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IOT-Based Ambulance Traffic Signal Priority and Emergency Route Management System

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Abstract

Traffic congestion at road intersections can cause significant delays to ambulances during medical emergencies. Conventional traffic signals generally operate according to predefined timing and may not automatically provide priority to approaching emergency vehicles. This paper presents a Smart Ambulance Priority System Using IoT that provides traffic-signal priority to authorized ambulances. The proposed system integrates an ESP32 microcontroller, RFID-based ambulance authentication, GPS-based location tracking, IoT communication, cloud data storage, traffic-signal control, and hospital-side monitoring. A registered ambulance is identified using an RFID tag, while GPS provides its location information. The ambulance information is transmitted through the Internet to the cloud platform. When an emergency request is generated, the traffic-signal controller provides green priority to the ambulance direction while conflicting directions remain red. After the ambulance passes the junction, the signal returns to normal operation. Firebase Realtime Database and a Flask-based web dashboard are used to monitor ambulance and junction information. The proposed prototype demonstrates the feasibility of integrating ambulance authentication, location monitoring, cloud communication, and traffic-signal priority into a low-cost IoT-based emergency traffic-management system.

Index Terms—*Internet of Things (IoT); ambulance priority; RFID; GPS; ESP32; smart traffic signal; emergency vehicle; Firebase; cloud monitoring.*

I. Introduction

Traffic congestion at road intersections can create significant delays for ambulances during medical emergencies. Conventional traffic signals normally operate according to predefined timing cycles and may not provide immediate priority to an approaching emergency vehicle. Such delays can affect the overall emergency response process.

The development of Internet of Things (IoT) technologies provides an opportunity to connect emergency vehicles, traffic infrastructure, cloud platforms, and hospitals. RFID can be used to authenticate registered ambulances, while GPS can provide their location. Cloud communication can then allow traffic controllers and monitoring systems to receive ambulance information.

The proposed Smart Ambulance Priority System Using IoT combines these technologies into an integrated prototype. The system uses ESP32 controllers, RFID, GPS, Firebase cloud storage, traffic-signal LEDs, and a web-based monitoring dashboard. When an authorized ambulance enters emergency mode, the system generates a priority request and provides a green signal to the required direction. After the ambulance passes the junction, the traffic signal returns to normal operation.

The main contribution of this work is the integration of ambulance authentication, GPS tracking, IoT cloud communication, traffic-signal priority, and hospital-side monitoring in a low-cost prototype suitable for demonstrating an emergency traffic-management system.

II. Problem Statement

Traditional traffic signals are generally designed for normal traffic flow and may cause ambulances to wait at red lights. Manual intervention by traffic personnel may also introduce additional delay.

Therefore, an automated system is required to identify an authorized ambulance, obtain its location, communicate its emergency status, provide traffic-signal priority, and return the traffic signal to normal operation after the ambulance passes.

III. Objectives

The main objectives of the proposed system are:

1. To develop an IoT-based ambulance priority system.
2. To authenticate authorized ambulances using RFID.
3. To obtain ambulance location using GPS.
4. To transmit ambulance information to a cloud database.
5. To provide automatic traffic-signal priority during emergencies.
6. To restore normal traffic operation after the ambulance passes.
7. To monitor ambulance information through a web dashboard.
8. To provide ambulance information to the hospital.

IV. Related Work

Several research works have investigated technologies for emergency vehicle priority.

RFID-based approaches use unique vehicle identification to recognize emergency vehicles and modify traffic-signal operation. Such systems demonstrate that RFID can be used for emergency vehicle identification and signal priority [1], [2]. Cloud-connected variants allow an RFID reader at the signal to report ambulance detection to a cloud service, with a mobile application supporting the ambulance driver [9], [12]. Other work combines RFID with GPS and LTE so that the signal changes only when the ambulance is near the junction [10].

IoT-based traffic signal systems have also been developed to allow communication between emergency vehicles and traffic controllers. These approaches can dynamically modify signal states when an emergency vehicle is detected [3], [11].

GPS and IoT have been combined for ambulance optimization and real-time emergency vehicle monitoring. Such systems use location information to improve emergency vehicle movement and signal preemption [4].

Other research has investigated IoT-based traffic-density management and emergency vehicle prioritization [5], [6]. Connected-vehicle and V2X technologies have also been investigated for emergency vehicle priority and communication with traffic infrastructure [7].

Further studies address emergency signalization using a mobile application and route determination between the vehicle's location and its destination [13], adaptive signal timing based on traffic volume with simulation-based validation [14], and sound-sensor and camera-based detection of emergency vehicles combined with adaptive green-phase control [15]. Recent research continues to investigate real-time IoT-based emergency vehicle signal adjustment [8].

Table I summarizes the technologies and main focus of the related work.

TABLE I. Comparison of Related Work

Ref.	Technology	Main focus
[1]	RFID + cloud	Ambulance identification and signal control
[2]	RFID	Emergency vehicle signal priority
[3]	IoT	Traffic-light control for ambulance
[4]	GPS + IoT	Ambulance optimization
[5]	IoT + GPS/RF	Emergency vehicle priority
[6]	IoT + traffic management	Emergency vehicle prioritization
[7]	V2X	Connected emergency vehicle communication
[8]	IoT	Real-time emergency signal adjustment
[9]	RFID + cloud + mobile app	Ambulance detection at signal and cloud update
[10]	RFID + GPS + LTE	Location-aware ambulance signal control
[11]	IoT	Smart ambulance system
[12]	RFID + IoT cloud service	Green signal on ambulance detection
[13]	Mobile application + routing	Smart signalization for emergency vehicles
[14]	Arduino-based adaptive control	Prioritized traffic-light control
[15]	Sound sensing + camera	Emergency vehicle detection and adaptive green phase
Proposed	RFID + GPS + ESP32 + cloud	Integrated ambulance priority prototype

V. Proposed System

The proposed architecture consists of four major units:

A. Ambulance Unit

The ambulance unit contains:

- ESP32
- RFID tag
- NEO-6M GPS
- Emergency button
- Wi-Fi/Internet connectivity

The RFID tag provides the ambulance's unique identity. GPS provides location information. The ESP32 collects the data and communicates with the cloud system.

B. Traffic Signal Unit

The traffic signal unit contains:

- ESP32
- RC522 RFID reader
- Red, yellow, and green LEDs
- Signal-control circuitry

The unit controls the prototype traffic signal according to the priority request.

C. Cloud Unit

Firebase Realtime Database is used to store:

- Ambulance ID
- Ambulance status
- GPS latitude
- GPS longitude
- Emergency status
- Junction information
- Signal status

D. Hospital/Monitoring Unit

The web dashboard provides information such as:

- Ambulance ID
- Driver information
- Ambulance status
- Current location
- Emergency request
- Junction status

VI. System Architecture

The overall architecture of the proposed system is shown in Fig. 1.

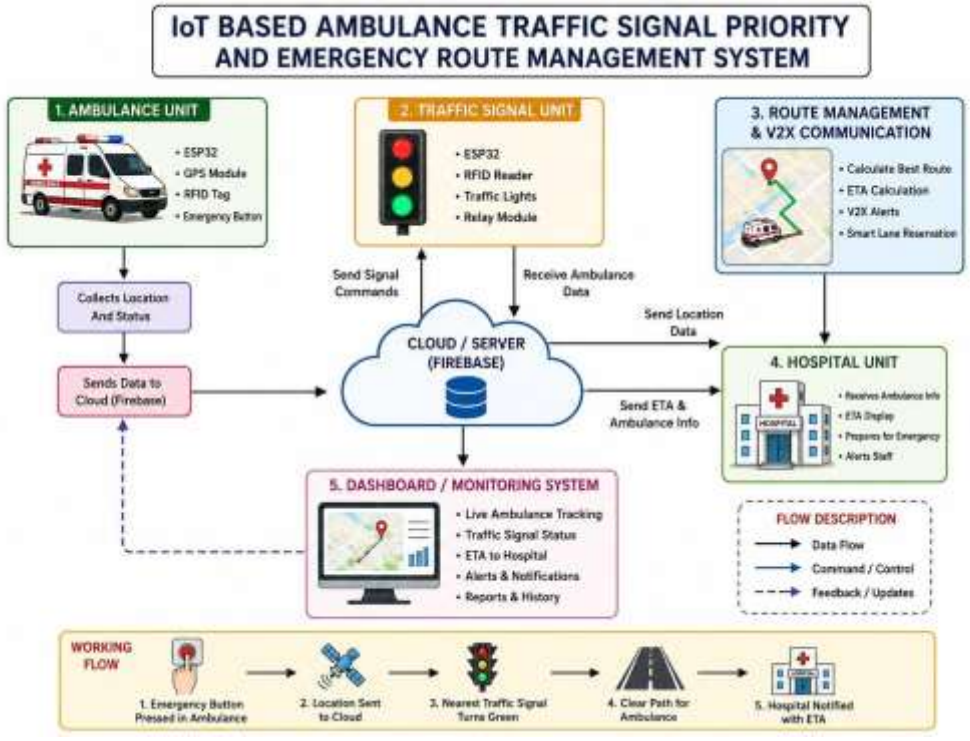


Fig. 1. System architecture of the proposed ambulance priority system.

VII. Hardware Implementation

The hardware components used in the prototype are listed in Table II.

TABLE II. Hardware Components

Component	Function
ESP32	Main controller and IoT communication
NEO-6M GPS	Ambulance location
RC522	RFID reading
RFID tag	Ambulance identification
Traffic LEDs	Traffic-signal representation
Emergency button	Emergency activation
Wi-Fi	Cloud communication
Relay/driver circuit	Signal-control interface where required
Lane LEDs	Emergency-lane indication
Servo motor	Optional lane barrier
Power supply	Hardware power

VIII. Software Implementation

The software architecture consists of four major parts.

A. ESP32 Firmware

The ESP32 receives data from the RFID and GPS modules and communicates with the cloud system.

B. Backend

The backend is implemented using Python and Flask. It manages communication between the web dashboard and the database.

C. Database

Firebase Realtime Database is used for storing and updating ambulance and traffic information.

D. Web Dashboard

The dashboard is developed using HTML, CSS, JavaScript, and Flask. It allows an administrator to monitor ambulance and junction information.

IX. Working Methodology

The complete operation is divided into the following steps, summarized in Fig. 2.

Step 1: Ambulance Registration

An authorized ambulance is registered in the system with a unique ambulance ID and RFID tag.

Step 2: Emergency Activation

The ambulance enters emergency mode when an emergency situation occurs.

Step 3: RFID Authentication

The RFID system verifies the ambulance identity.

Step 4: GPS Tracking

The GPS module obtains the ambulance's current location.

Step 5: Data Transmission

The ESP32 sends ambulance information through the Internet.

Step 6: Cloud Storage

Firebase stores the ambulance ID, location, status, and emergency information.

Step 7: Priority Request

The traffic controller receives the emergency request.

Step 8: Signal Priority

The traffic signal provides green priority to the ambulance direction while conflicting directions remain red.

Step 9: Ambulance Passage

The ambulance crosses the junction.

Step 10: Signal Restoration

After the ambulance passes, the signal returns to normal operation.

Step 11: Hospital Monitoring

The ambulance information can be monitored through the web dashboard.

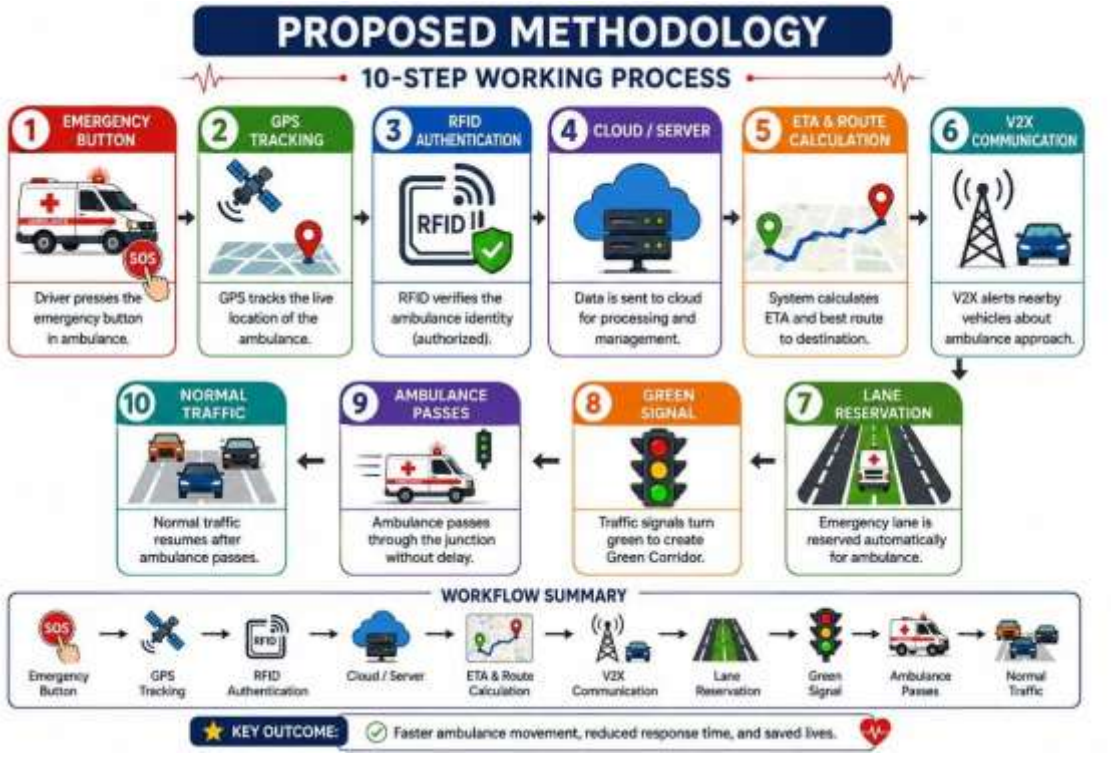


Fig. 2. Working process of the proposed system.

X. Experimental Setup

The proposed system is implemented as a small-scale physical prototype. The prototype contains:

- Cardboard road model
- Model ambulance
- Traffic signal

- ESP32
- RFID system
- GPS module
- Traffic LEDs
- Emergency control
- Firebase cloud database
- Laptop/web dashboard
- Hospital representation
- Optional emergency lane

The physical prototype is shown in Fig. 3, and the hardware connections of the ESP32, RFID reader, GPS module, and traffic signal are shown in Fig. 4. The web-based administrator dashboard is shown in Fig. 5.

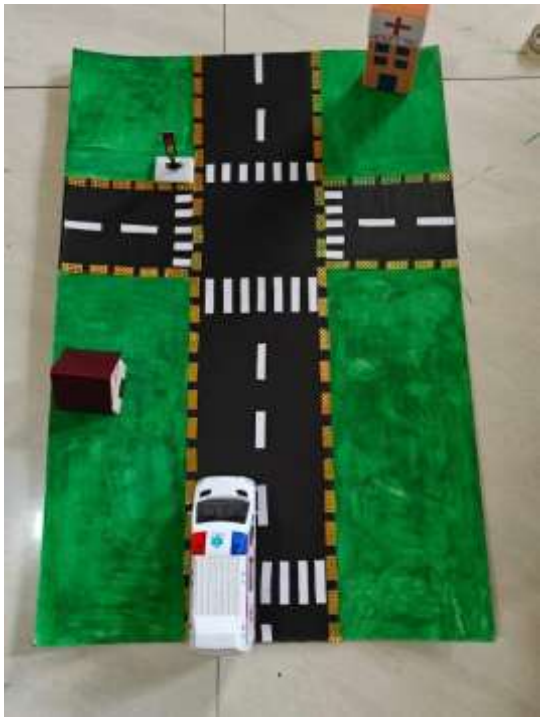


Fig. 3. Physical prototype of the proposed ambulance priority system.

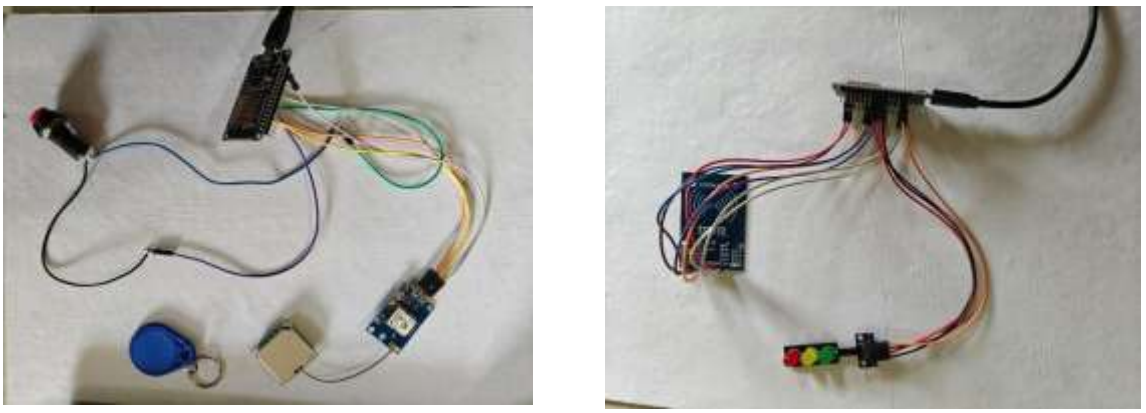


Fig. 4. Hardware connection of ESP32, RFID, GPS, and traffic signal: (a) ESP32 with GPS module, RFID tag, and emergency button; (b) ESP32 with RC522 reader and signal LEDs.

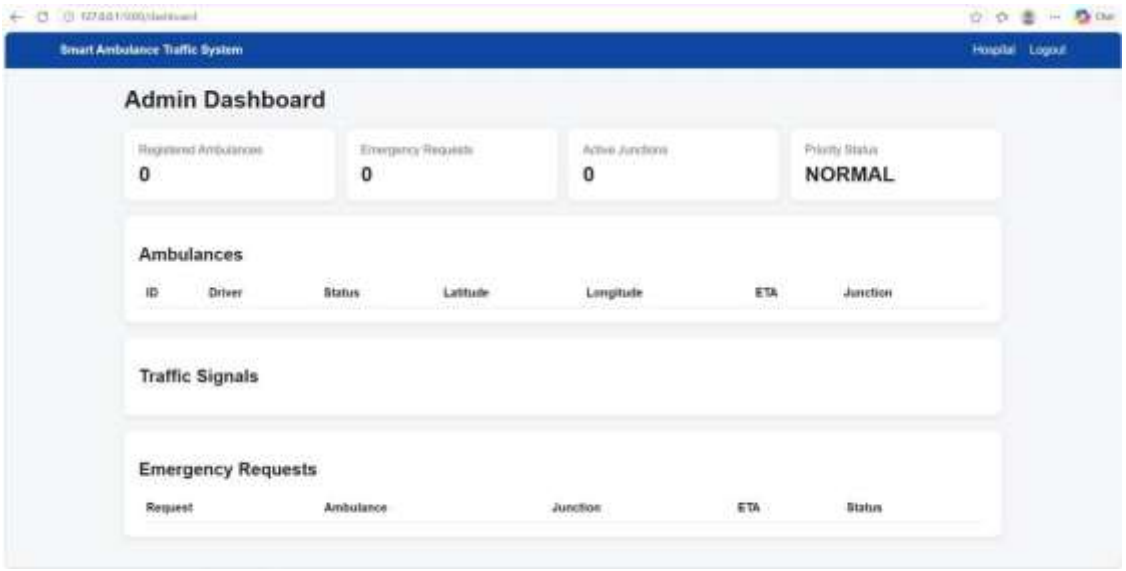


Fig. 5. Web-based admin dashboard.

XI. Comparison with Existing Systems

Table III compares the features of RFID-based, GPS/IoT-based, and V2X-based approaches with the proposed system.

TABLE III. Feature Comparison

Feature	RFID-based	GPS/IoT	V2X	Proposed
Ambulance identification	✓	—	✓	✓
RFID authentication	✓	—	—	✓
GPS tracking	—	✓	✓	✓
IoT communication	✓	✓	✓	✓
Cloud monitoring	✓	✓	—	✓
Signal priority	✓	✓	✓	✓
Hospital dashboard	Limited	Limited	Possible	✓
Low-cost prototype	✓	✓	—	✓

The proposed work focuses on integrating these functions into a single prototype rather than claiming that each individual technology is new.

XII. Limitations

The current prototype has the following limitations:

- It is implemented on a small-scale model.
- GPS accuracy depends on environmental conditions.
- Internet connectivity is required for cloud functions.
- Real-world traffic-signal deployment requires authorization.
- Actual traffic infrastructure requires proper electrical isolation and safety protection.
- Multiple-junction coordination requires additional infrastructure.

XIII. Future Scope

The system can be extended through:

A. V2X Communication

Communication between the ambulance, traffic signals, and nearby vehicles can provide more advanced emergency coordination.

B. Smart Lane Reservation

An emergency lane can be reserved using lane LEDs and a controlled barrier.

C. Multiple Junction Coordination

Multiple traffic signals can be connected to create a continuous green corridor.

D. 4G/5G Connectivity

Cellular connectivity can be added where Wi-Fi is unavailable.

E. Hospital Integration

The ambulance information can be integrated with hospital systems.

F. City-Level Deployment

The prototype can be expanded to multiple traffic intersections.

XIV. Conclusion

This paper presented a Smart Ambulance Priority System Using IoT for improving ambulance movement through traffic intersections. The proposed system integrates RFID-based ambulance authentication, GPS-based location tracking, ESP32-based IoT communication, Firebase cloud storage, traffic-signal priority, and web-based monitoring.

The system provides an integrated mechanism for identifying an authorized ambulance, transmitting its emergency information, providing traffic-signal priority, and monitoring ambulance information through a centralized dashboard. After the ambulance passes the intersection, the traffic signal can return to its normal operation.

The physical prototype demonstrates the feasibility of integrating low-cost IoT hardware and cloud technologies for emergency traffic management. Future development can extend the system through V2X communication, smart lane reservation, multiple connected intersections, cellular communication, and real-world traffic-management infrastructure.

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