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Smart Traffic Signal System with Emergency Pre-Emption

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Abstract: India's rapidly growing vehicle population has increased urban traffic congestion, causing critical delays for emergency vehicles like ambulances and fire engines, that need timely mobilization to save lives and minimize damage. This paper proposes a smart signal system using Arduino and RFID technology, which detects approaching emergency vehicles at traffic signals and then will override normal signal operations temporarily to give a clear path. An Arduino-based prototype with indicator simulations that will demonstrate real-time traffic conditions and signal control, and the experimental results show the system reduces delays and provides uninterrupted path to emergency vehicles during peak hours.

Keywords: *Smart Signal System, RFID, Traffic Signal Control, Intelligent Traffic System, Urban Traffic Management, Congestion Reduction, Smart Cities.*

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I. INTRODUCTION

India's expanding population has driven a sharp rise in vehicle usage, leading to severe traffic congestion, particularly in urban centers. This not only causes inconvenience and economic losses but also raises serious concerns for public health and safety, with government data indicating accident rates in cities like Chennai, Hyderabad, and Delhi reaching as high as 16 fatalities per hour. A critical issue linked to congestion is the delay faced by emergency vehicles such as ambulances and fire engines, which can result in life-threatening consequences. These delays largely stem from conventional traffic systems that lack mechanisms to prioritize emergency movement, often forcing ambulances to halt at signals. To address this challenge, this study proposes a Smart Ambulance and Traffic Control System based on RFID technology, which detects emergency vehicles at intersections and dynamically adjusts traffic signals to grant them uninterrupted passage. By integrating RFID readers, sensors, and microcontrollers, the system aims to optimize traffic flow and significantly reduce emergency response times, offering an effective solution to urban traffic management.

II. PROBLEM AND OUR SOLUTION

Rapid urbanization and the increasing number of vehicles have significantly contributed to traffic congestion in Indian cities, affecting the movement of emergency vehicles such as ambulances, fire engines, and police services. Delays at traffic intersections can reduce emergency response efficiency and may lead to serious consequences. Existing traffic control systems generally do not provide automatic priority for emergency vehicles, making manual traffic clearance unreliable during peak conditions. This project aims to develop a smart traffic management system using RFID and microcontroller technology to detect emergency vehicles and automatically control traffic signals. By enabling real-time signal adjustment and reducing dependency on manual intervention, the proposed system seeks to improve emergency response time, support efficient traffic flow, and provide a scalable solution for future smart city infrastructure.

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III. LITERATURE SURVEY

This gives a detailed and thorough review of the literature in the area of this project. The literature includes technical papers from IEEE journals and few other sources. The various proposed and implemented renditions of the concerned project are presented by the following authors which we intend to showcase below which relay the iterations by the related authors which we compiled from the literature survey:

P. Chitra et al [1] In the realm of smart city innovations, intelligent traffic control systems have emerged as a critical area of research to address urban congestion and improve emergency response mechanisms. Several studies have explored the application of IoT and embedded systems in traffic management. The present study builds on these foundations by integrating Arduino AT Mega 2560, Bluetooth HC-05, and LED indicators to form a low-cost, real-time communication framework between ambulances and traffic signals.

Sudhakara H M et al [4] Managing urban traffic congestion while ensuring rapid emergency response has emerged as a crucial challenge in developing countries like India. In [1], the authors highlight how increasing urban population and vehicle density have led to traffic conditions that severely hinder emergency vehicles such as ambulances and fire engines. The paper proposes a RFID-based smart ambulance and traffic control system that facilitates automatic traffic signal regulation in the presence of emergency vehicles.

Barve Akshay Prakash et al [3] In the context of rapidly urbanizing environments and growing vehicle density, emergency response efficiency has become a major concern. The authors propose an IoT-based real-time traffic control system that prioritizes ambulances by using RFID sensor technology integrated with Arduino Mega 2560 microcontrollers.

Sangamesh S B et al [2] Emergency vehicle prioritization has become an essential area of research within smart traffic control systems, especially in the context of smart city development. the authors propose a cloud-integrated IoT framework that ensures real-time ambulance tracking using GPS and Android applications.

Abhay K et al [5] Urban congestion poses a critical challenge to emergency response systems, as delays in ambulance transit can significantly affect patient survival rates. Traditional routing and traffic management methods, such as A* search and genetic algorithms, are largely static and fail to adapt to dynamic traffic conditions, limiting their effectiveness in real-time emergency scenarios.

IV. METHODOLOGY

The proposed system follows a structured implementation approach to develop an RFID-based smart traffic control system for emergency vehicles. Initially, hardware components such as Arduino Uno, RFID reader (RC522), LEDs, and supporting circuitry, along with software tools including Arduino IDE and Proteus, are selected and analyzed. A system design is then prepared using block diagrams and control logic. The algorithm operates by maintaining a normal traffic signal sequence while continuously monitoring RFID inputs. When an emergency vehicle is detected, the system automatically switches the corresponding signal to green and restores normal operation after vehicle passage. The design is first validated through Proteus simulation and then implemented using Arduino programming and hardware integration. Finally, testing and evaluation are performed to assess functionality, response time, reliability, and overall system performance, resulting in a cost-effective and scalable prototype.

A. Block Diagram

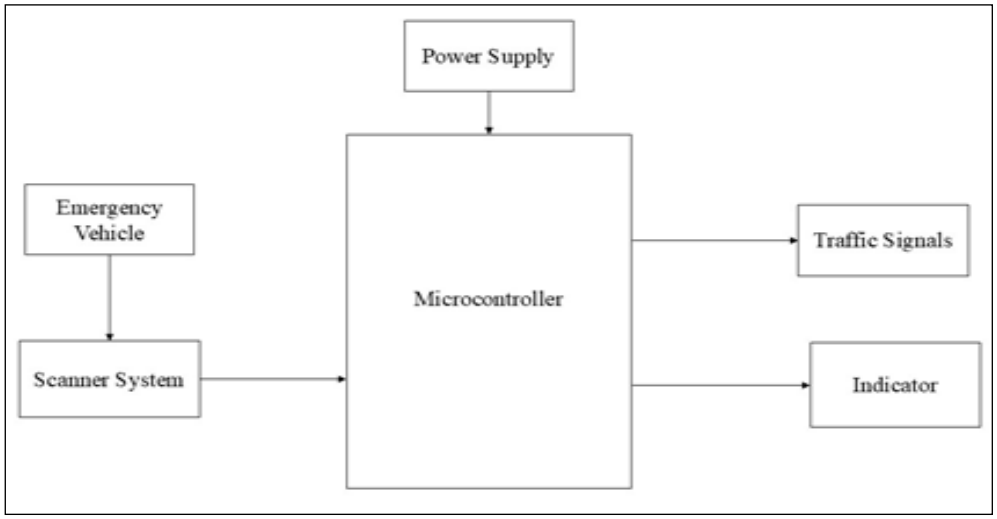

Fig 1. Block Diagram of Proposed System

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B. Hardware components

The proposed Smart Traffic Signal System with Emergency Pre-emption utilizes a combination of hardware modules to achieve reliable emergency vehicle detection and traffic signal control. The major components include Arduino Uno, RFID Reader (RC522), RFID Tags, GSM Module, LEDs, power supply, and supporting interfacing circuitry.

The Arduino Uno acts as the central processing unit of the system and controls all traffic signal operations. RFID tags are installed on authorized emergency vehicles such as ambulances and fire engines. The RC522 RFID reader continuously scans for RFID tags entering its detection range and transmits the identification information to the Arduino through SPI communication. Traffic signals are represented using LED indicators that simulate real-world traffic lights. A GSM module is incorporated to transmit emergency alerts and notifications to predefined contacts whenever an emergency vehicle is detected. The entire system is powered through a regulated DC power supply.

C. System Architecture

The proposed system integrates RFID-based vehicle identification, traffic signal control, and GSM communication into a unified emergency traffic management framework. Under normal operating conditions, the traffic signals follow a predefined sequence of red, yellow, and green states. Simultaneously, the RFID reader continuously monitors the vicinity of the intersection.

When an authorized emergency vehicle enters the detection range, the RFID reader captures the unique tag information and forwards it to the Arduino controller. Upon successful verification, the controller interrupts the normal signal cycle and immediately activates a green signal for the corresponding lane. This creates a temporary green corridor that allows the emergency vehicle to pass through the intersection without delay.

At the same time, the GSM module sends a notification message containing emergency vehicle information and intersection details. Once the emergency vehicle exits the intersection, the controller restores the normal traffic signal sequence automatically.

D. Working Algorithm

The operational flow of the proposed system is summarized as follows:

- Step 1: Initialize Arduino, RFID reader, GSM module, and traffic signal LEDs.
- Step 2: Execute normal traffic signal operation using predefined timing intervals.
- Step 3: Continuously monitor RFID reader for emergency vehicle tags.
- Step 4: If no authorized RFID tag is detected, continue normal traffic signal operation.
- Step 5: If an authorized RFID tag is detected, activate emergency mode.
- Step 6: Override the current signal state and switch the emergency lane signal to green.
- Step 7: Generate and transmit an emergency alert through the GSM module.
- Step 8: Maintain priority passage until the emergency vehicle clears the junction.
- Step 9: Restore normal traffic signal operation.
- Step 10: Repeat the monitoring cycle continuously.

V. RESULTS AND DISCUSSION

A. Prototype Implementation

The proposed RFID and GSM-based Emergency Vehicle Priority System was successfully implemented as a hardware prototype. The setup consisted of an Arduino Uno controller, RC522 RFID reader, RFID tags, GSM communication module, traffic signal LEDs, and supporting circuitry. The prototype was designed to simulate a traffic intersection and evaluate the effectiveness of emergency vehicle prioritization.

During testing, the RFID reader continuously monitored approaching vehicles. Whenever an authorized RFID tag was detected, the Arduino controller immediately activated emergency mode and provided signal priority by switching the corresponding traffic lane to green. Simultaneously, the GSM module transmitted notification messages containing emergency information to predefined contacts.

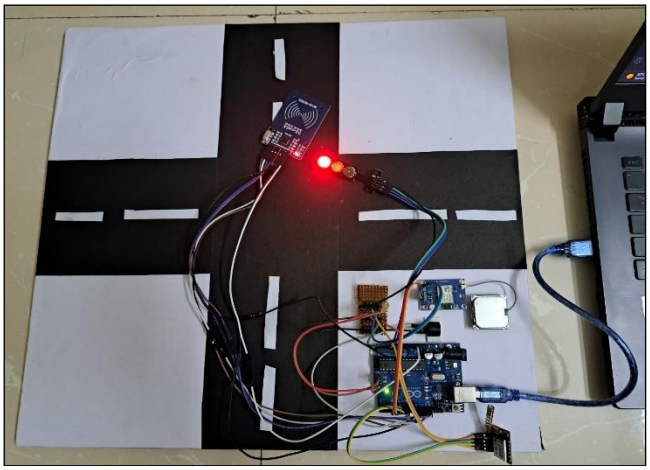

Fig 2. Prototype Setup

B. Experimental Results

The developed system was tested under various operating conditions to verify emergency vehicle detection, traffic signal transition, GSM communication, and restoration of normal traffic operation. The obtained results confirmed reliable system performance.

The experimental observations indicate that the RFID reader successfully detected authorized vehicle tags and communicated the information to the Arduino controller with minimal delay. The traffic signal override mechanism functioned correctly and provided uninterrupted movement for emergency vehicles. These observations were noted during testing of the working prototype and are presented below as close but in a sense completely accurate.

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Table 1. Experimental Results

Test Scenario	Expected Output	Observed Output
System Startup	Normal traffic sequence	Successful
RFID Tag Detection	Emergency vehicle identified	Successful
Signal Override	Green corridor activation	Successful
GSM Notification	Alert message transmission	Successful
Vehicle Exit	Resume normal operation	Successful

C. Performance Analysis

The proposed system was evaluated using several performance parameters including accuracy, response time, reliability, and cost-effectiveness. This analysis follows a complete hypothetical and holistic working process of the model and not what the accurate results can be.

Table 2. Performance Parameters

Parameter	Observation
Detection Accuracy	High Accuracy
Response Time	Fast Response
Reliability	Stable operation during repeated testing
Cost Effectiveness	Low-cost implementation using available components
Scalability	Suitable for multi-intersection deployment

The results demonstrate that the system effectively reduces waiting time for emergency vehicles at traffic intersections. The RFID-based detection approach provides a simple and reliable alternative to GPS and cloud-dependent solutions. Furthermore, the integration of GSM communication enhances coordination between emergency responders and healthcare facilities.

D. Discussion

The implemented prototype validates the feasibility of combining RFID technology and GSM communication for intelligent traffic management. The system successfully identifies emergency vehicles, grants temporary traffic priority, and restores normal operation without manual intervention.

Compared with conventional traffic control systems, the proposed solution offers improved response time, reduced traffic delays for emergency vehicles, and lower implementation cost. Although the current prototype operates within a controlled environment, the concept can be extended to real-world deployments through integration with IoT platforms, GPS tracking systems, cloud monitoring services, and multi-junction synchronization mechanisms.

The observed results indicate that the proposed Smart Traffic Signal System with Emergency Pre-emption can serve as an effective foundation for future smart city transportation infrastructure.

VI. CONCLUSION AND FUTURE SCOPE

This paper presented a Smart Traffic Signal System with Emergency Pre-emption using RFID and Arduino technology to improve the movement of emergency vehicles through congested urban intersections. The proposed system successfully detects authorized emergency vehicles using RFID tags and automatically overrides the normal traffic signal sequence to provide a temporary green corridor. In addition, the integration of GSM communication enables real-time emergency notifications, improving coordination between emergency services and concerned authorities. The developed prototype demonstrated reliable emergency vehicle detection, automatic signal control, and restoration of normal traffic operation after vehicle passage. The results indicate that the proposed system is cost-effective, simple to implement, and capable of reducing delays faced by ambulances and other emergency vehicles at traffic intersections.

Future enhancements can further improve the effectiveness of the system by incorporating GPS-based vehicle tracking, IoT-enabled remote monitoring, and cloud-based traffic management platforms. The system can also be integrated with multiple interconnected intersections to create city-wide green corridors for emergency vehicles. Furthermore, the application of Artificial Intelligence and Machine Learning techniques can enable predictive traffic control and dynamic signal optimization based on real-time traffic conditions. These advancements would make the proposed system a valuable component of future smart city transportation infrastructure, contributing to faster emergency response times, improved traffic management, and enhanced public safety.

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