

Smart Signal Optimization System

Kalpesh Thakur

Computer Engineering

V.E.S Polytechnic [MSBTE]

Mumbai, India co2023.kalpesh.thakur@ves.ac.in

Sarthak Jedhe

Computer Engineering

V.E.S Polytechnic [MSBTE]

Mumbai, India co2024.sarthak.jedhe@ves.ac.in

Avnish Singh

Computer Engineering

V.E.S Polytechnic [MSBTE]

Mumbai, India co2024.avnish.singh@ves.ac.in

Mrs. Shubhra Tonge

Lecturer

V.E.S Polytechnic [MSBTE]

Mumbai, India shubhra.tonge@ves.ac.in

Abstract

Urban traffic congestion has become a major problem due to the rapid increase in vehicle density and inefficient traffic management systems. Traditional traffic signals operate on fixed timing cycles without considering the actual number of vehicles on each road, which results in unnecessary delays, fuel wastage, and increased pollution.

This project proposes a Smart Signal Optimization System using ESP32 and IR sensors to dynamically control traffic signals based on vehicle density. The system uses four IR sensors placed at four different lanes to detect vehicles waiting at the signal. The ESP32 microcontroller processes the sensor data and controls the traffic signals through red, yellow, and green LEDs.

The system counts the number of vehicles waiting in each lane and automatically gives priority to the lane with higher traffic density. If a lane exceeds a predefined vehicle count threshold, the system temporarily prioritizes that lane to reduce congestion. Additionally, the ESP32 WiFi capability allows the system to host a simple web dashboard that displays real-time traffic signal status and vehicle count.

This smart traffic management approach improves traffic flow efficiency, reduces waiting time, and supports the development of intelligent transportation systems in smart cities.

Keywords: Smart Traffic System, IR Sensor, ESP32, Traffic Signal Optimization, IoT Traffic Control.

1. INTRODUCTION

Traffic congestion has become one of the most critical problems in modern cities due to increasing vehicle ownership and urban population growth. Conventional traffic signals operate using fixed time intervals for red, yellow, and green lights. These fixed systems do not adapt to real-time traffic conditions, often causing unnecessary waiting times and inefficient traffic movement.

Smart traffic management systems aim to solve this problem by dynamically adjusting signal timings based on vehicle density. With the help of sensors and microcontrollers, real-time traffic data can be collected and used to optimize signal control.

In this project, a Smart Signal Optimization System using ESP32 and IR sensors is developed to improve traffic flow at intersections. Four IR sensors are used to detect vehicles in four different lanes. The ESP32 microcontroller processes the sensor data and automatically adjusts signal timings.

The system also includes a vehicle counting mechanism that detects how many vehicles are waiting in each lane. If a particular lane has a higher vehicle count than others, the system provides priority to that lane by switching the signal earlier. This helps in reducing congestion and improving road efficiency.

Furthermore, the ESP32 WiFi module enables a simple web-based dashboard where traffic authorities can monitor signal status and vehicle counts in real time.

This project demonstrates how embedded systems and IoT technologies can be used to develop intelligent traffic control system for smart cities.

2. LITERATURE REVIEW

Traditional traffic signal systems operate based on predetermined timing cycles that do not consider the real-time traffic density on roads. Several studies have shown that such systems result in inefficient traffic flow and increased waiting time at intersections.

Recent research in intelligent transportation systems focuses on using sensor-based traffic monitoring and adaptive signal control. Infrared sensors, cameras, and ultrasonic sensors are commonly used to detect vehicle presence and traffic density.

IoT-based traffic systems allow real-time data collection and remote monitoring through cloud platforms or web dashboards. These systems can dynamically adjust signal timings according to traffic conditions.

Many advanced traffic systems also integrate Artificial Intelligence and Machine Learning algorithms to analyze historical traffic data and predict congestion patterns. However, such systems often require expensive infrastructure such as cameras and large data processing systems.

The proposed system provides a simple and low-cost solution using IR sensors and ESP32 microcontroller. It detects vehicle density using IR sensors and adjusts signal timing automatically while also providing real-time monitoring through a web dashboard.

3. SYSTEM ARCHITECTURE

The system follows a layered client-server architecture to ensure modularity, maintainability, and scalability.

3.1 Sensing Layer

The sensing layer consists of four IR sensors placed in four traffic lanes. These sensors detect the presence of vehicles by sensing infrared reflections when a vehicle passes in front of the sensor.

Each sensor continuously monitors vehicle movement and sends signals to the ESP32 microcontroller. When a vehicle is detected, the system increments the vehicle count for that lane.

3.2 Processing Layer

The processing layer is handled by the ESP32 microcontroller. The ESP32 receives input signals from the IR sensors and processes them using a programmed algorithm.

The controller maintains a vehicle count for each lane and determines which lane should receive the green signal. If a lane exceeds the predefined vehicle threshold, the system temporarily prioritizes that lane to reduce congestion.

3.3 Control Layer

The control layer consists of traffic signal LEDs representing red, yellow, and green lights for each lane. The ESP32 controls these LEDs through GPIO pins to simulate the operation of traffic lights.

The signals operate according to the following sequence:

1. Green signal for the active lane
2. Yellow signal transition
3. Red signal before switching to the next lane

The system continuously repeats this cycle while adapting to vehicle density conditions.

4. HARDWARE COMPONENTS REQUIRED

Components	Quantity
ESP32 Microcontroller	1
Jumper cables	Required amount
IR Sensor	4
Red, Yellow and Green LED	Each 3
USB cable	1
Breadboard	Required amount
Resistor (220ohms)	12

5. Software Requirements

- Arduino IDE
- Web Browser (for viewing dashboard)

The Arduino IDE is used to program the ESP32 microcontroller using C/C++ language.

6. BLOCK DIAGRAM

The smart traffic management system block diagram below illustrates the complete system architecture. Understanding the block diagram below is crucial for implementing this IoT-based traffic management system.

The smart traffic management system diagram demonstrates how four IR sensors connect to the ESP32 microcontroller’s GPIO pins. For the four lanes, a set of red, yellow, and green LEDs is used for each lane to indicate the traffic signal status. The system is powered through a suitable power supply connected to the ESP32. Additionally, the web dashboard is connected via the ESP32’s Wi-Fi network, allowing real-time monitoring and control.

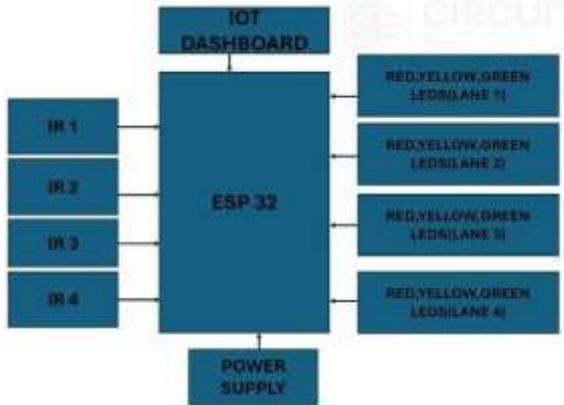


Fig: Block Diagram

7. CIRCUIT DIAGRAM

The detailed circuit diagram below shows the complete wiring schematic for this IoT-based traffic light controller:

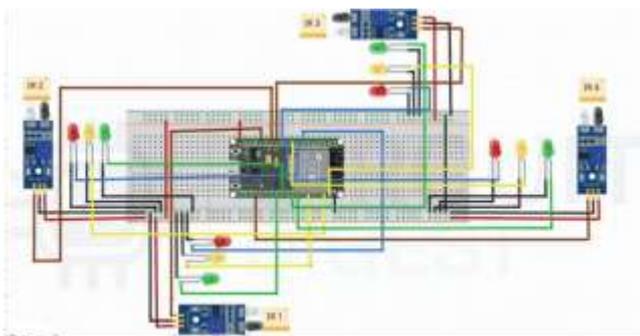


Fig: Circuit Diagram

The IoT-based traffic management system circuit diagram illustrates a Smart Traffic Management System using an ESP32. Four IR sensors (IR1–IR4) are connected to the ESP32 to detect vehicles in four lanes. Each lane has a set of Red, Yellow, and Green LEDs controlled by the ESP32 to manage traffic signals. A 5V regulated power supply powers all components, with a common ground connection. The ESP32’s Wi-Fi feature enables the system to connect to a dashboard for real-time monitoring and control. This setup ensures efficient traffic flow by adjusting signal timing based on vehicle density.

The hardware assembly photo above demonstrates the practical implementation of our IoT-based traffic management system project on a breadboard.

8. PIN CONNECTION TABLE

Components	Connection to ESP32
IR 1	13
IR 2	12
IR 3	14
IR 4	15
RED LED(LANE 1)	32
YELLOW LED	21
GREEN LED	16
RED LED (LANE 2)	33
YELLOW LED	22
GREEN LED	17
RED LED(LANE 3)	27
YELLOW LED	23
GREEN LED	18
RED LED(LANE 4)	26
YELLOW LED	25
GREEN LED	19

9. WORKING OF THE SYSTEM

The system operates by continuously monitoring vehicle presence through IR sensors. When a vehicle is detected in front of an IR sensor, the ESP32 increments the vehicle count for that lane.

If the traffic signal for a lane is red, the system continues counting vehicles waiting at that lane. Once the signal cycle changes, the lane with higher vehicle density can be prioritized.

The ESP32 controls the traffic lights using programmed timing sequences for green, yellow, and red signals. When a lane receives a green signal, its vehicle counter resets.

In the WiFi-enabled version, the ESP32 hosts a web page that displays real-time traffic signal status and vehicle counts for all lanes.

10. ADVANTAGES

- Reduces traffic congestion
- Improves traffic flow efficiency
- Low-cost implementation
- Automatic traffic management
- Real-time monitoring through web dashboard

11. LIMITATIONS

- Sensor accuracy may be affected by environmental conditions
- Requires reliable power supply
- Limited scalability without additional infrastructure

12. CONCLUSION

The Smart Signal Optimization System demonstrates how embedded systems and IoT technologies can improve traffic management efficiency. By using IR sensors to detect vehicle density and ESP32 to control signal timing, the system provides a dynamic traffic control mechanism.

The system reduces unnecessary waiting time and improves road utilization. The integration of WiFi connectivity further enables real-time monitoring through a web dashboard.

This project represents a practical step toward intelligent traffic systems that can be implemented in future smart city environments.

REFERENCES:

- [1] "Intelligent Traffic Light Control System using IoT," IEEE Xplore.
- [2] S. Sharma et al., "Smart Traffic Management System using IoT and Machine Learning," Springer, 2021.
- [3] Government of India, "Smart Cities Mission Report," 2023.
- [4] Circuit Digest, "Smart Traffic Management System using IoT," Available online.
- [5] Espressif Systems, "ESP32 Technical Reference Manual," 2023.
- [6] Arduino, "Arduino IDE Documentation," 2024.
- [7] K. P. Valavanis, "Intelligent Transportation Systems," Springer, 2018.