ECE 445
Senior Design Laboratory
Design Document

Urban Noise Pollution Monitoring System

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1 Introduction

1.1 Problem

Though expansion is great, as urban cities begin to grow in both population and commercial densities, they become riddled with overwhelming noise pollution from construction, traffic, businesses, and even people. While noise is measured in dB, noise pollution is typically measured in dBA, which refers to the sound that humans can hear. Some common nose ranges are 60 dBA for the human voice, 85 dBA for traffic, 100 dBA for a garbage truck, and 120 dBA for a jet takeoff [1]. Typical noise pollution for an urban city such as New York City ranges from 55- 95 dBA [2]. Although this range is broad, it is estimated by the National Library of Medicine that 30 million people are exposed to damaging levels of noise pollution every year [2].

Quick amounts of noise pollution are manageable for humans, but as people are continuously exposed to it in urban settings, it becomes damaging to health. At low levels of exposure to noise people are said to cause resentment, sleep disorders, insomnia and discomfort that interfere with one's thoughts [1]. At moderate exposure levels attention, memory, and concentration are negatively affected in young people [1]. At these levels and above , the body is physically affected with the release of stress hormones, uncontrollable body movements, and increased heart rate causing heart problems, and irreversible inner ear damage over time and since animals have more sensitive hearing, it affects pets much more [1]. In 2007, researchers did 200,000 hearing tests and found that city residents who were regularly exposed to moderate-high noise pollution found that their hearing was as if they were 10-20 years older, and the damage could not be reversed [3]. Of course, as these symptoms continue, work and school performance decreases, quality of life lowers, and potential for grave illness enlarges.

With the health of the general public in mind, there has become a need to actively fight noise pollution in urban settings, where millions of people can be harmed. Some examples of combative measures are personal relocation from harmful environments, soundproofing homes, and governmental policy to limit noise levels or when areas are allowed to be noisy. Before the government or people can combat noise pollution, however, they need to be able to accurately locate areas of high and low noise, which is where monitoring systems come into play. Current methods of monitoring noise pollution include handheld devices that measure at will or over a continuous period of time [4]. These systems are meant for more short term monitoring, are meant to monitor small areas, and only give numerical data. Larger IOT systems are complex cloud based systems made for commercial use that do analyses of noise pollution over larger areas over longer periods of time [4]. Our project is meant to be an upgrade from the handheld systems with border location based monitoring and providing graphic as well as numerical data to users. Furthermore in contrast to IOT based systems, our project will be more cost effective and easier to implement for the average person.

1.2 Solution

Our project aims to create a better solution through the use of wireless, battery-powered microphones strategically placed outdoors. This system will utilize a concentrator or gateway to collect and process data from distributed microphones, providing accurate and real-time noise pollution insights for urban planning and environmental conservation through the use of a geographical information system and web application. Through the web application, users will have the ability to see both numerical and graphical data in the form of a noise level heat map. Said heat map will use colors to differentiate between various sound levels: green, yellow, and red with gradients. Users may use this to accurately determine areas of low and high noise levels. With our project, the average person will be able to use the web application to determine what noise pollution combative method will be most effective and where it will be most effective.

1.3 Visual Aid

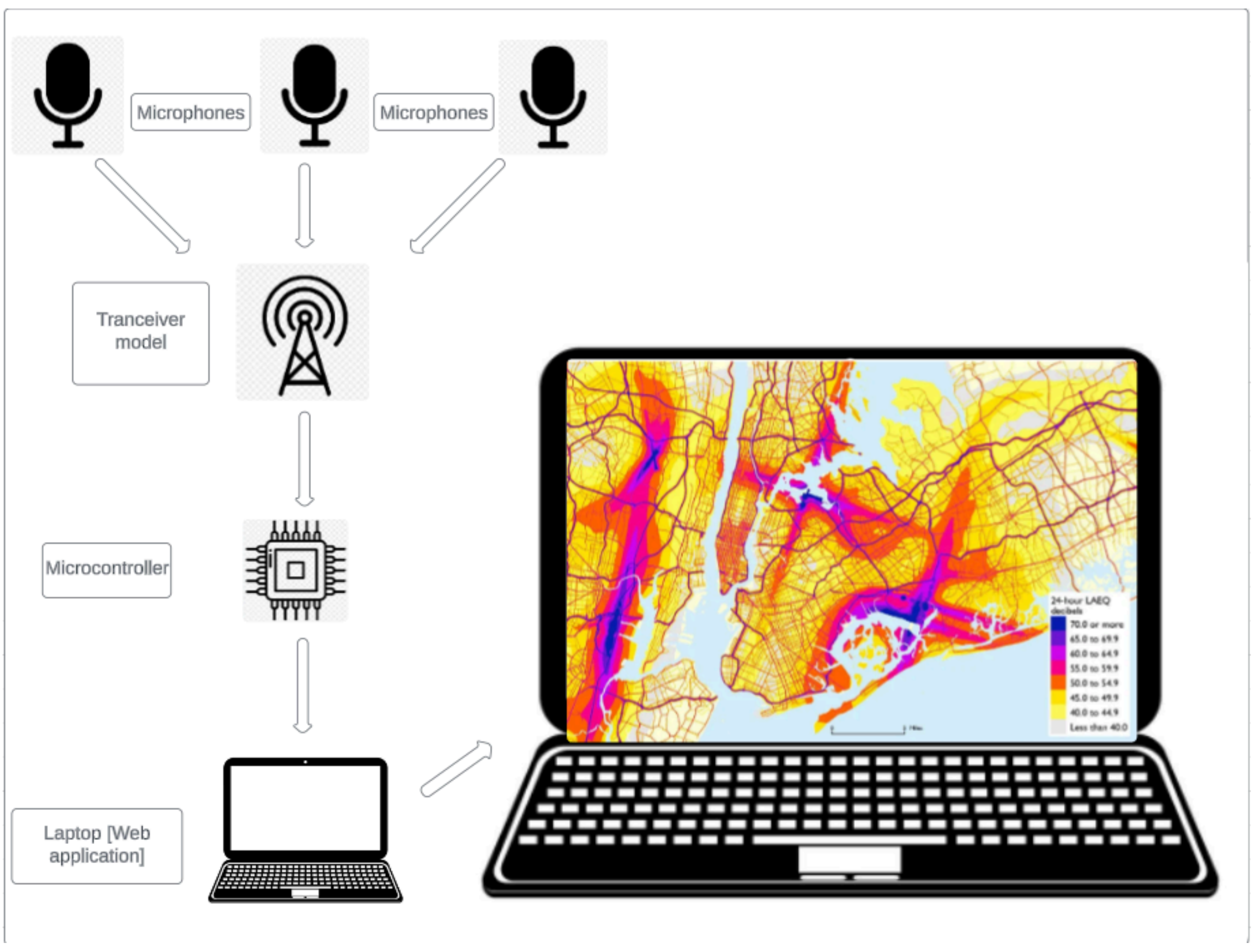

Figure 1: Visual Aid

Noise Level (dBA)	Common Sound Level	Color Indication
60	Normal Conversation	
75	Vacuum Cleaner	
85	Train or Heavy Traffic	

Figure 2: Noise Level Heat Map Sound Legend Example

1.4 High-level requirements list

1. **Real-time Monitoring and Hourly Data Reporting**: The central hub system should successfully report noise data to the central web application every hour, providing a consistent and reliable stream of information for analysis and decision-making. Furthermore, the system shall be designed such that noise level monitoring from the microphones will have a latency of being sent to the hub of no more than 5 minutes. This will ensure users have timely access to critical noise pollution information.
2. **Updating of Noise Map**: Noise map updates with each hourly upload from the central hub, ensuring an accurate representation of the space being monitored. It will use colors to differentiate between various sound levels. The representative colors will be green, yellow, and red with gradients of the colors being used to describe sound levels in between the specified sound levels.
3. **Operation Longevity:** Our system should be capable of running for at least a month utilizing a combination of proper battery choice and activation protocols. This will ensure that the system will not have to be frequently taken down in order to be charged.

2 Design

2.1 Block Diagram

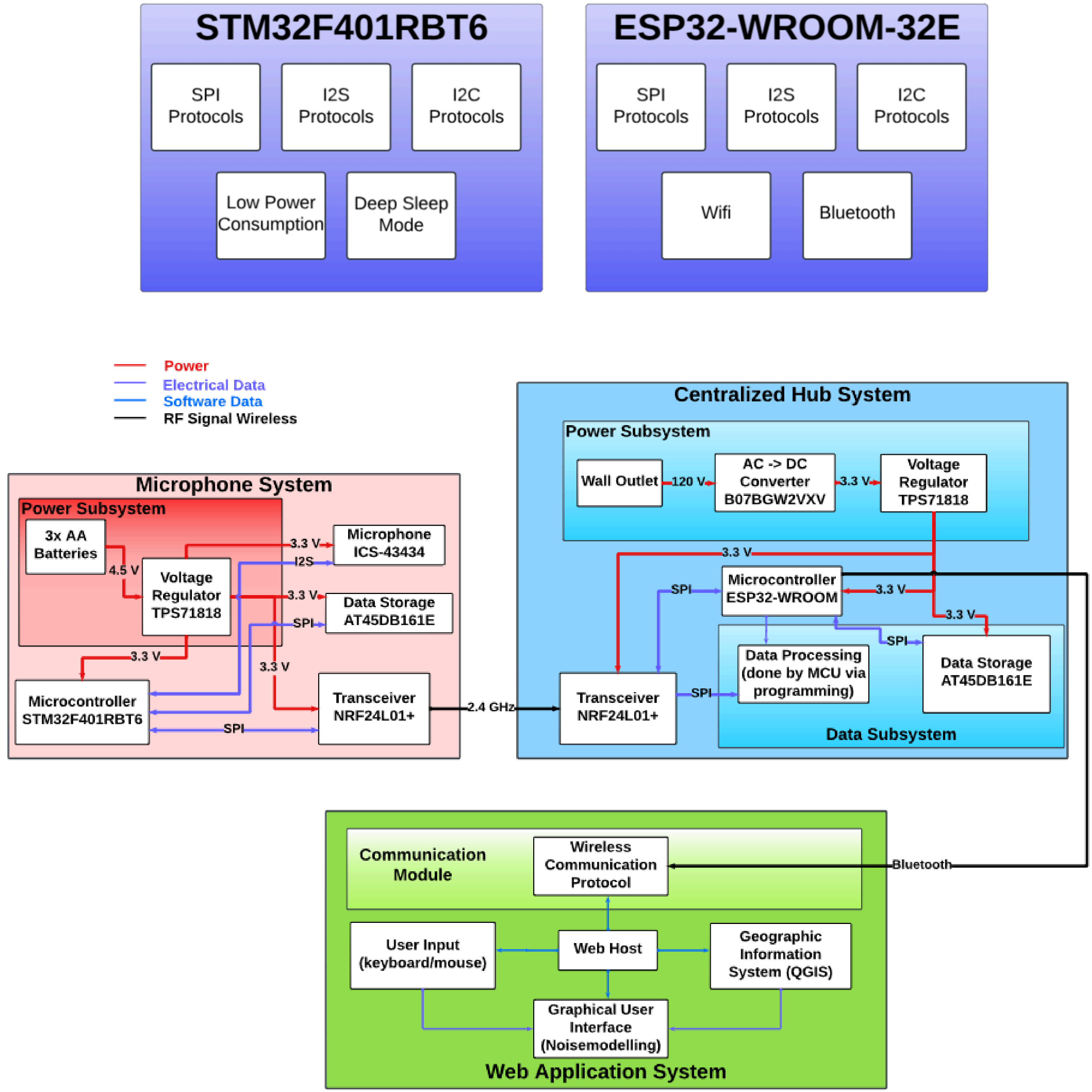

Figure 3: Block Diagram

2.2 Subsystem Overview

2.2.1 Microphone System Overview:

The microphone system consists of components designed to capture, process, and transmit sound data. Multiple microphone systems will be included in the design to enhance the system's overall accuracy in noise mapping. Each microphone system contributes to a more comprehensive and detailed understanding of the sound landscape, allowing for a representation of noise distribution in the urban environment. The microphone system consists of a power subsystem which is responsible for supplying the voltage to all components. All components outside of the power subsystem are connected to the microcontroller using wiring to transmit electrical signals. The signal transfer will be facilitated by the microcontroller, sending data to each component to complete its function outlined below.

1. Power Subsystem:
    a. AA Batteries
    Power is supplied to the system by AA batteries, emphasizing the need for a month-long operational capability to minimize downtime. This power is sent to the voltage regulator to convert the battery voltage to each component's operating point. The output voltage of the batteries will be 4.5 V, meaning there will be 3 connected in series.

    b. Voltage Regulator *(TPS71818-33)*:
    The voltage regulator converts the power supplied by the AA batteries to the correct operating voltage for each component. The regulator being used consists of two output voltages, designated by the last 4 digits in its model number. Due to the components being used in the system, we chose a 1.8 V and 3.3 V output model of the TPS718. With this, each device in the microphone system will be able to operate uninterrupted for the month-long battery life.

2. Transceiver Module *(NRF24L01+)*:
    A crucial element of the microphone system is the transceiver module, responsible for facilitating communication between the microphone system and the centralized hub. It will serve as a bidirectional communication device, receiving instructions from the central hub and transmitting data. The transceiver will also play a critical role in extending the battery life of the microphone system by providing a wake up protocol to the microphone. By receiving the instruction of when to wake the microphone from the central hub transceiver to collect data, valuable battery life can be saved. This wake up protocol allows for components in the system to not have to be active all the time, as every noise is not critical to collect, extending battery life. To accomplish this task, the

transceiver modules will communicate via 2.4 GHz RF signals and communicate with the microcontroller via an SPI protocol. The NRF24L01+ is able to transmit 2 Mbps, making it suitable for this application.

3. Microphone *(ICS-43434)*:

   The microphone itself is equipped with precision sound level detection capabilities, allowing it to capture and quantify environmental noise accurately in decibels. This capability ensures that the microphone system provides detailed and reliable information for creating a comprehensive noise map of the monitored area. Collected sound information will be sent to the microcontroller where it can then be stored to the data storage chip. It would be preferred to do this data transfer directly, but these two components cannot directly interface. All microphones will not be sending data at the same time to prevent corruption of data being received and processed by the central hub, further exemplifying the need to be able to communicate with the MCU. The microphone will communicate with the microcontroller based on an I^2S protocol.

4. Microcontroller *(STM32F401RBT6)*:

   To coordinate and control the functions of the transceiver module, the microphone system incorporates a microcontroller. This microcontroller plays a pivotal role in facilitating the transmission of data to the centralized hub, and enhancing the efficiency and reliability of the communication process. The microcontroller will provide the electrical signals necessary to communicate with each component, outlining the tasks each must complete. These tasks include beginning the microphone wake up protocol, transporting microphone information from the microphone to storage, gathering the sound information from the data storage chip to send from the transceiver, alerting the transceiver it is time to send data, and receiving the message from the central hub transceiver that it is time to send that microphone system's data. The microcontroller will communicate via SPI and I^2S protocols based on the needs of each component. Finally, the MCU features low power consumption to conserve battery life.

5. Data Storage *(AT45DB161E)*:

   The data storage component will play the role of storing the data collected by the microphone. With the data being stored it can be accessed and sent to the central hub. The data can then be written over once it has been accessed and sent to the central hub as it is now stored in another location. The data storage chip will communicate with the microcontroller via an SPI protocol in order to receive the microphone data.

2.2.2 Centralized Hub/Gateway System Overview:

The centralized hub system serves as the core infrastructure to aid in communication, data management, and processing for an accurate noise map. It incorporates a power supply, transceiver module, data storage capabilities, data processing abilities, and a microcontroller to complete these tasks. The central hub consists of a power subsystem which is responsible for supplying the voltage to all components. All components outside of the power subsystem are connected to the microcontroller using wiring to transmit electrical signals. The signal transfer will be facilitated by the microcontroller, sending data to each component to complete its function outlined below.

1. Power Subsystem:
    a. Wall Outlet
    Drawing power from a standard wall outlet, the wall outlet is responsible for supplying continuous power to the system.

    b. AC->DC Converter *(B07BGW2VXV)*:
    As the voltage from the wall outlet is in AC, the need to convert this supply to the usable DC for the components of the centralized hub is a must. Once the conversion is complete, the voltage can be regulated to each component's operating voltage. This device is a wall plug that transmits power via a universal output tip. This means that the PCB board for this device must have an adapter placed onto it to supply power.

    c. Voltage Regulator *(TPS71818-33)*:
    Given the varying voltage requirements of internal components, a voltage reduction mechanism is implemented to match the operating voltages, guaranteeing the proper functioning of the device. Like the microphone system, the TPS71818-33 chip will be used. Due to the advantage of the two output voltages, this component will be used in both systems.

2. Transceiver Module *(NRF24L01+)*:
    The transceiver module serves as the communication hub within the Urban Noise Pollution Monitoring System. Facilitating bidirectional communication, it interacts with the microphone system using radio frequencies for data reception and transmission. The bidirectional capabilities allow it to function as both a receiver and a transmitter, critical for our application. This communication flow ultimately connects the microphone system to the web application, contributing to the overall functionality of the system. When the transceiver receives the microphone data, it will send the package directly to the microcontroller for processing, where it can be stored after. It must send the data of when to wake up each microphone deployed so that the microprocessor is not overloaded with

data packages as well. This prevents any corruption of sound data and should ensure a streamlined flow of information. The transceiver module will communicate with the microphone's transceiver via 2.4 GHz RF signals and be told when to send these communication packages by the microcontroller. This component will operate on an SPI protocol to interface with the MCU.

3. Data Storage *(AT45DB161E)*:

Incorporating data storage functionality, the centralized hub system stores sound data before its transmission to the web application. This subsystem requires memory to accommodate data from multiple microphones, supporting organized data structures that facilitate retrieval and processing. The interaction between data storage and the microcontroller is critical for maintaining data integrity and reliability throughout the operation of the device. The data storage chip will communicate with the microcontroller via an SPI protocol. The MCU will be sending the transceiver data to this data chip, demonstrating the need to interface with the microcontroller effectively. This component must also have its memory accessed by the MCU to send the data to the web application.

4. Data Processing (*MCU*):

The data processing unit within the centralized hub categorizes sound data and identifies the source microphone. By efficiently processing the incoming data, this subsystem prepares it for transmission to the web application, contributing to the creation of a detailed noise map. The integration of data processing in the microcontroller ensures a streamlined flow of information and allows accurate categorization of sound data. This will be done by the microcontroller (MCU), emphasizing the necessity for the data storage chip to be able to interface with the microcontroller successfully. For the data processing, the microphone data will be characterized by its source microphone, converted into the decibel level that was recorded, and packaged into a file to be sent to the web application.

5. Microcontroller *(ESP32-WROOM-32E)*:

The microcontroller serves as the central orchestrator, handling various tasks within the centralized hub system. The microcontroller will provide the electrical signals necessary to communicate with each component, outlining the tasks each must complete. These tasks include managing/completing data processing, coordinating data storage, and overseeing communication tasks. It will also oversee the process of letting each microphone system know when to wake and collect data to preserve their battery life. The microcontroller will communicate via SPI protocols based on the needs of each component. Also, the microcontroller will have bluetooth capabilities, allowing for the transfer of the sound data after processing to the web application which will be hosted on a local computer.

2.2.3 Web Application System Overview:
The web application serves as a comprehensive and user-friendly interface to visualize, analyze, and dynamically update a noise map based on data received from the centralized hub in the Urban Noise Pollution Monitoring System. It is able to accomplish these functions by using a Graphical User Interface (GUI), a Geographic Information System (GIS), a web host, and a communication protocol. The noise map will be easily understandable by any user, displaying the noise map using color coding to indicate levels of sound. Green will indicate sound recording that is under the normal threshold for human conversation (< 60 dB), yellow for noise that begins to pose an issue for hearing (60 - 75 dB), and red will be used for sounds that can cause long term damage to a person in the vicinity (> 75 dB).

1. Graphical User Interface *(Noisemodelling)*:

    The GUI serves as the user's window into the system, displaying the noise map generated from microphone data, individual microphone files for in-depth analysis, and the spatial location of each microphone. Its connection with the GIS allows for a comprehensive representation of the monitored area. The noise map will display the decibel output in a color map, with the colors green, yellow, and red prescribed to the values above. A legend on the page will inform the user what each color represents, allowing for all users to understand the data. The noise map will also display the location of each microphone with an icon to denote the position of the microphone in the space being monitored. The icon will also be displayed in the legend. Finally, the application will allow the user to access the sound data collected from each microphone to better understand the data being collected. This will be available to the user by way of simple folders for each microphone.

    To create the noise map the open source software Noisemodelling will be used. This software allows the user to integrate with a GIS system (QGIS is the publisher's recommendation) and create a noise map of an urban area. The software allows the user to select the location they would like to produce the noise map, select the source point of where their data collection will take place, and upload their own files to create the noise map. There is also a customization option to the noise map that has the capability to color code the map, just as desired for the project.

2. Geographic Information System *(QGIS)*:

    The GIS plays a crucial role in creating the noise map background and providing an updated and adaptable map of the monitored area. This subsystem is designed to be flexible, allowing modifications based on newly acquired geographic information.

The GIS that will be used for this project is an open source software called Quantum GIS. This program allows the user to manage geospatial data. Prominent features of QGIS include the ability to create, edit, visualize and analyze this geographic data.

3. Web Host:

The necessity for a designated web host service ensures the seamless operation and accessibility of the web application. It serves as the base of operations for the user to access the collected data.

4. Communication Protocol:

The implementation of a communication protocol facilitates the reception of data from the centralized hub, enabling the upload of relevant information to the noise map. The protocol must be secure and follow all standards for transmitting captured sound data. Furthermore, it must be able to receive the data via bluetooth from the central hub microcontroller. The web application will be hosted on a local computer so bluetooth capabilities will be easily available.

2.3 Subsystem Requirements

2.3.1 Microphone System Requirements:

1. Power Subsystem:

Contribution to Overall Design:

- Provides necessary power for the entire microphone system, ensuring continuous operation and minimizing downtime.

Requirements:

- Must supply 3.3 V +/- 0.2 V continuously for approximately one month.
- Must regulate and correctly drop the supply voltage to each chip's respective operating point.

Requirement	Verification
1.) Must supply power continuously for approximately one month	1.) Turn on the digital multimeter 2.) Set the multimeter to DC mode 3.) Connect the positive probe to the V_{DD} pin of the linear regulator and connect the negative probe to ground 4.) Verify that the voltage is being supplied at 3.3 V. 5.) Repeat steps 1-4 weekly for one month

2.) Must regulate and correctly drop the supply voltage to each chip's respective operating point	1.) Turn on the digital multimeter 2.) Set the multimeter to DC mode 3.) Connect the positive probe to the V_{DD} pin on the component you are testing and connect the negative probe to ground 4.) Verify that the voltage is at the correct operating point

Table 1: Table 1: Requirement and Verification Table

2. Transceiver Module *(NRF24L01+)*:

Contribution to Overall Design:

- Facilitates real-time communication with the centralized hub, enabling transmission of sound data.

Requirements:

- 2.4 GHz radio frequency communication must be established and maintained with the centralized hub.
- Must interface with the microcontroller via SPI protocol.
- Must receive the data to wake up the microphone at the specified intervals by the central gate.

3. Microphone *(ICS-43434)*:

Contribution to Overall Design:

- Captures precise sound levels in the environment, forming the foundation for accurate noise mapping.

Requirements:

- Must detect sound levels with precision in decibels.
- Should have a wide detection range suitable for urban environments.
- Be able to send its collected sound data to the microcontroller where it can be sent to the data storage chip.
- Must be able to interface with the microcontroller to create a wake up protocol.
- Must interface with the microcontroller via I2S protocol.

4. Microcontroller *(STM32F401RBT6)*:

Contribution to Overall Design:

- Controls and coordinates the functions of the transceiver module, ensuring efficient data transmission.

Requirements:

- Must effectively control the transceiver module for data transmission.
- Should be capable of interfacing with the power supply and other components via SPI or I2S protocol.

- Must be able to access the storage chip and allow for the transfer of data to the microcontroller.
- Must be able to pass the data from the microphone to the data storage chip.

5. Data Storage *(AT45DB161E)*:
Contribution to Overall Design:
- Stores microphone sound data that is collected and allows it to be transmitted to the central hub.

Requirements:
- Must be able to interface with the microcontroller to store the sound data.
- Must be able to allow the microcontroller to access its data to send to the transceiver.
- Must be able to have new data written over the data that has been sent to the central hub.
- Must interface with the microcontroller via SPI protocol.

2.3.2 Centralized Hub/Gateway Requirements:

1. Power Subsystem:
Contribution to Overall Design:
- Supplies continuous power to all subsystems, ensuring uninterrupted operation.

Requirements:
- Voltage must be converted from AC to DC from the wall outlet and reduced from 120 V to 3.3 V +/- 0.2 V before being delivered to system components
- Voltage output must be reduced within the specified operating voltages for internal components.
- The system must provide short-circuit, undervoltage, overvoltage, and overcurrent protection

Requirement	Verification
1.) Voltage must be converted from AC to DC from the wall outlet and reduced from 120 V to 3.3 +/- 0.2 V before being delivered to system components	1.) Make sure device is connected to the wall outlet 2.) Turn on an oscilloscope 3.) Connect channel one of the oscilloscope to the AC portion of the circuit 4.) Connect channel two of the oscilloscope to the DC portion of the circuit 5.) Set both channels to read the output

	voltage of the probes 6.) Ensure that channel one reads an AC sine wave signal and that channel two is a constant DC signal and that the voltage falls to the right tolerance limits
3.) Voltage output must be reduced within the specified operating voltages for internal components.	1.) Make sure device is on 2.) Turn on digital multimeter 3.) Set the multimeter to DC mode 4.) Connect the positive probe to the V_{DD} pin on the component you are testing and connect the negative probe to ground 5.) Verify that the voltage is at the correct operating point
4.) The system must provide short-circuit, undervoltage, overvoltage, and overcurrent protection	1.) Connect an external power supply to the input of the device where the wall outlet normally supplies power 2.) Using the external supply, provide AC voltage outside the range of the standard wall outlet values 3.) Using a multimeter, measure voltage, current, and resistance and connect the probes to the power and ground pins of each component to check that all their values are within their allowed range.

Table 2: Requirement and Verification Table

2. Transceiver Module *(NRF24L01+)*:
Contribution to Overall Design:
- Facilitates bidirectional communication between the microphone system and the web application, serving as a link between the two.

Requirements:
- Communicate with multiple microphone transceivers using 2.4 GHz radio frequencies.
- Serve as both an input and output, ensuring seamless data exchange.
- Transmit collected sound data to the microcontroller when it is received.
- Send the wake up protocol to each microphone.
- Must be able to communicate with the microcontroller via SPI protocol.

3. Data Storage *(AT45DB161E)*:
Contribution to Overall Design:

- Preserves sound data before transmission, ensuring data integrity and reliability.

Requirements:

- Must have sufficient memory capacity for data from multiple microphones.
- Organized data structures must facilitate easy retrieval and processing.
- Must be able to interface with the microcontroller via SPI protocol.
- Must be able to receive the processed sound data from the microphone as well as have it be retrieved to send to the web application.

4. Data Processing (*MCU*):

Contribution to Overall Design:

- Categorizes sound data, identifying source microphones and preparing it for transmission, contributing to the creation of an accurate noise map.

Requirements:

- Categorize data based on the originating microphone for accurate representation.
- Must be able to extract the decibel level from the sound data.
- Must be able to send data to the data storage unit.

5. Microcontroller *(ESP32-WROOM-32E)*:

Contribution to Overall Design:

- Coordinates various tasks, ensuring efficient communication, data processing, and storage.

Requirements:

- Must control the transceiver module for communication.
- Handle data processing tasks, including categorization and preparation for transmission.
- Interface with data storage to manage stored information.
- Facilitate seamless collaboration among subsystems.
- Must be able to support the incoming stream of data to process, letting each microphone know when to wake up and send sound data.
- Should be capable of interfacing with the power supply and other components via SPI protocol.

2.3.3 Web Application System Requirements:

1. Graphical User Interface (*Noisemoddeling*):

Contribution to Overall Design:

- Provides users with a visual interface to interpret noise data, displaying noise maps, individual microphone files, and spatial locations of microphones.

Requirements:

- Must be responsive and user-friendly for ease of interaction.
- Display accurate noise maps generated from microphone data.

- Show individual microphone files for detailed analysis.
- Present the spatial location of each microphone on the map.

2. Geographic Information System (*QGIS*):

Contribution to Overall Design:
- Creates and adapts the noise map background, allowing visualization of the monitored area based on provided geographic information.

Requirements:
- Generate an accurate noise map background.
- Be adaptable for modifications based on new geographic information.
- Interface effectively with the GUI.

3. Web Host:

Contribution to Overall Design:
- Ensures the operational stability and accessibility of the web application.

Requirements:
- Host the web application to make it accessible to users.
- Provide sufficient bandwidth to handle user traffic.
- Maintain high uptime for continuous service availability.

4. Communication Protocol:

Contribution to Overall Design:
- Facilitates the reception of data from the centralized hub, enabling the update of the noise map with real-time information.

Requirements:
- Establish a reliable communication link with the centralized hub's microcontroller via bluetooth.
- Receive and process data from the centralized hub in a timely manner.
- Interface seamlessly with the GIS and GUI for real-time updates.

2.4 Tolerance Analysis

The most critical component of the Urban Noise Pollution Monitoring System is the microphone. Without these microphones collecting data on the surrounding environment's noise levels, there would be no feasible way to create a noise map of the monitored area. Therefore, it is critical that this component of the system work, and be able to tolerate any small changes in the circuit.

Pameteter	Maximum Rating	Comment
Supply Voltage (Vdd)	3.63V	From Datasheet [5]

Supply Current	2.5mA	From Datasheet [5]
Sound Pressure Level	160 dB	From Datasheet [5]

Table 3: Microphone Chip Data

To begin, the tolerance of the voltage will be examined for the microphone. The microphone planned to be used is an ICS-43434. According to its datasheet, the microphone can be supplied by a voltage range of 1.65 V to 3.63 V and that the V_{DD} pin needs to be decoupled by a 0.1 µF capacitor [5]. There must be careful care taken to select a capacitor that has a low uncertainty range for its capacitance in order for the microphone to operate as specified.

Next, the datasheet specifies that the SD pin must have a 100 kΩ pulldown resistor with a minimum power rating of 0.625 W [5]. Using the supply current from the data sheet and the resistor value specified we find the max power that should go to the resistor as:

$$P = I^2 \times R = 0.0025^2 * 100,000 = 0.625\, W$$

This means that in choosing a resistor, it must be able to handle this wattage.

The datasheet specifies the temperature range that the microphone can operate safely between -40°C to +85°C [5]. This is well outside the weather conditions for almost any urban environment so this does not pose an issue in the design process.

Next, a heat analysis of the components in the microphone system will be conducted in order to ensure that all temperature fluctuations can be tolerated. From the datasheet of the linear regulator (TPS71818-33), the following graph is found:

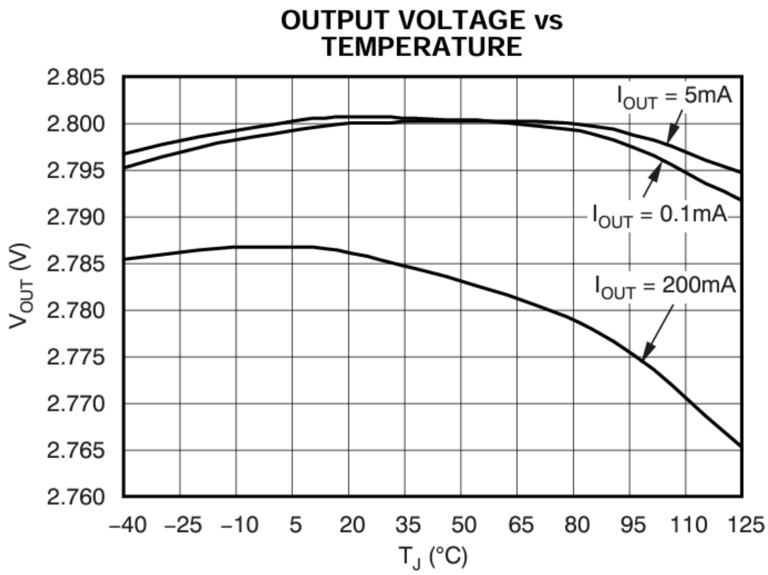

Figure 4: Output voltage vs temperature graph for TPS71818-33 [6]

From this graph it is evident that the operating temperature of the linear regulator has an impact on its output voltage that it will supply to connected components. This heat can come about from environmental conditions, or from heat dissipation in the chip itself when stepping down the input voltage. Note that this data was taken for a Vout = Vin - 0.5 V, so the voltage output is not exactly what our system would be operating in [6]. To account for this, we will examine the change in the voltage and ensure that all of our components can handle not only the seen condition, but an extreme case of our operating voltage of 3.3 V. Below is a table of all chip operating voltage ranges present in the microphone system that are connected to the regulator, as well as operating temperatures:

	Operating Voltages [V]	**Operating Temperatures [℃]**
Microcontroller [7]	1.7 - 3.6	-40 - 85
Microphone [5]	1.65 - 3.63	-40 - 85
Data Storage Chip [8]	2.3 - 3.6	-40 - 85
Transceiver [9]	1.9 - 3.6	-40 - 85

Table 4: Operating voltages and operating temperatures of components in microphone system

From this table we can observe that these components fall within the voltage fluctuations of the tested values, meaning that so far they are compatible with the regulator. Even with the average voltage swing of 8.3 mV it is clear that this won't be an issue for the system. Scaling these values up with an output voltage of 3.3 V still yields less than the 3.6 V minimum the components possess. However, they do not operate at the high end of the temperature range for the TPS71818-33, meaning the heat problem is an issue for the system. While this temperature is likely localized to the chip itself and the surrounding board space, this analysis indicates that we may need some kind of heat sink to be present in the system. Diving into the datasheet for the linear regulator reveals that it has an internal dissipation rating $R_{\Theta ja}$= 95℃/W [6]. This value indicates the junction-to-air thermal resistance. We can conduct a heat analysis now with this value. Looking at the scenario of the 3 AA batteries in series applying 1.5 V per battery into the regulator, outputting 3.3 V to the system, and utilizing the P_D from the regulator's datasheet we find [6]:

$$P_D = (V_{in} - V_{out}) * I_{out} = [3(1.5\,V) - 3.3] * 0.2\,A = 0.24\,W$$

With the 0.24 W being dissipated by the chip, we can then use the following equation to make sure that the Θja is within the limits; where T_j is the max operating temperature of the regulator (125 ℃), T_a is ambient temperature (25 ℃), and P_D is the power found above. If the value is above the listed datasheet value, the component can handle the power dissipation. If not, then we will have to consider heat sink options. The equation was derived from a Texas Instrument Linear Regulator Guide [10]:

$$\theta_{ja} = \frac{T_j - T_a}{P_D} = \frac{125-25}{0.24} = 416.67\ ℃/W$$

This value is well above the listed value on the datasheet of 95 ℃/W. This indicates that the component will run cooler than the max temperature for our use. Therefore, we can confidently conclude that the linear regulator will not reach the operation point of 125 ℃ and the components are safe.

The final analysis needed is to determine our maximum power consumption in comparison to the the power that can be delivered by our battery.

Microphone System						
Component	Typical Current			Max Current		
	Sleep/Standby	Low	High Performance	Sleep/Standby	Low	High Performance /RUN
Microphone	1.20E-05	2.30E-04	4.90E-04	2.00E-05	3.00E-04	5.50E-04
Voltage Regulator						2.00E-01
Microcontroller				1.20E-05		1.28E-04

Transceiver					3.20E-04		1.35E-02
Storage					2.50E-05		7.00E-03
Total Current					3.77E-04	3.00E-04	2.06E-02
Total Time(h)					1.59E+04	2.00E+04	2.91E+02

3 Cost and Schedule

3.1.1 Component Price

Part Description	Model Number	Quantity	Price Per Item	Extended Price	Part Link
Microphone	ICS-43434	5	$3.13	$15.65	Mic
Linear Regulator	TPS71818-33	4	$2.26	$9.04	Lin Reg
Battery	AA Batteries	1	$6.98	$6.98	Batteries
Microcontroller for Mic	STM32F401RBT6	5	$6.40	$32.00	MCU for Mic
Microcontroller	ESP32-WROOM-32E	2	$2.50	$5.00	Micro
Data Storage Chip	AT45DB161E	7	$2.70	$18.90	Data Storage
Transceiver	NRF24L01+	1	$13.99	$13.99	Transceiver
AC -> DC Converter	B07BGW2VXV	1	$6.99	$6.99	AC-DC
Resistor	100kOhm	10	$0.23	$2.30	Cap1
Capacitor	0.1uF	10	$0.10	$1.00	Cap2
DC Universal Output Pin	COOLM Green F to F	1	$5.90	$5.90	DC Adapter
Capacitor	2.2uF	10	$0.12	$1.20	Cap3
Capacitor	4.7uF	10	$0.10	$1.00	Cap4
			Total Part Cost:	$119.95	

3.1.2 Labor Breakdown

The Labor cost is based on the assumption that an Illinois ECE graduate would be compensated on average $43.64/hour.

Project Component	Description	Time	Cost
Centralized Hub	Research	15	$654.60
	Design	10	$436.40
	Assembly	2	$87.28
Microphone System	Research	8	$349.12
	Design	6	$261.84
	Assembly	2	$87.28
Web Application	Research	20	$872.80
	Creation	20	$872.80
Cost Per Person			$9,055.30
Team Cost			$27,165.90

3.2 Schedule

Week	Task	Person
February 22nd - March 2nd	**Finalize Proposal and Submit February 23rd 3:00-5:00 PM**	Everyone
	Design Review February 28th 2:30 PM	Everyone
	PCB Review March 1st 3:00-5:00 PM	Everyone
March 3rd - March 9th	**Start KiCAD for all subsystems March 5th**	Marc & CJ
	Continue KiCAD for all subsystems March 6th	Marc & CJ
	Continue KiCAD for all subsystems March 7th	Marc & CJ
	PCBway Order March 5th 4:45 PM	Everyone
	Teamwork Evaluation I March 6th 11:50 PM	Everyone
March 10th - March 16th	SPRING BREAK	
March 17th - March 23rd	**Solder March 17th**	Everyone
	Start Web Development for Noise Map March 18th	Cornell
	Continue Solder and Web Development March 19	Marc
	PCBway Order March 19th 4:45 PM	Everyone

March 24th - March 30th	**Test Microphones and Transceivers March 24**	CJ
	Continue Web development (with Jason hopefully) March 25	Cornell
	PCBway Order March 26th 4:45 PM	Everyone
	Individual Progress Reports March 27th 11:59 PM	Everyone
March 31st - April 6th	**Get transceiver and Microphone to communicate March 31**	CJ
	Get transceiver and Microphone to communicate April 1	Marc & Cornell
	Repeat for other 2 Microphones April 4	Marc
	PCBway Order April 2nd 4:45 PM	Everyone
April 7th - April 13th	**Web Development April 8**	Cornell
	Web Development April 9	Cornell
	Finalize everything April 10	Everyone
	PCBway Order April 9th 4:45 PM	Everyone
April 14th - April 20th	**Start Presentation Prep**	Everyone
	Start Final Presentation	Everyone
	Work on Final Presentation	Everyone
	Mock Demo April 16th 5:30 PM	Everyone
	Team Contract Fulfillment April 19th 11:50 PM	Everyone
April 21st - April 27th	**Work on Final Presentation**	Everyone
	Work on Final Presentation	Everyone
	Work on Final Presentation	Everyone
	Final Demo April 22nd - April 24th	Everyone
	Mock Presentation April 25th - April 26th	Everyone
April 29th - May 4th	**Work on Final Presentation**	Everyone
	Work on Final Presentation	Everyone
	Final Presentation	Everyone
	Final Paper May 1st 11:59 PM	Everyone
	Lab Notebook May 2nd 11:59 PM	Everyone

4 Ethics and Safety

4.1 Ethics

When it comes to the use of microphones, there are a couple of things that need to be considered in terms of privacy and/or misuse of information collected. We comprehend and are aware of the potential dangers and violations of rights our idea can cause. Our group acts in alignment with the IEEE Code of Ethics adopted by the IEEE Board of Directors along with revisions through June 2020 [11, 12]. We aim to uphold and abide by the standards of:

1. **Holding in high value the safety, and health of the public making sure our design complies with ethical and contained practices, and securing the privacy of others.**

   Our group will adopt technological practices that involve only storing the numerical information relating to the decibels of the loudness of the sounds being picked up and not storing the content of the words being spoken. Such practices have already been done by companies like Amazon with their Alexa and Apple with their Siri, where the device only stores data when keywords are spoken. This is done through the study of acoustic patterns which we aim to also adopt.

   We are committed to ethical and contained practices, ensuring that the collected sound data is used solely for the purpose of monitoring decibel levels to assess and mitigate noise pollution. We will not use the data to analyze or extract conversations or voice data. Any stored data will be securely managed and protected to prevent unauthorized access, aligning with our commitment to safeguarding privacy.

   To avoid inadvertently collecting and using private conversations or voice data, our urban noise pollution monitoring system will employ a sound filtering and processing approach. The system will be designed to filter out low frequencies such as speech, as that is not dangerous to human hearing, and focus on capturing and analyzing environmental noise levels that can cause harm. This will involve implementing digital signal processing algorithms to differentiate speech and other types of environmental noise, such as traffic, construction, or industrial sounds. By implementing these signal processing algorithms, we can confidently assure the public that private conversations will not be stored in our system or data collection practices.

2. **Avoiding the illegal behavior of professional conduct and accepting any forms of bribery.**

   Our team understands that technology with the ability to listen in on others is very sought after in politics, the finance business, and many other professions for the aim to benefit financially, or politically over another. We strive to uphold integrity by undeniably refusing to sell or be bribed by anyone to modify our idea to store the content of the conversation in order to be bought or sold.

3. **Accepting and even looking for constructive and beneficial feedback of ideas, technical work and processes; being willing enough to implement those changes for the betterment of the project.**

   We understand that we are limited in time and resources for this project, thus we understand that we need to be as efficient as possible, capitalizing on the brainpower and experience we have around us. That information gathered is only valuable through actual implementation though, so we will strive to be humble and make sure the project is done in an efficient manner.

4. **To treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others.**

   We understand that the people that comprise our team are human and deserve love and respect regardless of race, ethnicity, religious or political views. We will uphold the same amount of respect for all. This is a non-negotiable standard that we will uphold. We will consider all ideas equally and never discriminate while fleshing out the project. This goes the same for the advice we seek and take as well.

4.2 Safety

In this section we will discuss the consideration of public safety regarding our idea and the assembling of it.

4.1.2 Avoid harm

The only harm we can envision occurring in regard to our idea is our suspended microphone devices potentially falling and hitting someone. We will be certain of its secure suspension using the knowledge of the workers in the hardware shop on the first floor of ECEB. Also, as a backup, we will make sure to place them in positions where people would not be walking (i.e. a corner or above a shelf); this way it couldn't harm them if it did fall. We will also have to be cautious in the assembly of our idea. We plan to incorporate a microprocessor which requires us to solder and deal with heat. We plan to only work in the lab, where we are provided safety measures, instead of in our rooms with our own equipment.

We also plan to use batteries in order to make our design wireless. In order to appropriately do so, we will take the correct measures by reading the necessary documents, like datasheets and safety precautions, needed in order to avoid fires or the overloading of the batteries. In case of failure, we will familiarize ourselves with the safety equipment in the lab and understand what to do in case of an exploding battery.

5 References

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