Roadside Sound Meter

ECE 445 Design Document

Jordan Rodier, Charlie Yang, Wentao Jiang
Team 27
TA: Mengze Sha
10/3/2019

Table of Contents

1 Introduction **2**
1.1 Problem and Solution Overview 2
1.2 Background 2
1.3 High-level Requirements List 2
1.4 Visual Aid 2
2 Design **3**
2.1 Block Diagram 3
2.2 Physical Design 4
2.3 Block Design 5
2.4 Schematics 12
2.5 Calculations 14
2.6 Flow Charts 16
2.7 Tolerance Analysis 17
3 Costs **18**
3.1 Labor 18
3.2 Parts 18
3.3 Sum of Costs 19
4 Schedule **20**
5 Ethics and Safety **21**
References **22**

1 Introduction

1.1 Problem and Solution Overview

Despite regulations and laws limiting the maximum amount of noise vehicles can produce in some areas, many drivers fail to comply. Common sources of noise made by drivers include music played at high volumes, vehicle horns, and noisy exhausts. The noise can be especially disturbing near residential areas, schools, and churches, to name a few. However, it is both expensive and unrealistic to assign police officers to monitor the noise [1]. An automatic monitoring system is much more practical and economical.

Our proposed solution to this problem is a roadside system that warns the drivers of these noisy vehicles, which is similar to speed radars. This roadside system utilizes a pair of microphones on each side of the road to detect and track the noisy vehicle. A warning signal will then be sent to the lane the loud vehicle is on. For the law-enforcement purpose, our system also includes a camera that captures the license plate of the noisy vehicle.

1.2 Background

There are laws governing the noise the vehicle can produce. For example, in Illinois Vehicle Exhaust Noise Laws, passenger and other vehicles under 8,000 pounds in weight to emit no more than 76 A-weighted decibels (dBA) on highways where the speed limit is under 35 miles per hour, or 85 dBA on highways with a speed limit over 35 miles per hour. Violation can lead to a $75 - $125 fine [2]. In Florida, the state laws clearly regulate that the amplified sound produced by the vehicle cannot be audible 25 feet from the vehicle [3].

However, currently, there is no automated system for detecting vehicle noise in Illinois. A system similar to our project is being tested in France, but it requires overhead mounting on a tall pole [1]. Unlike the French system, the units in our project could be mounted much lower at the same height as roadside speed radars.

1.3 High-level Requirements List

- This system must be able to use a pair of microphone arrays to track vehicles in up to 4 lanes of traffic, moving up to 40 miles per hour.
- Each unit should detect loud vehicles above 76 dBA and give loud vehicles at least 2 seconds of warning before passing the system.
- Cameras should capture the license plate clearly so the characters can be read in at least 80% of detections outside the volume limit.

1.4 Visual Aid

Figure 1 shows the placement of the units in our project. The two array units (marked in red) will be deployed so that they are parallel to each other, the same height above the road surface, and the same distance *d* away from the edge of the road as each other. The spacing *r* between the two microphones (marked in purple) in each array will be 1 inch. The other distances, *w* and *m*, represent the individual lane width and median width respectively.

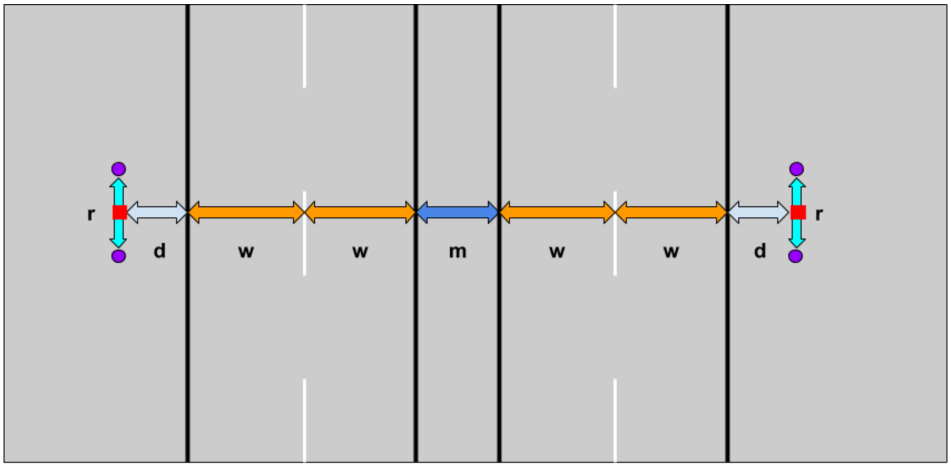

Figure 1. Unit Roadside Placement

2 Design

2.1 Block Diagram

Having two separate units, as shown in Figure 2, on each side of the road allows for 2 arrays to be used with less sound obstruction from multiple cars. Each array's localization angle outputs could then be compared to track cars in 2-dimensional space. This will allow for better accuracy in tracking than a single array while still being able to be mounted closer to the ground.

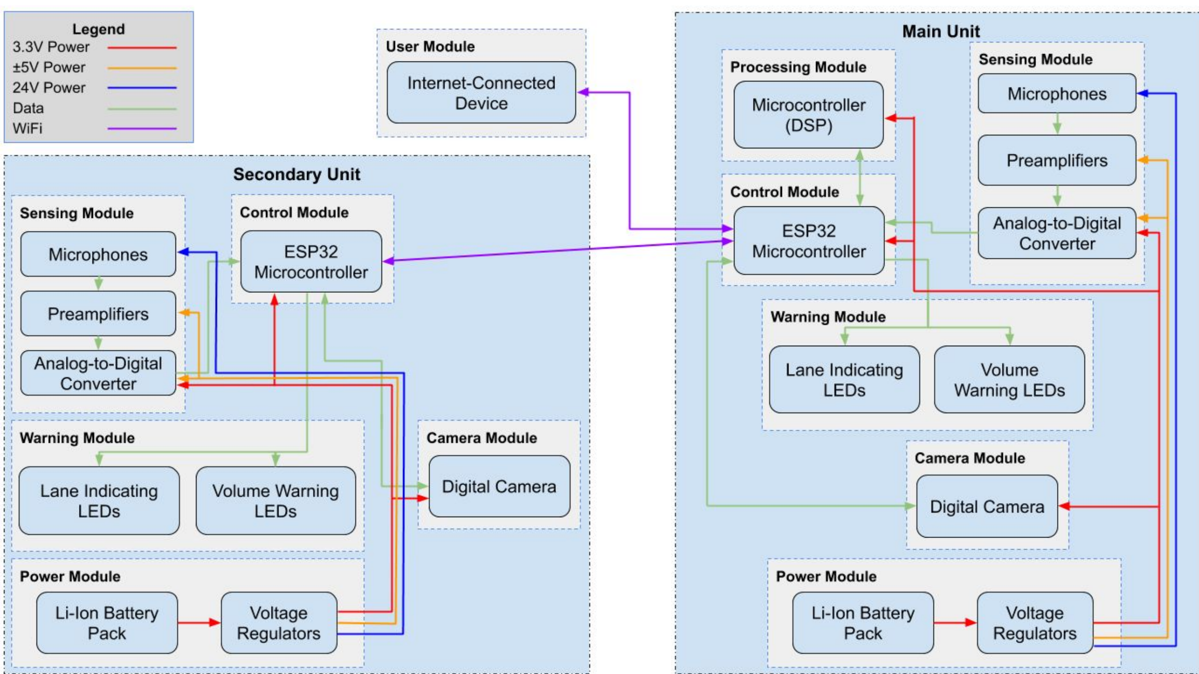

Figure 2. Block Diagram

2.2 Physical Design

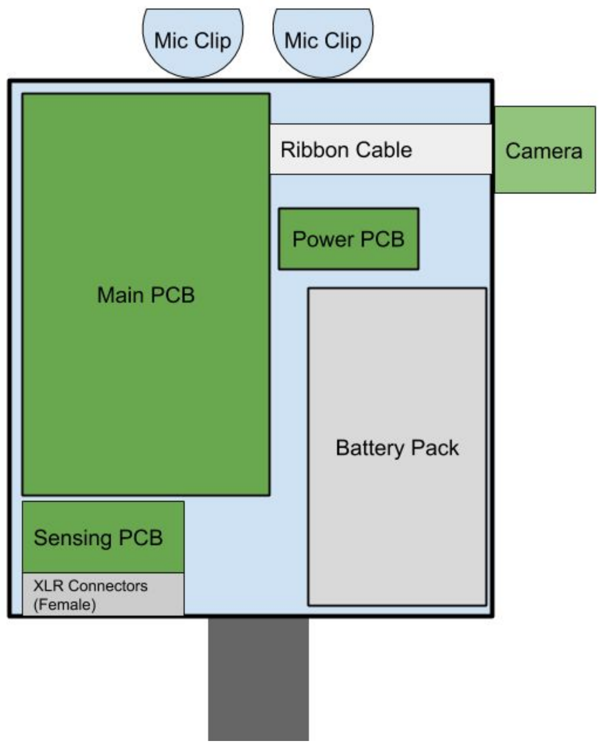

Figure 3. Physical Unit Layout

Each unit will be contained within a sealed box that can be mounted to a short pole, about four to seven feet tall. At the top of the box will be mic clips allowing a microphone capsule separation equal to *r* from Figure 2. There will be a camera enclosure mounted to the side that will be angle adjustable. Female XLR receptacles are mounted to the bottom for connecting the microphones to each unit. Most microphone cables are three to five feet long and will need to be managed and tied down to the outside of the box. The battery pack should be mounted with the output connector near the power PCB. For modular design, we decided to use three PCBs for each unit. The Power PCB contains the voltage regulators, connected to the battery pack. The Sensing PCB contains the preamplifier, which receives inputs from the XLR connectors, and the ADC. The Main PCB contains the connection to the ESP32 microcontroller development board and the LEDs. In the main unit, the Main PCB will also contain the STM32 microcontroller. The two LEDs in the warning module are also contained on the Main PCB for demonstration purposes. The cases are openable, so we can observe the LEDs when testing.

2.3 Block Design

2.3.1 Sensing Module

Each sensing module receives the sounds of passing cars and translates them to a signal usable by the control modules. Microphones typically produce fairly low voltages [4] that need to be amplified before being converted to digital. The preamplifier will take the microphone outputs which are on the order of 5-50 mV and convert them to up to 3 V. The analog-to-digital converter (ADC) then takes the amplified signals and samples them, converting them to binary samples for processing. These samples are then sent to the control module, and in the end, they will be analyzed by the processing module.

- **Microphones**

  We will use the Behringer ECM8000 for its generally flat response from 20-20000 Hz, as seen in Figure 4 [5]. Using a flat response makes applying the A-weighted filter simpler since no frequency correction would be needed before the A-weighted filter. The omnidirectional response ensures ease of use in array processing. The ECM8000 is a condenser microphone and will require 15-48V DC power to work [5].

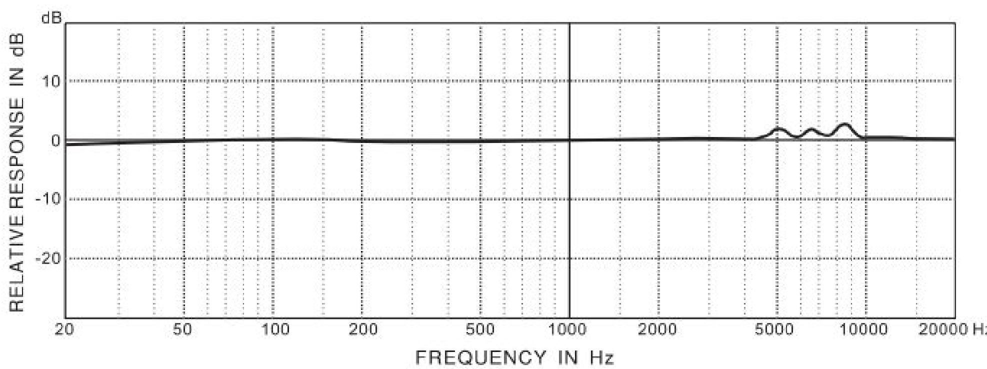

Figure 4. Relative Response of Behringer ECM8000 Microphone [5]

Requirements	**Verification**
1. Flat response from 40-20000 Hz	1a. Measure voltage output on a multimeter in response to a constant volume sound source playing tones from 40-20000 Hz at a distance of five feet away. 1b. Check output voltages differ by only ±3 dB.
2. Output voltage follows directly inversely to distance over 5-250 feet	2a. Use constant volume sound source at multiple distances on axis from the

	microphone. 2b. Measure the output voltages on a multimeter, ensuring the voltage stays within 5% of the median voltage after accounting for loss over a distance.

- **Preamplifier**

  We are planning to use Texas Instruments INA217 as the preamplifier in our sensing module. The preamplifier takes in the low outputs from the microphone, which are typically in the millivolt range, and converts them to around 3V, which is the recommended analog input voltage for most ADCs on the market. The output is fed into the ADC. Our project is very demanding on the fidelity of the collected data, so the distortion in the audio signal should be as low as possible. The datasheet of INA217 lists it as a professional microphone preamp, so it meets the requirement of our project perfectly. Furthermore, on the 6th page of the datasheet, the amplifier’s gain error is less than 0.5%, the nonlinearity is less than 0.0006, and the voltage noise is less than 3.5 nv for every square root Hz [6]. In Figure 5, we can also see that the frequency response is constant for our frequency range.

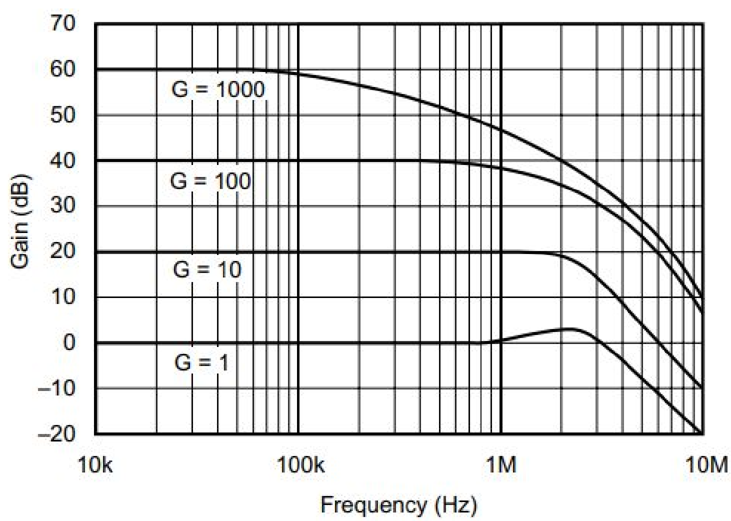

Figure 5. Frequency Response of INA217 Amplifier [6]

Requirements	Verification
1. Linear gain of 30-40 dB over 20-20000 Hz	1a. Set gain to within range. 1b. Using a signal generator, input a constant magnitude sine wave into the input of the preamplifier circuit and

	adjust over the whole range. 1c. Measure the output voltage on a multimeter, ensuring the voltage stays within 5% of the set amplified voltage.
2. Linear phase delay over 20-20000 Hz	2a. Connect the input of the preamplifier to a signal generator, and the output to a vector network analyzer. 2b. Configure the signal generator to send a constant magnitude sine wave into the preamplifier and adjust the frequency over the whole range. 2c. Record the phase delay of each frequency and make sure that the phase delay is within 5% of the linear approximation line.

- **ADC**
  The PCM1803A stereo A/D converter we are using has two analog inputs, which are the L-channel and R-channel respectively. The A/D converter would then sample them and convert them into 24-bit 2-channel audio data. PCM1803A's sampling rate ranges from 16 kHz to 96 kHz, which is sufficient for our project. The audio data can be transferred to the ESP32 via 24-bit I^2S format [7].

2.3.2 Control Module

Both units will contain an ESP32 microcontroller development board that will handle WiFi communications between the main unit and the secondary unit [8]. They send control signals between each other and the user module. In both units, the ESP32 controls the sensing module, warning module, and camera module. The ESP32 in the secondary unit will additionally transmit pictures from the camera module and audio from the sensing module to the main unit. The incoming audio signals from both units are then passed to the processing module.

Requirements	**Verification**
1. Transmit and receive data over at least 100 feet using 2.4 GHz WiFi	1a. Power each ESP32 module separately with 3.3V. 1b. Transmit data from one to another from at least 100 feet away.

2. Communication delay less than 100 ms at 100 feet	1c. Ensure identical data is received on the second unit by outputting to a computer over UART. 2a. Turn on an LED on one unit to signal the beginning of data transmission and begin a timer. 2b. Transmit data from one unit to another from 100 feet away. 2c. Turn on an LED on second unit when first bit of data is received and stop timer. 2d. Ensure identical data is received on the second unit by outputting to a computer over UART.

2.3.3 Processing Module

The processing module acts as a digital signal processor (DSP) for the entire system. Support for 32-bit floating point operations is essential. The STM32F446 contains an ARM Cortex M4 processor that includes floating point instructions. The onboard memory is enough to store at least 100 ms of audio samples and localization computations. This microcontroller supports SPI for communicating with the ESP32 control module and UART for outputting debug signals to a computer [9].

The processing module will receive a 24-bit 2-channel audio input from each ADC through the ESP32. Each channel of the inputs will then need to be converted to frequency domain and processed through localization. The phase delays for each frequency bin and angle used will be pre-calculated and stored in program memory. At the end of localization a set of angles where a vehicle is detected is sent back to the ESP32 for location tracking. Additionally, if a vehicle's sound level is above the threshold, that set of angles will be flagged.

Requirements	**Verification**
1. Can process data fast enough to output angle results every 200 ms	1a. Supply 100 ms of audio from two microphones. 1b. Raise an output pin to HIGH to show start of computation. 1c. Process this input twice and lower an output pin to LOW to show computation is finished. 1d. Measure time output pin is high on an oscilloscope and check accuracy of output

	angles over UART connection to computer.

2.3.4 Warning Module

Each warning module contains two pairs of LEDs, one pair for each possible lane on each unit's side of the road. The green LED indicates the detection of a car in that lane. The red LED indicates the detected car's volume is above a certain threshold. These are for demo purposes and only need to be visible to an observer near each unit.

Requirements	**Verification**
1. Each LED must be visible 10 feet away with a drive current of 10 mA	1a. Connect LED through a resistance to a power supply set to 3.3V. 1b. Measure current of circuit on a multimeter to ensure near 10 mA. 1c. Point LED directly at the viewer and observe from 10 feet away. 1d. Ensure LED is easily visible.

2.3.5 Camera Module

Each camera module has one OV7670 camera mounted. Similar to the warning module, it will be triggered by the control module. The camera should be pointed at the back of cars to capture their license plate as they pass the system. The camera is programmed and controlled by the control module using I^2C [10]. The pictures are sent to the control module by a parallel connection.

Requirements	**Verification**
1. Can focus at a minimum of 150 feet away	1a. Program the camera for VGA output (640 x 480) 1b. Set focal length at maximum range 1c. Stand 150 feet away with a license plate 1d. Take pictures at varying distances above 150 feet until picture is in focus and license plate is readable

2.3.6 Power Module

We will use a battery pack that outputs power via a barrel connector in each unit. A voltage regulator will then convert the battery output voltage to voltages usable by the active components. Ideally, the battery packs would charge from a solar panel on each unit, but we determined this to be unnecessary for the purposes of showing the system functions properly within this course.

- **12V DC Battery Pack**
  Each unit needs its own battery pack to store and supply power. Components in our project uses different supply voltages, including 3.3V, 5V, and 48V. Therefore, we decide that it is best to use a battery pack that supplies 12V to facilitate conversion, and we are using Talentcell Rechargeable 6000mAh Li-Ion Battery Pack. We would use linear regulators and boost converters to supply voltage for different components, so the current output wouldn't be an issue, as listed on the datasheet of the regulators [11].

- **Linear Regulators**
  The microcontrollers, preamplifiers, and ADCs require 3.3V and ±5V power to work. We will be using two versions of LD1117 low-dropout regulators, which would take the battery's 12V output and convert it down to 3.3V and 5V [11].

Requirements	**Verification**
1. The 3.3V linear regulator takes in 12V output convert it down to 3.0-3.6V.	1a. Connect the input of the linear regulator to a power supply, and the output to a multimeter. 1b. Observe the output voltage on the multimeter and make sure that it stays within the range.
2. The 5V linear regulator takes in 12V output convert it down to 4.8-5.5V.	2a. Connect the input of the linear regulator to a power supply, and the output to a multimeter. 2b. Observe the output voltage on the multimeter and make sure that it stays within the range.

- **Switching Converter**
  The linear regulators are best for converting a DC voltage to a lower voltage. They are not good for converting to negative voltages. A switching converter is able to do this conversion well. We will use the TPS6755 to convert the +5V from the linear regulator to -5V [12].

Requirements	Verification
1. The switching regulator takes in +5V and convert it down to -4.8 to -5.5V.	1a. Connect the input of the switching regulator to a +5V power supply, and the output to a multimeter. 1b. Observe the output voltage on the multimeter and make sure that it stays within the range.

- **Boost Converter**
  The microphones require phantom power to work. The LM2577 DC-DC boost converter should convert a 12V input to +15-48V at a current up to 50 mA [13]. Note that the output range can be found on the microphone's datasheet [5].

Requirements	Verification
1. Supplies at least 50 mA at 23.5-24.5V output.	1a. Assemble the complete boost converter circuit. 1b. Attach a DC electronic load to the output of the circuit and increase current up to 50 mA. 1c. Measure output voltage and check stability within 23.5-24.5V.

2.3.7 User Module

Because this system can be deployed on a variety of roads with different lane widths, median width, and the number of lanes, we will input this information through a Raspberry Pi 3 that has at least 1 GB of storage and supports full-size HDMI. While connected, the Raspberry Pi 3 should enable us to see the most recent 100 pictures taken on a 1920x1080 monitor through HDMI for debugging. The ESP32s will be able to communicate with the Raspberry Pi 3 using WiFi within the range [8], [14]. From this Raspberry Pi 3, various parameters can be changed from within a Graphic user interface such as an internet browser locally. Pictures should be viewable through the same internet browser accessed locally.

Requirements	Verification
1. Transmit and receive data over Raspberry Pi from ESP32 using 2.4 GHz WiFi.	1a. Power each ESP32 module separately with 3.3V and power Raspberry Pi with 5V.

	1b. Transmit data from ESP32 to Raspberry Pi from at least 10 feet away. 1c. Ensure data is received on the Raspberry Pi.

2.4 Schematics

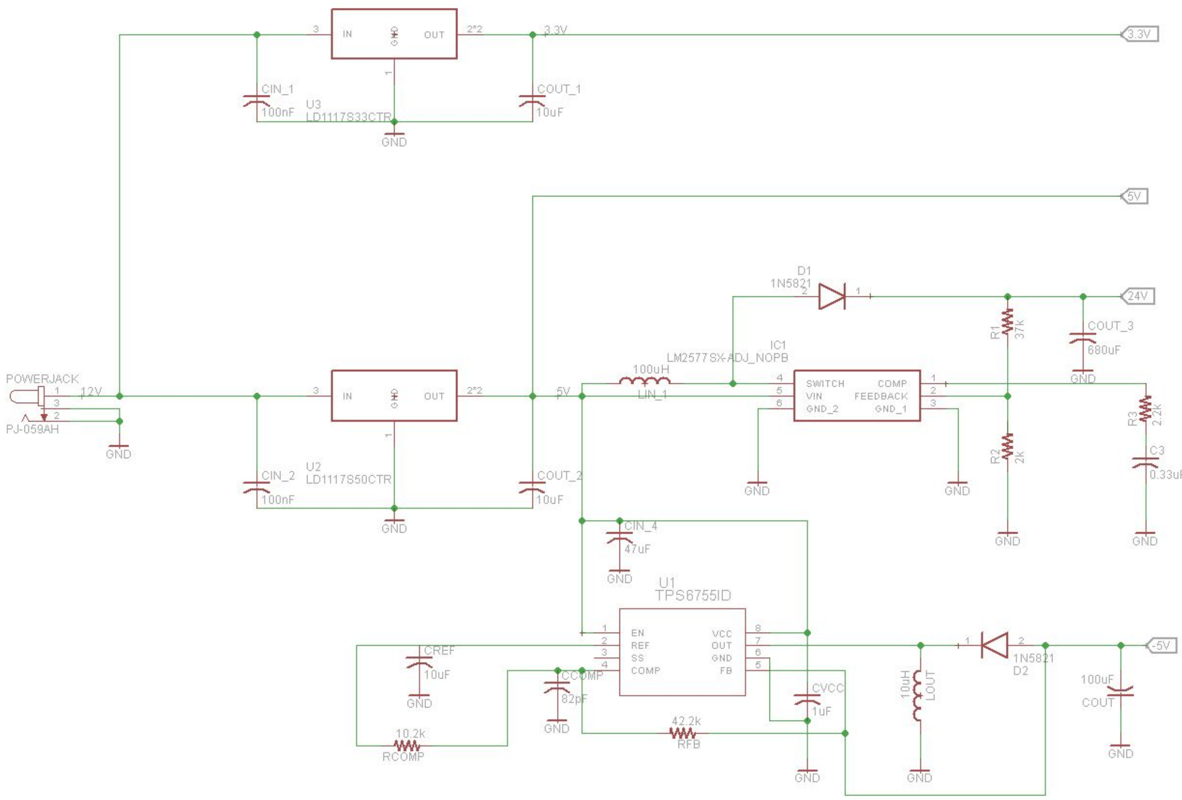

Figure 6. Schematic for Power Module

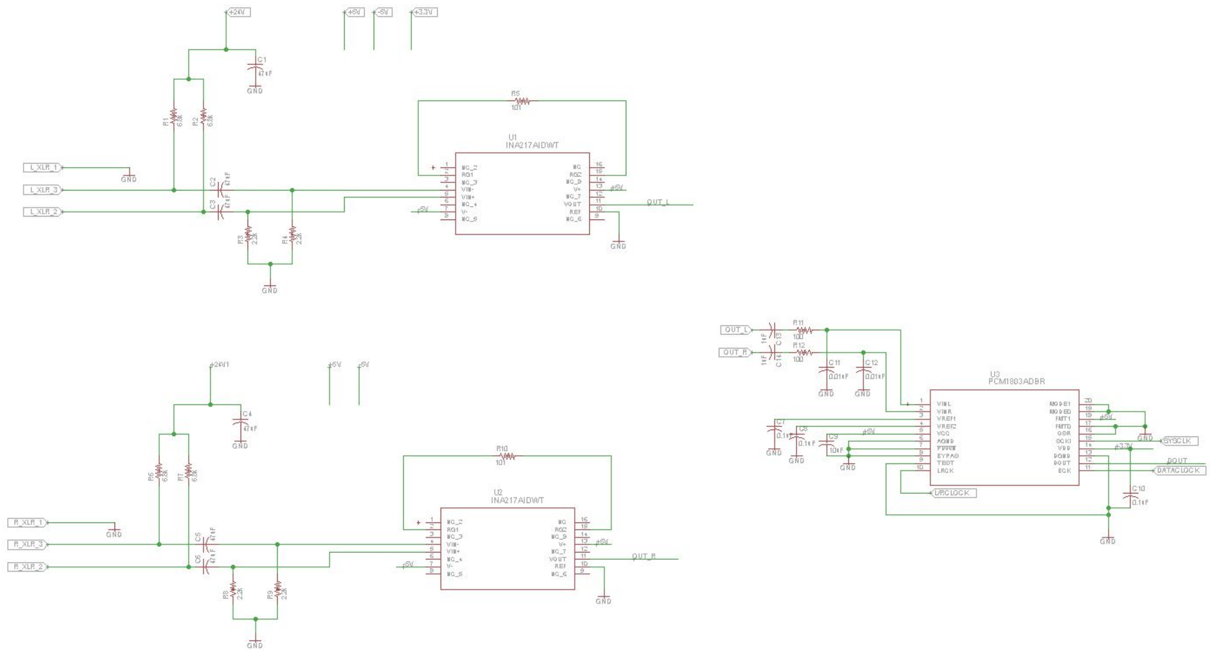

Figure 7. Schematic for Overall Sensing Module

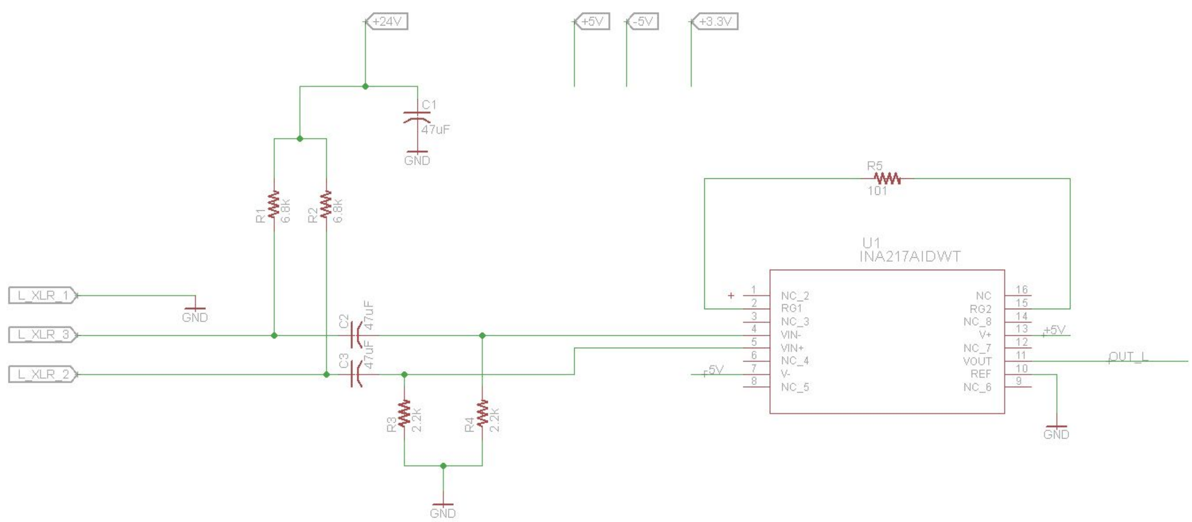

Figure 8. (Part of Sensing Module) Schematic for L-Channel Preamplifier (Same as R-Channel)

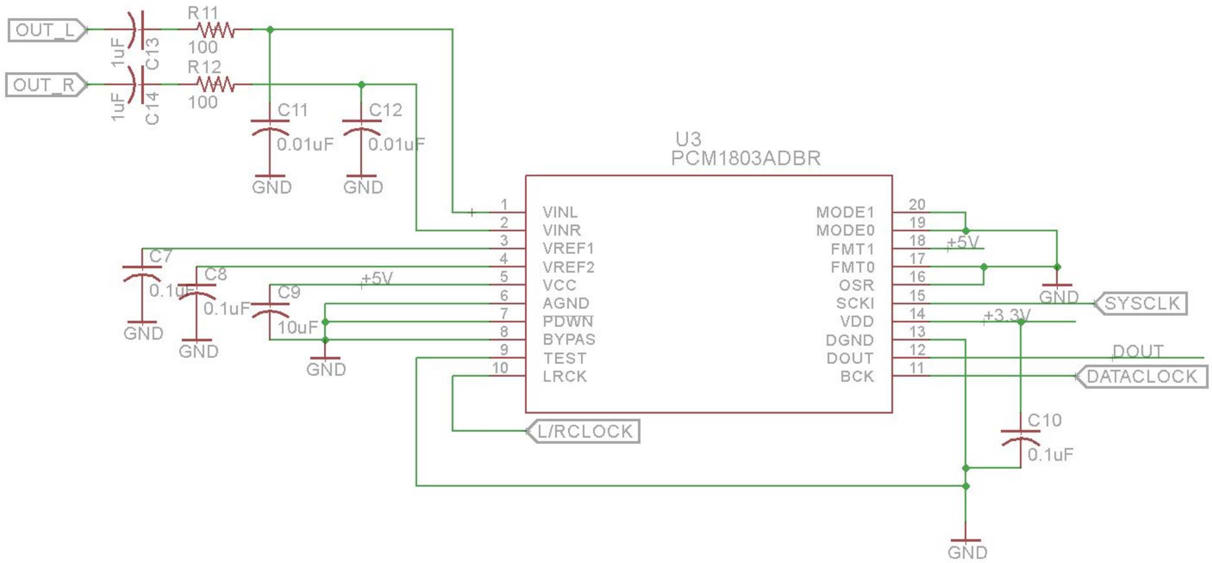

Figure 9. (Part of Sensing Module) Schematic for ADC

2.5 Calculations

2.6.1 Preamplifier Gain

At a range of 30-39 MPH, typical passenger vehicles have a road noise range of 60-74 dBA [15]. Our microphone has a sensitivity of 11 mV/Pa [16]. For our purposes, we will assume a maximum limit of 100 dB SPL will be picked up on our system before clipping. The maximum output voltage of the preamplifier should also be 3V at the maximum input volume. A minimum gain could be considered if we want to have an output voltage of at least 750 mV.

Gain Limits

- $100\ [\text{dB SPL}] = 20 * \log_{10}\left(\frac{P}{2.0 \times 10^{-5}[Pa]}\right),\ P{=}2\ \text{Pa}$ (1)
- $V_{in} = 2\ [\text{Pa}] * 11\ [\text{mV/Pa}] = 22\ \text{mV}$ (2)
- $G_{max} = V_{max} \div V_{in} = 3\text{V} \div 22\ \text{mV} = 136.4$ or $42.7\ \text{dB}$ (3)
- $G_{min} = V_{min} \div V_{in} = 750\ \text{mV} \div 22\ \text{mV} = 34.1$ or $30.7\ \text{dB}$ (4)

The preamplifier we are using, which is INA217, requires external resistors to set the gain [6]. As shown in Figure 10 below, the gain is calculated as

- $G = 1 + \frac{10k}{R_G}$ (5)

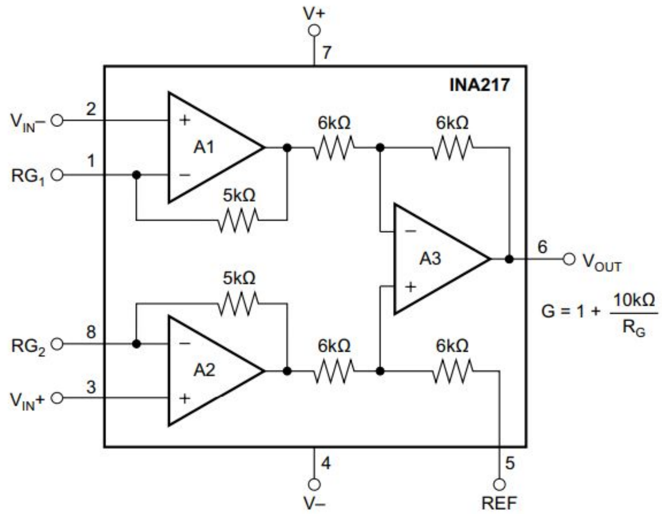

Figure 10. INA217 Functional Block Diagram [6]

Setting the gain we need to be 40 dB, which is equivalent to 100 V/V, we are able to calculate

- $R_G = \frac{10k}{100-1} = 101\Omega$ (6)

2.6.2 LM2577 Resistor Combination Calculation

The LM2577 step-up voltage regulator we are using in this project requires a combination of external resistors to set the output voltage, as shown in Figure 11.

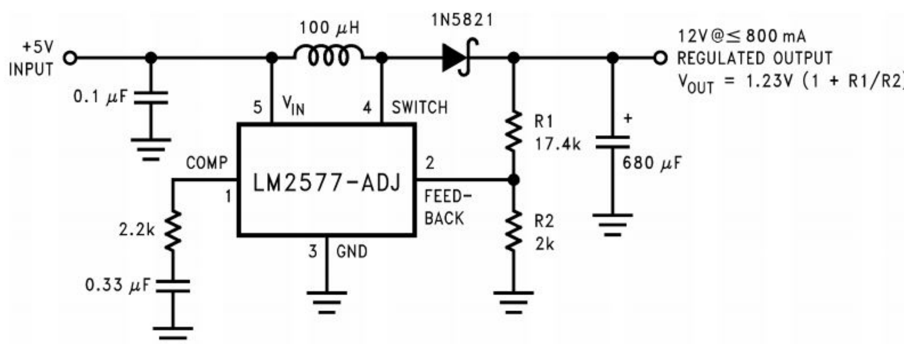

Figure 11. LM2577 Example Schematic [13]

As shown, the relationship between the output voltage and the resistor combination is

- $V_{OUT} = 1.23\text{V}\ (1 + \frac{R_1}{R_2})$ (7)

The phantom power for our condenser microphone requires 24V. We set R_2 to be 2000Ω, then we are able to calculate

- $R_1 = 2000\left(\frac{24}{1.23} - 1\right) = 37000\Omega$ (8)

2.6 Flow Charts

2.8.1 Control Flow

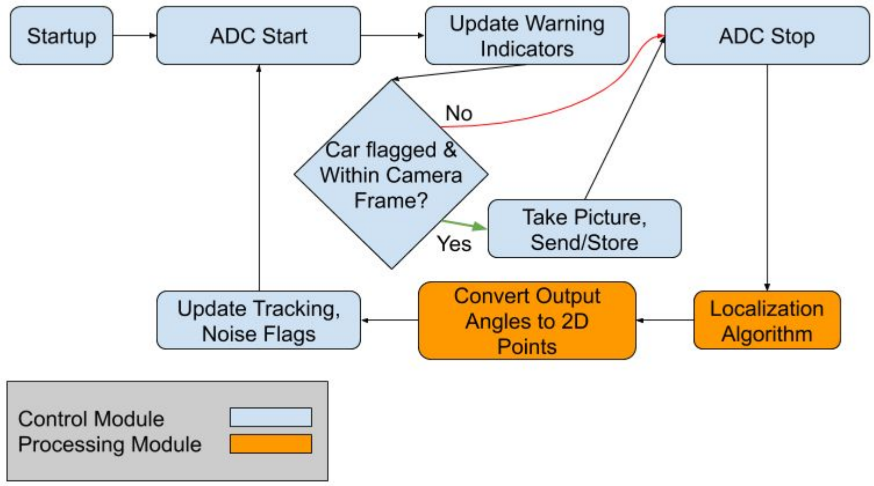

Figure 12. Control flow chart

2.8.2 Localization Process

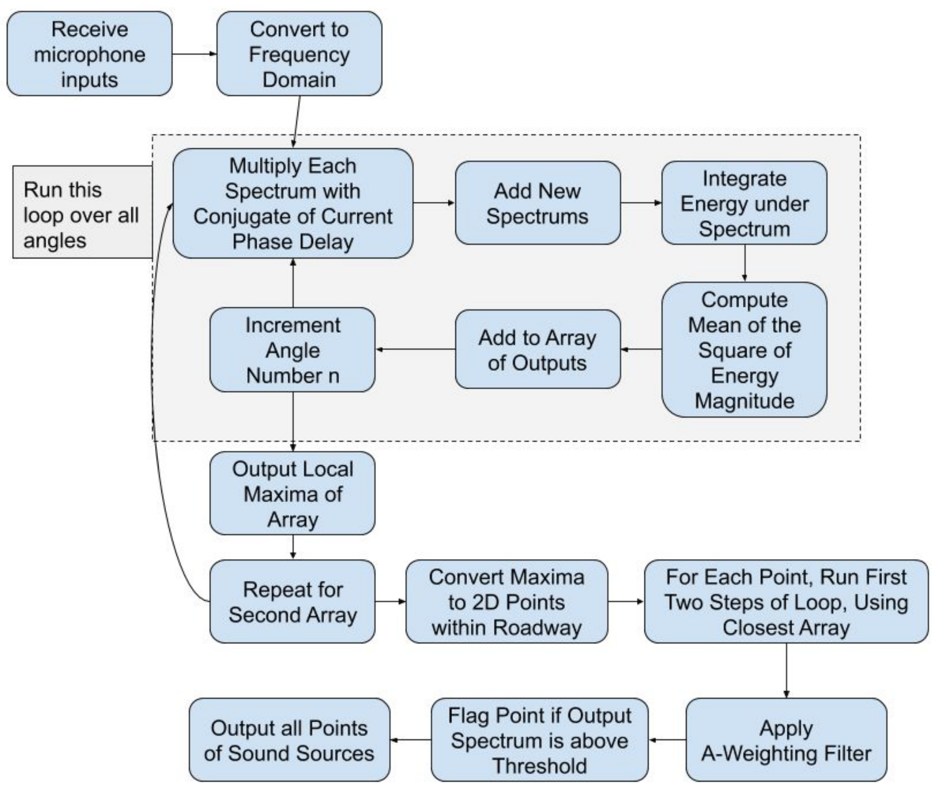

Figure 13. Localization Algorithm Process

2.7 Tolerance Analysis

Correct usage of this system depends on accurate steering vectors for a beamformer. As seen in equation 1, the steering vectors are pre-calculated using the distance between microphones *r*, the number of angles being used *N*, the size of the DFT *D*, the number of microphones *M*, the sampling rate *R*, and the speed of sound *C*.

- $v(n,\ m,\ k)\ =\ e^{-j\frac{(m-1)r\times cos(n\pi\div N)2\pi Rk}{CD}}$ (9)

  $n \in [0, N-1],\ m \in [0, M],\ k \in [0, D/2]$
- $C\ =\ 331.5\ +\ 0.6T_C$ (10)
- $< v(n,\ m,\ k)\ =\ \frac{-(m-1)r\times cos(n\pi\div N)2\pi Rk}{CD}$ (11)

Errors can come from having clock cycle rates that vary from the sampling rate *R* and the temperature T_C changing the speed of sound *C*. Both of these errors would result in the output angles from the localization algorithm varying from the real angles. To reduce the percentage of erroneous output angles, we would allow a maximum angle number error of 1, equal to the space between each angle used in the pre-calculations. The greatest error would occur at n=N-1, m=M, and k=D/2. For our system we are using r=25.4mm, R=44100 Hz, M=2, C=345 m/s, N=50, and D=512.

- $< v(49,\ 2,\ 512)\ = 3.2404\pi$ (12)
- $< v(48, 2, 512) = 3.2404\pi\ = 0.07917 \times (\frac{R}{C})_{max}$ (13)
- $< v(50, 2, 512) = 3.2404\pi\ = 0.07980 \times (\frac{R}{C})_{min}$ (14)

Variable	Minimum	Maximum
R/C	127.575	128.589
R	44013.3 Hz	44363.1 Hz
C or T_C	342.95 m/s or 19.09℃	345.68 m/s or 23.63℃

Table 1. Variable ranges

To keep R within range, we will allow 44025 to 44350 Hz. In a future design, a range of steering vectors covering a larger range of temperatures could be used. A temperature sensor would allow for correct selection of which set of vectors to use. For demo purposes, the speed of sound used will be set according to ±1℃ of the current ambient temperature.

3 Costs

3.1 Labor

Our fixed development costs are estimated to be $45/hour, 10 hours/week for a total of 16 weeks this semester per person

$45/hour * 10hours/week * 16weeks * 2.5 = $18,000

The total labor cost for the three of us would be:

$18,000/per person * 3 people = $54,000

3.2 Parts

Part	Cost (prototype)	Cost (bulk 1000 systems)
4 * Microphones (Musician's Friend; Behringer ECM8000)	$215.96	$200
4 * XLR Cables (Sparkfun; 15308)	$20	$15
4 * Amplifiers (Digikey; INA217)	$26.96	$14.74
2 * ADCs (Digikey;)	$7.74	$3.78
2 * WiFi Microcontroller (Digikey; ESP32)	$20	$8.40
1 * Microcontroller (Digikey; STM32F446RET6)	$7.75	$4.40
2 * Cameras (Amazon; OV7670)	$20	$20
2 * Battery Banks (Amazon; TalentCell 12V 3000 mAh)	$60	$60
Linear Voltage Regulators (Digikey)	$1.70	$0.33
Switching DC Regulator	$8.62	$4.55

Boost Converter IC (Mouser; LM2577)	$12.20	$6.94
Assorted Connectors	$15.82	$8.78
Assorted Resistors, Capacitors, Inductors, LEDs	$12	$4
Raspberry Pi 3	$34.99	$34.99
Total	**$463.74**	**$385.91**

Table 2. Components Cost

3.3 Sum of Costs

Since we are only making one product for this project, our sum of costs = Total costs for labor + Total costs for parts = $54,000 + $463.74 = **$54.463.74**

4 Schedule

Week	Jordan Rodier	Charlie Yang	Wentao Jiang
9/30/2019	First parts order	Research server communication	Start schematics
10/7/2019	Test warning, and sensing modules	Setup ESP32 communication and test range	Discuss case design with machine shop, finish schematics and start PCBs
10/14/2019	Begin STM32 localization programming and Second parts order	Design and test server communication	Finish and order PCBs
10/21/2019	Finish STM32 localization programming	Setup and test camera unit, including transmission to server	Finalize case design and assemble PCBs
10/28/2019	Test Two Lanes	Test camera modules and user module	Test sensing module and power modules
11/4/2019	Refine/optimize localization programming	Refine/optimize server and communication programming	Design any version 2 PCBs needed
11/11/2019	Test Four Lanes	Continue work on communication programming	Design setup and measure for demo presentation
11/18/2019	Refine/optimize localization programming and Debug demo setup	Test demo presentation	Test demo presentation
11/25/2019	Break	Break	Break
12/2/2019	Prepare Final Presentation	Prepare Final Report	Prepare Final Presentation
12/9/2019	Final Presentation/ Finish Report	Final Presentation/ Finish Report	Final Presentation/ Finish Report

5 Ethics and Safety

There are some safety issues related to our project. Since our device will be used outside and most likely near combustible trees and grassland, the battery pack in the power module of our project, if misused, can be a hazard to the environment, the public property, and nearby people. Damaging the casing and the connections of the battery can have detrimental effects[17], so we should take care to make a visible sign to ensure that people do not accidentally damage the device. Batteries should not be exposed to direct sunlight for a long time [17], and the casing will provide protection for the batteries. In reality, the batteries need to be inspected frequently, and the damaged batteries should be disposed of promptly [17]. Preventing the malfunction of the device adheres to #1 and #9 of the IEEE Code of Ethics [18].

There are cameras and microphones that are constantly operating in this project, which can be a potential threat to privacy. To avoid misuse, we should take care to ensure that the cameras and microphones only monitor the vehicles on the road. In the United States, photographing and videotaping in public places, such as roads, streets, and sidewalks, are legal [19]. However, since the system might be used in residential areas, we should avoid filming the inside of houses through the windows. Therefore, the cameras should be placed so that only the image of the road is captured. They should be kept as low as possible, as long as the license plates of the vehicles can be captured. In previous sections, we mentioned that the microphones should be able to reject sound behind them. They should also be placed and directed toward the road so that the conversation of people nearby is not recorded, as the laws of the U.S. require at least one-party consent for recording conversations [20]. The recorded audio signal should only be used in the tracking of the noisy vehicles, and it will not be sent to the user module. Additionally, there should be signs nearby warning people of the recording device, which adheres to #2 of IEEE Code of Ethics [18].

Since the tracking of the noisy vehicles requires analysis of data, we have to consider #3 of IEEE Code of Ethics [18]. In order to interpret the data realistically [18], we would test and debug our tracking algorithms painstakingly. In our high-level requirements list, we have also explicitly stated the threshold of the loud vehicles. Since the device is used primarily in residential and construction areas, we also put limits on the speed and distance of the vehicles, ensuring that the tracking algorithm correctly functions.

References

[1] G. D. Clercq, 'Paris Suburb Pioneers 'Noise Radar' to Fine Roaring Motorcycles', Aug. 30, 2019. [Online]. Available: https://www.reuters.com/article/us-france-noise-motorcycles/paris-suburb-pioneers-noise-radar-to-fine-roaring-motorcycles-idUSKCN1VK1AA. [Accessed: 19-Sept-2019].

[2] Illinoiscarlaws.com, 'Illinois Vehicle Exhaust Noise Laws', 2019. [Online]. Available: http://illinoiscarlaws.com/exhaust-noise/. [Accessed: 19-Sept-2019].

[3] The Florida Legislature, 'The 2019 Florida Statutes', 2019. [Online]. Available: http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0300-0399/0316/Sections/0316.3045.html. [Accessed: 19-Sept-2019].

[4] Austrian Academy of Science, 'Commonly used Voltage and Audio Levels', 2018. [Online]. Available: https://www.kfs.oeaw.ac.at/manual/3.8/html/userguide/461.htm. [Accessed: 01-Oct-2019].

[5] Behringer, 'Measurement Condenser Microphone ECM8000 Technical Specifications', 2013. [Online]. Available: https://media63.musictribe.com/media/PLM/data/docs/P0118/ECM8000_P0118_S_EN.pdf. [Accessed: 01-Oct-2019].

[6] Texas Instruments, 'INA217 Low-Noise, Low-Distortion Instrumentation Amplifier Replacement for SSM2017 Datasheet', 2015. [Online]. Available: http://www.ti.com/lit/ds/symlink/ina217.pdf. [Accessed: 02-Oct-2019].

[7] Texas Instruments, 'PCM1803A Single-Ended, Analog-Input 24-Bit, 96-kHz Stereo A/D Converter Datasheet', 2016. [Online]. Available: http://www.ti.com/lit/ds/symlink/pcm1803a.pdf. [Accessed: 03-Oct-2019].

[8] Espressif Systems, 'ESP32 Series Datasheet', 2019. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf. [Accessed: 19-Sept-2019].

[9] STMicroelectronics, 'STM32f446xC/E Datasheet', 2016. [Online]. Available: https://www.st.com/resource/en/datasheet/stm32f446re.pdf. [Accessed: 01-Oct-2019].

[10] Omnivision, 'OV7670 Datasheet', 2006. [Online]. Available: http://web.mit.edu/6.111/www/f2016/tools/OV7670_2006.pdf. [Accessed: 03-Oct-2019].

[11] ST, 'LD1117 Adjustable and Fixed Low Drop Positive Voltage Regulator Datasheet (Rev 34)', 2019. [Online]. Available: https://www.st.com/resource/en/datasheet/ld1117.pdf. [Accessed: 03-Oct-2019].

[12] Texas Instruments, 'TPS6755 Adjustable Inverting DC/DC Converter', 1996. [Online]. Available: http://www.ti.com/lit/ds/slvs155a/slvs155a.pdf [Accessed 03-Oct-2019].

[13] Texas Instruments, 'LM1577/LM2577 SIMPLE SWITCHER® Step-Up Voltage Regulator Datasheet (Rev. D)', 2013. [Online]. Available: http://www.ti.com/lit/ds/symlink/lm2577.pdf. [Accessed: 03-Oct-2019].

[14] Raspberrypi.org, ‘Raspberry Pi Compute Module 3+ Datasheet’, 2019. [Online] Available: https://www.raspberrypi.org/documentation/hardware/computemodule/datasheets/rpi_DATA_CM3plus_1p0.pdf [Accessed 3 Oct. 2019].
[15] N. Olson, ‘Survey of Motor Vehicle Noise’, 1972. [Online]. Available: https://asa.scitation.org/doi/abs/10.1121/1.1913246?class=pdf&journalCode=jas. [Accessed: 01-Oct-2019].
[16] Cross Spectrum Labs, ‘Microphone Frequency Response Measurement Report’, 2011. [Online]. Available: http://www.cross-spectrum.com/cslmics/001_mic_report.pdf. [Accessed: 01-Oct-2019].
[17] Duracell Batteries, ‘Battery Care, Use and Disposal’, April, 2016. [Online]. Available: https://www.duracell.com/en-us/technology/battery-care-use-and-disposal/. [Accessed: 19-Sept-2019].
[18] IEEE, ‘IEEE Code of Ethics’, 2019. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 19-Sept-2019].
[19] B.P. Krages, ‘The Photographer’s Right’, 2003. [Online]. Available: http://www.krages.com/ThePhotographersRight.pdf. [Accessed: 19-Sept-2019].
[20] Mwl-law.com, ‘Laws On Recording Conversations in All 50 States’, June. 18, 2019. [Online]. Available: https://www.mwl-law.com/wp-content/uploads/2018/02/RECORDING-CONVERSATIONS-CHART.pdf. [Accessed: 19-Sept-2019].