Smart Traffic Management System

An Emergency Vehicle Detection System for Traffic Junctons

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***Abstract*—Vehicular traffic is endlessly increasing everywhere in the world and can cause terrible traffic congestion at intersections. Most of the traffic lights today feature a fixed green light sequence,therefore the green light sequence is determined without taking the presence of the emergency vehicles into account. Therefore, emergency vehicles such as ambulances, police cars, fire engines,etc. get stuck in a traffic jam and are delayed in reaching their destination. This can lead to the loss of property and valuable lives. In general, emergency service vehicle such as ambulances, fire trucks, and police cars use sirens to warn other road users for quick passage, especially for moving through the traffic. However, due to the well soundproofing techniques in modern cars, drivers may not be aware of the approach of emergency vehicles, especially when in-vehicle audio systems are used.As a consequence, emergency vehicles may be blocked and even collided with other vehicles. The proposed system can help prioritize the movement of these emergency vehicles.**

I. Introduction

The traffic light control plays a vital role in any intelligent traffic management system. The green light sequence and green light duration are the two key aspects to be considered in traffic light control. In many countries, most traffic lights feature fixed sequences and light length duration. Fixed control methods are however only suitable for stable and regular traffic, but not for dynamic traffic situations. Looking at the present state of practice, the green light sequence is determined without taking the possible presence of emergency vehicles into account. Therefore, emergency vehicles such as ambulances, police cars, fire engines, etc. must wait in traffic at an intersection which delays their arrival at their destination causing loss of lives and property.

The objective of this project is to design and implement a unique and cost effective traffic management system to control and monitor the traffic at junctions based on real time data.The system should be able to prioritize the movement of emergency vehicles across the junction by detecting the sirens of the emergency vehicles.

Multiple methods exist to detect emergency vehicles from a traffic environment such as optical and camera-based techniques. However these methods utilize a camera and other image processing techniques that may be expensive and less accurate. Acoustic methods use the sirens of emergency vehicles to detect them from a noisy environment. Using Artificial Neural Networks for detection was found to be a very efficient method for detecting sirens from background noises as compared to other techniques that use FFT or pitch detection algorithms. Supervised learning of the Neural Network is done using a Back-propagation algorithm in Python. This is then implemented on Raspberry Pi using two separate programs to train and evaluate the neural network and to execute real time detection.

The hardware of the system consists of a sound sensor (Unidirectional Microphone) which receives all incoming sound signals, a Raspberry Pi 4B which acts as the control system module, a Wi-Fi module for short range wireless communication, a micro controller (TI MSP 430G2553) for controlling the traffic lights and a set of LED's acting as the traffic lights. The sound sensor accepts all the incoming sound signals that are wirelessly transmitted through a Wi-Fi module to the control system module. The Control system determines whether the incoming signal is a siren or not and sends a control signal to a micro controller for controlling the traffic lights.

II. System Overview

The complete system can be realised in terms of its hardware and software components.The block diagram can be realised as shown below:

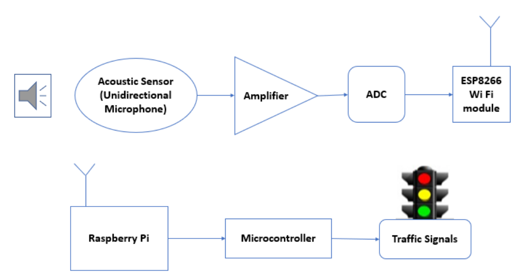

Fig. 1. Schematic of Smart Traffic Management System

The hardware components of the system are:

- Microphone Condenser Type (Unidirectional)
- Raspberry Pi 4 Model B
- Micro controller - TI MSP 430G2553
- Wi-Fi module - ESP-8266

The software side of this project mainly deals with the detection of siren of emergency vehicles and wireless transmission of audio. This is done using Python and Arduino IDE. The detection method involves Machine learning algorithms. This includes the use of Artificial Neural Networks which are a series of Back-propagated algorithms that use Supervised learning techniques. This method has very high accuracy and very low time delays around 200ms. Moreover this method is not affected by Doppler effect.

III. Siren Detection Using Artificial Neural Networks

In this section we focus on the detection of siren sounds from ambulance in which the operation modes are basically different from those of other vehicles.The spectrum of an ambulance siren is as shown below:

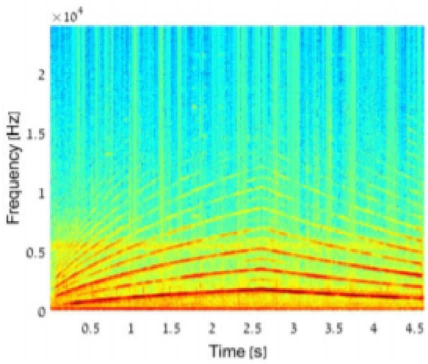

Fig. 2. Frequency spectrum of an Ambulance Siren

Feature Extraction From Siren

Selection of features is a key issue when designing an effective signal detector.Each time frame, requires features that comprise the essence of information relevant to classification, are robust to variations in the signal and to noise, and are efficient in terms of computational and space complexity. To find such features, a large set of features that were previously used for different tasks of audio processing are used. These are divided into 3 categories:

- Time domain features
- Frequency domain features
- Wavelet-based features

A. Time Domain Features

Time domain features include: Pitch, Short Time Energy, Zero crossing rate (ZCR), mean, median, standard deviation (std), etc.

B. Frequency Domain Features

Frequency Domain Features include MFCC or Mel-Frequency Cepstral Coefficients and Spectral flux. MFCC are used to describe the spectral shape of the signal.These coefficients are extracted by applying the discrete cosine transform (DCT) to the log-energy outputs of the nonlinear mel-scale filter-bank

C. Wavelet-based features

The wavelet coefficients capture time and frequency localized information about the audio waveform. The wavelet transform can be viewed as a multi-level process of filtering the signal using a low-pass (scaling) filter and a high-pass (wavelet) filter. They are Discrete Wavelet transform (DWT) and Wavelet packet transform (WPT).

In this method we have used frequency domain features such as MFCCs for siren detection. MFCCs are computed from its spectral representation by setting the upper and lower cutoff frequencies to 600Hz and 1625Hz respectively, since the siren sounds of ambulance have frequencies range from 650 Hz to 1550 Hz.

Siren Sound Detection

The Siren Sound identification (SSI) system was created by using neural networks including Multi-layer perceptron (MLP) or Long Short Term Memory Recurrent Neural Network (LSTM-RNN), which are trained using the back propagation (BP) algorithm and back propagation through time (BPTT) algorithm respectively. In each of the network, the MFCCs vector is used as input of the first layer which connects to a hidden layer in front of an output layer with 3 nodes. MLP is a simple form of feed forward neural network and is easy to implement.

The implementation of a typical neural network for SSI includes three steps:

- Training
- Validation
- Testing.

1) Training: In the training stage, the extracted MFCC features of training dataset are provided as input to estimate the weight parameters in a neural network.

2) Validation: In the validation phase, we use the validation dataset to evaluate the performance of trained model, and through this basis to tune the parameters to achieve the best one.

3) Testing: In the testing phase we pass the unknown audio signal to the fully-trained network to obtain corresponding output, the output with maximum response value is selected as identified result.

Structure of Siren Signal Identification Network is as shown below:

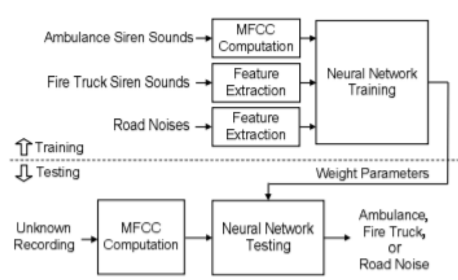

Fig. 3. Siren Signal Identification System

Implementation In Python

The above method is implemented in Python version 3 using APIs such as Tensorflow, Keras etc.Two separate Python programs were implemented:

- To train and Evaluate the Neural Network
- To execute Real Time Detection

Two separate sets of data were also used for training and evaluation titled Emergency and Non Emergency sound signals.The dataset is pre recorded for training. 70% of the dataset used for training 30% for evaluation of sound signals.

IV. Hardware Implementation

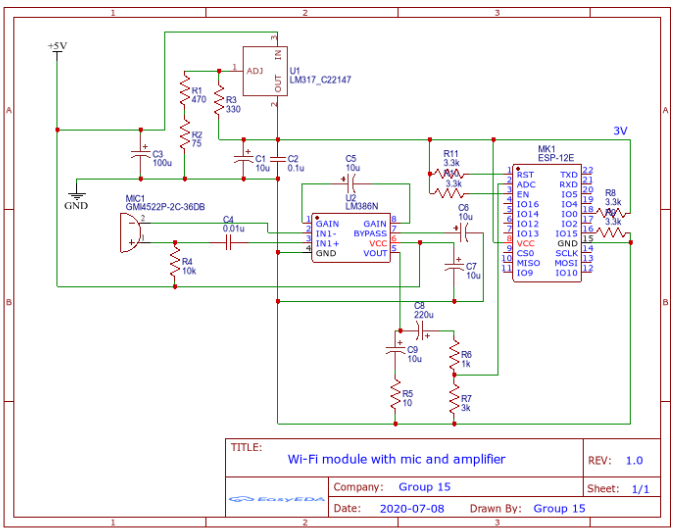

Fig. 4. Interfacing Microphone and Wi-Fi Module

The audio from the microphone is given to an amplifier circuit that uses LM 386 to amplify the received signals. This is converted from 16 bits to 10 bit for the ADC of the Wi-Fi Module (ESP-8266). The audio is sent wirelessly to the Raspberry-Pi where the detection program will be running. The sampling rate used is 5000 samples per second which can be increased up to 8000 samples per second by compromising the time delay.

V. Results and Observations

Software Simulation

Sounds of the ambulance siren and background noises were all recorded and stored as **.wav** files in two separate folders namely **Emergency** and **Non-Emergency** respectively.These recorded sound signals are then used for training and evaluation. During training and evaluation a confusion matrix is created (as shown in Figure 5) and these trained values are stored in **.h5 file** (HDF5 format).

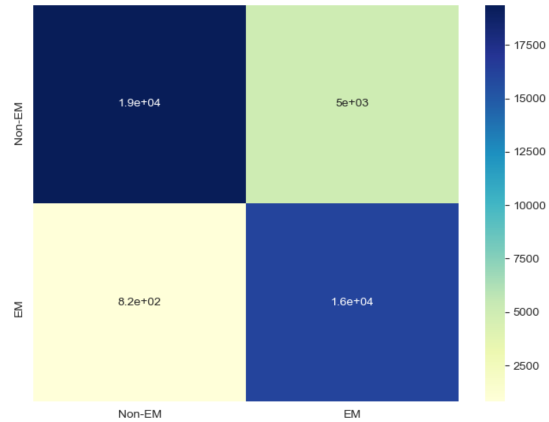

Fig. 5. Confusion matrix of the trained signals. X-axis represents the predicted values and Y-axis represents the true values

A confusion matrix is a table that is often used to describe the performance of a classification model (or "classifier") on a set of test data for which the true values are known. It allows the visualization of the performance of an algorithm.It allows easy identification of confusion between classes e.g. one class is commonly mislabeled as the other. The X-axis represents the predicted values and Y-axis represents the true values. Using the h5 file generated during the training phase real time detection is carried out.The results obtained are shown below:

```
Non Emergency vehicles-[0.01973708]
Non Emergency vehicles-0.02119359001517296
Non Emergency vehicles-[0.02153529]
Non Emergency vehicles-0.01616440713405609
Non Emergency vehicles-[0.01332215]
Non Emergency vehicles-0.011351789347827435
Non Emergency vehicles-[0.00998128]
Non Emergency vehicles-0.02130311354994774
Non Emergency vehicles-[0.0125683]
Non Emergency vehicles-0.02921970933675766
Non Emergency vehicles-[0.01588701]
Non Emergency vehicles-0.018318533897399902
Non Emergency vehicles-[0.02634609]
Non Emergency vehicles-0.03468741849064827
Non Emergency vehicles-[0.02570292]
Non Emergency vehicles-0.021894171833992004
Non Emergency vehicles-[0.02570378]
Ambulance is coming. Set the Green signal quick- 0.39174729585647583
Ambulance is coming. Set the Green signal quick- [0.55065596]
Ambulance is coming. Set the Green signal quick- 0.508156295910645
Ambulance is coming. Set the Green signal quick- [0.4164407]
Ambulance is coming. Set the Green signal quick- 0.46899640560150146
Ambulance is coming. Set the Green signal quick- [0.5491031]
Ambulance is coming. Set the Green signal quick- 0.40760108828544617
Ambulance is coming. Set the Green signal quick- [0.37539792]
Ambulance is coming. Set the Green signal quick- 0.30927056074142456
Ambulance is coming. Set the Green signal quick- [0.3476838]
Ambulance is coming. Set the Green signal quick- 0.4439692795276642
Non Emergency vehicles-[0.2268623]
Non Emergency vehicles-0.122481569647789
Non Emergency vehicles-[0.07475618]
Non Emergency vehicles-0.04444292560219765
Non Emergency vehicles-[0.03173444]
```

Fig. 6. Real Time Detection - Software Simulation

Output

The components were interfaced as shown and the output after detecting the siren is shown (Figure 7 and Figure 8). The Wi-Fi module acts as an access point and the Raspberry-Pi is connected to it for wireless transmission.

After detection, a control signal is given as an interrupt from the Raspberry-Pi to the micro-controller to set the corresponding side of the junction to green to allow the emergency vehicle to pass through.

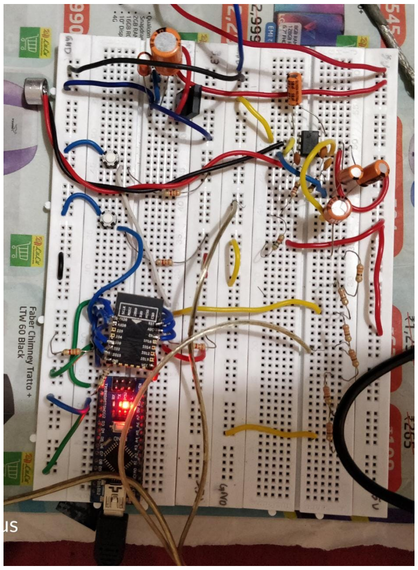

Fig. 7. Experimental Setup

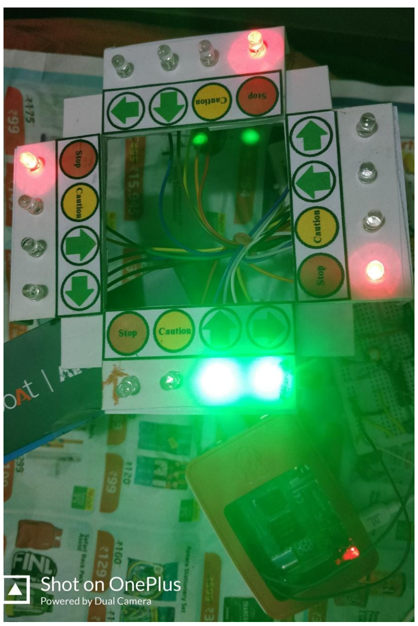

Fig. 8. Traffic junction After Detecting Siren

After the vehicle passes through, the junction returns to its original loop.

VI. Conclusion and Future Scope

The designed system was successful in detecting the Siren of the emergency vehicles and thereby scheduling the movement of emergency vehicles through the junction.Three different siren sound signals of different frequency ranges were successfully trained and detected using Artificial Neural Networks.The siren sound signals were detected with an accuracy of around 84% by the Siren Detection System.
The present traffic management system is designed based on the assumption that only one emergency vehicle crosses the traffic junction at a single point of time.This can be further improved by developing python codes for real time scenarios like multiple emergency vehicles crossing the traffic junction at the same point of time. Another improvement which can be done is the implementation of a 4 way traffic junction where the inter-junction communication is facilitated by IoT based communication network.

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