Wireless Traffic Management System for Ambulance Route Optimization

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Abstract

This paper presents an IoT-enabled smart ambulance system designed to optimize emergency response by automating traffic signal control for swift ambulance transit. The system employs ESP8266 modules for real-time wireless communication between ambulances and traffic infrastructure, while IR sensors detect ambulance approach, prompting automatic signal override to ensure unobstructed passage. An Arduino Uno microcontroller governs the operational logic, supporting seamless and adaptive signal control. Key components include a manual emergency mode switch, LCD display for live status updates, and roadside sensors to enhance detection accuracy. The system also offers route optimization and congestion avoidance by coordinating signal updates dynamically. With features such as secure data transmission, real-time monitoring, sensor calibration, and an uninterrupted power supply, the proposed solution is cost-effective, scalable, and well-suited for smart city integration. By significantly reducing emergency response times, this system contributes to more efficient healthcare delivery and life-saving outcomes.

Keywords: LCD, ESP8266, IR Sensor, Arduino Uno, Wireless Communication.

1. Introduction

This project operates primarily on the reliability and availability of the GSM network, which serves as the foundation for its communication functionality. The effectiveness of the entire system is significantly influenced by the strength of the GSM signal in the area of deployment. To facilitate wireless communication, a GSM SIM 900A module is integrated with the Arduino microcontroller. A stable power supply is essential for the consistent performance of the system components, and therefore, a 12-volt adapter is employed to ensure that all modules function efficiently and without interruption.

The GSM functionality is specifically incorporated into the system to enhance the safety and communication capabilities for workers in coal mining environments. In the event of an emergency, the system includes a buzzer that can be activated based on a preset time

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configuration, which serves as a signal for initiating an emergency communication process. When the control room personnel place a call to the GSM module in the system, the module is programmed to automatically detect the incoming call and respond by displaying a message on the OLED screen, confirming the reception of the call.

To initialize and operate any GSM module, the use of AT (Attention) commands is essential. These standard commands enable communication between the microcontroller and the GSM module, ensuring that various operations such as sending messages, receiving calls, and network registration can be executed effectively. The system's functionality is driven by software programmed in the C language, where proper implementation of AT commands plays a crucial role. The programming logic is responsible for managing communication tasks, device responses, and overall coordination of the system, making it a critical aspect of the project's success.

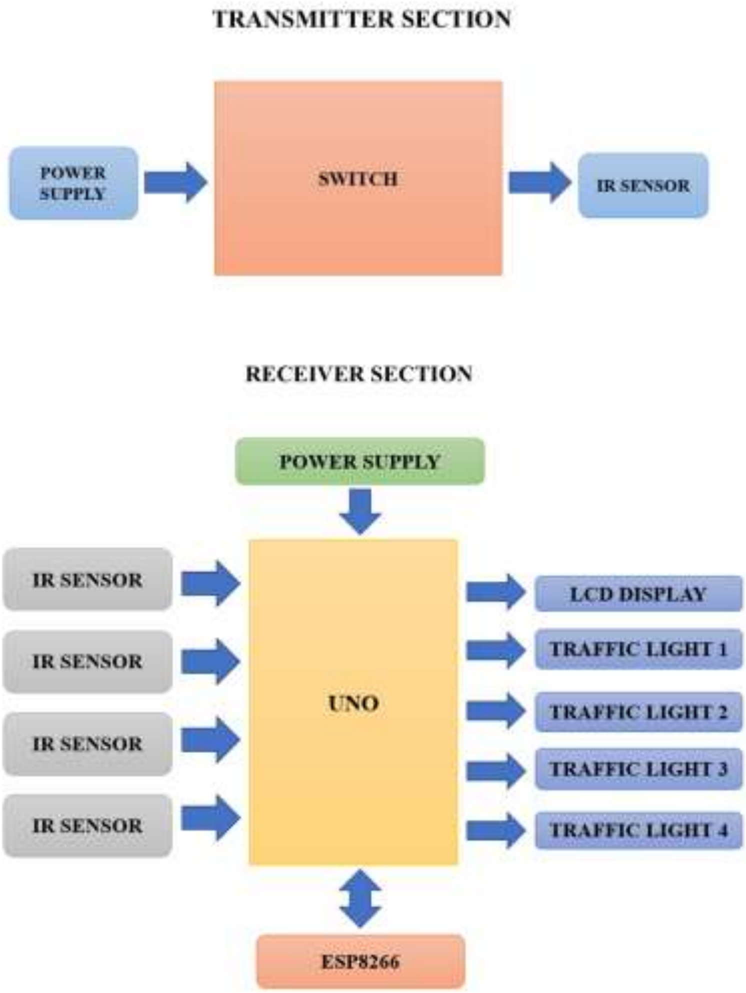

Figure 1: Block Diagram of Proposed System

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2. Internet of Things (IoT)

The Internet of Things (IoT) represents a rapidly growing ecosystem in which physical objects—ranging from household appliances to industrial machinery—are embedded with sensors, software, and connectivity features that allow them to gather, exchange, and act upon data over the internet. These interconnected devices operate with minimal or no human intervention, enabling the creation of intelligent systems that respond dynamically to changing conditions. By facilitating wireless communication between devices, IoT fosters the development of smart environments in various domains, including homes, urban infrastructure, healthcare, agriculture, and manufacturing. Sensors serve as the primary data collection tools within this network, transmitting real-time information to cloud-based platforms or local servers. These platforms then analyze the data to trigger automated actions, optimize processes, and provide actionable insights.

The integration of machine learning algorithms further strengthens IoT systems by enabling predictive analytics and smarter decision-making. For instance, smart devices can anticipate maintenance needs, detect faults before they occur, and allow for remote control and monitoring, significantly reducing downtime and operational costs. As a result, resource efficiency is improved, energy consumption is minimized, and sustainable practices are promoted. IoT's influence is evident across multiple sectors: in agriculture, it supports precision farming; in healthcare, it enhances patient monitoring; and in industry, it streamlines production and supply chain operations. This convergence of technologies—including affordable sensors, widespread internet access, powerful cloud computing, and advanced data analysis tools—has accelerated IoT's adoption worldwide.

As IoT infrastructure continues to evolve, its impact on daily life, economic systems, and technological innovation becomes increasingly profound. It is reshaping how devices interact, how decisions are made, and how environments adapt—ultimately paving the way for a more connected, intelligent, and efficient future.

3. Smart Ambulance System

Traffic congestion poses a serious challenge during emergency situations, often resulting in delayed responses by ambulances and risking patient lives. As urban populations grow and road networks become increasingly saturated, traditional traffic management systems—typically based on fixed signal timings—fail to adapt to the dynamic demands of

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emergency transport. These out dated systems lack responsiveness to real-time traffic conditions and offer no specialized provisions for emergency vehicles. Consequently, ambulances frequently experience slowdowns, as other drivers may be unaware of their approach or lack direction on how to react appropriately.

To address these shortcomings, the IoT-Enabled Smart Ambulance System with Automatic Traffic Clearance provides a technologically advanced approach that leverages real-time data, automation, and wireless communication. The system utilizes GPS tracking to monitor the ambulance's location, speed, and direction. Based on this information, microcontrollers coordinate with traffic signals to dynamically alter their timing, ensuring that ambulances receive priority passage through intersections. Simultaneously, GSM modules deliver immediate notifications to nearby traffic control units and healthcare facilities.

Integrated infrared (IR) sensors at traffic junctions detect the ambulance as it approaches, relaying data to a central control unit for swift signal adjustments. Emergency alerts are also transmitted to nearby motorists via mobile applications and electronic roadside displays, prompting them to clear the path. Hospitals receive early warnings about the ambulance's estimated arrival, allowing medical teams to prepare necessary treatment areas, including ICU or operating rooms.

Cloud-based infrastructure supports the system by storing data such as ambulance routes, traffic signal responses, and system performance metrics. This historical data enables continuous improvement of emergency response strategies. Embedded systems featuring GPS, GSM, and microcontroller units ensure reliable, real-time communication between all components. Mobile applications assist drivers by suggesting the most efficient, congestion-free routes. To ensure reliability under all conditions, the system includes an uninterrupted power supply, enabling consistent operation even during peak traffic hours or infrastructure failures. Centralized control centres manage the entire network, coordinating ambulance movement, synchronizing signal patterns, and forming temporary green corridors for rapid transit.

Secure cloud platforms handle system configuration, access control, and data management, ensuring privacy and protection against unauthorized access. This integrated

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solution not only enhances the efficiency of emergency medical services but also contributes to the broader vision of smart, responsive urban infrastructure.

4. Existing System

The existing ambulance and traffic coordination system relies largely on manual processes, which significantly slows emergency response times. Traffic signals typically function on present timing cycles and lack the capability to adapt dynamically for prioritizing emergency vehicles. As a result, ambulances are often delayed in heavy traffic due to obstructed lanes, inattentive drivers, and infrastructure that cannot respond in real time to urgent needs.

Communication between emergency responders and traffic control centers is commonly handled through radio or phone calls, which are time-intensive and inefficient during critical situations. Although emergency lanes exist, they are frequently misused by regular vehicles or blocked, further impeding the ambulance's progress. Even in cities with smart traffic infrastructure, emergency vehicle integration is minimal, and traffic signals rarely adjust to accommodate ambulances automatically.

While CCTV cameras are widely deployed, their real-time integration with ambulance movement is limited. RFID-enabled ambulances still require human operators to signal for traffic clearance, and while GPS-based navigation apps provide route suggestions based on traffic conditions, they cannot alter traffic signal behavior to assist emergency vehicles. Manual rerouting is heavily dependent on dispatcher judgment, lacking the support of intelligent automation or predictive systems. Critical patient information is usually not shared with hospitals until after the ambulance arrives, delaying medical team preparedness. Coordination between emergency departments, traffic authorities, and hospitals is often disorganized, leading to unnecessary confusion. Most urban traffic infrastructures are optimized for everyday vehicle flow and do not account for dynamic emergency scenarios.

There is no unified or automated interface linking ambulances with traffic signal control systems. Existing infrastructure lacks the flexibility and intelligence to respond effectively to emergencies. Traditional GPS systems offer routing assistance but do not prioritize or streamline paths based on emergency urgency. Red lights, traffic congestion, and urban bottlenecks continue to extend response times. Moreover, current systems lack integration with modern technologies such as IoT, artificial intelligence, or real-time

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automation. Public awareness and adherence to rules requiring vehicles to yield to ambulances remain inadequate. In essence, out dated technologies and a fragmented approach across systems severely limit the efficiency of emergency services.

5. Proposed Method

The developed IoT-enabled smart ambulance system introduces a comprehensive solution for automated traffic management by incorporating intelligent control mechanisms that interact directly with traffic signal infrastructure. At the heart of this system is a NodeMCU microcontroller integrated with a GPS module, which provides precise and continuous real-time tracking of ambulance location and movement.

As an ambulance nears an intersection, the traffic control units automatically switch the relevant signal to green, allowing the vehicle to pass through with minimal delay. Wi-Fi communication modules facilitate seamless data transfer between ambulances and signal poles. A centralized control server processes real-time inputs, such as the vehicle's location and speed, and adjusts traffic signals dynamically to prioritize emergency movement.

An Android-based mobile application not only estimates the ambulance's arrival time at the hospital but also transmits patient health information, eliminating the need for manual communication. The system employs machine learning algorithms to recommend the most efficient and least congested routes. Cloud-based storage systems archive journey details, historical traffic behaviour, and incident-related data for further analysis. Smart traffic poles are equipped with audio-visual alert systems—such as flashing lights and buzzers—to notify surrounding drivers of an approaching emergency vehicle. Additionally, mobile alerts are sent to nearby users to clear paths promptly. The system uses priority protocols and synchronized signalling to ensure a clear and uninterrupted route for ambulances. Communication is protected with encrypted data exchange, and traffic cameras help authenticate ambulance identity, enhancing system integrity.

In rare situations where automation might fail, manual override functions are available to maintain control. The infrastructure is designed for reliability, featuring solar-powered traffic poles and backup battery systems to maintain operation during power outages. Real-time data dashboards provide a comprehensive overview of emergency scenarios, while analytics tools support better city infrastructure planning. Vehicle-to-vehicle (V2V) communication further reduces delays, especially during high-traffic periods. IoT gateways

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improve connectivity across a wider geographic range, and artificial intelligence enhances decision-making for routing and traffic signal control. Smart poles with self-diagnostic features can report malfunctions automatically for immediate servicing.

The system is capable of managing multiple ambulances simultaneously, with route management algorithms ensuring there are no conflicts. In addition, paramedics can use mobile tools to relay updates to hospital teams' en route, improving preparedness. Fleet tracking features offer valuable insights for health service administrators to optimize operations. Highly adaptable and scalable, this system can also be extended to support fire trucks, police vehicles, and other emergency services—contributing to a safer, smarter urban environment.

6. Results and Discussions

The IoT-enabled smart ambulance system employed ESP8266 Wi-Fi modules to establish real-time wireless communication, which played a vital role in automating traffic signal operations during emergency scenarios. When the emergency switch inside the ambulance was engaged, the ESP8266 module immediately transmitted a signal over Wi-Fi to designated traffic light control units. Upon receiving the signal, the system changed red lights to green, allowing the ambulance to proceed without delay.

An LCD module with an I2C interface was used to provide on-screen updates such as emergency alerts, destination information, and current operational status. Infrared (IR) sensors were installed at road junctions to detect the ambulance's approach, serving as an additional validation mechanism before initiating signal transitions. Each system component was powered by batteries supported by voltage-regulated adapters to ensure efficient energy management. A centralized power distribution board allocated electrical power evenly and reliably across all modules.

Performance evaluation of the system revealed that traffic signals could switch in less than two seconds, and the LCD responded with updates in mere milliseconds. The IR sensors consistently demonstrated high accuracy, exceeding 95% in varying ambient light conditions, effectively minimizing false detections. The ESP8266 modules maintained a stable Wi-Fi connection and were capable of logging operational metrics for system analysis and future optimization. Battery backup systems were able to support continuous operation for more than four hours, ensuring resilience during power interruptions. Field deployments confirmed

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rapid system response, with immediate adjustments in traffic signals upon switch activation, and no recorded instances of network failure or signal delay. The interaction between components—such as switch input, data transmission, light control, and display output—occurred in a fluid and synchronized manner.

Furthermore, the system demonstrated adaptability by automatically adjusting to route changes without needing manual reprogramming. In the absence of internet connectivity, the ESP8266 modules continued to communicate locally via hotspot networks. The IR sensors efficiently distinguished ambulances from general traffic, reducing erroneous signal changes. LCDs displayed real-time updates such as “Clear Route Ahead” or “Please Wait for Signal” to keep drivers informed.

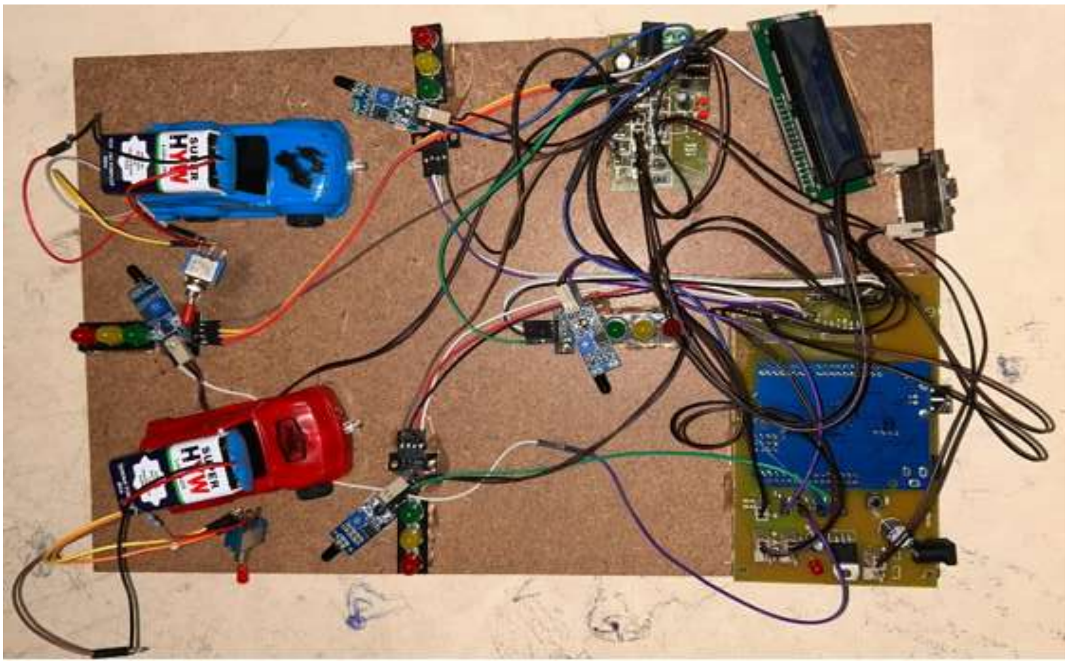

Figure 2: Experimental Setup

Traffic lights shifted seamlessly between red and green phases, maintaining smooth traffic flow and prioritizing emergency vehicles. Scalability testing confirmed that multiple signal modules could function concurrently without communication lags or interference. Auto-reconnect protocols built into the ESP8266 ensured continuity of signal transmission even after temporary network disruptions. All electronic components operated within safe thermal thresholds and required minimal upkeep, affirming the system’s reliability for long-term, real-world application.

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7. Conclusion

The project introduced an IoT-enabled smart traffic control system aimed at improving the efficiency of ambulance and emergency vehicle operations. It combines technologies such as IoT, cloud computing, and RFID to facilitate live traffic management and route optimization. Utilizing sensors and data analysis, the system guides ambulance drivers along the quickest and safest paths. Traffic lights are automatically adjusted to give priority to emergency vehicles. This approach helps decrease response times and lowers the chances of traffic-related incidents. Additionally, real-time notifications assist drivers in avoiding potential dangers, thereby enhancing overall road safety. The system represents a significant advancement in both emergency response and urban traffic regulation.

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