Roadside Sound Meter

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1 Introduction

1.1 Objective

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 [2]. 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 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 [1]. In Florida, the state laws clearly regulate that the amplified sound produced by the vehicle cannot be audible 25 feet from the vehicle [7].

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 [2]. 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 microphone array to track vehicles in up to 4 lanes of traffic to within 3-5 feet, moving up to 35-55 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.

2 Design

2.1 Block Diagram

Having two separate units on each side of the road allows for a 2-dimensional array to be used with less sound obstruction from multiple cars. This will allow for better accuracy in tracking while still being able to be mounted closer to the ground.

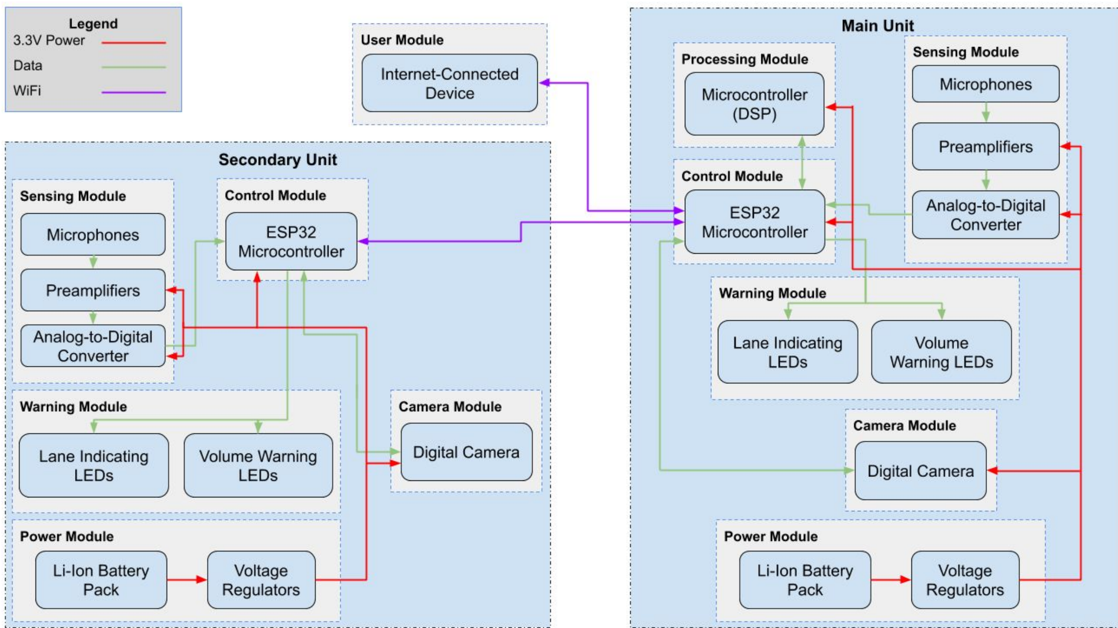

Figure 1. Block Diagram

2.2 Physical Design

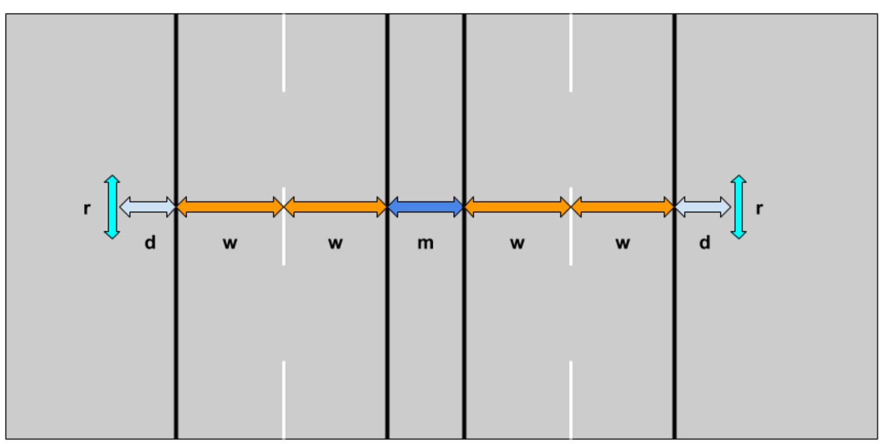

Figure 2. Units Placement

The two array units will be deployed so that they are parallel to each other, the same height above the road surface, and the same distance away from the edge of the road (d) as each other. The spacing between the two microphones (r) in each array will be 6 to 12 inches. The other distances, w and m, represent the individual lane width and median width respectively.

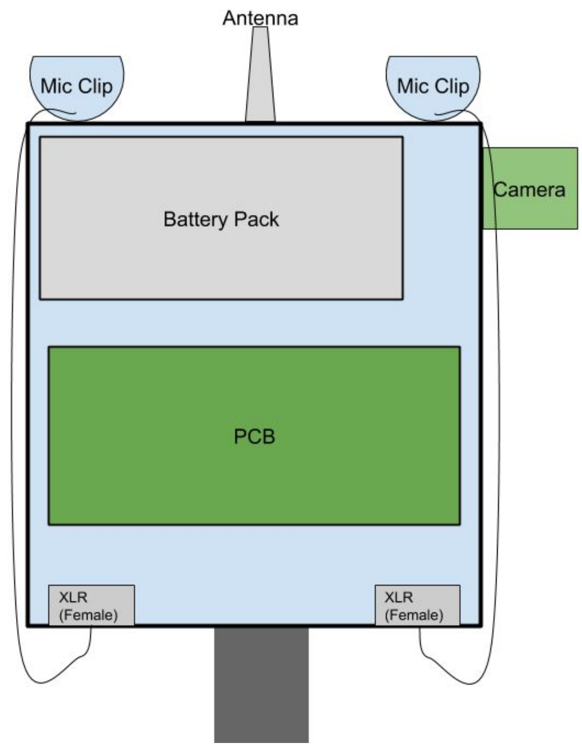

Figure 3. Unit Design Layout

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 with a separation equal to (r) from Figure 2. There will be a camera enclosure mounted to the side. An antenna can also be mounted outside of the box to increase transceiving capability. 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 box. The battery pack should be mounted with the output connector near the power input on the PCB.

2.3 Functional Overview

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 [8] that need to be amplified before being converted to digital. The preamplifier will take the microphone outputs which are on the order of 10 mV and convert them to up to 3.3 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 at the end they will be analyzed by the processing module.

2.3.2 Control Module

Both units will contain an ESP32 microcontroller that will handle WiFi communications between the two units [9]. They send control signals between each other and the user module. In the secondary unit, the ESP32 controls the warning module and camera module. It will additionally transmit pictures from the camera module and audio from the sensing module. The incoming audio signals are then passed to the processing module.

2.3.3 Processing Module

In the primary unit, there is another microcontroller that will handle processing the audio, determining vehicle locations, and deciding if noise levels are above a certain threshold. The audio inputs are first converted to frequency domain. Steering vectors can be used to correct for phase delays between each microphone pair. Localization will then add the phase adjusted signals together for a variety of angles and determine where each sound source is located. By tracking where each sound source is over time, we can essentially track a vehicle by its noise output. An A-weighting will be applied to each frequency output before determining if the volume is above a threshold.

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 first LED indicates the detection of a car in that lane. The second 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.

2.3.5 Camera Module

Each camera module has one camera mounted along the microphones. 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.

2.3.6 Power Module

We will use a lithium-ion rechargeable 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.

2.3.7 User Module

Because this system can be deployed on a variety of roads with different lane widths, median width, and number of lanes, we need a way to input this information. The ESP32s will be able to communicate with another device connected using WiFi within range [9]. From this external device, various parameters can be changed from within an internet browser. While connected, the external device should be able to see the most recent pictures taken as well.

2.4 Block Requirements

2.4.1 Sensing Module

1. The microphones need to be able to reject sounds from behind them.
2. They should also be able to withstand up to 120 dB SPL.
3. The preamplifier should amplify the microphone outputs to a range up to near 3.3V.
4. Each ADC needs to operate at 44.1 kHz, 3.3V output, and communicate via Inter-IC Sound (I2S) or Serial Peripheral Interface (SPI).

2.4.2 Control Module

1. The control modules must be able to communicate wirelessly between each other over up to 120 feet using 2.4 GHz WiFi.
2. General purpose IOs (GPIOs) must be able to drive the LEDs.
3. Inter-Integrated Circuit (I2C) must be supported to configure the camera module.
4. I2S or SPI must be supported to communicate with each ADC.
5. Onboard storage should be at least 8 MB, enough to hold at least three VGA pictures along with the current samples from the sensing modules.

2.4.3 Processing Module

1. The microcontroller should be able to communicate to the control module using SPI or Universal Asynchronous Receiver/Transmitter (UART).

2. This microcontroller needs to be capable of single-precision floating point operation and discrete Fourier transforms. This should be fast enough to perform localizations at least five times each second.

2.4.4 Warning Module

1. All LEDs should be bright enough to view in daylight from next to each unit.
2. The placement and color of the LEDs should clearly identify the lane and type of indication being shown.

2.4.5 Camera Module

1. Field-of-view should be greater than 20° to capture two lanes in frame.
2. The camera must be able to focus between 100 and 300 feet away.
3. The camera should be programmable over I2C or SPI and able to transmit pictures directly to the control module.

2.4.6 Power Module

1. The power module should have enough capacity to run for up to 12 hours overnight.
2. A rechargeable battery pack must provide 6-12V at 500 mA or more.
3. The voltage regulator should be able to convert the battery output to 3.3V for the active components.
4. Circuit protection must be able to disconnect from the voltage regulators if battery polarity is reversed.

2.4.7 User Module

1. A user interface needs to be accessible in a browser through a local WiFi connection to change parameters in the system during setup.
2. At least three previous pictures must be viewable while connected using the same user interface.

2.5 Risk Analysis

The processing unit is the greatest risk to the successful completion of the project. While the other units are mostly supporting hardware components that would work if selected and assembled correctly, the successful implementation of the processing unit is highly demanding.

The most difficult part of the processing unit is the implementation of the algorithm for tracking the noisy vehicles. While theoretically, the algorithm might be straightforward, in reality, the ideal solution would not always work. For example, the audio signal from the sensing module is delayed because of the units that process and wirelessly transfer it. The delay might vary depending on the WiFi connection. The delays from the sensing modules in the two modules are also different. Unwanted noise from the signal path will also be present in the audio signal after it reaches the processing module. Therefore, the algorithm has to be modified to accommodate for the disturbance in the real world situation. There will also be a lengthy process of testing, debugging, and modifying to ensure that the algorithm reaches its highest potential.

In the block requirements section, we mentioned that the processing module has to be able to perform localizations at least five times each second. This requirement, however, is not only placed on the performance of the hardware. To meet this criterion, the algorithm for detecting the noisy vehicle needs to be optimized for the timing requirement, while the accuracy of detection cannot be impaired too much. What we might do is to adjust the sampling frequency until the computational time and the accuracy reach a perfect balance. We could also let the microcontroller in the control module to handle parts of the computing without obstructing the operation of the control module too much.

3 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 Li-Ion 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[3], so we should take care to make a visible sign to ensure that people do not accidentally damage the device. The batteries might also burn or explode if contacted conductive materials such as water [3], so the casing of the device needs to be water-proof. Batteries should not be exposed to direct sunlight for a long time [3], and the previously mentioned water-proof casing will also provide protection in this aspect. In reality, the batteries need to be inspected frequently, and the damaged batteries should be disposed of promptly [3]. Preventing the malfunction of the device adheres to #1 and #9 of the IEEE Code of Ethics [4].

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 [6]. 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 [5]. 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 [4].

Since the tracking of the noisy vehicles requires analysis of data, we have to consider #3 of IEEE Code of Ethics [4]. In order to interpret the data realistically [4], 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.

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