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Implementation of IoT in Traffic Control System for Effective Emergency Services in Bengaluru City

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Abstract: Bengaluru City has experienced steady demographic growth over the past twenty years. The city's rich cultural diversity, thriving ecosystem, and quality education have made it an attractive destination for settlement. The population increased from approximately 13 million in 2023 to 14 million by 2025, representing a growth of about 2.76%. This increase has led to a corresponding rise in the number of vehicles, resulting in severe traffic congestion, longer commute times, and an increased number of road accidents. Consequently, emergency vehicles such as ambulances and fire engines often struggle to reach their destinations promptly.

To address this issue, a traffic signal management system has been designed to clear vehicle queues during peak hours and provide priority passage for emergency vehicles. Existing literature provides limited focus on this aspect, prompting the proposal of a system based on RFID (Radio Frequency Identification), a microcontroller, Arduino Nano, and IR sensors to manage and regulate traffic signals at road junctions whenever an emergency vehicle approaches. The proposed system ensures the smooth and uninterrupted movement of emergency vehicles through congested traffic.

Keywords: RFID Technology, Traffic Signals, Congestion Clearance, Ambulance

INTRODUCTION

In today's world, where more people are opting for cars over motorcycles and cities are becoming increasingly crowded due to rapid urban development, traffic congestion has become a common problem. Unfortunately, amid the demands of modern life, the importance of saving lives during medical emergencies is often overlooked. During emergencies such as heart attacks, timely medical intervention is critical. However, ambulances frequently become trapped in traffic, delaying their arrival at hospitals and reducing the chances of successful treatment.

To address this challenge, the concept of **Smart Ambulances** has been proposed. These ambulances not only monitor the patient's health but also interact with traffic control systems to reduce travel time to hospitals. In India, ambulance services play a vital role in providing timely medical assistance. Operated by government, private, and non-profit organizations, these services continue to face challenges such as inadequate infrastructure and heavy traffic congestion. Despite these obstacles, ambulances serve as frontline responders, bridging the gap between patients and healthcare facilities, particularly during critical emergencies.

The proposed Smart Ambulance system incorporates devices that continuously monitor vital signs, such as heart rate, and transmit this information to hospitals in real time. Simultaneously, the ambulances are equipped with communication technology that interacts with traffic signals, enabling traffic lights to turn green along the ambulance's route. By integrating patient health monitoring with intelligent traffic control, the proposed system aims to reduce emergency response time and improve patient survival rates. This innovative approach demonstrates how modern Internet of Things (IoT) technologies can effectively address the challenges of urban traffic management while enhancing emergency healthcare services.

LITERATURE

The authors proposed an application based on Android and a hardware module for traffic signal operation at road intersections. The system includes four buttons representing four directions, allowing the ambulance driver to select the desired route. The driver selects the appropriate direction and sends an activation command to the traffic signal. Simultaneously, the patient's information, including name, age, blood group, and other details, is stored. The hardware module comprises an Arduino for traffic signal implementation and a Wi-Fi module to receive information from the server and connect directly to the Android application. The location data are retrieved using latitude and longitude coordinates. The direction of movement of the emergency vehicle is determined using the compass heading [1].

After thorough analysis, it is evident that the proposed system effectively meets its objectives. Installation and maintenance are cost-effective and efficient, saving both time and resources. Its user-friendly interface requires no specialized training, thereby enhancing accessibility for all users. Designed to prioritize the smooth movement of emergency vehicles such as ambulances and fire engines, the system ensures their swift passage while restoring normal traffic flow seamlessly. By automating traffic signal operations, it reduces the workload of traffic personnel and minimizes human error, thereby improving overall efficiency. Additionally, its route-finding algorithm identifies the shortest available paths, which is invaluable in today's fast-paced society where time is critical. Overall, the system significantly improves traffic performance and enhances road safety [2].

In this work, the authors describe a real-time tracking system based on the Global System for Mobile Communications (GSM) and the Global Positioning System (GPS). The system is designed for real-time monitoring of emergency vehicles, thereby avoiding delays in reaching hospitals. The proposed GSM/GPS-based system enables the transmission of SMS alerts along with the current location of the vehicle. This methodology facilitates efficient tracking of emergency vehicles and enables traffic clearance to ensure faster arrival at hospitals. With widespread adoption and greater public awareness, this technology can reduce travel time and improve the survival chances of critically ill patients [3].

Parida incorporated the use of an RF transmitter-receiver module and Zigbee transceiver along with the ATmega328 microcontroller. The system enables emergency vehicles to override the existing traffic signal sequence, allowing them to reach their destinations without interruption. The entire system relies on communication between emergency vehicles and traffic signals. Both the RF transmitter-receiver module and the Zigbee transceiver are connected to the microcontroller. However, if traffic congestion is caused by road construction or a minor accident, the driver may remain unaware of the obstruction. In such situations, the system becomes ineffective because the emergency vehicle may still become trapped in traffic despite controlling the traffic signals. Additionally, the hardware used in this system has limited communication range and low transmission power [4].

The author highlights the challenges associated with handling emergency vehicles, particularly ambulances, in urban areas and ensuring their timely arrival to save critically ill patients. The proposed system utilizes technologies such as an in-built GPS, **Arduino UNO**, and a GSM modem connected to Traffic Control (TC) rooms. These TC rooms coordinate with ambulances to ensure timely hospital arrival by requesting changes in traffic signals whenever necessary. The implemented solution demonstrated positive results by integrating an Arduino-based system that enables communication among the TC room, hospitals, and ambulances [5].

This study presents a traffic density control system based on a microcontroller. In every ambulance, a navigation module is installed for routing purposes. However, due to the limitations of GPS signals in detecting short-distance movements, a keypad with multiple routing options is employed instead. When the driver selects a route by pressing a key, a binary signal is transmitted to the microcontroller. This signal, containing the ambulance's current location, the selected route, and traffic congestion information, is then transmitted to the RF transmitter through the TxD pin [6].

Kandhari and Antonov proposed a congestion management system for densely populated urban areas, where traffic congestion has become a significant cause of delays in emergency services. Their approach utilizes an RFID system combined with strobe detection of emergency vehicles. RFID tags act as sensors in emergency vehicles. When the driver activates the RFID tag, it is detected by RFID readers installed several meters before or at traffic intersections. These readers continuously transmit signals to the traffic controller, which regulates the traffic lights accordingly. Once the emergency vehicle passes through the intersection, the RFID tag stops transmitting signals, and the traffic conditions return to normal [7].

Another proposed method utilizes a low-cost and efficient RF transponder consisting of a transmitter and receiver. The transmitter is installed inside the emergency vehicle, while the receiver is mounted on the traffic signal pole. Whenever the emergency vehicle enters the transmitter's communication range, the receiver detects the transmitted code and changes the traffic signal to green, thereby providing priority passage. The proposed system consists of an RF transmitter, RF receiver, RF modules, and a microcontroller that manages traffic signal operation. The transmitting unit is installed in the emergency vehicle, whereas the receiving unit is installed at the traffic signal pole. Communication is established whenever the vehicle enters the communication range. The ambulance is equipped with an RF transmitter module that can be activated using a switch. As the ambulance approaches the traffic signal, the driver activates the switch, enabling the RF receiver at the signal to receive the transmission and automatically change the signal to green [8].

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The paper also introduces a framework that offers multiple options for integrating logistics and traffic management, enabling traffic managers to better estimate traffic flow and predict user responses to network changes. This flexibility supports decision-making for different categories of road users and broadens the scope of urban traffic network optimization. A case study demonstrates the framework by analyzing street traffic patterns in an urban environment. The study shows that aggregating all traffic flows without distinguishing user groups often produces suboptimal outcomes because the optimal traffic configuration for logistics differs from that for regular commuters. Depending on traffic management objectives, different traffic configurations may be preferred. Through such detailed analysis, traffic managers can prioritize one category of road users while maintaining acceptable service levels for others and may introduce incentives or penalties to encourage desired travel behavior [9].

OBJECTIVES AND SCOPE OF WORK

The primary objective of the proposed system is to reduce the travel time of emergency vehicles and minimize delays in reaching their destinations by implementing an alternative traffic signal control system. The system aims to ensure channelized traffic flow, thereby enabling emergency vehicles to navigate efficiently through congested road networks.

The present work proposes a practical solution to one of the major challenges associated with emergency ambulance services in India. At present, emergency medical transportation is primarily dependent on **108 ambulance services**. Conventional traffic signals in India operate using fixed timing cycles, and there is generally no dedicated signal priority mechanism for emergency vehicles during periods of heavy traffic congestion. In real-world scenarios, when an ambulance reaches a signalized intersection, it often encounters long vehicle queues and must wait several minutes before receiving a green signal. Such delays may lead to preventable fatalities by preventing critically ill patients from reaching hospitals within the required time. The proposed IoT-based traffic control system seeks to address this challenge by providing priority signal clearance for emergency vehicles, thereby improving emergency response efficiency.

MATERIALS AND METHODS

FIG. 1. MDF SHEETS (Medium-Density Fiberboard)

High-quality plywood is known for its exceptional durability. The veneer layers are bonded together using a strong resin, resulting in significantly enhanced strength. In contrast, Medium-Density Fiberboard (MDF) is manufactured from wood fibers rather than solid wood veneers, making it comparatively less strong. The working model utilizes MDF sheets with dimensions of **2 ft × 2 ft**.

FIG. 2. Microcontroller

Microcontrollers are widely used in modeling for control systems, data acquisition, and embedded applications. They govern simulated phenomena, automate various operations, and facilitate instrumentation, feedback control, and communication, thereby ensuring system efficiency and accuracy across a wide range of engineering applications.

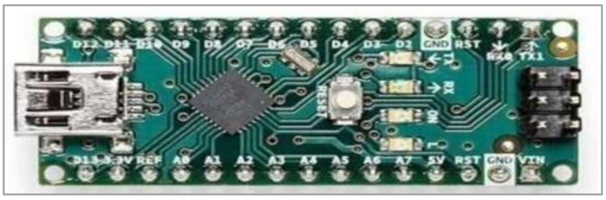

FIG. 3. Arduino Nano

The Arduino Nano, equipped with multiple digital input/output pins, serves as a versatile microcontroller suitable for a wide variety of applications. It is extensively used in both small-scale prototypes and industrial automation projects due to its compact size, ease of programming, and reliable performance.

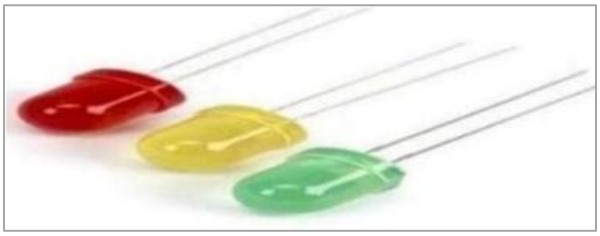

FIG. 4. Light Emitting Diode (Led)

The Light Emitting Diode (LED) is one of the most widely used light sources in electronic and electrical devices, with applications ranging from mobile phones to large advertising displays. LEDs are commonly employed in devices that display time and other forms of information. In the proposed model, four traffic signals equipped with LEDs display green, red, or amber indications based on real-time traffic conditions, ensuring efficient and safe traffic movement. The traffic

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signal corresponding to the lane through which the ambulance is traveling switches to **blue**, while all other traffic signals turn **red**, thereby providing a clear and unobstructed path for the ambulance through the intersection.

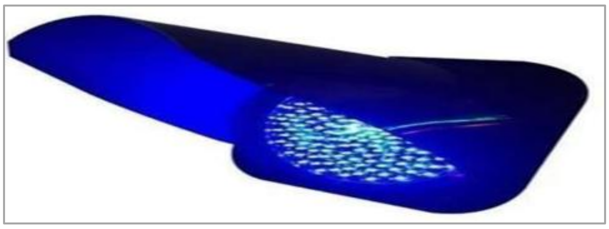

FIG. 5. Blue-Colored Signal Bulb

Blue signal lights are installed on poles at intervals of approximately **100 m**. These lights remain off under normal conditions and illuminate when an ambulance approaches, signaling road users to yield and clear the path. The flashing blue beacon is clearly visible under various weather conditions, including daylight, thereby ensuring effective ambulance prioritization and safe navigation.

FIG. 6. Jumper Wires

A jumper wire is an electrical conductor used to establish temporary electrical connections between circuits on printed circuit boards (PCBs). By connecting two points within a circuit, jumper wires provide an alternative electrical path, facilitating circuit testing, prototyping, and hardware integration.

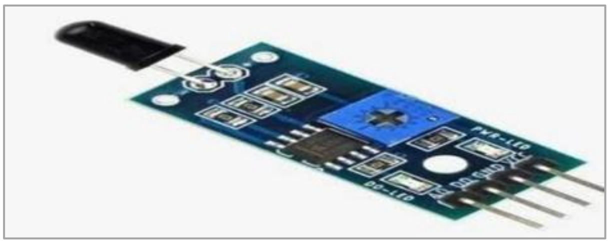

FIG. 7. IR Sensor (Infrared Sensor)

An infrared (IR) sensor emits and detects infrared radiation to identify nearby objects and measure motion or heat. Since all objects emit thermal radiation in the infrared spectrum, IR sensors can detect objects that are invisible to the human eye. These sensors are widely used in security systems, automation, robotics, and industrial applications due to their reliability in object detection and motion sensing.

FIG. 8. Radio Frequency (Rf) Module

The RF communication system utilizes a **434 MHz transmitter-receiver (Tx/Rx) module**. The transmitter receives serial input data and transmits it through radio frequency signals. The receiver captures these signals and relays the information to the corresponding module, enabling reliable long-distance wireless communication. RF technology is extensively used in remote control systems, wireless data transmission, telemetry, home automation, industrial monitoring, and automotive electronics.

METHODOLOGY

The proposed methodology involves installing blue-colored LED indicators on poles located at key points along the **Hebbal Flyover**. These indicators remain switched off during normal traffic conditions and illuminate blue whenever an approaching ambulance is detected. Digital maps are utilized for navigation and to retrieve the required traffic information effectively.

Key Map and Index Map

A key map and an index map provide essential geographical information by representing features such as buildings, roads, and water bodies using standardized symbols. These maps enable users to identify important landmarks quickly and determine the precise location of the study area. The enlarged map enclosed within a rectangle indicates the selected study area and highlights the locations requiring detailed investigation.

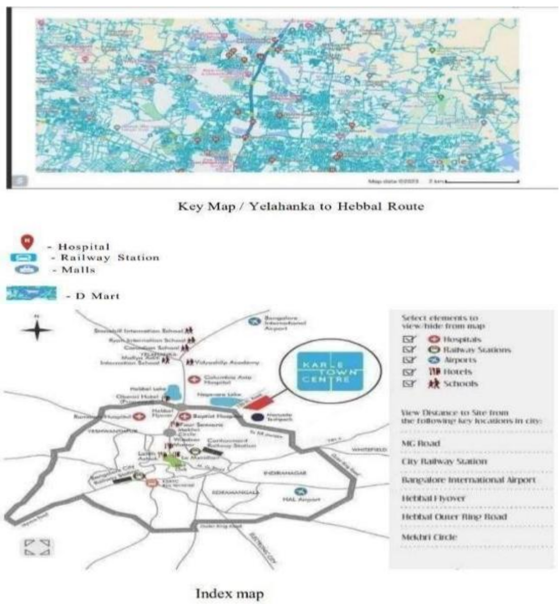

FIG. 9. Key Map and Index Map

A traffic survey was conducted to determine the traffic flow characteristics around the Hebbal area. The survey provided traffic volume information for the selected locations. Traffic studies were carried out at three different sections: **Esteem Mall**, **Hebbal Flyover**, and **Dairy Circle**. Observations were recorded between **7:00 a.m. and 6:00 p.m.** This division enabled comparison of traffic patterns among the three study locations.

Whenever an ambulance approaches an intersection, it transmits a dedicated signal to the traffic control system. Upon receiving the signal, the traffic controller recognizes the approaching emergency vehicle and activates the blue LED indicators installed at the traffic signals. The visual indication alerts motorists about the approaching ambulance, enabling them to clear the roadway promptly. This system improves the ambulance's ability to travel safely and efficiently through congested intersections, thereby reducing emergency response time and potentially saving lives.

WORKING MODEL

The working model initially detects the ambulance siren, transmits the required control signals, changes the traffic signal sequence during ambulance movement, redirects signal control to the subsequent traffic poles, and finally restores normal traffic operation after the ambulance passes. The process is continuous and cyclic.

When an ambulance comes within approximately **120 m**, the sound sensor detects the ambulance siren, which typically produces a sound level of around **120 dB**. When an ambulance travels at speeds greater than **60 km/h**, the siren is generally audible up to **30–40 m**. At a constant speed of **60 km/h**, the audible range extends to approximately **50–60 m**, whereas at speeds below **30–40 km/h**, the audible range may exceed **100 m** (**IRC SP:87-2019**). Based on this detection, the system continuously transmits control signals, identifies the ambulance near successive traffic poles, changes the traffic lights accordingly, and restores the normal signal sequence after the ambulance crosses the intersection. These timely signal adjustments ensure efficient ambulance movement while maintaining traffic safety and order.

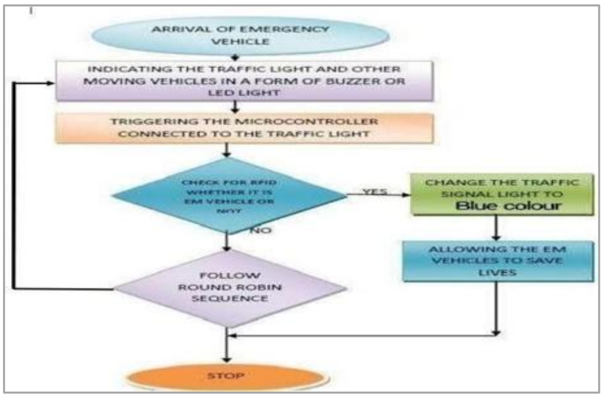

FIG. 10. Flow Diagram for Operation of the Blue LED

FIG. 11. Working Model

Vehicle Travel in One Direction Only

When an ambulance approaches within **100 m** of a traffic signal, a special traffic control protocol is activated. All traffic lights switch to **red**, stopping vehicles from every direction except the lane in which the ambulance is traveling. This provides a clear and unobstructed path for the ambulance to cross the intersection safely and quickly. By restricting traffic from all other directions, the system minimizes delays and ensures the rapid movement of emergency vehicles. This protocol significantly improves emergency response efficiency and facilitates the timely delivery of critical medical services.

All Vehicles Must Give Way to the Ambulance

All road users are expected to give way to approaching ambulances. However, some drivers fail to respond appropriately to ambulance sirens or ignore the installed blue warning lights. Such behavior should be avoided, and all motorists should cooperate by clearing the roadway immediately to facilitate the safe passage of emergency vehicles.

All Warning Lights Should Blink

All warning lights should blink simultaneously to ensure that approaching motorists are alerted effectively. Occasionally, individual lights may become defective or fail to operate. If a warning light is not functioning properly, drivers may remain unaware of the approaching ambulance. Therefore, periodic inspection and maintenance of the warning lights are essential to ensure reliable system operation.

RESULTS AND ANALYSIS

Clearance Time in Sec	No of Vehicles are Arrived	No of Vehicles are Departure	Length Covered in m
38	60	45	76.16
31	44	30	58.46
27	38	29	38.46
12	25	14	29.36
25	47	37	55.46
30	50	39	43.46
38	60	48	75.46
31	48	39	42.46
39	60	51	63.46
25	40	32	57.46
40	65	58	58.46
41	75	63	68.46
42	80	71	83.46
39	60	55	60.46

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Average field time required for clearing the queue length: 32 s
Number of vehicles arriving per hour: 50 vehicles
Number of vehicles departing per hour: 38 vehicles
Average queue length: 55 m

Analysis

According to IRC SP:87-2019, when an ambulance travels at an average speed of 45 km/h, the siren can be heard up to 90 m. At 60 km/h, the audible range decreases to approximately 50 m, and when the speed exceeds 60 km/h, the audible distance becomes less than 50 m. Therefore, it is recommended to install blue warning lights at 100 m intervals to ensure adequate visibility and effectively alert road users.

Speed	Hearing Distance
45 km/h	90 m
60 km/h	50 m
>60 km/h	<50 m

Based on the traffic survey, the average queue length was found to be **55 m**, requiring approximately **32 s** for complete clearance. Therefore, it is proposed to install blue warning lights at every **100 m** interval along a **1 km** stretch of roadway to improve visibility and enhance traffic management efficiency.

According to the National Highway Traffic Safety Administration (NHTSA), the maximum operating speed of an ambulance can reach 112 km/h (approximately 70 mph) under suitable conditions. On highways, ambulances generally operate at speeds of 70–80 km/h, whereas in urban areas they typically travel at 40–50 km/h.

Based on the NHTSA guidelines, an ambulance traveling at 112 km/h can cover the study section in approximately 32 s. From the field observations, the average queue length was 55 m, and the clearance time without implementing an intelligent traffic control system was approximately 32 s. By implementing an alternative traffic signal control system, travel time can potentially be reduced and delays minimized. Although the proposed design has been developed theoretically, field implementation and real-time evaluation are required for complete validation.

The proposed system continuously checks RFID signals to determine whether the approaching vehicle is an emergency vehicle (EV). If an EV is detected, the traffic signals switch to blue, allowing the emergency vehicle to proceed without delay toward hospitals or other emergency destinations. If no emergency vehicle is detected, the controller follows the normal round-robin traffic signal sequence as described in the system flowchart.

Based on the survey findings, the traffic flow on the Hebbal road stretch was approximately 5,670 vehicles/h. In addition, an average of 53 ambulances passed through the study location each day. These observations provide valuable insights into both the traffic demand and emergency service requirements of the study area.

The survey also revealed that the average queue length was approximately 55 m, requiring around 32 s for clearance without implementing the proposed traffic signal control system. It is expected that installing sensor-equipped poles with blue warning lights at every 100 m interval will reduce ambulance travel time and minimize delays during emergency situations.

DISCUSSION

India has one of the largest populations in the world, and many households own one or more vehicles, leading to increasing traffic congestion in urban areas. Heavy traffic significantly affects the movement of emergency vehicles, particularly ambulances, preventing them from reaching hospitals within the required time. Consequently, valuable lives may be lost due to delays in emergency medical response.

The proposed IoT-based traffic control system provides an effective approach for prioritizing ambulance movement by automatically controlling traffic signals and alerting road users through blue warning lights. If implemented in real-world conditions, the proposed system has the potential to reduce traffic congestion for emergency vehicles, improve emergency response time, and ultimately contribute to saving lives.

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