Indoor noise monitor

ECE 445 Design Document - Spring 2019

William Xu, Ziyao Li and Quan Liu
Team 50
TA:Zhen Qin

2/16/19

1 Introduction

1.1 Objective

Maintaining acceptable noise levels in crowded areas such as apartments has always been an issue. Some people like to live in quiet environments and are easily disturbed by their neighbors. Some scenarios could include when a neighbor is having a party or playing an instrument. This can be very distracting for their neighbors especially in apartments with thin walls. Most apartments don't control the noise well. So we need a product for landlords to maintain a quiet environment so that tenants will have a good living experience. We need something to tell and warn the people indoor when they are being too noisy especially during certain times of the day such as late night. If they keep being noisy after several warnings, the device will be able to quickly resolve the issue by automatically notifying the device administrator or landlord.

Our goal is to create a portable and easy to use device that can go in rooms in the apartment and can warn people indoors when they are going above the acceptable noise levels. The device will also notify the device administrator through WiFi if they ignore the warnings. We want this device to very customizable and adjustable by offering the landlord many options in how they control their quiet environment. Some parameters we plan to let the landlord adjust are the acceptable decibel levels, the time of days where certain thresholds are set, the length of time that a certain decibel level can be maintained before a warning is sent out, and the amount of warnings to the person creating the noise until the device administrator is notified.

1.2 Background

There is definitely a noise problem in residential apartments. Numerous articles and research have been done on how residential noise levels can affect a person's health and productivity. A study from the Grantham Research Institute highlights the issues of noise, it "*analyze the health effects of residential noise annoyance using a high quality longitudinal survey of over 5000 adults in the Netherlands between 2007 and 2013."* and finds that "*health effects of residential noise annoyance, with neighbour noise relatively more damaging than street noise*" [1]. Another article from Berkeley points out the specific health effects that residential noise can have such as "*stress which, in turn, can increase your heart rate, cause your blood pressure to rise, slow down digestion*" [2]. Clearly this issue is very widespread especially in urban areas and needs to be addressed.

Currently some products exist on the market such as NoiseAware which can sense noise and send property owners alerts if the noise level exceeds a threshold [3]. However our product has a number of advantages over this. First we are capable of battery power, which makes the product more portable and easier to move around. Also our product will be cheaper because it will have a one time hardware cost, while the NoiseAware has both a hardware cost and a subscription cost. Another advantage our product has over NoiseAware is that it can give warnings to the people indoor at first which gives them a chance to fix the noise problem, whereas the competing product only just sends to the device administrator without a warning. Also to highlight why our product is better than a decibel meter, our product can give notifications and warnings through a wifi connection, adjustable thresholds, and 24 hour monitoring, all features that decibel meter does not have. Thus, it is necessary for us to build this indoor noise monitor to solve residential noise problem effectively.

1.3 High-Level Requirements

- User can set noise level thresholds on the device through WiFi, it will output light and sound alarm when threshold is exceeded and will send notifications to the user after multiple warnings are ignored.
- The device should be able to accurately measure sound levels of from 60 dB SPL to 85 dB SPL with an accuracy of ± 3 dB SPL.
- The device should be able to operate on battery power for 24 hours on a full charge.

2 Design

The device should have 5 different subsystems to make it work which is a power supply, a noise sensor, control unit, alert system, and wifi module. The power supply will make sure the device can be powered with lithium ion batteries, a power adapter to charge the batteries, and a voltage regulator to give the correct 3.3V ± 0.05V to the rest of the subsystems. The control unit accepts the noise levels and adjustable parameters from the wifi module and controls the alert system. The alert system receives the signal from the control unit to know when to alert. The wifi module will connect to user's phone via wifi and give the parameters set by the user to the control unit, and receive when to send the phone notification from the control unit.

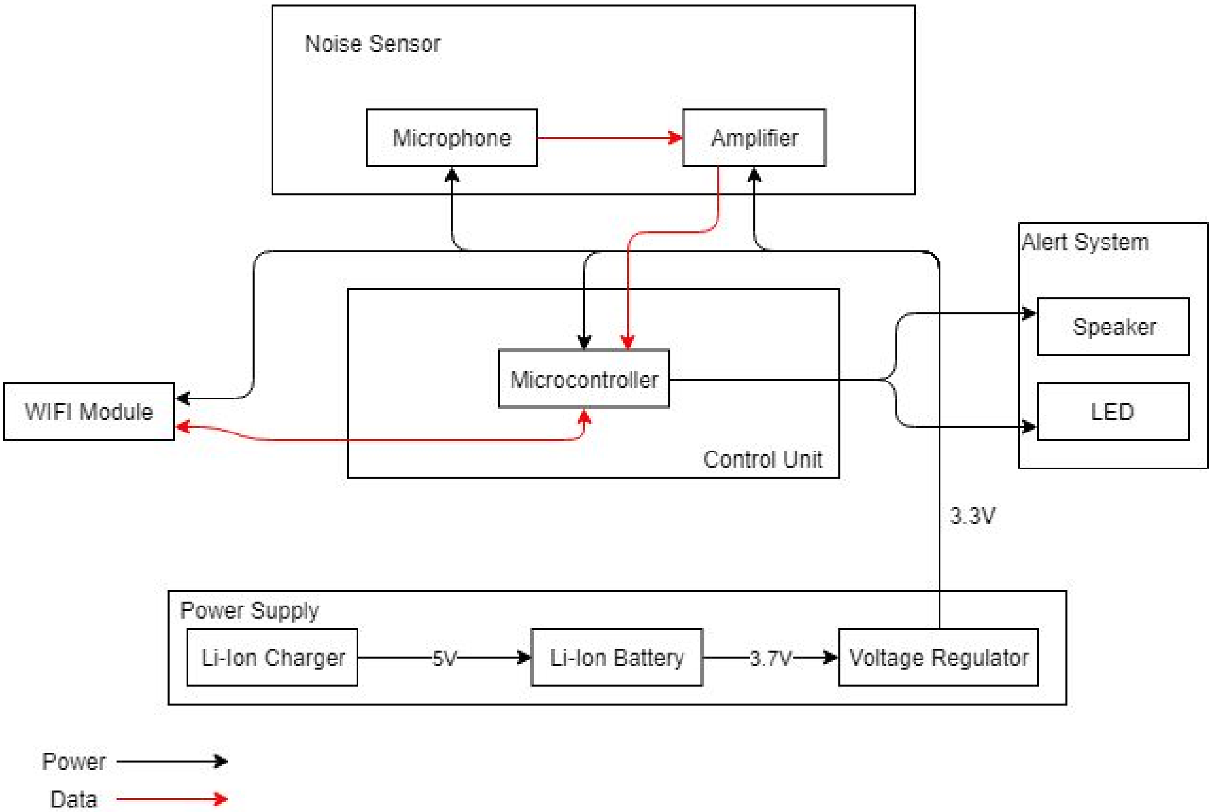

Figure 1: Block Diagram

2.1 Power Supply

The power supply will keep the device powered continuously which is 3.3V ± 0.05V with the voltage regulator. Initially the charger will output 5V ± 0.05V to both battery and voltage regulator. Then the voltage regulator convert it to 3.3V ±0.05V. While plugged, the device will be powered by the charger, and while it is unplugged it is powered by the battery.

2.1.1 Lithium ion charger

This will plug into the wall and charge the battery and power the entire device will still plugged in. This will output 5 V ±0.05V to the battery and voltage regulator.

Requirement	Verification
1. Maximum output voltage/current: 5 V ±0.05 V/1A. 2. Fully charge the battery at about 3-4 hours.	1. Connect the adaptor output to a circuit load of total resistance of 5 ohms. Use a voltmeter to measure the voltage across the load, use an ammeter in series to measure the current flowing through the load. 2. Connect the adaptor to an empty battery with the same capacity as we use. Charge the battery until it's fully charged, by connecting in series an ammeter to see when the current reaches 0.05C of the battery. Record the time used.

2.1.2 Lithium ion battery

The battery does not supply power to the rest of the circuit when the power adapter is plugged in. And it should be able to output 3.7V ±0.05V to voltage regulator when the power adapter is unplugged.

Requirement	Verification
1. Should provide 200mA at 3.7V ± 0.05V for about 24 hours.	1. Connect the battery to a circuit load of 18.5 ohms. Use an voltmeter in parallel with the circuit to measure the voltage across the load. Record the time until the voltage drops to zero.

Calculation process of capacity:

$$3.7V \times 0.2A = 0.74W$$
$$0.74W \times 24h = 17.76Wh$$

2.1.3 Voltage Regulator

It is able to accept 3.7V ±0.05V and 5V ±0.05V input and will give 3.3V ±0.05V to the rest of components in the device.

Requirement	Verification
1. Stabilize the DC voltage at 3.3V ± 0.05V which will be supplied to the rest of the components in the device.	1. Connect the output of the 5V adaptor to the voltage regulator, and connect the output of voltage regulator to a certain circuit load. Use a voltmeter in parallel to measure continuously the voltage across the circuit load to see whether it's 3.3V(an oscilloscope is also applicable to measure the output voltage level across the load over a period of time). Connect the voltage regulator again to the 3.7V battery, and the output to a certain circuit load. Use a voltmeter in parallel with the battery and a voltmeter in parallel with the load to measure the voltage across the battery as well as across the load. Continue measuring voltage across the load until the voltage across the battery drops to zero to see whether the voltage supplied to the circuit can be stabilized throughout the process.

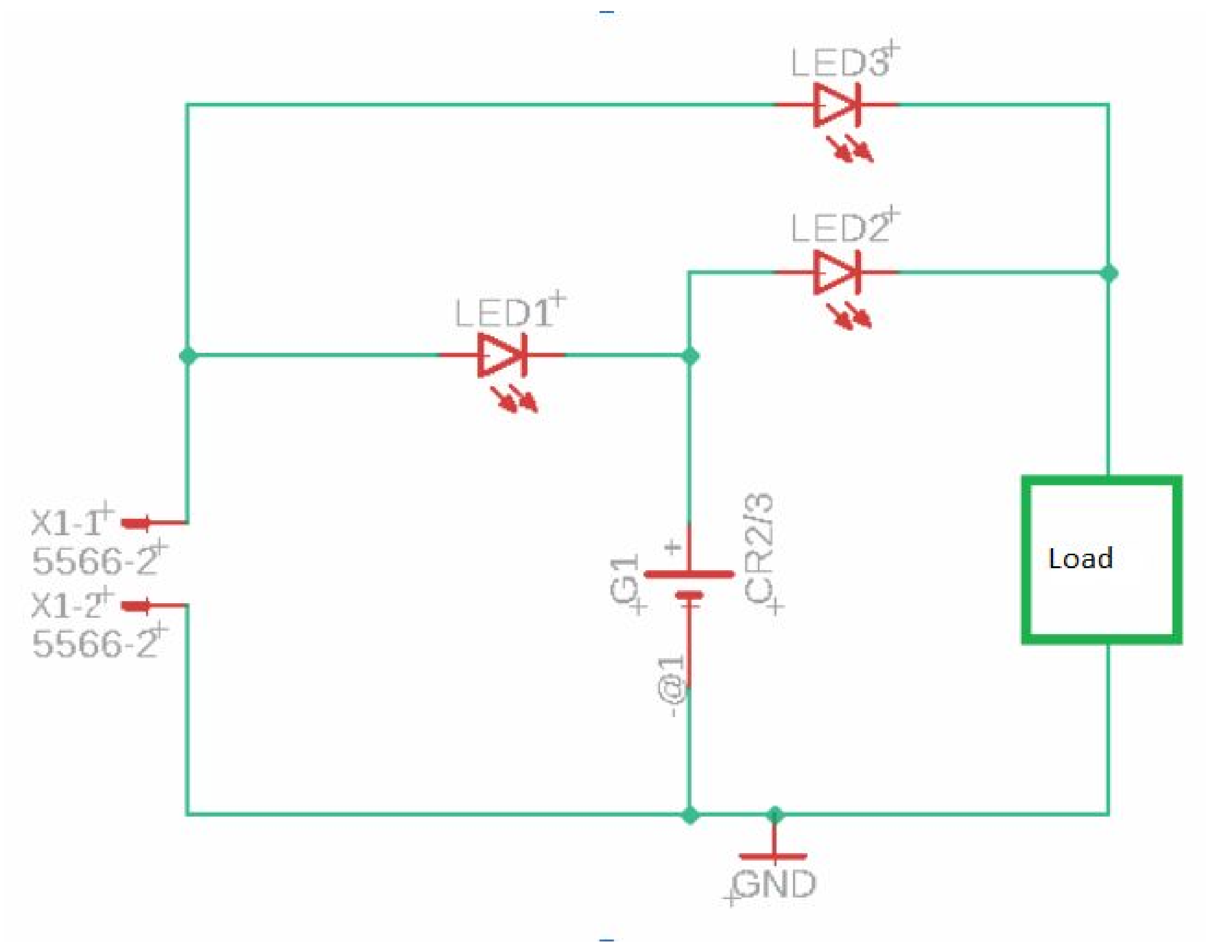

Figure 2: Power Supply Circuit

2.2 Wifi module

The module can access a WiFi network to get the threshold parameters set by the device administrator, and can send notifications to the device administrator.

2.2.1 Wifi IC

The wifi IC(ESP8266) will use UART to connect with the microcontroller. It has an SPI flash of 1MB. It will accept threshold parameters from the user's phone and output that data to the microcontroller. It will also accept the phone notification signal from the microcontroller so that it knows when to notify the phone.

Requirement	Verification
1. The wifi IC must be able to output and receive data of at least 0.1 Mbps 2. The wifi IC will use UART to communicate with the	1. A. Program the ESP8266 to connect to wifi network. B. Send a HTTP get request to the AWS server. Check whether we receive the request from the ESP8266 in the server 2. A. Connect ESP8266 to ATMEGA328 with UART. B. Send AT commands using UART

microcontroller	from the microcontroller to the wifi IC ESP8266 and see if the ESP8266 sends a response back [4]

2.3 Noise Sensor
This module contains microphone array together with amplifier. The amplifier will amplify the output of microphone and feed it into the microcontroller which contains an ADC. The digital signals will be processed by the control unit to calculate the noise levels.

2.3.1 Microphones
The microphone array will contain two MEMS microphones(**ICS-40180**) in opposite sides parallel to the floor.

Requirements	Verification
1. The microphone must sense 60 dB SPL or greater with an accuracy of $\pm$5 dB SPL	1. A. Check by connecting output of microphone to ADC of microcontroller and read ADC values. B. Keep track of the ADC value and its corresponding real dB SPL value measured by a Sound Meter. C. Then use linear regression to find the dB SPL value based on the ADC value(dB SPL= k * ADC value + b). D. Calculate accuracy by comparing the real dB SPL value to the calculated dB SPL from our linear regression.

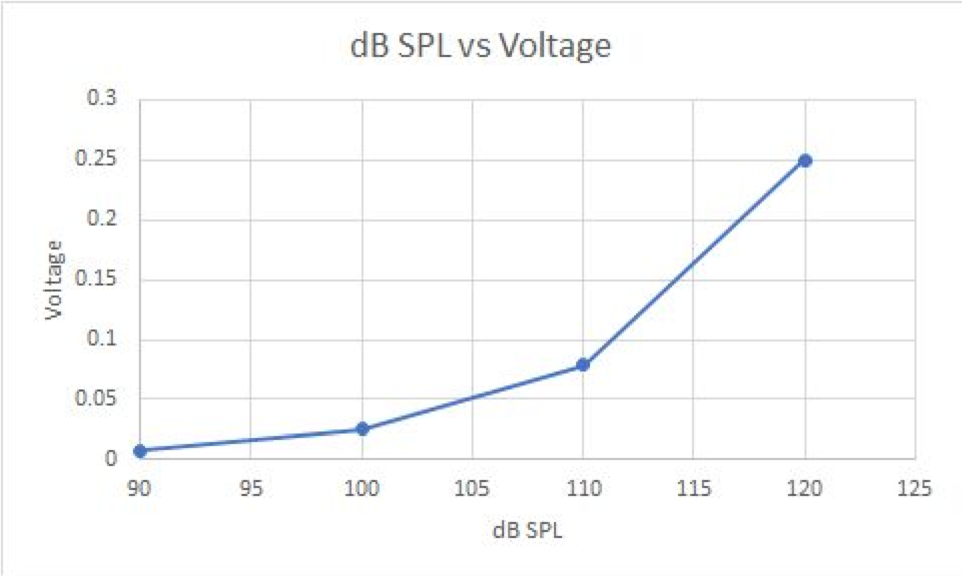

Figure 3: db SPL vs Voltage graph

2.3.2 Amplifier

Since the maximum output voltage of the microphone is 0.075V given a 110 DB SPL input, and the output DC Offset is 0.7V. Also, the ADC in the microcontroller accepts 0 - 3.3V input. So we set the gain as 4. (3.3 / (0.7+0.075) = 4.25) to amplify the output of microphone. Since the output of microphone is dependent on the loudness, we might adjust the gain when testing the microphone. The output of the amplifier will go the ADC of microcontroller.

Requirements	Verification
1. The amplifier should output an analog signal	1. A. Connect an oscilloscope to the output of the amplifier B. Give an input voltage of 2V. C. Verify in the oscilloscope that it is an analog signal.
2. The amplifier should produce a gain of 4 $\pm$0.25 to produce the desired strength output	2. A. Give the amplifier a 2V input B. Use voltage meter to test if the output voltage actually increases by the desired amount

$$A = \frac{V\,out}{V\,in} = 1 + \frac{Rf}{Rin} = 1 + \frac{30ohms}{10ohms} = 4$$

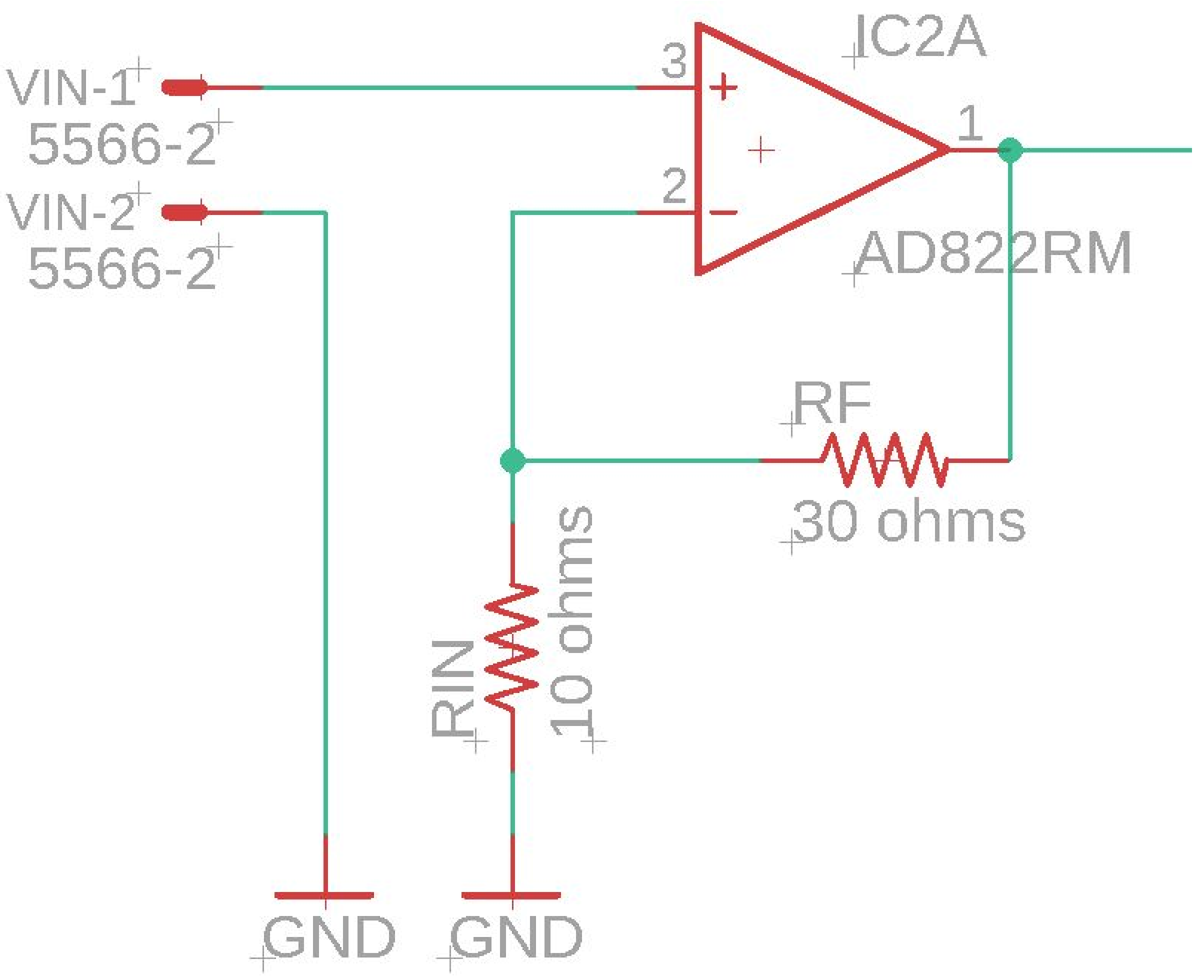

Figure 4: Amplifier

2.4 Alert System

Alert system contain a speaker and LED lights. The microcontroller will output analog wave to drive the speaker and LEDs when the sound thresholds are exceeded. The purpose is to make people indoor aware that they are being too loud.

2.4.1 Speaker

The speaker will create some kind of sound alarm and is driven by the microcontroller.

Requirement	Verification
1. The speaker should start to emit noise when microcontroller drives it. 2. The speaker should be able to	1. A. Connect the speaker with the microcontroller's PWM port. B. Hard code 3.3V analog output from microcontroller to see if the speaker emits a sound

output a sound of 80 ± 5 dB SPL	2. A. Deliver 3.3 V to the speaker, B. Measure the dB SPL with a sound meter to verify that it is 80 dB SPL, and adjust the voltage.

2.4.2 LED lights

The LED lights, driven by the microcontroller, will light up to a let people indoor know that they are creating too much noise.

Requirements	Verification
1. The LEDs should light up when the microcontroller drives it with an analog wave	1. A. Connect the LEDs with the microcontroller's PWM port. B. Hard code 3.3V analog output from microcontroller to see if the LEDs light up

2.5 Control Unit

The control unit will handle all the calculations of when to set certain thresholds of sound levels, the time of the day, when to give warnings, and when to notify the device administrator.

2.5.1 Microcontroller

The microcontroller we will be using is the ATmega328. It calculates the dB SPL with the linear regression formula we give it, and then check if noise threshold is exceeded. It also drives the LEDs and speaker with analog wave. In addition, it will use UART to connect and communicate with the wifi module ESP8266 to accept threshold parameters and send notifications.

Requirements	Verification
1. The microcontroller should be able to connect to the wifi IC ESP8266 using UART	1. A. Connect ESP8266 to ATMEGA328 with UART. B. Send AT commands using UART

2. The microcontroller should be able to control the alert system of speakers and lights through the PWM port	from the microcontroller to the wifi IC ESP8266 and see if the ESP8266 sends a response back [4] 2. Hard code to send analog output through the PWM port to see if the speakers and LED lights turn on and off

Tolerance Analysis:

One of the most important part in our circuit is where the microphone output feeds into the amplifier, which will amplify the signal so that it is at a strength where it can be processed by the microcontroller. It is important that the ATMEGA328 microcontroller receives the correct voltage so the gain produced by the amplifier needs to be accurate.
As shown in Figure 4 and the calculations below it, the amplifier gain is controlled by the resistances with the following equation:

$$A = \frac{V\,out}{V\,in} = 1 + \frac{Rf}{Rin} = 1 + \frac{30ohms}{10ohms} = 4$$

The ADC in the microcontroller only accepts voltages between 0 to 3.3 V so if we have too much gain, it could cause error in the sound level calculation. Resistor tolerance is very important because it could cause the gain to be too high. For example if the resistor error is 10% then the works case would be a 33 ohm resistor and a 7 ohm resistor which would give this gain:

$$A = \frac{V\,out}{V\,in} = 1 + \frac{Rf}{Rin} = 1 + \frac{33ohms}{7ohms} = 5.71$$

As a result, the amplified voltage output of microphone at 110 DB SPL will change from 0.775 * 4 to 0.775 * 5.71 = 4.425 V, which exceeds the input range. More importantly, even the 0.7 voltage output of microphone when the the DB SPL is low will be amplified to 0.7 * 5.71 = 3.99 V, which cannot be used by the ADC. The microcontroller will mistakenly detect it as exceeding the noise threshold even though the sound is not very loud.

Here is another calculation where we check the worst case scenario of a resistor with a 4% error. The worst case would be a 31.2 ohm resistor and a 9.6 resistor. When we calculation the gain:

$$A = \frac{V\,out}{V\,in} = 1 + \frac{Rf}{Rin} = 1 + \frac{31.2ohms}{9.6ohms} = 4.25$$

This will have amplified voltage in the range of 0.7 * 4.25 to 0.775 * 4.25, which is 2.975 V - 3.3V acceptable for the ADC. So we need to use resistors that have a tolerance of equal to or less than 4% if we want to use a 30 ohm and 10 ohm resistors for our amplifier.

In addition the way we convert the voltage from the ADC to accurate decibel values is very essential. The process is as follows, the sound goes to the microphone which outputs a voltage to the amplifier, then the amplified signal goes to the ADC which then converts it into a digital signal to be processed by the MCU.

We will use a decibel meter to measure the actual dB SPL value (using a sound meter) against the ADC values, then we will use linear regression to find the relationship between ADC value and dB SPL (dB SPL = k * ADC value + b).

Since the final ADC value goes through many devices such as microphone, amplifier and ADC, we need to take care of the errors caused by the hardwares. If there is a large error caused by the hardware, the linear regression formula won't fit the data well. So we use R^2 to determine how well the the model fits the data. We pick 0.7 as a good R^2 value, meaning that our R^2 should be greater than 0.7 and smaller than 1 to accurately measure the dB SPL.

3 Costs

For our labor costs, we are estimating that each of the 3 people will earn $30 per hour, for 7 hours a week. Our total labor costs will be:

$3 \times \$30/hr \times 7hrs/wk \times 16weeks = \$10080$

Part	**Cost**
WIFI IC ESP8266	$6.95
Microcontroller ATMEGA328	$1.96
Microphone ICS-40180	$1.52
Speaker CMR-12062S-67	$2.70
LEDs *3 LXK8-PW27-0012	$0.81
Battery	$11.50
Li-Ion Charger	$9.99
Voltage regulator	$8.25
Resistors, Capacitors, wires, etc	$10.00
PCB	$15
Total	$68.68

4 Schedule

Date	**William**	**Ziyao**	**Quan**
2/25	Design WIFI and MCU module in eagle including the schematics and PCB layout	Design noise sensor and Alert system module in eagle including the schematics and PCB layout	Design power supply module in eagle including the schematics and PCB layout
3/4	Test wifi signal and speed	Test voltage to dB SPL accuracy from the linear regression	Test power supply requirements of the PCB
3/11	Revise WIFI module schematic and PCB layout	Revise noise module schematic and PCB layout	Revise power module schematic and PCB layout
3/18	Order revised PCB and test	Order revised PCB and test	Order revised PCB and test
3/25	Assemble WIFI module	Assemble noise sensor module	Assemble power supply module
4/1	Assemble and combine all subsystems together	Assemble and combine all subsystems together	Assemble and combine all subsystems together
4/8	Prepare for mock demo	Prepare for mock demo	Prepare for mock demo
4/15	Mock Demo and debug project	Mock Demo and debug project	Mock Demo and debug project
4/22	Begin final report	Begin final report	Begin final report
4/29	Prepare for final presentation	Prepare for final presentation	Prepare for final presentation

5 Safety and Ethics

For safety, while assembling the device in the ECE lab, we will be using high voltage power sources which can potentially lead to electric shock. Also when assembling the device we will use soldering irons which can potentially lead to burns and lead to fires. We will also wear eye protection because soldering can shoot sparks as said in Cambridge safety guidelines[5] and we want to protect our eyes. We have already taken the lab safety tests, but we will review the lab safety rules further to make sure that we remember them correctly and make sure the operations are safe.

Unfortunately there are ways that the device can be abused that would go against certain code of ethics such as IEEE or ACM. A landlord could violate IEEE code of ethics #9 and ACM code 1.2 which states that we should avoid hurting others and their property [6]. Landlords can possibly set threshold levels to extremely low and unfair values so that tenants cannot do any type of activities that involve any types of noise which would violate code #9 and 1.2 because extremely low thresholds could stress them out and prevent them from necessary activities which could hurt their health. To avoid this issue we could do things like set a limit to how low of a threshold users can set for this device. Another code that could potentially could be faced with our products would be ACM code 1.6 which states that we should respect privacy [7]. Tenant might think that these devices breach their privacy rights because they will always be listening, just like people nowadays are paranoid of computer webcams spying on them or how social networks are using their data. We can prevent this by making sure our device does not save any audio being fed into the MCU, rather it will just measure the dB SPL levels and the amount of time that it happens.

References

[1] Graham Research Institute, 'Sick of Noise: the health effects of loud neighbors and urban din' 2015. [Online]. Available: http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/10/Working-Paper-213-Weinhold.pdf

[2] Berkeley Wellness, 'Sounding off on Noise' 2017. [Online]. Available: http://www.berkeleywellness.com/healthy-community/environmental-health/article/sounding-noise

[3] Noiseaware, 'FAQ' 2019. [Online]. Available: https://noiseaware.io/resources/faqs

[4] Circuit Digest 'Interfacing ESP8266 with PIC16F877A Microcontroller', 2017. [Online] Available: https://circuitdigest.com/microcontroller-projects/interfacing-pic-microcontroller-with-esp8266

[5]
Cambridge Department of Engineering Health and Safety 'Soldering Safety', 2018. [Online]. Available: https://safety.eng.cam.ac.uk/safe-working/copy_of_soldering-safety

[6]
Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html

[7]

Acm, ‘ACM Code of Ethics and Professional Conduct’ 2018. [Online] Available: https://www.acm.org/code-of-ethics