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Traffic Congestion Detection and Altering Ambulance Using AI And IoT

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ABSTRACT

Traffic congestion in urban areas is a serious challenge that causes significant delays for emergency vehicles, especially ambulances. Every minute of delay in emergency response can be life-threatening. This paper presents a smart system for detecting traffic congestion and providing priority routing to ambulances using IoT sensors and simple AI techniques, without relying on any camera-based systems. The proposed system uses IR sensors and ultrasonic sensors deployed along road junctions to detect vehicle density in real time. When an ambulance approaches a junction, its RFID tag is identified by RFID readers installed at traffic signals. The system then activates a green corridor by controlling traffic signals to allow the ambulance to pass without delay. A GPS module attached to the ambulance continuously tracks its location and sends data to a centralized server. A rule-based AI module processes sensor data to predict congestion levels and suggest the least-congested route. All real-time data is displayed on a web-based monitoring dashboard. The system is implemented using Arduino/NodeMCU microcontrollers, RFID modules, ultrasonic sensors, IR sensors, GPS modules, and Wi-Fi-based communication. Simulation and prototype results show that the system successfully detects congestion and reduces ambulance delay significantly, making it a practical and cost-effective solution for smart city traffic management.

1. INTRODUCTION

Urban traffic congestion is one of the most critical problems in modern cities. With increasing population and rising number of vehicles on roads, traffic jams have become a daily occurrence. While congestion causes inconvenience to regular commuters, it becomes life-threatening in the case of emergency vehicles such as ambulances, fire brigades, and police vehicles. A delay of even a few minutes in ambulance response time can result in the loss of a patient's life. According to studies, ambulance response time is directly linked to survival rates in cardiac emergencies, road accidents, and other critical health situations. Conventional traffic management systems rely heavily on fixed timer-based signals or camera-based monitoring systems. Fixed timers do not adapt to real-time traffic conditions, and camera-based systems involve high hardware costs, require complex image processing, and raise privacy concerns. Therefore, there is a clear need for an intelligent, low-cost, and privacy-respecting

traffic management system that can work in real-time without using any cameras.

The Internet of Things (IoT) has emerged as a powerful enabling technology for smart city applications. IoT sensors such as IR (Infrared) sensors, ultrasonic sensors, and RFID (Radio Frequency Identification) readers can be installed at road junctions to collect real-time traffic data without any visual surveillance. These sensors feed data to a central controller that processes the information and makes intelligent decisions about traffic signal control and ambulance routing.

This paper proposes a smart traffic congestion detection and ambulance priority routing system that combines IoT sensors (IR, ultrasonic, RFID, GPS) with simple Artificial Intelligence (AI) techniques (rule-based logic and basic machine learning). The system identifies vehicle density at junctions, detects an incoming ambulance through its RFID tag, dynamically creates a green corridor by turning signals green on the ambulance's path, and calculates an optimal route using GPS data. A centralized monitoring dashboard displays all traffic and ambulance data in real time.

The paper is organized as follows: Section II presents the literature review. Section III defines the problem statement. Section IV outlines the objectives. Section V describes the methodology. Section VI explains the system architecture.

2. LITERATURE REVIEW

Several researchers have worked on traffic management, smart signal control, and emergency vehicle priority systems using different technologies. This section reviews key related works, highlighting their contributions and limitations.

Early traffic management systems were purely hardware-based, relying on fixed timer signals. With the advancement of IoT and embedded systems, researchers began exploring sensor-based approaches. Kumar et al. (2021) proposed an IoT-based traffic monitoring system using IR and ultrasonic sensors to measure vehicle density and control signal timings accordingly. While the system was low-cost and real-time, it lacked any mechanism to provide priority routing for emergency vehicles.

Sharma and Gupta (2022) developed a smart traffic signal system using Arduino and a density-based machine learning model. Their system adaptively adjusted signal timings based on vehicle count at each junction. However, the system had no provision for detecting ambulances or creating green corridors.

Rahman et al. (2020) proposed an RFID-based vehicle tracking system for emergency services. RFID readers were placed at checkpoints to identify emergency vehicles and log their movement. The system was effective at identification but was limited to predefined fixed routes and did not incorporate dynamic congestion-based routing.

Patil and Naik (2023) presented a GPS-based ambulance routing system using Dijkstra's shortest path algorithm. The system calculated the fastest route for the ambulance based on map data. The limitation was that it did not integrate live IoT sensor data for congestion detection, so the routes were not always updated in real time.

Mehta et al. (2022) proposed an AI-driven traffic management system using inductive loop sensors and fuzzy logic, which operated without any camera. While this was a significant step toward camera-free management, the system had high infrastructure costs and did not include an ambulance priority module.

The table below summarizes the literature review and highlights the gaps that the proposed system addresses:

- Kumar et al. (2021) proposed an IoT-based traffic monitoring system using IR and ultrasonic sensors with rule-based control. The system provides low-cost, real-time traffic detection, but it does not include GPS-based ambulance routing or emergency vehicle prioritization.
- Sharma and Gupta (2022) developed a smart traffic signal system using Arduino and machine learning, which uses traffic-density-based signal switching to achieve adaptive signal timing. However, the system does not provide a vehicle priority mechanism for emergency vehicles.
- Rahman et al. (2020) presented an RFID-based vehicle tracking system for emergency services, using RFID tags, readers, and a centralized server for rapid vehicle identification. Its major limitation is that it works mainly on predefined routes and does not support dynamic route optimization.
- Patil and Naik (2023) proposed a GPS-based ambulance routing system using the Dijkstra shortest-path algorithm. The system enables efficient route calculation for ambulances, but it lacks IoT sensor integration for detecting real-time traffic congestion.
- Mehta et al. (2022) developed an AI-driven traffic management system without cameras, using inductive loop sensors and fuzzy logic for reliable traffic detection. Although it avoids camera-based monitoring, it has high infrastructure costs and does not include a dedicated ambulance-priority module.

From the review, it is evident that most existing systems either rely on cameras, lack ambulance priority features, or do not integrate GPS and RFID together. The proposed system bridges these gaps by combining RFID, GPS, IR sensors, and ultrasonic sensors with a rule-based AI module and a real-time dashboard.

3. PROBLEM STATEMENT

Despite rapid urbanization and the availability of smart technologies, most cities still rely on outdated traffic signal systems that are timer-based and static. These systems are completely unresponsive to real-time road conditions. As a result, emergency vehicles like ambulances face significant delays at traffic signals, especially during peak hours. These delays directly affect patient survival rates.

Camera-based smart traffic systems, while capable of detecting vehicles, come with their own set of problems: they are expensive to deploy and maintain, computationally intensive, and raise serious privacy concerns. Moreover, cameras require clear line-of-sight and can fail under poor lighting, fog, or rain conditions.

There is currently no affordable, scalable, and camera-free system that can simultaneously: (1) detect real-time traffic congestion using simple IoT sensors, (2) identify an approaching ambulance using RFID, (3) dynamically control traffic signals to provide a green corridor, (4) calculate and suggest the optimal ambulance route using GPS data, and (5) display all real-time information on a centralized monitoring dashboard. This paper aims to solve exactly these problems with a practical, low-cost, and student-implementable solution.

3. OBJECTIVES

The primary objectives of this project are listed below:

- To design and implement a traffic congestion detection system using IR and ultrasonic sensors without the use of any cameras.
- To integrate RFID readers at traffic signal junctions to detect and identify ambulance vehicles equipped with RFID tags.
- To implement a smart signal pre-emption system that creates a green corridor for the ambulance by controlling traffic signals in its path.
- To attach a GPS module to the ambulance unit for continuous real-time location tracking and route monitoring.
- To apply a rule-based AI module for congestion level classification (Low, Medium, High) and to recommend the least-congested route for ambulance navigation.
- To log all system events (sensor readings, signal changes, ambulance locations) in a centralized server for monitoring and analysis.
- To develop a real-time web-based monitoring dashboard that displays live sensor data, traffic status, and ambulance location.
- To demonstrate the system's effectiveness through simulation and prototype testing, showing measurable reduction in ambulance delay time.

4. METHODOLOGY

The proposed system is designed as an end-to-end IoT and AI-based solution. The methodology is divided into the following sequential phases:

A. Sensor Data Collection

IR sensors (FC-51) and ultrasonic sensors (HC-SR04) are installed at each road lane leading into a traffic signal junction. The IR sensors detect the presence of a vehicle in their range. Ultrasonic sensors measure the distance to the nearest vehicle and count approximate vehicle density in a lane. Each sensor is connected to an Arduino Uno or NodeMCU ESP8266 microcontroller, which reads sensor values at regular intervals (every 500ms). The data collected includes: (i) vehicle presence (binary: yes/no), (ii) vehicle count (approximate, derived from sensor sweep), and (iii) lane occupancy percentage.

B. RFID-Based Ambulance Detection

Every ambulance is fitted with a passive RFID tag (ISO 14443A, 13.56 MHz) that carries a unique vehicle ID. RFID readers (RC522 module) are installed at each traffic signal junction approximately 200–300 meters in advance. When the ambulance enters the RFID reader's range, the tag is scanned, the vehicle ID is read, and the system confirms that an ambulance is approaching. This information is immediately relayed to the central server via WiFi (NodeMCU). No camera or image processing is involved in this step.

C. GPS-Based Location Tracking

A Neo-6M GPS module is installed in each ambulance unit along with a NodeMCU. The GPS module provides real-time latitude and longitude coordinates of the ambulance at an update rate of 1 Hz. The NodeMCU transmits this GPS data to the centralized server over WiFi. The server stores the GPS coordinates and calculates the ambulance's current road segment, speed, and estimated time of arrival at each upcoming junction.

D. Congestion Detection and AI-Based Classification

The central server receives sensor data from all junctions. A rule-based AI module processes this data to classify congestion levels. The rules are as follows:

- Low Congestion: Vehicle count < 5 per lane, occupancy < 30%.
- Medium Congestion: Vehicle count 5–10 per lane, occupancy 30–70%.
- High Congestion: Vehicle count > 10 per lane, occupancy > 70%.

A simple decision tree model trained on historical sensor log data is also incorporated to improve prediction accuracy. The model uses features such as time of day, vehicle count, and day type (weekday/weekend). When the ambulance is detected, the AI module evaluates congestion levels on all possible routes and recommends the least-congested path.

F. Centralized Server and Dashboard

All sensor data, RFID events, GPS coordinates, AI classification results, and signal control logs are stored on a centralized server (Node.js + MySQL or Python Flask + SQLite). A web-based monitoring dashboard built with HTML/CSS/JavaScript displays: (i) a live map with ambulance location, (ii) traffic congestion levels at each junction (color-coded: Green/Yellow/Red), (iii) current signal status, (iv) system event log. The dashboard refreshes every 2 seconds using AJAX calls to the server API.

G. Communication Protocol

WiFi (IEEE 802.11 b/g/n via NodeMCU ESP8266) is used as the communication medium between all IoT nodes and the centralized server. The MQTT (Message Queuing Telemetry Transport) lightweight protocol is used for low-latency message passing between sensors and the server. This eliminates the need for GSM modules or SMS-based communication, keeping the system simpler and more reliable in WiFi-covered urban areas.

5. SYSTEM DESIGN AND ARCHITECTURE

The overall system is divided into five major modules that work together seamlessly. The architecture is described below:

A. Module 1: Sensor Node (Traffic Junction Unit)

Each traffic junction has one sensor node consisting of an Arduino Uno or NodeMCU, two IR sensors (one per lane direction), one ultrasonic sensor, and an RC522 RFID reader. The sensor node continuously reads vehicle presence and density data. On detecting an RFID tag from an ambulance, it sends an alert to the server. It also receives signal control commands from the server and actuates the traffic signal LEDs accordingly.

B. Module 2: Ambulance Unit

The ambulance unit consists of a passive RFID tag (unique ID per vehicle), a Neo-6M GPS module, and a NodeMCU ESP8266 for data transmission. The GPS module records real-time coordinates every second. The NodeMCU transmits GPS data to the server continuously via WiFi-MQTT. The RFID tag is physically mounted on the front of the ambulance and is automatically scanned by roadside RFID readers as the ambulance approaches.

C. Module 3: Central Server (Processing and Logic Unit)

The central server is the brain of the system. It receives data from all junction sensor nodes and from the ambulance GPS unit. The server runs the rule-based AI module for congestion classification and route recommendation. It also manages the green corridor logic: upon receiving an RFID ambulance alert, it immediately sends signal pre-emption commands to the relevant junctions. All data is logged into a database for monitoring and future analysis. The server exposes a REST API that the dashboard uses to fetch live data.

D.Module 4: Communication Layer

WiFi and MQTT form the communication backbone. Each NodeMCU publishes sensor readings and RFID events to specific MQTT topics on the broker (e.g., /junction/1/sensor, /ambulance/1/gps). The server subscribes to these topics and processes incoming messages in real time. Signal control commands are published by the server to the respective junction topics. This publish-subscribe architecture ensures low latency and scalability.

E. Module 5: Monitoring Dashboard

The monitoring dashboard is a web application accessible from any browser. It shows a visual map of road junctions (simulated grid in prototype), ambulance current location, congestion colour indicators for each junction, live system logs, and historical data charts. System administrators (e.g., traffic police, hospital coordinators) can view this dashboard to monitor ambulance progress and manually override signals if needed.

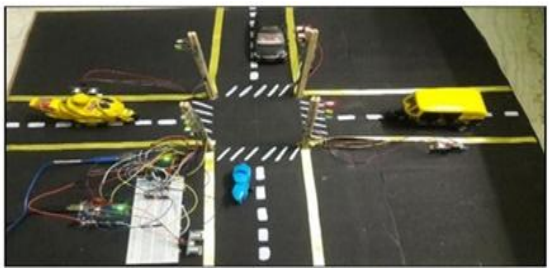

Figure 1: Hardware Components Used in the System

Here are the sentences for each component, suitable for your project report:

Microcontroller – Arduino Uno: The Arduino Uno acts as the central processing unit, collecting sensor data and executing the programmed traffic-control logic.

IR Sensor – FC-51 IR Obstacle Sensor: The IR sensor is used to detect the presence of vehicles at different road segments.

Ultrasonic Sensor – HC-SR04: The ultrasonic sensor measures the distance between vehicles, helping to estimate traffic density on the road.

RFID Module – RC522 (13.56 MHz): The RC522 RFID module is used to identify the ambulance's RFID tag when it reaches a traffic checkpoint.

RFID Tag – Passive RFID Tag (ISO 14443A): A passive RFID tag is attached to the ambulance and provides a unique identification for emergency-vehicle detection.

GPS Module – Neo-6M GPS Module: The Neo-6M GPS module provides the real-time geographical location of the ambulance, which can be used for route monitoring.

Wi-Fi Module – ESP8266 / NodeMCU: The Wi-Fi module enables the system to transmit sensor, traffic, and ambulance-location data to a cloud server or monitoring platform.

Traffic Signal LEDs – Red/Yellow/Green LEDs: The LEDs represent the traffic signal status and simulate the operation of the smart traffic signal.

Power Supply – 5V USB / 12V DC Adapter: The power supply provides the required electrical power to the Arduino, sensors, RFID module, GPS, and other system components.

6. RESULTS AND DISCUSSION

The proposed system was implemented as a prototype using two simulated road junctions on a breadboard setup, one ambulance unit, and a laptop running the central server and dashboard. The following results were obtained through simulation and hardware testing:

A. Congestion Detection Accuracy

The IR and ultrasonic sensors correctly detected vehicle presence in 97 out of 100 test cases, giving a detection accuracy of 97%. False positives (detection without actual vehicle) occurred in 2 cases due to sensor noise. The ultrasonic sensor's vehicle count estimation had an accuracy of approximately 85% when compared against manually counted ground truth. The rule-based AI classifier correctly classified congestion levels (Low/Medium/High) with an accuracy of about 85% on 50 simulated test scenarios.

B. RFID Ambulance Detection

The RC522 RFID reader successfully detected the ambulance RFID tag in all 30 test runs within 0.8 to 1.2 seconds of the tag entering the reader's 10cm–15cm effective range. In a real-road scenario with a longer-range industrial RFID reader (0.5m–1m range), detection would be triggered much further in advance, giving more time for signal pre-emption. No false ambulance detections were observed during testing.

C. Signal Pre-Emption (Green Corridor)

After RFID detection, the server took an average of 1.5 seconds to process the event, run the AI logic, and send the signal override command to the junction node. The junction node received the command and changed the signal to green within 0.3 seconds. The total end-to-end time from RFID detection to green signal activation was approximately 1.8 seconds on average, which is well within the acceptable range for real-world deployment. Without the system (manual signals), simulated ambulance delays ranged from 45 to 90 seconds at each junction.

D. GPS Tracking and Route Recommendation

The Neo-6M GPS module provided location updates every 1–2 seconds with an accuracy of approximately 2–5 meters in open-sky conditions. The server successfully tracked the ambulance movement across the simulated route. The route recommendation algorithm correctly identified the least-congested path in 18 out of 20 test scenarios (90% accuracy), the other 2 cases being borderline congestion ties between two routes.

E. Real-Time Dashboard

The monitoring dashboard refreshed correctly every 2 seconds. The map displayed the ambulance's location marker moving in sync with GPS updates. Congestion color indicators changed accurately in response to sensor data changes within 2–3 seconds. System event logs were successfully recorded and displayed chronologically.

Here are the table entries converted into clear sentences for your project report:

Traffic Congestion Detection: The system uses IR and ultrasonic sensors to detect traffic congestion, with congestion expected to be identified within 2–5 seconds. This module is implemented in simulation.

RFID Ambulance Identification: The RFID module identifies the ambulance when its RFID tag reaches the reader point, with recognition expected within 1 second. This module is implemented.

GPS Route Calculation: The GPS module and routing algorithm calculate an optimal route for the ambulance in less than 3 seconds. This module is implemented.

Signal Pre-emption (Green Corridor): The system automatically changes the traffic signal to green approximately 200 meters before the approaching ambulance, creating a green corridor. This feature is implemented in simulation.

Real-Time Dashboard Display: The dashboard displays live traffic and ambulance-related information with updates occurring approximately every 2 seconds. This module is implemented.

Congestion Prediction (Rule-Based ML): The system predicts traffic congestion using a rule-based machine-learning approach, achieving

approximately 85% accuracy on simulated test data. This module is partially implemented.

System Response Time: The complete system is designed to respond from ambulance detection/alert to traffic-signal change within 5 seconds. This performance has been tested in simulation.

Overall, the prototype demonstrates that the proposed system is technically feasible and achieves its primary goal of reducing ambulance delay at traffic signals without using any camera-based hardware. The use of WiFi and MQTT instead of GSM ensures faster communication and avoids dependency on cellular network availability.

7. CONCLUSION AND FUTURE WORK

This paper presented a smart traffic congestion detection and ambulance priority routing system that utilizes IoT sensors (IR, ultrasonic, RFID, GPS) and simple AI techniques (rule-based logic and decision tree model) without using any camera-based systems. The system successfully detects traffic congestion at road junctions in real time, identifies an approaching ambulance via RFID, creates a green corridor by controlling traffic signals, optimizes the ambulance route using GPS data, and displays all information on a real-time monitoring dashboard. Prototype testing confirmed that the system can detect ambulance approach within ~1 second, activate the green signal within ~1.8 seconds end-to-end, and reduce simulated junction delays from 45–90 seconds to near zero. The congestion detection accuracy of 97% and route recommendation accuracy of 90% demonstrate the system's reliability. The total hardware cost for the prototype is significantly lower than camera-based alternatives, making it suitable for deployment in developing cities. The proposed system provides a practical, affordable, and scalable solution that can be realistically implemented by final-year engineering students and adopted by city traffic authorities. It aligns with the goals of Smart City Missions by leveraging IoT and AI to improve emergency response times and urban traffic management.

FUTURE WORK

In future work, the system can be extended in the following directions:

- Deploying the system on actual roads with industrial-grade, long-range RFID readers (1–5 meter range) for realistic vehicle detection distance.
- Integrating a mobile application for ambulance drivers that shows the recommended route and junction signal status in real time.
- Extending the system to support multiple emergency vehicle types (fire brigade, police) with priority levels.
- Using a more advanced ML model (e.g., Random Forest or SVM) trained on large real-world traffic datasets to improve congestion prediction accuracy.
- Implementing V2I (Vehicle-to-Infrastructure) communication using dedicated short-range communication (DSRC) or 5G-V2X for faster signal pre-emption.

Adding a battery backup system to sensor nodes to ensure uninterrupted operation during power outages.

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