Intelligent Traffic Signal Control for Emergency Vehicles Using Raspberry Pi

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***Abstract*—Urban traffic congestion poses a significant challenge, leading to delays in emergency response and increasing fatalities. In India, approximately 1.46 million deaths occur annually due to traffic-related issues, with nearly 30% involving emergency vehicles like ambulances and fire engines trapped in congestion. To address this issue, we propose a Smart Traffic Light Control System that dynamically prioritizes emergency vehicles using Raspberry Pi, RFID technology, and Programmable Integrated Circuits (PIC).The system consists of two key components: one embedded in emergency vehicles and another deployed at traffic intersections. Utilizing RFID-based vehicle detection, the system identifies approaching emergency vehicles and automatically switches traffic signals to green, ensuring an uninterrupted passage. Additionally, an AI-driven adaptive traffic control mechanism leveraging infrared (IR) sensors, machine learning algorithms, and edge computing optimizes signal timings based on real-time traffic density. Integration with IoT-based traffic monitoring systems further enhances data-driven decision-making and urban traffic efficiency. This cost-effective, scalable, and AI-enhanced solution improves emergency response times, reduces congestion, and enhances road safety. By incorporating real-time traffic analytics, cloud-based traffic management, and connected vehicle technology, the system represents a substantial advancement in intelligent urban mobility solutions.**

***Index Terms*—Traffic Congestion, Emergency Response, Smart Traffic Light Control, Raspberry Pi, RFID Technology, Programmable Integrated Circuits (PIC), Infrared Sensors, AI-Based Traffic Optimization, IoT Traffic Management, Edge Computing, Machine Learning, Real-Time Traffic Analytics, Adaptive Signal Control, Urban Mobility, Connected Vehicles.**

I. Introduction

Traffic congestion remains a critical challenge in urban areas, [1]–[6] leading to significant delays, increased fuel consumption, and hindered emergency response times. In densely populated countries like India and Bangladesh, inefficient traffic signal management exacerbates these issues, particularly during peak hours when students, employees, and essential services face prolonged delays. The primary goal of this project is to develop a Smart Traffic Light Control System that dynamically adjusts signal timings based on real-time traffic conditions, ensuring smoother vehicle flow and reducing unnecessary waiting times at intersections. By integrating RFID technology for emergency vehicle prioritization and IR sensors for traffic density detection, the system enhances road efficiency and minimizes congestion-related delays.

Additionally, the project aims to improve emergency response times by providing an automatic green signal for ambulances and fire engines, preventing life-threatening delays caused by traffic jams. The cost-effective and scalable nature of the proposed solution makes it suitable for urban traffic management, ultimately contributing to reduced fuel consumption, lower carbon emissions, and improved road safety. This initiative aligns with modern urban mobility trends, incorporating IoT-based traffic monitoring, real-time data analytics, [8] and programmable control mechanisms to create a more adaptive and efficient traffic management system.

II. Methodology

The Smart Traffic Light Control System is designed to dynamically manage urban traffic flow and prioritize emergency vehicles using real-time data. The methodology involves the following key components:

III. System Architecture

The proposed system consists of two major units:

- Emergency Vehicle Unit: Equipped with RFID tags to identify and communicate with traffic signals.

- Traffic Signal Control Unit: Installed at intersections and integrated with RFID readers, IR sensors, and Raspberry Pi for data processing.

A. *Traffic Detection and Signal Control*

- RFID-Based Emergency Vehicle Detection
  o Each emergency vehicle (ambulance, [9] fire engine) is assigned an RFID tag.
  o When the vehicle approaches an intersection, the RFID reader at the traffic signal detects the tag and sends a signal to prioritize the emergency vehicle by switching the light to green.

- Density-Based Traffic Signal Control
  o Infrared (IR) sensors are placed at different lanes to measure real-time traffic density.
  o The system dynamically adjusts signal durations based on vehicle flow, reducing unnecessary wait times and optimizing traffic movement.

B. *Hardware and Processing Unit*

- Raspberry Pi is used as the core processing unit to collect data from RFID readers and IR sensors.

- The system processes real-time traffic density and emergency vehicle presence to make instant decisions on signal changes.

- Programmable Integrated Circuits (PIC) are used to interface with traffic lights and ensure seamless operation.

C. *Communication and Integration*

- The system can be integrated with IoT-based traffic monitoring systems to enable remote monitoring and management.

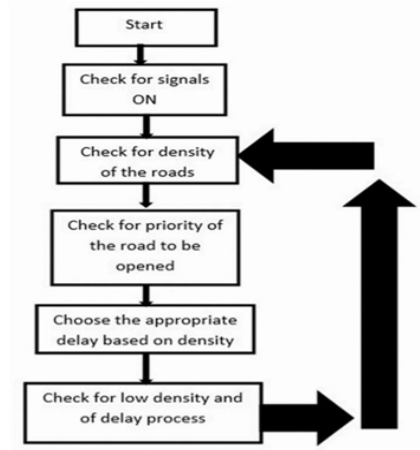
- Data analytics and cloud-based insights can help optimize traffic flow patterns over time.

D. *Implementation and Testing*

- The prototype is first tested in a controlled environment to evaluate real-time responsiveness and accuracy.
- After validation, it is implemented at selected intersections to analyse its effectiveness in reducing congestion and improving emergency response times.

IV. WORKFLOW:

The flowchart of this proposed method is as follows:



V. CIRCUIT OPERATION

The Smart Traffic Light Control System operates in two primary modes: Normal Mode and Adaptive Mode, ensuring efficient traffic management while prioritizing emergency vehicles.

A. *Normal Mode (Fixed Signal Operation*

- In the absence of emergency vehicles or significant traffic congestion, the system functions like a traditional traffic light, following preset time intervals for green, yellow, and red signals.

- IR sensors continuously monitor vehicle movement, and if the density remains low (below a threshold value), the system maintains standard signal timings.

- The Raspberry Pi-based controller manages signal transitions using data from IR sensors and microcontrollers.

B. *Adaptive Mode (Traffic Density and Emergency Vehicle Priority)*

- Traffic Density Detection:
  o IR sensors placed at each lane measure real-time traffic density.
  o If congestion increases (voltage from sensors exceeds a predefined threshold), the system dynamically adjusts signal durations to clear heavy traffic.

- Emergency Vehicle Detection and Priority:
  o RFID readers at intersections detect emergency vehicles (ambulances, fire engines) equipped with RFID tags.
  o Upon detection, the system immediately turns the signal green for the emergency vehicles path while holding red for other lanes.

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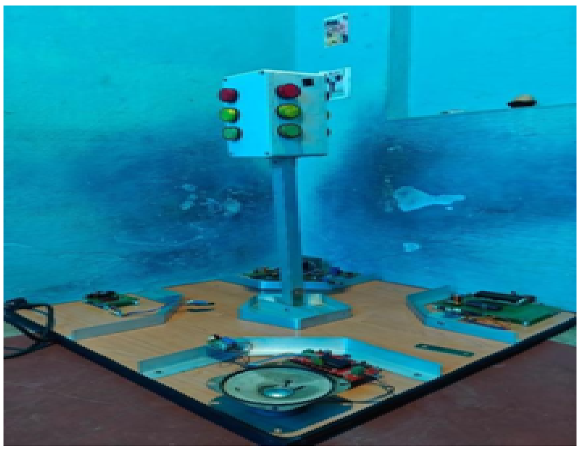

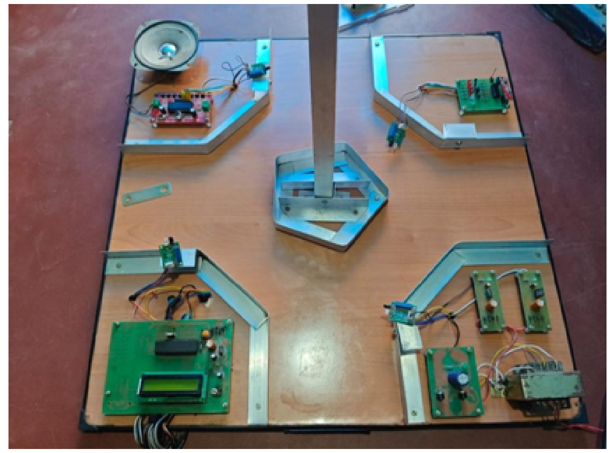

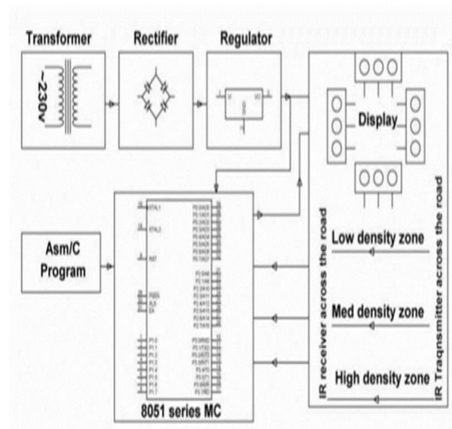

Fig. 1. Block Diagram of Density Based Traffic Signal Control System

- The system automatically transitions back to Normal Mode once the emergency vehicle has passed or traffic density normalizes.

C. Physical Appearance and Summary

The Smart Traffic Light Control System uses RFID, IR sensors, and a Raspberry Pi controller to dynamically adjust traffic signals. It prioritizes emergency vehicles by granting green signals and optimizes congestion management through real- time traffic density monitoring. This cost-effective, scalable system enhances urban traffic flow, reduces delays, [10] and improves emergency response efficiency for safer roads.

VI. Result

The Smart Traffic Light Control System successfully reduces traffic congestion and enhances emergency response times by dynamically adjusting signals. RFID technology ensures priority passage for ambulances and fire trucks, while IR sensors and Raspberry Pi controllers optimize signal durations based on real-time traffic density. This system significantly minimizes waiting times and improves overall traffic efficiency.

VII. Conclusion

This intelligent system integrates real-time traffic monitoring, emergency vehicle prioritization, and adaptive signal control to enhance urban mobility. By leveraging RFID, IR sensors, and microcontrollers, it ensures efficient traffic flow, reduces accident risks, and supports faster emergency responses. Implementing this cost-effective solution can revolutionize urban traffic management, making roads safer and transportation more efficient.

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