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An Intelligent Traffic Control System for Emergency Vehicles

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Abstract: This paper presents the design and development of an intelligent traffic control system designed to provide priority to emergency vehicles and enhance overall flow of traffic in urban environments. The proposed system integrates the RF communication technology with Arduino IDE boards to enable real-time communication amongst emergency vehicles and traffic signals. By utilizing RF transmitters, the system creates a green wave for emergency vehicles, allowing them to move through traffic intersections without delay. The control system operates in both manual and automatic modes, providing flexibility for traffic personnel to override or automate signal control depending on the situation. The dual-mode functionality ensures quick, reliable communication and reduces waiting time for emergency vehicles, addressing critical delay times. The system's design offers a practical solution for improving emergency response times while managing urban traffic congestion.
Keywords: Arduino boards, RF Module, Traffic signal.

I. INTRODUCTION

The unavoidable traffic related road congestion in cities and urban areas often leads to delays, increased fuel consumption, and environmental pollution. This traffic congestion induced delays potentially have life-threatening consequences in cases of ambulances, fire trucks and other emergency vehicles. The proposed work aims to develop an intelligent traffic control system that integrates emergency vehicle management along with regular traffic flow using Arduino IDE boards and RF communication technology. The system ensures that quick response vehicles can navigate traffic with minimal delay, improving response times and thus possibly saving lives by creating a green wave of priority access through intersections. The system operates in both manual and automatic modes, offering flexibility in traffic management. RF transmission enables quick and reliable communication between emergency vehicles, traffic lights thus facilitating real-time signal changes to clear a path for safe passage. In manual mode, traffic personnel can take control when needed, while automatic mode prioritizes emergency vehicles. This dual-mode operation, combined with the reliability of RF communication, addresses delays emergency vehicles face during critical situations and improves overall urban traffic management.

An automated traffic management and control system is considered extremely essential during emergencies. By stopping or diverting other vehicles, the system ensures a zero-traffic path for emergency vehicles, reducing driver stress and enabling faster, safer travel. This proposed system aims to significantly improve the overall safety and efficiency of urban traffic, particularly in high-pressure emergency scenarios.

II. LITERATURE SURVEY

The Intelligent Traffic Control Systems (ITCS) are vital in managing traffic flow efficiently and providing public safety while taking care of controlling the congestion. These systems aims also aim to enhance traffic management by leveraging advanced technologies such as Artificial Intelligence, real-time data analysis, and automated decision-making [1].

The core concept of E-Views Safety Systems is to establish seamless communication between the pedestrians, vehicles, and infrastructure. In this concept the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication protocols are leveraged, enabling the real-time exchange of critical information related to traffic conditions, road hazards, and pedestrian presence. By using the V2V communication, vehicles can transmit and receive position, speed data, allowing for better situational awareness. This helps to proactively avoid collisions and move through complex traffic situations [2]. An alarm device for traffic accidents is proposed, that detects a traffic accident automatically and responds promptly by utilizing advanced technologies for automatic accident detection and remote alerting. The objective of the alarm device is to minimize response time to traffic accidents, ensuring timely assistance and improving overall road safety [3]. A novel intelligent control strategy called Green Wave has been proposed, the main objective is to minimize traffic congestion while improve traffic efficiency by coordinating traffic signal timings along major urban trunk roads, by focussing on two-directional traffic flow, synchronizing traffic signals to create a continuous green wave for vehicles traveling in both directions and making the average delay time minimal.

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The strategy employs advanced technologies such as real-time traffic monitoring using real-time sensors, perform data analysis, and achieve adaptive signal control [4]. A geometric fuzzy multiagent system (GFMAS) is developed for a traffic responsive signal control system, based on the geometric type-2 fuzzy interference system that is capable of handling different levels of uncertainty based on traffic signal controller [5]. Similarly, a VTL-Priority Intersection Control (VTL-PIC) protocol is proposed that aims to identify any emergency vehicle and assign priority to it, as it passes through the intersection [6]. Fully automated mechanisms for controlling traffic lights based on sound detection, visual sensing, traffic density are proposed [7,8,9]. A system for controlling traffic based on Internet of Things is proposed [10]. Radio Frequency modules based automated traffic system for emergency vehicles offering an innovative solution is proposed [11]. It is thus evident that there is a requirement for advanced technology-driven solutions for efficient traffic management and control, especially in the scenario of limited physical space for expanding road infrastructure in urban areas.

III.METHODOLOGY

The proposed traffic management system relies on the integration of Arduino microcontroller with RF communication modules, deployed across four key intersections (Nodes A, B, C, and D). Each intersection is equipped with traffic lights controlled by the Arduino boards, which serves as the core processing unit. The RF modules enable wireless communication amongst emergency vehicles with the traffic control infrastructure. Emergency vehicles are outfitted with RF transmitters that send signals to receivers installed at each traffic light, triggering the system to prioritize their passage. The RF receivers operate within a specific frequency range to ensure that only authorized signals are processed. The traffic control system operates in two modes: Manual Mode and Automatic Mode. Manual Mode: The manual mode provides direct control to traffic personnel via an RF transmitter. In scenarios like public events, roadworks, or emergencies where immediate human intervention is required, traffic operators can use a control panel to override the system and adjust traffic signals manually. The manual override allows for real-time traffic management decisions, ensuring flexibility during unforeseen circumstances. Automatic Mode: The system functions autonomously in this mode. Emergency vehicles are detected via RF signals transmitted from onboard devices. Upon signal reception, the Arduino microcontroller calculates the vehicle’s path and activates a "green wave" sequence across the vehicle's route. This green wave ensures uninterrupted passage by synchronizing green lights along the vehicle's path, while adjusting signals at other lanes to red or yellow to avoid traffic conflicts. Automatic mode is particularly efficient in high-density traffic areas where manual control might be less responsive.

The detailed process chart illustrating the controlling of traffic flow depicted in Figure 1. The system operation after RFID reader and transmitter installation is depicted. When everything is normal, the signal works. Whenever an emergency vehicle is identified, the device receiving it gets the signal and converts it to green for a predetermined amount of time.

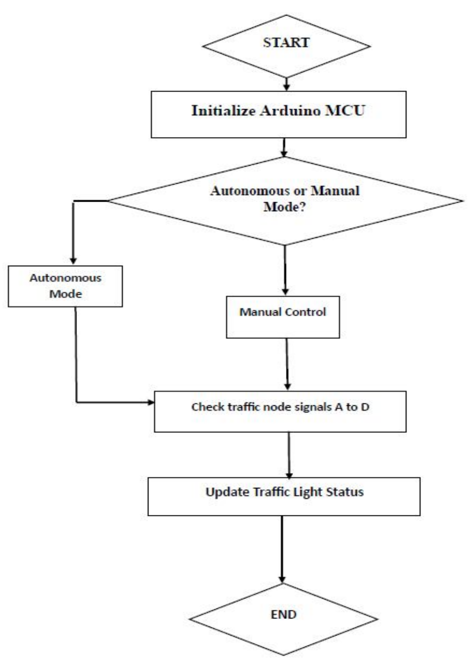

Fig. 1: Process chart

IV. IMPLEMENTATION

An Arduino Uno microcontroller is used in the intelligent traffic control system, along with peripherals supporting both input and output. The transmitter section connections and received section connections are shown in Figure 2 and Figure 3 respectively. RFID tags are placed in emergency vehicles, and RFID readers are installed in traffic lights or other key locations. When an emergency vehicle approaches, the system can change traffic lights to green or otherwise prioritize the emergency vehicles' passage.

1) Step 1: Setting Up the RFID System

Connected the RFID reader to Arduino uno using the appropriate pins (SDA, SCK, MOSI, MISO, RST, GND, and VCC). Install the MFRC522 library in Arduino IDE. Implement code for RFID tags from the reader and store their unique IDs. When an RFID tag is read, the Arduino identifies it as emergency vehicle and triggers the intelligent traffic control logic.

2) Step 2: Communication

The RF communication module is central to the system, providing real-time interaction between the traffic control infrastructure and the emergency vehicles. An RF transmitter placed on the emergency vehicle emits encoded signals when activated. The RF receivers, installed at traffic lights, decodes these signals and relays to the Arduino microcontroller, the information for further processing. The utilization of Radio Frequency technology allows for long-range, low-power communication, ensuring minimal interference from other devices and rapid response times. Additionally, the communication system is designed with security protocols to prevent unauthorized access and ensuring only signals from recognized emergency vehicles are processed.

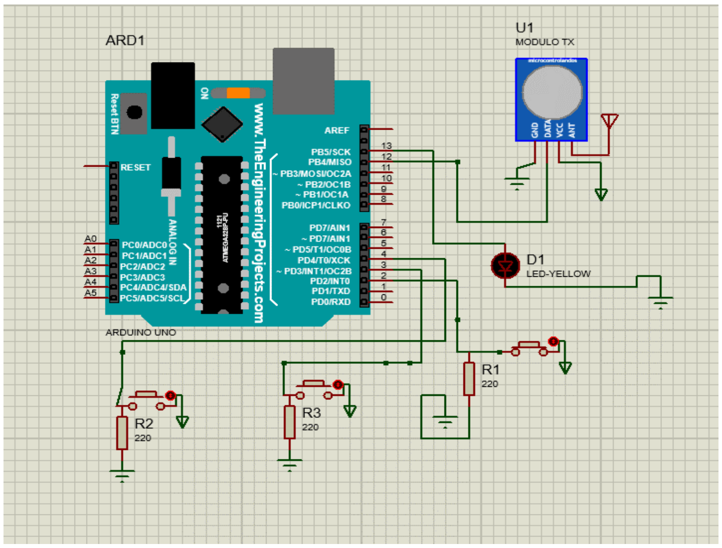

Fig. 2: Transmitter section connections

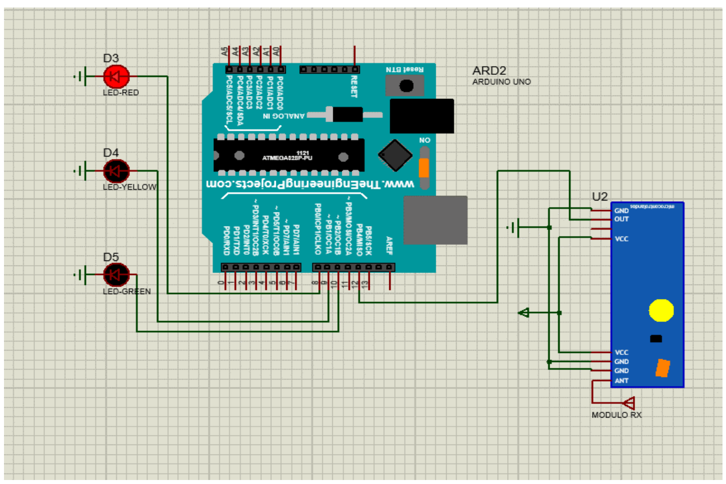

Fig. 3: Receiver section connection

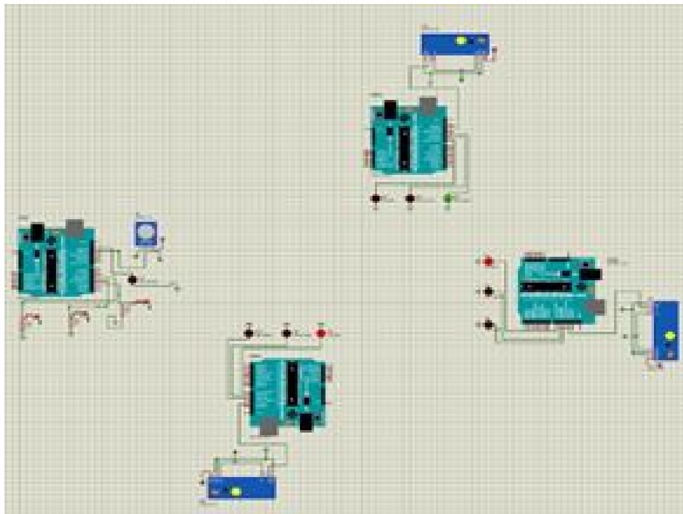

Fig. 4: Four Lane Traffic Signal System

The four-lane traffic signal system is shown in Figure 4. The system prioritizes emergency vehicles by dynamically creating a "green wave." Upon receiving an RF signal from an emergency vehicle, the Arduino microcontroller calculates the vehicle's route through the urban road network. Based on the vehicle’s current location and speed, traffic signals along the route are synchronized to turn green in sequence, providing an uninterrupted path. This coordination is continuously adjusted in real-time as the vehicle moves, allowing for seamless transit through intersections. Simultaneously, traffic in other lanes is controlled by setting corresponding lights to red or yellow to ensure safety.

The green wave mechanism significantly minimizes response times for the emergency vehicles and also minimizes traffic disruptions, improving overall urban traffic flow.

3) Step 3: Hardware Integration

Connected with LEDs and relays to the Arduino microcontroller. The RFID reader along with the necessary components are securely installed in the traffic control system.

4) Step 4: Testing

During the testing, an RFID tag assigned to an emergency vehicle. When the system is working ensures traffic lights changes appropriately whenever RFID reader detects an emergency vehicle. Again, the RF receiver checks whether the emergency vehicle has moved past the signal. If it is not passed, then again it keeps the signal in green till the emergency vehicle passes the traffic signal. Once the vehicle passes the signal comes back to normal condition and works accordingly. Each time the emergency vehicle arrives, the process is repeated.

V. RESULTS AND DISCUSSIONS

The Intelligent Traffic Control System for Emergency Vehicles demonstrates improvements in managing traffic flow together with prioritizing emergency vehicles.

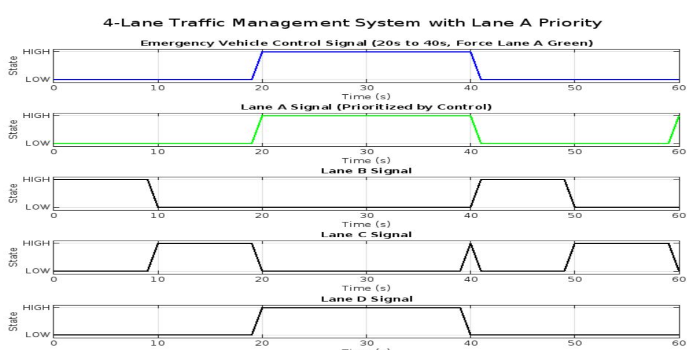

Fig 5: 4-Lane Traffic Signals with Emergency vehicle control signal prioritized to Lane A turning Green

As illustrated in Figure 6, the system effectively detects the presence of any emergency vehicle and prioritizes the corresponding lane, in this case, Lane A. Whenever the emergency vehicle approaches, the control signal is activated, causing Lane A's traffic light to turn green. This action ensures an uninterrupted path for the emergency vehicle, while the other lanes (B, C, and D) are appropriately controlled to red, thereby minimizing potential conflicts and delays. Figure 5: 4-Lane Traffic Signals with Emergency Vehicle Control Signal Prioritized to Lane A Turning Green shows the state of the traffic signals at the intersection. The green colored light for Lane A indicates that the system has successfully prioritized the emergency vehicle's passage, allowing it to move through the intersection without delay. This prioritization is crucial in emergency situations, where delays can have life-threatening consequences.

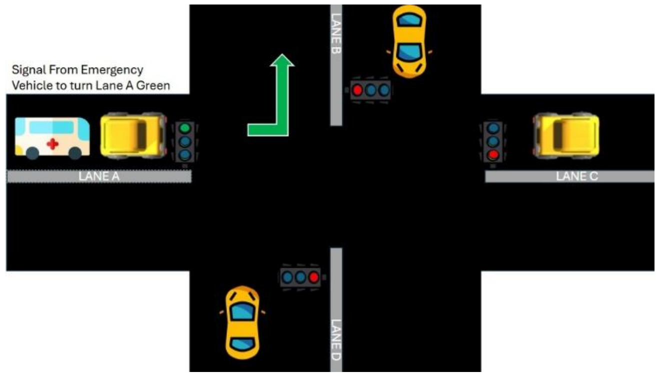

Fig 6: Green Wave pulled to Lane A for Emergency vehicle prioritizing.

Figure 6 illustrates the manner in which the traffic signals along the route of the emergency vehicle are synchronized to create a continuous green light sequence. The Arduino microcontroller calculates the path and adjusts the traffic signals lights accordingly when it detects the emergency vehicle. The green wave mechanism ensures that the emergency vehicle moves through the urban road network, it encounters a series of green lights, significantly minimizing stopping time at intersections.

As shown in the Figure 6: Green Wave Pulled to Lane A for Emergency Vehicle Prioritizing highlights the dynamic nature traffic control system. The synchronization of traffic signals facilitates the rapid transit of emergency vehicles and also minimizes disruptions to regular traffic flow. By adjusting the signals in real-time, the system maintains a balance between prioritizing emergency responses and managing overall traffic efficiency.

The implementation showcases the potential for integrating advanced technologies, such as RF communication and Arduino microcontrollers, to enhance urban traffic management. The dual-mode functionality allows for both automated and manual control, providing flexibility in various traffic scenarios. This adaptability is crucial for ensuring quick movements of emergency vehicles in congested urban environments effectively, ultimately improving response times and enhancing public safety. The RF-based communication ensures reliable and fast signal transmission to traffic lights, facilitating real-time adjustments in response to the signals from emergency vehicle.

The system's cost-effectiveness and scalability make it adaptable for modern urban traffic management, ensuring that it's implementation in various settings without excessive financial burden. Furthermore, the design ensures that other lanes, such as Lane B and Lane D, are not left without signals for extended durations, maintaining periodic state changes to avoid confusion or unnecessary delays. Overall, the integration of Arduino IDE boards and RF technology contributes to system's efficiency, practicality, and suitability for real-world applications.

VI. CONCLUSIONS

The design and development of the Intelligent Traffic Control System for Emergency Vehicles underscores the transformative capability of combining Arduino microcontrollers with RF communication technology in urban traffic management. This innovative system effectively prioritizes emergency vehicles, significantly minimizing delays that could have critical, life-threatening implications. By employing real-time signal adjustments and a green wave mechanism, the system not only enhances the efficiency of emergency responses but also maintains overall traffic flow, ensuring that other lanes are managed effectively. The adaptability, cost-effectiveness, and scalability of this system makes it a practical solution for modern urban environments, thus helping achieve improved public safety and improved, efficient traffic management strategies. Ultimately, this approach promises to enhance emergency response times and contribute to safer, more responsive city traffic systems.

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