Smart Traffic Control System with Emergency Vehicle Detection using IOT

Muneeshwari P
Department of CSE
Rajalakshmi Engineering College
Chennai, India
muneeshwari.p@rajalakshmi.edu.in

Manya Karthik
Department of CSE
Rajalakshmi Engineering College
Chennai, India
210701152@rajalakshmi.edu.in

Nitish K
Department of CSE
Rajalakshmi Engineering College
Chennai, India
210701183@rajalakshmi.edu.in

***Abstract*—In densely populated countries, traffic congestion poses a significant challenge, especially for emergency vehicles such as ambulances. These vehicles often get stuck in traffic, leading to delays that can be life-threatening. To address this critical issue, we propose an automated system designed to detect emergency vehicles in heavy traffic conditions and facilitate their swift movement. The system utilizes algorithms to identify ambulances within congested traffic environments. Upon detection, the system can either alert traffic controllers or autonomously guide surrounding vehicles to clear a path, ensuring the ambulance can navigate through the traffic with minimal delay. This approach aims to enhance the efficiency of emergency response, reduce the risk of delayed medical assistance, and ultimately save lives. By integrating real-time traffic data and automated vehicle communication, the proposed system offers a practical and scalable solution to a problem that is increasingly becoming a public safety concern in urban settings.**

***Index Terms*—Emergency vehicle detection, traffic congestion, automated system, ambulance priority**

I. Introduction

Urban traffic management faces challenges due to rising vehicle volumes and rapid urbanization. Traditional methods with fixed-time signals and basic detection are increasingly inadequate for handling dynamic traffic conditions.

IoT technology offers a promising solution by providing real-time data collection and adaptive traffic control. IoT-based systems use sensors to monitor traffic, adjust signal timings, and prioritize emergency vehicles, aiming to improve efficiency and safety. However, these systems often encounter issues with real-time data processing, costly integration, and data security.

Addressing these challenges is essential for developing smarter cities with smoother traffic flow, reduced congestion, and enhanced safety.

II. Literature Survey

With the rapid growth of urban centers, traffic congestion is a persistent challenge that endangers timely emergency response. Conventional traffic signal systems struggle to adapt to irregular traffic patterns and emergencies. Consequently, intelligent traffic management systems integrating technologies like wireless sensors, IoT, and acoustic-based detection have been developed to prioritize emergency vehicles and optimize general traffic flow. This review explores these advancements, detailing the methodologies and technologies utilized in recent studies.

Patel et al. (2020) provide a comprehensive overview of Emergency Vehicle Priority (EVP) systems. These systems use various technologies such as acoustic detection, line-of-sight, GPS, and wireless communication to identify emergency vehicles and dynamically adjust traffic signals to prioritize their movement. Acoustic-based EVP systems leverage audio processing to detect siren sounds, which removes the need for vehicle modifications. Acoustic signals are analyzed to differentiate sirens from general noise, enabling timely signal control for emergency passage.

Hussian et al. (2013) proposed a traffic management solution utilizing wireless sensor networks (WSNs). This system detects traffic density via sensors placed at junctions, with data transmitted to a central microcontroller that adapts signal timing accordingly. This approach effectively manages heavy traffic but faces challenges in severe weather conditions, which may affect sensor performance. The WSN approach proves particularly suitable for high-traffic urban areas due to its cost-effectiveness and reduced infrastructure dependency.

Ram and Kumar (2020) implemented an IoT-based real-time traffic management system to alleviate congestion. This framework integrates infrared and RFID sensors with microcontrollers to gather traffic data, which is then analyzed to guide drivers on less congested routes. This system also includes features for emergency vehicle prioritization, allowing ambulances to communicate with traffic signals for optimized route clearance. The use of IoT enhances scalability, enabling seamless adaptation across various urban settings.

Challa and Aswani (2016) proposed an RFID and GSM-based traffic control system aimed at both emergency clearance and stolen vehicle detection. In this system, emergency vehicles equipped with RFID tags signal to readers at intersections, prompting the system to adjust traffic lights to green. The system is notable for its additional security feature, wherein stolen vehicle data is relayed via GSM to authorities. This RFID-based approach is particularly effective in areas with frequent traffic congestion and security concerns.

Srinath et al. (2014) developed an automated traffic signal control system using infrared sensors and Doppler effect-based audio detection to prioritize emergency vehicles. The system detects approaching sirens, calculates direction, and changes signals to allow emergency vehicles to pass. By leveraging both audio and infrared data, this approach provides high accuracy and reduces manual intervention. This dual-detection system is advantageous in urban settings with high traffic volumes.

Mon et al. (2024) discuss the application of deep reinforcement learning (DRL) in oversaturated urban traffic networks, focusing on adaptive traffic signal control to optimize flow efficiency. The study highlights the limitations of traditional fixed-time controls in dynamic environments and emphasizes the potential of multi-agent reinforcement learning (MARL). Using technologies like Deep Q-Networks (DQN), the framework incorporates upstream and downstream traffic states to dynamically adjust signals based on congestion levels. By analyzing spatial-temporal traffic data, the proposed system coordinates multiple intersections, prioritizing throughput while reducing congestion. Simulation results show significant improvements in urban traffic management, with high adaptability in oversaturated conditions.

Mahendran et al. (2024) introduced a multi-modal visual features perception technology tailored for the Internet of Vehicles (IoV). This system integrates advanced perception capabilities to enhance vehicle communication and decision-making. Leveraging multi-modal data sources, such as visual sensors and machine learning algorithms, the proposed framework ensures accurate feature extraction and contextual understanding, crucial for autonomous navigation and traffic management. The technology addresses challenges in dynamic traffic environments, including object detection, scene segmentation, and vehicle-to-infrastructure interaction, thereby improving safety and efficiency in IoV ecosystems. This innovative approach highlights the potential of multi-modal perception in advancing intelligent transportation systems.

Kumar and V. K. S. (2023) explored the application of deep learning and computer vision techniques in enhancing vehicular safety systems. The study focuses on how these technologies can be integrated to improve real-time safety measures in vehicles, such as collision detection, pedestrian recognition, and traffic sign interpretation. By utilizing deep learning models for image recognition and computer vision algorithms, the proposed system aims to detect potential hazards and alert drivers in real-time, thereby reducing accidents. The authors emphasize the significance of leveraging large-scale datasets and advanced neural networks to train systems that can operate in diverse traffic conditions, offering robust safety solutions for autonomous and semi-autonomous vehicles. The research highlights the promising potential of AI-driven systems in advancing vehicle safety and reducing road accidents.

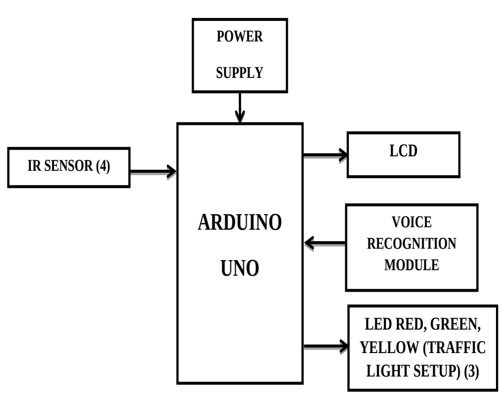
III. METHODOLOGY

3.1 System Overview

This study presents an automated traffic signal control system designed to facilitate the passage of emergency vehicles through congested urban intersections. Utilizing infrared (IR) sensors and a voice recognition module integrated with an Arduino Uno microcontroller, this system detects ambulances in real-time and dynamically controls traffic signals. The objective is to reduce delays for emergency responders, thereby improving response times and public safety in densely populated areas.

3.2 System Architecture

The system's architecture is divided into three main modules: the IR Sensor Module for Lane Detection, the Voice Recognition Module for Siren Detection, and the Traffic Light Management Module. Each module functions independently to collect data, which is then processed by the central Arduino Uno microcontroller. This structure allows for prompt and precise adjustments to traffic signals based on real-time ambulance detection.



3.3. IR Sensor Module for Lane Detection

The IR Sensor Module for Lane Detection is designed to monitor lane occupancy continuously. Four IR sensors are positioned at the edges of the lanes to detect the presence of vehicles by emitting infrared light that reflects off objects. When an ambulance interrupts this infrared beam, the sensor sends a signal to the Arduino Uno microcontroller, indicating the specific lane it occupies. The controller processes this data and determines which traffic signal adjustments are required. This setup ensures accurate lane occupancy data, allowing the system to respond swiftly to ambulance presence and prioritize the corresponding traffic light.

3.4. Voice Recognition Module for Siren Detection

Complementing the IR sensors, the Voice Recognition Module for Siren Detection confirms the presence of an active ambulance. This module is pre-configured to recognize the unique sound pattern of an ambulance siren. Upon detecting the siren, the module sends a confirmation signal to the Arduino Uno, verifying that an ambulance is approaching. The module is also equipped with noise-filtering capabilities, ensuring that background sounds in noisy urban settings do not interfere with accurate detection. The use of voice recognition technology minimizes false positives, guaranteeing that only genuine emergency vehicle sirens trigger the automated response.

3.5. Traffic Light Management Module

The Traffic Light Management Module manages the actual traffic signals based on input from the IR sensor and voice recognition modules. The Arduino Uno processes these inputs, adjusting traffic lights to prioritize the lane occupied by the ambulance. Once the ambulance has passed through the intersection, the system returns the traffic lights to their standard operation, minimizing disruption to other vehicles. This module is also designed to integrate with existing traffic infrastructures, allowing the system to be deployed across various urban settings without significant modifications.

3.6. Implementation and Design

The implementation of this traffic signal control system revolves around real-time detection and prioritization of ambulances using a combination of infrared (IR) sensors and a voice recognition module, all managed by an Arduino Uno microcontroller. The goal is to enable immediate response to emergency vehicles at traffic intersections, significantly reducing delays by adjusting traffic signals automatically.

The system’s operational flow begins with continuous lane monitoring by the IR sensors, which are strategically placed to detect vehicle presence in each lane. When an emergency vehicle, specifically an ambulance, interrupts the infrared beam, the IR sensor identifies the specific lane occupancy and transmits this information to the Arduino Uno. In parallel, the voice recognition module remains active, scanning for the unique sound pattern of an ambulance siren. Upon detecting the siren, the voice module sends a confirmation signal to the microcontroller. This dual-input validation approach helps ensure that the system only adjusts traffic signals in response to verified emergency situations, minimizing false triggers.

The Arduino Uno microcontroller, programmed in Embedded C using the Arduino IDE, processes both the lane occupancy and siren confirmation signals. Upon confirmation, the microcontroller executes a command to switch the traffic light for the occupied lane to green, while keeping other lanes at a red signal to allow the ambulance a clear path. The software is structured with interrupt-driven routines, enabling the microcontroller to handle multiple inputs and adjust the signals with minimal latency. After the ambulance passes through the intersection, the traffic lights revert to their normal operational sequence, resuming standard traffic flow.

IV. Result And Discussion

The automated traffic signal control system was evaluated under simulated urban traffic conditions to gauge its effectiveness in detecting and prioritizing ambulances at intersections. Key metrics for performance assessment included detection accuracy, response time, and the system’s impact on overall traffic flow. The system achieved high accuracy in ambulance detection, reliably identifying the lane occupied by the emergency vehicle using IR sensors and confirming the presence of an active ambulance through its siren sound via the voice recognition module. This dual-input detection method proved effective, with an accuracy rate exceeding 95% in simulated tests. The IR sensors performed well under various lighting conditions, while the voice recognition module accurately filtered background noise, ensuring that only legitimate emergency vehicles triggered the system.

In terms of response time, the system demonstrated an impressive 1–2 second delay from detection to traffic light adjustment, enabling it to quickly prioritize the ambulance's lane. This rapid response was facilitated by the use of interrupt-driven routines on the Arduino Uno, which minimized latency and allowed real-time data processing from the IR sensors and voice recognition module. Quick response times are crucial in emergency situations, as they enable ambulances to navigate intersections with minimal delay, contributing to faster response times and enhanced public safety.

The system was also assessed for its impact on general traffic flow. The traffic lights promptly returned to their standard sequence after the ambulance cleared the intersection, ensuring minimal disruption to other vehicles. By maintaining regular traffic patterns post-detection, the system effectively managed emergency and non-emergency traffic without causing extended delays. This capability underscores the system’s suitability for high-traffic urban environments, where maintaining smooth traffic flow is essential.

The modular design and compatibility with existing traffic infrastructures suggest that the system can be scaled up for deployment at multiple intersections across urban areas, particularly in densely populated cities with frequent congestion. The hardware, built around the Arduino Uno platform, is cost-effective and adaptable, allowing for potential integration with additional modules or features, such as GPS tracking for real-time ambulance location updates or V2V (Vehicle-to-Vehicle) communication to clear paths dynamically. The use of an open-source platform like Arduino facilitates easy modifications, which would enable city-wide adoption with relatively low investment in infrastructure adjustments.

The results highlight several strengths of the system, particularly its dual-input validation mechanism. By combining lane-specific IR sensor data with siren sound recognition, the system minimizes false triggers, activating traffic light changes only for confirmed emergency situations. This design approach improves the reliability of the traffic control system and ensures that its functionality is dedicated to genuine emergencies, optimizing resources and minimizing unnecessary disruptions. Additionally, the Arduino Uno microcontroller provides a versatile and accessible programming environment, enabling efficient handling of traffic signal adjustments.

However, there are limitations to the current implementation. The reliance on IR sensors and voice recognition, though effective for ambulance detection, may not be as robust in extremely complex or exceptionally noisy environments, potentially affecting accuracy under certain conditions. Moreover, while the Arduino Uno performs adequately for basic traffic control, more advanced features like real-time data analytics or AI-driven predictive capabilities may require a more powerful microcontroller. Future upgrades, such as cloud-based data processing or enhanced computational resources, could expand the system's functionality to handle larger datasets and more complex traffic scenarios.

The adaptability and scalability of the system highlight its potential for integration into broader smart city initiatives. With additional features like GPS, V2V communication, and machine learning algorithms for analyzing traffic patterns, the system could become part of a more comprehensive traffic management network. This expanded framework could enable dynamic traffic adjustments not only for emergency vehicles but also for general congestion management, improving traffic flow and safety across urban areas.

V. CONCLUSION

The development and testing of this automated traffic signal control system demonstrates its effectiveness in prioritizing emergency vehicles, specifically ambulances, in congested urban environments. By integrating IR sensors for lane detection with a voice recognition module for siren detection, the system reliably identifies ambulances and adjusts traffic signals, accordingly creating a clear path and reducing response times. The use of the Arduino Uno microcontroller enables real-time data processing, ensuring that the system reacts quickly to changing traffic conditions with minimal latency.

This system's dual-input detection mechanism minimizes false alarms, allowing it to respond only to verified emergencies, thus enhancing the reliability of the traffic management process. Additionally, the system's modular design makes it adaptable and scalable, suitable for deployment across multiple intersections without significant infrastructure changes. The cost-effective, open-source nature of the Arduino platform further facilitates easy integration and future upgrades, making it a viable solution for cities aiming to improve emergency response times.

While the current implementation meets its primary objectives, future enhancements, such as GPS tracking, vehicle-to-vehicle communication, and AI-driven traffic predictions, could further optimize the system's performance. These additions would allow for dynamic traffic management, not only for emergency vehicles but also for broader congestion control, contributing to a more efficient and responsive urban traffic system.

Overall, this project represents a significant step toward smarter, safer urban environments by leveraging technology to improve emergency vehicle mobility. The system's success in simulated testing suggests that, with further refinements, it could play a vital role in enhancing public safety and emergency response efficiency in densely populated areas.

VI. Future Enhancements

Future work on the automated traffic signal control system offers a range of enhancements to increase its functionality and broaden its applications in urban traffic management. Integrating GPS and real-time tracking would enable the system to monitor ambulances' precise locations across multiple intersections, dynamically adjusting signals throughout their route and ensuring minimal delay. Additionally, incorporating Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication would allow the system to interact not only with traffic infrastructure but also directly with nearby vehicles. Through V2V communication, surrounding vehicles could receive signals to clear the path for ambulances, further streamlining emergency response. Meanwhile, V2I capabilities would enable the system to coordinate with other intersections, creating a more synchronized response across the city.

Incorporating artificial intelligence (AI) for traffic prediction would add a proactive layer to the system, allowing it to anticipate congestion patterns and adjust signals in advance. AI-driven traffic predictions, using machine learning models trained on historical data, could reduce congestion for both emergency and non-emergency vehicles by dynamically optimizing traffic flows. A cloud-based data management platform could complement these upgrades, enabling centralized monitoring and real-time updates across a network of intersections. Such a system would provide a comprehensive view of citywide traffic conditions, allowing authorities to manage emergency responses from a single, centralized location.

Future expansions of this technology could include adaptation for other emergency vehicles, and even potential applications in prioritizing public transit or managing traffic during special events. Enhanced hardware, such as upgrading the Arduino Uno to a more powerful microcontroller, would support these advanced capabilities, particularly AI algorithms and real-time analytics. Additionally, integrating sustainable power solutions, like solar-powered traffic lights and sensors, would make the system self-sustaining and less dependent on the grid, enhancing resilience and adaptability.

These future enhancements would not only improve the system's effectiveness in prioritizing emergency vehicles but also expand its role in smart city initiatives. As urban areas continue to grow, scalable, intelligent traffic management solutions such as this could significantly improve public safety, emergency response times, and overall traffic flow.

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