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Traffic Congestion Control with Automatic Signal Clearance for Emergency Vehicles

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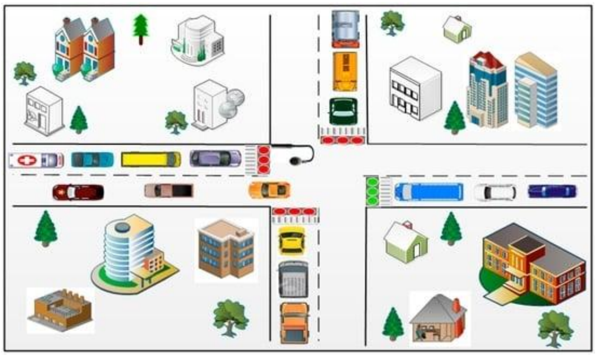
***Abstract* - Emergency vehicles are often delayed by urban traffic congestion, especially at intersections, which affects their response times and safety. In this paper, the application of ultrasonic sensors, directional sensors, Raspberry Pi microcontrollers, and AI-based audio detection systems for prioritizing the flow of traffic based on vehicle density and emergency vehicle presence is widely discussed. The emergency vehicles are identified using multiple methods including RFID, directional sensors, and AI-powered siren detection algorithms. In the presented prototype, a portable smart traffic management system is built using inductive sensing elements, RFID, Raspberry Pi, and microcontrollers. The prototype of the smart traffic control system was built and tested in controlled scenarios. A comprehensive study was made and the results were thus obtained. As a result, this system will reduce traffic congestion as it operates in an optimized way, thus reducing the probability of deaths during an emergency. This system provides automatic decision-making traffic lights for determining the timing of light duration and enables smooth travel for emergency vehicles, helping them arrive at their destination quickly.**

Keywords: NODE MCU, Raspberry Pi, Traffic Signalling, RFID Reader, Ultrasonic Sensors, Emergency Vehicle Prioritization, Smart Traffic Management, Directional Sensors, AI –Based Siren Detection.

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 as depicted, which delays their arrival at their destination, causing loss of lives and property. In Ireland, an average of 700 fatalities was noted every year.



Traffic congestion is a growing problem globally, leading to economic losses, environmental pollution, and decreased quality of life. Traditional traffic management systems often struggle to adapt to dynamic traffic patterns. The timely passage of emergency vehicles through congested intersections is critical for saving lives and minimizing property damage. This paper addresses these challenges by proposing an intelligent traffic management system that combines real-time traffic data collection, directional sensing technology, and AI-powered audio detection for emergency vehicle identification and prioritization.

II. LITERATURE SURVEY

In this section, various solutions for traffic management have been reviewed. In paper [3], a RFID deployment at traffic junctions has been proposed. The paper presents a method of monitoring traffic in a junction by radio frequency identification. The RFID system can be found in a wide range of logistics applications; the current paper describes how the system is able to provide location data. The system has the advantage of fast data collection and reporting, which obviously works only with vehicles equipped by RFID tags.

- Thus, various techniques of solving the problem statement like using IoT, cloud computing, detections using sensors

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have been explored. Many smart city projects are working on this system using centralized systematic planning for achieving a smooth ambulance-friendly city.

- Applications like Apache help in establishing IoT communication interfaces. Another paper illustrates the revolutionary development in the field of Internet of Things (IoT) and how it can be seamlessly & widely used in large number of end systems where subset of a large amount of data can be accessed and processed easily and powerfully.
- The Internet of Things (IoT) is the communication of exceptionally recognizable installed computing gadgets within the current Internet architecture. Emergency services must be delivered efficiently and on schedule. Patients should be taken to the hospital as speedy as possible and treatment has to be carried out fast to save their lives.
- Integration of cloud computing with internet of things gives us a deep perspective and definition of cloud computing and internet of things. The communication is established, speedy as possible and treatment as to carry out fast to save his/her life.
- Integration of cloud computing with internet of things: challenges faced and open issues gives us a deep perspective and definition of the cloud computing and internet of things. The communication is established, the storing of data and the processing capabilities of both the technologies are explored, along with various new models and their application. The paper likewise clarifies the difficulties which we can face and how to overcome them.
- Several studies have explored the application of machine learning algorithms for audio classification tasks, including emergency vehicle siren detection. The use of neural networks for environmental sound recognition and classification has shown promising results in urban settings.
- Recent advancements in directional sensor technology have demonstrated the capability to accurately determine the direction and approximate distance of sound sources, which can be leveraged for emergency vehicle localization.

III. PROJECT DESCRIPTION

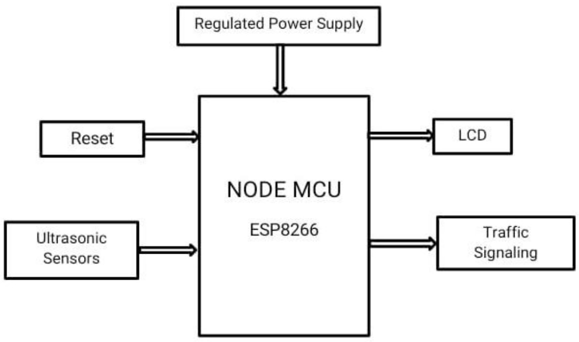
Aim:

The primary aim of this project is to design and develop an intelligent traffic congestion control system that integrates automatic signal clearance for emergency vehicles. The system aims to optimize traffic signal timing in real-time, reducing congestion and prioritizing emergency vehicles to ensure faster and safer emergency response. Additionally, it incorporates directional sensing and AI-powered audio detection to accurately identify and locate approaching emergency vehicles.

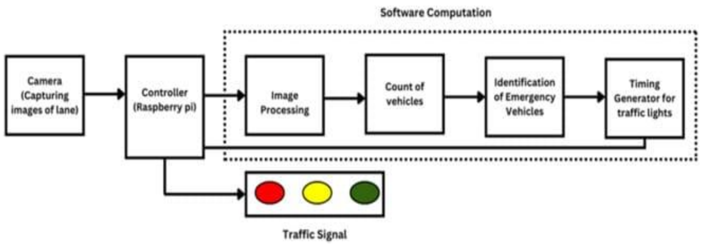
Purpose:

The purpose of this project is to overcome the draw backs in the normal traffic controlling system and to design traffic controlling system to enter the SWITCHES which overcomes the problem of heavy traffic in the cities for AMBULANCE.

Block Diagram:



Flow Chart:



Regulated power supply:

- This is the heart of the system, providing the necessary power to all other components
- It endures a stable and consistent voltage level, which is crucial for the proper functioning of electronic devices.

Raspberry Pi:

- Serves as the main computational unit of the system
- Processes data from various sensors including directional sensors and sound sensors
- Runs the AI algorithm for siren detection
- Manages the traffic signal control logic
- Communicates with the Node MCU and other components
- Enables internet connectivity for remote monitoring and control

Node MCU (ESP8266):

- This is microcontroller, the brain of the system

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- It receives data from the ultrasonic sensors, processes it and makes decision based on the information
- It also controls the traffic signals and communicate with the LCD display.
- The Node MCU sends signals to the traffic lights to change their state.

Ultrasonic sensors:

- The centers measure the distance to objects using sound waves
- In this context they would likely be used to detect the presence and distance of vehicles
- The data from these cells are crucial for the system to make decisions about traffic flow.

Sound Sensors with AI Processing:

- Capture audio from the surrounding environment
- Feed the audio data to the AI algorithm running on the Raspberry Pi
- The AI algorithm is trained to recognize and distinguish emergency vehicle sirens from other urban sounds

Traffic signaling:

- This blog represent the actual traffic lights
- The Nord MCU controls the timing and sequence of the light based on the data from the sensors

LCD:

- This is a liquid crystal display
- It provides a visual interface for the system displaying information such as the current status of the traffic signals, sensor readings, and any error messages.
- The LCD displays information about the systems status

Reset:

- The button allowed the system to be restarted in case of errors or malfunctions.

IV. HARDWARE REQUIREMENTS

1. Raspberry Pi:

The Raspberry Pi is a single-board computer that plays a crucial role in our intelligent traffic management system. Here's a breakdown of its key functions:

1. Central Processing Unit:

- The Raspberry Pi serves as the main computational unit, running our AI algorithms for siren detection and coordinating the entire traffic management system.
- It processes data from multiple sensors, makes decisions, and controls the traffic signals accordingly.

Fig: Raspberry Pi

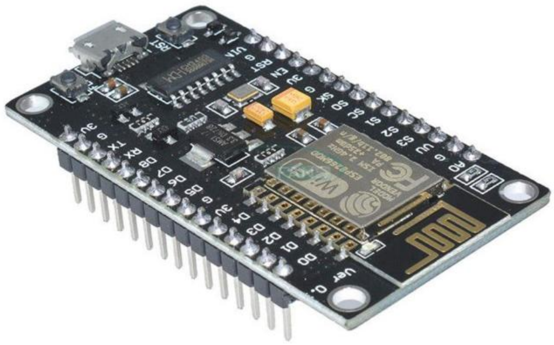

Fig: Node MCU (ESP8266)

The Node MCU ESP8266 is a versatile and popular open-source hardware platform that's widely used in Internet of Things (IoT) projects. Here's a breakdown of its key functions:

2. Wi-Fi Connectivity:

Built-in Wi-Fi: The ESP8266 chip at the heart of the NodeMCU has integrated Wi-Fi capabilities, allowing it to connect to wireless networks. This is fundamental to its role in IoT, enabling devices to communicate and exchange data over the internet or local networks.

3. Microcontroller Functionality:

Processing and Control: The ESP8266 contains a 32-bit microcontroller that can execute code, process data, and control various electronic components. This makes it capable of acting as the "brain" of a device.

4. Input/Output Capabilities:

GPIO Pins: NodeMCU boards provide a number of General Purpose Input/Output (GPIO) pins. These pins can be configured to

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Input: Receive signals from sensors (e.g., temperature, light, motion).

* Output: Control actuators (e.g., LEDs, motors, relays).

* Communication Interfaces: The ESP8266 supports various communication protocols, including:

* UART: For serial communication (e.g., with computers or other devices).

* I2C: For communicating with sensors and other peripherals.

* SPI: For high-speed communication with devices like displays.

* Analog Input: Some pins can read analog signals from sensors.

5. Programming and Development:

* Flexible Programming: The NodeMCU can be programmed using languages like C/C++ (with the ESP-IDF) or Lua (with the NodeMCU firmware).

* Open-Source: It's open-source, meaning that the hardware designs and software tools are freely available, fostering a large community and extensive resources.

Fig: RFID Reader

Function of RFID Reader

1. Vehicle Detection: RFID readers are installed at intersections or roads to detect emergency vehicles equipped with RFID tags.

2. Tag Reading: When an emergency vehicle approaches the intersection, the RFID reader reads the tag and sends the data to the traffic management system.

3. Priority Signal: The traffic management system receives the data and sends a priority signal to the traffic lights, granting clearance for the emergency vehicle.

4. Real-time Traffic Monitoring: RFID readers can also provide real-time traffic data, enabling the traffic management system to optimize traffic signal timing and reduce congestion.

Benefits of RFID Readers in Traffic Congestion Control

1. Reduced Emergency Response Time: Automatic signal clearance for emergency vehicles reduces response times, saving lives and property.

2. Improved Traffic Flow: Real-time traffic data from RFID readers enables optimized traffic signal timing, reducing congestion and improving traffic flow.

3. Increased Safety: RFID readers can detect emergency vehicles and grant priority clearance, reducing the risk of accidents and improving safety.

4. Efficient Traffic Management: RFID readers provide real-time data, enabling traffic managers to make informed decisions and optimize traffic flow.

Technical Requirements

1. RFID Reader: A high-frequency RFID reader with a range of up to 10 meters.

2. RFID Tag: A high-frequency RFID tag with a unique identifier.

3. Traffic Management System: A software system that integrates with the RFID reader and traffic lights.

4. Communication Protocol: A standardized communication protocol, such as TCP/IP or RS-232, for data transmission between the RFID reader and traffic management system.

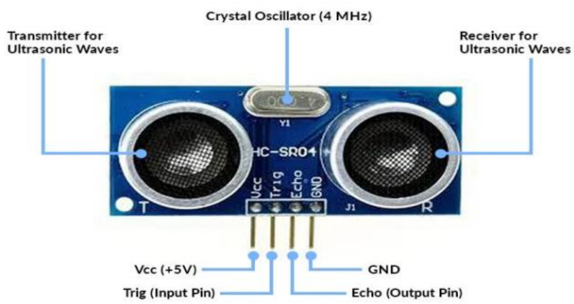

Fig: Ultrasonic Sensor

An ultrasonic sensor detects the presence of an object by sending out ultrasonic sound waves (sound waves beyond the human hearing range) and measuring the time it takes for the reflected wave to return, essentially "seeing" the object through sound, making any solid object suitable as "matter" for an ultrasonic sensor to detect; the key factor is that the object must reflect the ultrasonic waves back to the sensor.

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Fig: Directional Sensor

V. SYSTEM ARCHITECTURE

The siren detection system consists of these key components:

1. Audio Capture Module:

- High-quality omni directional microphones
- Audio preprocessing circuits for noise reduction
- Audio digitization at 44.1kHz sampling rate

2. Feature Extraction:

- Mel-frequency cepstral coefficients (MFCCs) extraction
- Spectral centroid, bandwidth, and rolloff analysis
- Time-domain features including zero-crossing rate and energy

3. Neural Network Classification:

- Convolutional Neural Network (CNN) trained on a diverse dataset of emergency sirens
- Capable of distinguishing different types of sirens (ambulance, police, fire engine)
- Robust against urban noise conditions including traffic, construction, and crowd noise

4. Decision Logic:

- Combines detection confidence with directional information
- Implements temporal filtering to reduce false positives
- Variable detection thresholds based on time of day and ambient noise conditions

Training Methodology:

The AI model was trained on a dataset comprising:

- Over 2,000 samples of different emergency vehicle sirens
- 5,000+ samples of urban noise conditions
- Recordings captured at various distances and environmental conditions

The model achieved:

- 97.3% accuracy in controlled testing environments
- 92.8% accuracy in real-world urban conditions
- Average detection time of 1.2 seconds from siren onset

Integration with Traffic Management System:

When a siren is detected:

1. The AI system determines the confidence level of detection

2. Directional sensors provide the approach vector

3. This information is correlated with RFID data (if available)

4. The Raspberry Pi calculates the optimal traffic signal timing

5. Priority signals are issued to create a clear path for the emergency vehicle

Results and Discussions

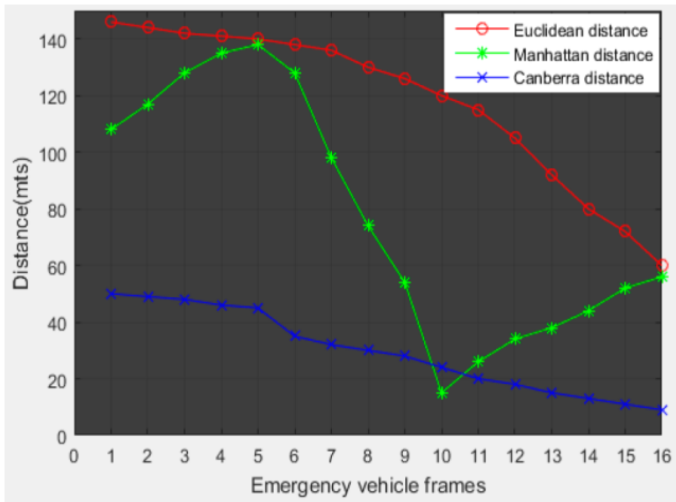

Fig: Comparison between distance measurement techniques

After obtaining the Euclidean distance, we measured the speed of the emergency vehicle (using $\Delta d/\Delta t$) and counted the vehicles moving along with the emergency vehicle towards next intersection. The measured values of vehicle count, Euclidean distance and speed are shown in Figure. The traffic management center can utilize this information in a traffic signal control module, resulting in an efficient emergency traffic management process. All the existing works depend on some kind of infrastructure and require extra cost equipment. Our scheme utilizes ultrasonic sensors, RSUs and existing surveillance cameras. The image processing-based approach cuts the installation and maintenance costs compared to existing emergency vehicle pre-emption (EVP) systems.

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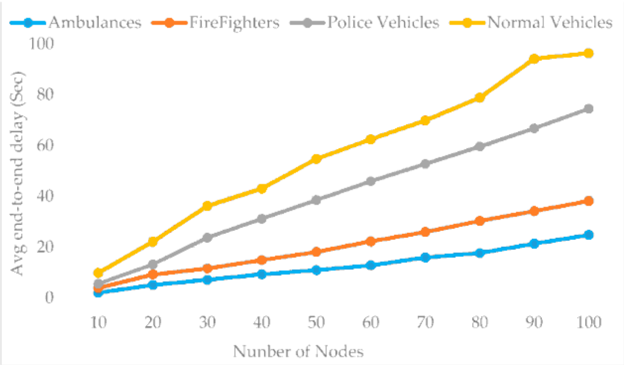

Fig: Graph of different vehicles

Figure shows the impact of the network size on the average end-to-end delay of all the data type messages. We run our simulation with the PE-MAC and the results depicted in this figure clearly show that the end-to-end delay of the ambulance data is very small compared to the other emergency vehicles and normal vehicles. From these results, we can also observe that the average end-to-end delay increases with the network size. The results have proven that the proposed PE-MAC delivers the emergency messages to the TMC with less delay.

The performance of any sensor network is typically evaluated based on the Packet Delivery Ratio (PDR), which, in the proposed method, is approximately 99.1%. For emergency message transmission, the PMAC protocol shows enhanced efficiency compared to IEEE 802.15.4, particularly in terms of the average duration required for data to travel from the origin to the destination. This improvement is clearly reflected in the results. Additionally, it has been identified that end-to-end latency is significantly influenced by the size of the network. As the number of deployed nodes increases, there is a corresponding rise in network activity, communication, and data exchange between nodes, which in turn leads to a proportional improvement in throughput. The term "delay" denotes the time span needed for data to be transmitted and received between two network nodes. This study also involves an experiment where the number of nodes is altered, and the resulting latency values are analyzed.

VI. CONCLUSION

Human life is precious, and safety measures, including ambulance services, must be prioritized. Using Advanced Traffic Signal Control (ATSC) with Raspberry Pi, directional sensors, and AI-based siren detection can enable uninterrupted service by optimizing traffic flow for emergency vehicles. This cost-effective, multi-use IoT solution improves vehicle tracking and precise signal control, while AI enhances detection even without RFID tags. The Raspberry Pi ensures efficient processing of these advanced algorithms.

This system not only enhances emergency response times but also reduces congestion by dynamically adjusting traffic signals. Its scalability and flexibility make it an ideal solution for urban environments, improving overall traffic management.

VII. FUTURE SCOPE

Further improvement we can add is to integrate the GPS module. The GPS can track the latitude and longitude values and send them to GSM, and the tracked value is sent to the traffic light signal through the internet. We can fix a GPS module in the ambulance to track the location. When it reaches our fixed point, the signals start toopen by the indication of plus and green signals in the traffic light pole. We have another fixed value for returning to the normal position of the signal. We can control this anywhere, anyplace through a control room.

Additional future enhancements may include:

1. Integration with Smart City Infrastructure: Connecting with other smart city systems such as smart parking, public transport, and environmental monitoring to create a comprehensive urban traffic management solution.

2. Advanced Machine Learning Development: Continuously improving the AI models through federated learning across multiple intersections, allowing the system to adapt to changing traffic patterns and emergency vehicle characteristics.

3. Extended Sensor Networks: Deploying additional sensors along major routes to create a more comprehensive coverage area for emergency vehicle detection.

4. Vehicle-to-Infrastructure (V2I) Communication: Implementing direct communication between emergency vehicles and traffic infrastructure to further enhance coordination and response times.

5. Predictive Analytics: Developing predictive models that can anticipate traffic patterns and emergency vehicle routes, allowing for proactive traffic management rather than reactive responses.

6. Edge Computing Implementation: Moving some of the computational load to edge devices to reduce latency and improve system responsiveness.

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