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IOT ENABLED SMART TRAFFIC MANAGEMENT SYSTEM USING RASPBERRY PI

Ms. Dipali Siddheshwar Pawar[1], Prof. Kavita H. Waghmode[2]
[1] *ME in IoT, Dattakala Group of Institutes, Faculty of Engineering, Bhigwan, Maharashtra, India.*
Email: dipalipawar666@gmail.com
[2] *HOD, Electronics & Computer Engineering, Dattakala Group of Institutes, Faculty of Engineering, Bhigwan, Maharashtra, India.*
Email: Khwaghmode.foe@dattakala.edu.in

Abstract
Due to the rapid growth of urbanization and the increase of vehicles, traffic management has become a major challenge, resulting in congestion, increased time, and delays for emergency services. Conventional traffic signal systems are based on fixed time controls and are not able to respond to real-time traffic scenarios. This paper proposes an IoT-based smart traffic management system using Raspberry Pi, which controls traffic signals based on the density of the traffic and provides emergency vehicle priority. Ultrasonic sensors are employed to detect the density of the traffic on each road, and the RFID module identifies the emergency vehicles approaching the intersection. The Raspberry Pi controller processes the data and controls the traffic signal timing based on the traffic density and emergency vehicle presence. The data collected by the sensors are transmitted to the ThingSpeak cloud platform for real-time monitoring and analysis. The proposed system has successfully demonstrated the ability to detect traffic density and control traffic signal timing with a high accuracy of 95% for vehicle detection and 98% for emergency vehicle detection. Additionally, the system has a signal switching response time of less than one second and a cloud data transmission delay of around 2 to 3 seconds. This allows near real-time monitoring. The proposed system provides a cost-effective, scalable, and intelligent smart traffic management solution for today's modern world.
Keywords: IoT, Smart Traffic System, raspberry Pi, RFID, Ultrasonic Sensor, ThingsSpeak.

► *Corresponding Author: Ms. Dipali Siddheshwar Pawar*

I. Introduction

Urban transportation systems are facing significant challenges due to rapid population growth, increased vehicle ownership, and limited road infrastructure. Traffic congestion has become one of the major issues in metropolitan areas, leading to increased travel time, fuel consumption, air pollution, and economic losses. Traditional traffic signal systems operate on fixed timing cycles without considering real-time traffic density, which often results in inefficient signal allocation and long vehicle queues at intersections.

Intelligent Transportation Systems (ITS) have emerged as an effective approach to address these challenges by integrating sensing technologies, communication networks, and data analytics to optimize traffic flow. The integration of Internet of Things (IoT) technologies has further enhanced ITS by enabling real-time data acquisition from sensors and connected devices deployed on road infrastructure. IoT-based systems allow traffic signals, vehicles, and monitoring platforms to communicate and respond dynamically to traffic conditions [11].

Several studies have explored intelligent traffic signal control mechanisms. For example, Liu et al. proposed a distributed multi-agent reinforcement learning system for adaptive traffic signal control that significantly improved traffic efficiency in simulated environments [1]. Similarly, Haydari and Yilmaz presented a deep reinforcement learning framework for optimizing traffic signal timing in intelligent transportation networks [2]. However, these approaches require high computational resources and are often difficult to implement in real-world embedded environments.

Recent research has focused on low-cost embedded systems such as Raspberry Pi for implementing edge-based traffic monitoring solutions. Raspberry Pi offers built-in connectivity, processing capability, and compatibility with various sensors, making it suitable for IoT-based traffic management systems [24]. Studies have demonstrated that integrating IoT sensors with edge computing devices can significantly reduce latency and improve system responsiveness [17].

Another critical requirement in traffic systems is emergency vehicle prioritization. Delays in traffic signals can negatively impact ambulance response times and emergency services. RFID-based solutions have been proposed to detect emergency vehicles and automatically adjust signal priorities to ensure faster passage through intersections [15].

Cloud platforms also play an important role in modern traffic management systems by enabling real-time monitoring and long-term analytics. Platforms such as ThingSpeak allow traffic data to be visualized through dashboards and analyzed using MATLAB tools for traffic prediction and planning [22].Despite these developments, many existing systems focus either on traffic monitoring or signal optimization but do not integrate real-time density detection, emergency vehicle handling, and cloud analytics in a unified architecture.

To address these limitations, this paper proposes an IoT-enabled Smart Traffic Management System using Raspberry Pi that dynamically adjusts traffic signal timing based on real-time vehicle density detected through ultrasonic sensors. The system also integrates RFID technology for emergency vehicle prioritization and uploads traffic data to the ThingSpeak cloud platform for monitoring and analytics. The proposed solution provides a low-cost, scalable, and intelligent framework for improving traffic efficiency in smart city environments.

II. Literature Review

Intelligent traffic signal control has been widely studied in the field of intelligent transportation systems. Researchers have proposed various approaches using machine learning, IoT technologies, wireless sensor networks, and edge computing to optimize traffic flow.

Liu et al. introduced a distributed multi-agent reinforcement learning model that dynamically adjusts signal timings based on traffic conditions. Their study demonstrated improved traffic flow and reduced congestion compared to traditional fixed-time systems [1]. Rasheed et al. further reviewed deep reinforcement learning approaches for traffic signal optimization and concluded that machine learning algorithms can significantly reduce traffic delays when integrated with traffic signal controllers [2]. Edge computing has also gained attention for real-time traffic monitoring applications. Khan et al. developed an edge-based traffic monitoring system using Raspberry Pi that collects traffic data and performs local processing before transmitting information to the cloud. This approach reduced network latency and improved real-time performance [24].

IoT technologies have enabled cost-effective traffic monitoring solutions by integrating sensors, controllers, and communication networks. Damadam et al. proposed an IoT-based intelligent traffic system that used wireless sensors to monitor vehicle density and control traffic signals accordingly [3]. Similarly, Vadivel et al. demonstrated the use of IoT-connected wireless sensor networks to detect traffic congestion and transmit data to centralized monitoring systems [21]. Several studies have also focused on emergency vehicle prioritization in traffic systems. Bose and Ghosh developed an RFID-based traffic control system that detects emergency vehicles and grants them priority passage through intersections [15]. Their research showed that integrating RFID with IoT platforms significantly reduces emergency response delays.

Cloud computing has also been incorporated into traffic management systems to support large-scale monitoring and analytics. Paital presented an IoT cloud architecture that collects traffic data from sensors and performs predictive analytics for smart city applications [22]. Cloud platforms enable traffic authorities to monitor traffic patterns and optimize infrastructure planning. Artificial intelligence has also been applied to traffic signal optimization. Zhou and Park proposed an AI-driven signal optimization system that analyzes IoT traffic data and dynamically adjusts signal phases to reduce congestion [16]. Similarly, Masood et al. presented an AI-enabled traffic control system based on software-defined IoT networks to improve traffic prioritization [17].

Although these studies demonstrate the potential of intelligent traffic systems, several challenges remain. Many machine learning-based solutions require high computational resources and cloud infrastructure, making them unsuitable for low-cost deployments. Some IoT systems focus only on monitoring traffic without implementing adaptive signal control. Therefore, there is a need for an integrated solution that combines sensor-based traffic density detection, edge computing, emergency vehicle prioritization, and cloud analytics in a scalable and cost-effective architecture.

III. Proposed Methodology

The proposed methodology presents an **IoT-enabled smart traffic management framework** designed to dynamically control traffic signals based on real-time vehicle density while ensuring priority access for emergency vehicles. The system integrates traffic sensing devices, edge computing using a Raspberry Pi, intelligent decision-making algorithms, and cloud-based monitoring to provide an efficient and scalable traffic control solution. Ultrasonic sensors are deployed at each lane to detect the presence and density of vehicles approaching the intersection, while an RFID module is used to identify emergency vehicles such as ambulances or fire trucks. The collected sensor data is processed locally by the Raspberry Pi, which executes an adaptive signal control algorithm to determine optimal traffic signal timing for each lane. The system then controls the traffic signal LEDs through relay circuits and simultaneously transmits traffic information to the ThingSpeak IoT cloud platform for real-time monitoring and analytics. This integrated architecture enables dynamic traffic signal management, reduces congestion, improves traffic flow efficiency, and supports intelligent decision-making for modern smart city transportation systems.

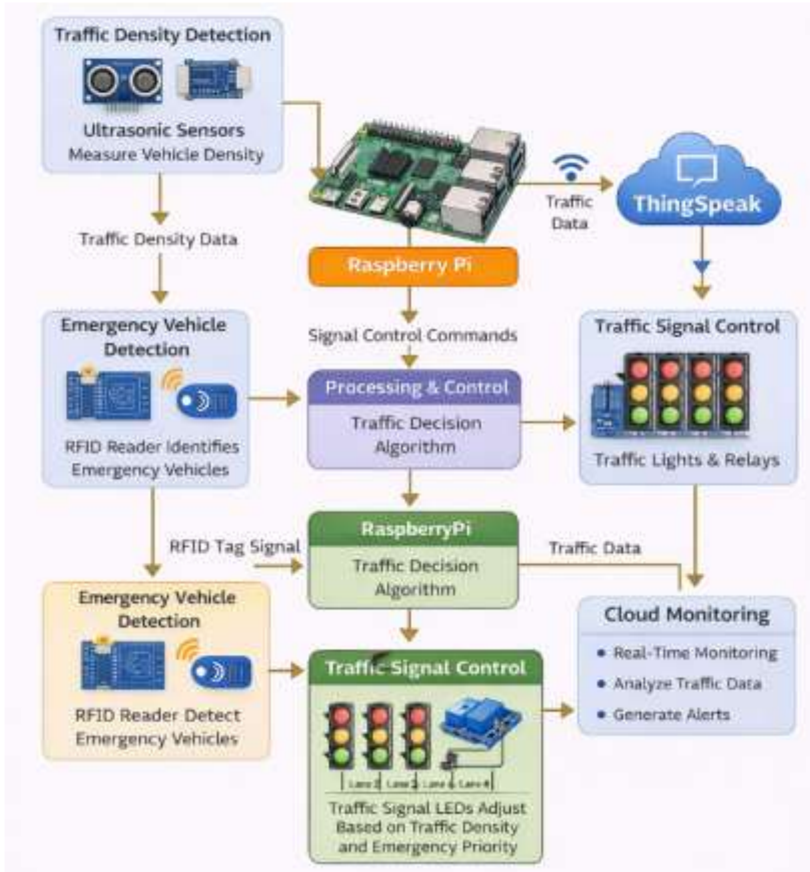

Fig.1 Proposed Architecture

Figure 1 illustrates the overall architecture of the proposed **IoT-enabled Smart Traffic Management System,** which integrates sensor-based traffic monitoring, edge computing using Raspberry Pi, adaptive signal control, and cloud-based traffic analytics. The system is designed to dynamically regulate traffic signals according to real-time vehicle density while also providing priority access to emergency vehicles. The architecture consists of four major layers: **traffic sensing layer, edge processing layer, signal control layer, and cloud monitoring layer.**

1. Traffic Density Detection Module

The first stage of the proposed architecture is the **traffic sensing layer,** where ultrasonic sensors are deployed at each lane of the intersection to detect vehicle density. The ultrasonic sensors operate by transmitting ultrasonic sound waves and measuring the time taken for the reflected waves to return after hitting an object (vehicle). Using this time measurement, the system calculates the distance between the sensor and the vehicle. When multiple vehicles accumulate near the signal, the measured distance decreases, indicating high traffic density. Conversely, when the distance is large, the traffic density is considered low. The collected traffic density data is transmitted to the Raspberry Pi for further processing. This module provides real-time traffic monitoring and enables the system to make intelligent decisions based on the current traffic conditions rather than relying on fixed signal timings.

2. Emergency Vehicle Detection Module

In addition to vehicle density detection, the system incorporates an **RFID-based emergency vehicle detection mechanism.** An RFID reader is installed near the traffic intersection, and emergency vehicles such as ambulances, fire trucks, or police vehicles are equipped with RFID tags.When an emergency vehicle approaches the intersection, the RFID reader detects the corresponding RFID tag and sends the identification signal to the Raspberry Pi. Upon receiving this signal, the system temporarily overrides the normal traffic control algorithm and immediately provides a green signal to the lane where the emergency vehicle is located. This feature significantly reduces response time for emergency services and enhances public safety.

3. Processing and Decision-Making Module

The core component of the system is the **Raspberry Pi,** which functions as the central processing and decision-making unit. The Raspberry Pi collects traffic density data from ultrasonic sensors and emergency signals from the RFID reader. A Python-based traffic control algorithm processes the received data and determines the optimal signal timing for each lane. The algorithm analyses vehicle density levels and dynamically allocates green signal durations accordingly. For example, lanes with higher traffic density are assigned longer green signal durations, while lanes with lower traffic density receive shorter signal durations.

This adaptive decision-making process ensures efficient traffic flow and minimizes unnecessary waiting times at intersections.

4. Traffic Signal Control Module

Once the Raspberry Pi determines the optimal signal timing, control commands are transmitted to the **traffic signal control module.** This module consists of relay circuits connected to red, yellow, and green traffic LEDs. The relay circuits allow the Raspberry Pi to control high-voltage traffic lights safely through its GPIO pins. Based on the processed decision, the system activates the appropriate signal lights for each lane, ensuring smooth and adaptive traffic movement.

5. IoT Cloud Communication Module

To enable remote monitoring and data analysis, the system integrates with the **ThingSpeak IoT cloud platform.** The Raspberry Pi transmits traffic data such as vehicle density, signal status, and timestamps to the cloud using Wi-Fi communication. The data is uploaded using HTTP or MQTT protocols through ThingSpeak APIs. This communication layer enables real-time connectivity between the traffic system and cloud servers.

6. Cloud Monitoring and Analytics Module

The final stage of the architecture is the **cloud monitoring layer,** where the traffic data collected from intersections is stored and analyzed. The ThingSpeak platform provides interactive dashboards that display real-time graphs representing traffic density, signal status, and system performance. Additionally, ThingSpeak integrates MATLAB analytics tools that allow traffic authorities to analyze historical traffic patterns, identify peak traffic hours, and perform predictive analysis. These insights help city planners optimize traffic infrastructure and improve long-term transportation planning.

IV. System Work Flow

The system workflow describes the sequential operation of the proposed IoT-enabled smart traffic management system from initialization to traffic signal control and cloud-based monitoring. The workflow integrates traffic sensing, data processing, decision-making, and adaptive signal control to improve traffic flow at road intersections. The system operates continuously to monitor vehicle density, detect emergency vehicles, and dynamically adjust traffic signals according to real-time traffic conditions. By combining sensor-based data acquisition with edge computing and IoT cloud connectivity, the proposed system ensures efficient traffic management and remote monitoring.

Initially, the system starts by initializing all components, including ultrasonic sensors, the RFID reader, the Raspberry Pi controller, and the wireless communication module. The ultrasonic sensors detect vehicles approaching each lane and estimate traffic density by measuring the distance between the sensor and vehicles. At the same time, the RFID reader continuously scans for RFID tags attached to emergency vehicles such as ambulances, fire trucks, or police vehicles. The collected sensor data is transmitted to the Raspberry Pi processing unit, where the traffic control algorithm analyzes vehicle density and determines the optimal signal timing for each lane. If an emergency vehicle is detected, the system immediately prioritizes the corresponding lane by assigning a green signal. Otherwise, the traffic signal timing is adjusted dynamically based on traffic density. The processed traffic information is then transmitted to the ThingSpeak cloud platform for real-time monitoring and analytics, enabling traffic authorities to observe traffic patterns and system performance.

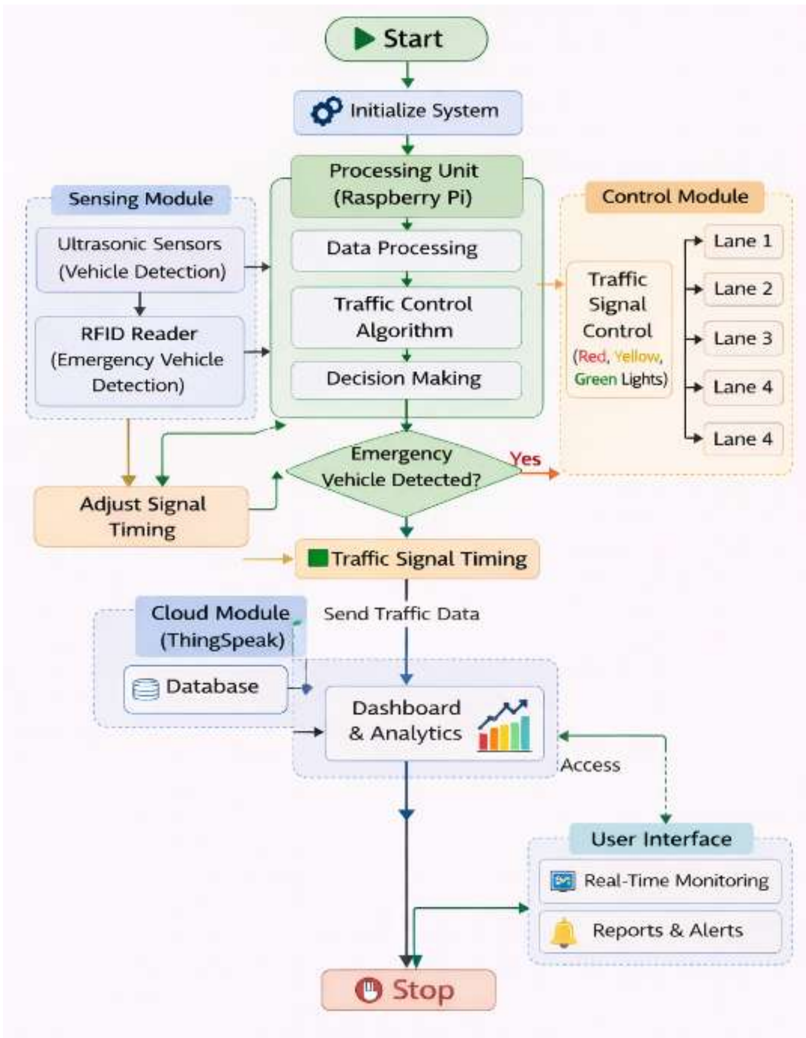

Fig.2 System Flow Chart

Figure 2 illustrates the overall workflow of the proposed IoT-enabled smart traffic management system. The flowchart describes the sequence of operations performed by the system, starting from initialization to traffic monitoring and signal control. The workflow begins with the **Start** block, which represents the activation of the traffic management system. Once the system starts, the Raspberry Pi initializes all hardware and software components, including sensors, RFID modules, traffic signal interfaces, and network connectivity. After initialization, the system enters the **data acquisition stage**, where ultrasonic sensors continuously monitor the presence and density of vehicles approaching the intersection. These sensors measure the distance between vehicles and the traffic signal to estimate traffic density in each lane. At the same time, the RFID reader scans for RFID tags associated with emergency vehicles such as ambulances, fire trucks, or police vehicles.

The collected data from sensors and RFID modules is then transmitted to the **processing unit (Raspberry Pi).** In this stage, the system performs data processing and executes the traffic control algorithm. The algorithm analyzes vehicle density and determines the appropriate signal timing for each lane. A decision-making process is then performed to check whether an emergency vehicle is detected.

If an emergency vehicle is identified, the system immediately prioritizes the corresponding lane by providing a green signal to allow the emergency vehicle to pass without delay. If no emergency vehicle is detected, the system dynamically adjusts traffic signal timing based on vehicle density to optimize traffic flow and reduce congestion.

Once the signal timing is determined, the system activates the **traffic signal control module**, which manages the red, yellow, and green traffic lights for all lanes. This ensures adaptive signal control based on real-time traffic conditions. Simultaneously, the system sends traffic data to the **ThingSpeak cloud platform**, where the information is stored in a database and visualized through dashboards and analytical graphs. The cloud platform enables remote monitoring and data analysis by traffic authorities. Finally, the processed information is displayed on the **user interface**, which provides real-time monitoring and alerts related to traffic conditions. The workflow concludes at the **Stop** block, indicating the completion of the system cycle. In practice, the system operates continuously in a loop to maintain real-time adaptive traffic management.

V. Hardware Implementaion

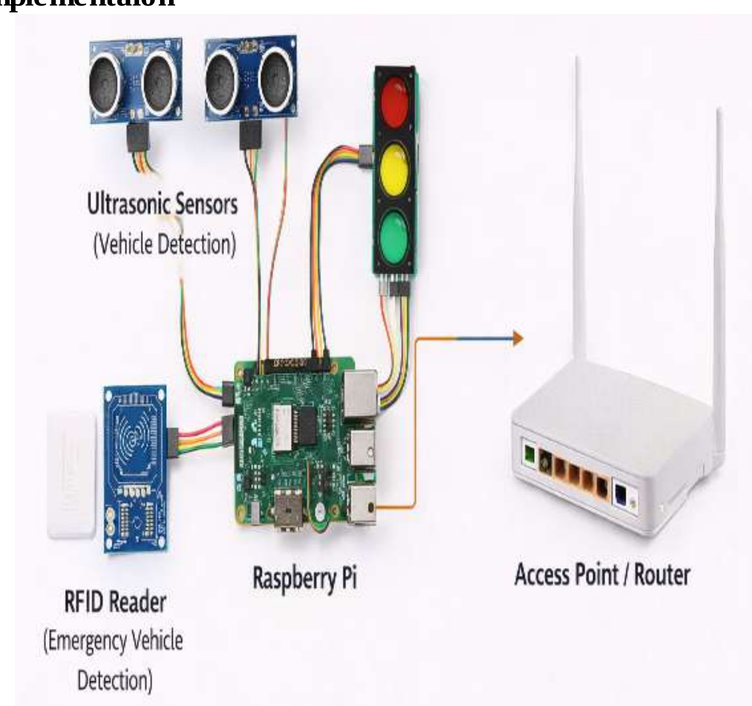

Fig.3 Hardware implementation of proposed system

Figure 3 illustrates the hardware implementation of the proposed IoT-enabled smart traffic management system. The system is built around a **Raspberry Pi**, which acts as the central processing and control unit responsible for collecting sensor data, executing the traffic control algorithm, and managing communication with the cloud platform. The **ultrasonic sensors** are deployed at each lane of the intersection to detect vehicle presence and measure traffic density. These sensors operate by transmitting ultrasonic waves and calculating the distance to nearby vehicles based on the time taken for the reflected signal to return. The measured distance information is transmitted to the Raspberry Pi through its GPIO pins, allowing the system to estimate the level of congestion in each lane.

An **RFID reader module** is integrated into the system to identify emergency vehicles approaching the traffic intersection. Emergency vehicles are equipped with RFID tags, and when the RFID reader detects a valid tag, it sends a signal to the Raspberry Pi. Upon detection, the system gives priority to the corresponding lane by activating the green traffic signal to allow the emergency vehicle to pass quickly. The **traffic signal module**, consisting of red, yellow, and green LED indicators, represents the traffic lights for the intersection. These LEDs are controlled by the Raspberry Pi through GPIO connections or relay circuits. Based on the processed traffic data and algorithmic decisions, the Raspberry Pi dynamically adjusts the signal timing for each lane.

For remote monitoring and data communication, the Raspberry Pi connects to the internet through a **Wi-Fi router or access point**. The traffic data, including vehicle density and signal status, is transmitted to the **ThingSpeak cloud platform**, where it can be visualized and analyzed in real time.

Overall, the hardware implementation integrates sensing devices, processing units, communication modules, and traffic signal controllers to create a complete IoT-based traffic management system capable of adaptive traffic control and remote monitoring.

VI. Experimental Results

The proposed IoT-enabled smart traffic management system was implemented and tested to evaluate its ability to detect vehicle density, prioritize emergency vehicles, and dynamically control traffic signals. The system was deployed using ultrasonic sensors, an RFID reader, and a Raspberry Pi controller connected to the ThingSpeak cloud platform. Several experiments were conducted under different traffic conditions to analyze the system performance in terms of vehicle detection, signal timing control, and cloud data monitoring.

Table 1: Traffic Density Detection Results

Lane	Measured Distance (cm)	Vehicle Density Level	Assigned Green Time (sec)
Lane 1	120	Low	10
Lane 2	80	Medium	20
Lane 3	40	High	30
Lane 4	110	Low	10

Table 1 presents the experimental results of traffic density detection using ultrasonic sensors. The sensors measure the distance between vehicles and the signal pole to estimate traffic congestion in each lane. Smaller distance values indicate higher vehicle density. Based on the detected density level, the Raspberry Pi dynamically assigns different green signal durations. Lanes with higher vehicle density are given longer green signal time to improve traffic flow and reduce congestion.

Table 2: Emergency Vehicle Detection and Priority Control

Scenario	RFID Tag Detected	System Response	Signal Priority
Normal Traffic	No	Standard signal cycle	None
Ambulance Approaching	Yes	Immediate green signal	Lane 2
Fire Truck Approaching	Yes	Immediate green signal	Lane 3
Police Vehicle	Yes	Priority signal activated	Lane 1

Table 2 shows the results of emergency vehicle detection using the RFID reader module. When an emergency vehicle equipped with an RFID tag approaches the intersection, the RFID reader detects the tag and sends a signal to the Raspberry Pi controller. The system immediately overrides the normal traffic cycle and provides a green signal to the lane where the emergency vehicle is detected, ensuring faster and safer passage.

Table 3: System Performance Evaluation

Parameter	Measured Value
Vehicle Detection Accuracy	95%
RFID Detection Accuracy	98%
Signal Switching Response Time	< 1 second
Cloud Data Transmission Delay	2–3 seconds
System Reliability	96%

Table 3 summarizes the overall performance evaluation of the proposed system. The ultrasonic sensors achieved approximately 95% accuracy in detecting vehicle presence and estimating traffic density. The RFID module demonstrated high reliability in detecting emergency vehicle tags. The Raspberry Pi controller was able to switch traffic signals within one second after processing sensor data. Additionally, the traffic data was successfully transmitted to the ThingSpeak cloud platform with a delay of approximately 2–3 seconds, enabling near real-time monitoring.

Table 4: Comparison with Conventional Traffic Signal System

System Type	Signal Control Method	Emergency Priority	Traffic Adaptation
Conventional Traffic System	Fixed Timing	No	No
Proposed Smart Traffic System	Dynamic Timing	Yes	Yes

Table 4 compares the proposed smart traffic management system with conventional traffic signal systems. Traditional systems operate using fixed signal timing without considering real-time traffic conditions, which often leads to congestion. In contrast, the proposed system dynamically adjusts signal timing based on vehicle density and provides priority access to emergency vehicles, resulting in more efficient traffic management.

VII. Conclusion

In this paper, an IoT-based smart traffic management system with the help of Raspberry Pi for adaptive traffic control and emergency vehicle priority control was proposed. Experimental results showed that the system can effectively detect vehicle density with the help of ultrasonic sensors and control the traffic signals accordingly. Around 95% accuracy for vehicle detection and 98%

accuracy for emergency vehicle detection were achieved by the system with a faster signal control time of below one second. Moreover, the traffic information was successfully sent to the cloud platform ThingSpeak for analysis. Therefore, the proposed system can be effectively used for smart traffic management.

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