest accepted red value is 107 dB.
1. LED readings accurately convey integrated SPL within 10% tolerance.	1. Using OSHA's standard for noise regulation, we know that an increase of 5 dB corresponds to half the time of exposure. 2. Send mock dB input values of 105 dB, 110 dB, and 115 dB to the interface. 3. Verify that LED flashing occurs between 54-60 minutes for 105 dB, 27-30 minutes for 110 dB, and 13.5-15 minutes for 115 dB.
1. LED readings switch between a certain value to another within 2s.	1. Use mock sound intensity data to send a valid green dB reading and yellow

	dB reading using the prior defined ranges. 2. Verify that once the dB intensity changes ranges, the LEDs switch within 2s. 3. Repeat the procedure with yellow to red, green to red, red to yellow, red to green, and yellow to green.
1. The sound report software should be correct within 5% tolerance both intensity wise (dB) and frequency wise (Hz).	1. Send mock sound data simulating background noise, a majority of sound between 50-60 dB, to the software and to an oscilloscope for 58-62s. 2. Check that the sound report is consistent with the oscilloscope readings within 5%. 3. Repeat with different majority noise intensity levels: 70-80 dB, 90-100 dB, and 100-110 dB.

2.3 Tolerance Analysis

The most critical part of our project is the LED warning system, as it conveys the entire purpose behind our project. If the LEDs erroneously go off too much when there's no danger, then our project will rarely be used. However, if the LEDs go off too little when there is danger, then our project will not have fulfilled its purpose: it has not warned musicians when they are unsafe.

However, we believe that it will still be feasible. Given the abundance of commercially available instantaneous exposure devices, the static warning should be more than effective. The only difficulty is then showing the industry grade integrated SPL, i.e., LEP'd via the flashing. The LEP'd equation is given by [3]:

$$LEP'd\ or\ L_{EX}, 8h = L_{eq} + 10 \times log_{10}\left[\frac{T_2 - T_1}{T_n}\right]\ \text{dB}$$

- *Leq* = frequency weighted (A or C), equivalent-continuous sound pressure level in dB
- T_n *Tn* = normalization period on criterion duration (8 hours by standard)
- $T_2 - T_1$ *T*2 - *T*1= measurement period or Run Time

Given that all of these functions are fairly simple mathematical operations, we believe that our microcontroller should be more than qualified to calculate integrated SPL to a 5% tolerance leaning on the conversative side. 5% should be enough to allow for some error, and the conservative qualifier indicates that we accept being more safe than sorry than allowing possible danger.

3 Cost and Schedule

3.1 Cost Analysis

First, we would like to consider the labor costs of our project. To begin with, we consider the average salary of an ECE graduate. We use the most recent data from the official ECE and average the Electrical and Computer Engineering starting salaries to get an average yearly salary of $92,824 [4]. Next, dividing that yearly salary by 52 weeks and 40 hours/week, we get to an average hourly salary of around $44.63/hour. Next, we assume that each group member works an average of around 6 hours a week on the project, which should be about reasonable given in person meetings with TAs, independent research and design, etc. Finally, we see that we have 11 weeks of work from 9/19 to 12/5 not including the break. Summing everything together, we calculate our labor cost as $44.63/hour x 2.5 x 6 hours/week x 11 weeks x 3 group members = $22091.85 total. Thus, we calculate a total labor cost over the entire project as $22091.85.

Next, we would like to calculate the costs of the parts of the project. While we may use more or less parts as we further design our project, we reason that these parts will be most crucial.

Component	**Manufacturer**	**Part Number**	**Quantity**	**Cost**
USB Connector (dual port)	Global Connector Technology (GCT)	USB1100-30-A	2	$2.47
Microphone	PUI Audio	TOM-1537L-HD-LW100-B-R	2	$3.16
Pre-amp	Texas Instruments	INA166UA	2	$12.93
Microcontroller	Microchip Technology / Atmel	ATMEGA4808-AU	2	$1.68
LEDs	Inolux	HV-5RGB60	10	$0.663

In total, our parts will cost $47.11.

We will not be using the machine shop.

In total, our project will cost $22091.85+$47.11 = $22138.96.

3.2 Schedule

Week	Deliverables	Alex	Jake	Jinzhi
9/19	Design Document	Finish initial draft of design doc	Finish initial draft of Design Doc	Finish initial draft of Design Doc
9/26	Design Document Check PCB Design Prototype	Finalize design doc Work on PCB, focus on user interface.	Finalize design doc Work on PCB, focus on sensor interface.	Finalize design doc Work on PCB, focus on microcontroller interface.
10/3	Design Review PCB Design	Revise PCB design based on feedback and focus.	Revise PCB design based on feedback and focus.	Revise PCB design based on feedback and focus.
10/10	PCB Order 1 Teamwork Evaluation	Complete teamwork evaluation Start sound report code Edit PCB design if needed	Complete teamwork evaluation Start microcontroller code Edit PCB design if needed	Complete teamwork evaluation Start microcontroller code Edit PCB design if needed
10/17	Finish Initial Design Assembly	Assemble Design Finish initial sound report code	Assemble Design Start verification process on sensors	Assemble Design Finish microcontroller code
10/24	Debug/Verify Modify Design (If Initial Design Inadequate)	Start verification process on user interface Revise sound report code if necessary	Continue verification process on sensors If needed, modify design or continue assisting in verification process	Start verification process on microcontroller

10/31	PCB Order 2 (If Needed) Individual Progress Reports	Complete individual progress report Continue verification	Complete individual progress report Continue verification	Complete individual progress report Continue verification
11/7	Continue Debug/Verification	Revise sound report software if necessary Prepare for mock demo	Prepare for mock demo	Revise microcontroller software if necessary Prepare for mock demo
11/14	Mock Demo	Final verification of full design	Final verification of full design	Final verification of full design
11/21	**Thanksgiving Break**			
11/28	Final Demo	Complete final presentation Work on final report	Complete final presentation Work on final report	Complete final presentation Work on final report
12/5	Final Presentation Turn in Lab Notebook Teamwork Evaluation	Complete final report and teamwork evaluation	Complete final report and teamwork evaluation	Complete final report and teamwork evaluation

Reference for schedule as well as other minor design document features from Spring 2022 UV Sensor and Alert System design document [6].

4 Ethics and Safety

Given that our project aims to give industry level safety to groups that otherwise would not have it, ethics and safety are a primary focus.

On ethics, one issue we have to keep in mind is that some people may be suspicious that since the project uses a microphone, it may be used to secretly record people. This misuse in turn would violate the IEEE code of ethics I.1 [7]. To dissuade these fears, we believe we would have to make sure the microprocessor only keeps track of what it needs to: instantaneous and integrated SPL and frequency.

On safety, as our project is primarily devoted to promoting safe SPL according to the previously mentioned OSHA standards, we would have to guarantee that our final product accurately, within our defined tolerance levels, converys SPL safety through both the LEDs and report. During the project, we would have to be careful to not expose any of ourselves and/or others to unsafe sound levels during testing. We would alleviate these concerns through simulating when possible and soundproofing and testing remotely when necessary.

5 Works Cited

[1] J. J. Eggermont, “Effects of long-term non-traumatic noise exposure on the adult central auditory system. hearing problems without hearing loss,” *Hearing Research*, vol. 352, pp. 12–22, 2017.

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[6] E. Boehning, G. Chan, and J. Huh, “UV Sensor and Alert System for Skin Protection (Design Document),” 05-Mar-2022. [Online]. Available: https://courses.engr.illinois.edu/ece445/getfile.asp?id=20032. [Accessed: 22-Sep-2022].

[7] “IEEE code of Ethics,” *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 13-Sep-2022].