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Smart traffic signal control system

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Abstract — Rapid urbanization and the continuous increase in vehicular traffic have made conventional traffic signal systems inefficient, leading to congestion, increased travel time, and higher fuel consumption. Traditional fixed-timing traffic lights fail to adapt to real-time traffic conditions, resulting in unnecessary delays even when certain lanes have minimal or no traffic.This project proposes a Sub-Smart Traffic Signal Control System, an intelligent yet cost-effective solution designed to optimize traffic flow using real-time data. The system utilizes sensors such as infrared (IR), ultrasonic, or camera-based modules to detect vehicle density on different lanes. Based on the collected data, the signal timing is dynamically adjusted, giving priority to lanes with higher traffic density while reducing idle time for less congested routes.Additionally, the system can be extended to include emergency vehicle detection, enabling automatic signal clearance for ambulances and fire services. The proposed solution aims to minimize traffic congestion, reduce fuel wastage, and improve overall road efficiency without the high infrastructure costs associated with fully smart traffic systems.The implementation demonstrates how a semi-automated ("sub-smart") approach can significantly enhance traffic management in developing urban areas, making it a practical and scalable solution for modern cities.

Keywords — Traffic Signal Control, RFID, Traffic Density Detection, Smart Traffic System, Emergency Vehicle Priority, Embedded Systems, IoT

I. INTRODUCTION

In recent years, traffic congestion has emerged as a serious problem in both urban and semi-urban areas. The rapid growth in population, coupled with a significant increase in the number of vehicles, has put immense pressure on existing road infrastructure. As a result, roads frequently experience heavy traffic, long queues at intersections, and delays during peak hours. These issues not only waste time but also lead to increased fuel consumption, air pollution, and driver frustration.Most of the currently used traffic signal systems are based on fixed time intervals. In such systems, each signal is programmed with a predefined time duration for red, yellow, and green lights, regardless of the actual traffic density on each road. Considering these challenges, there is a need for a solution that balances efficiency and cost.

The Sub-Smart Traffic Signal Control System is designed to fulfill this requirement. It acts as a bridge between conventional fixed-time systems and fully automated smart systems. The term "sub-smart" refers to a semi-intelligent system that incorporates basic automation and real-time decision-making without relying on highly complex or costly technologies.In this proposed system, traffic density is monitored using simple and affordable sensors such as infrared (IR) sensors, ultrasonic sensors, or camera modules. These sensors are placed on each lane to detect the presence and number of vehicles. The collected data is then processed by a micro-controller (such as Arduino, Raspberry Pi, or similar platforms), which determines the traffic load on each lane.Based on this real-time data, the system dynamically adjusts the duration of green signals. Lanes with higher vehicle density are given longer green signal times, while less congested lanes receive shorter adjurations. This adaptive mechanism ensures better utilization of road space and reduces unnecessary waiting time. Additionally, the system can be enhanced with features such as emergency vehicle detection, where signals automatically change to allow ambulances or fire trucks to pass without delay.The main goal of this project is to design a system that is cost-effective, easy to implement, and scalable for real-world applications. By improving traffic flow and reducing congestion, the Sub-Smart Traffic Signal Control System contributes to saving time, reducing fuel consumption, lowering emissions, and enhancing overall road safety.In conclusion, this project demonstrates how a semi-automated approach can significantly improve traditional traffic systems while remaining practical and affordable, especially for developing regions.

II. LITERATURE SURVEY

1. Title: OPAC - A Demand-Responsive Strategy for Traffic Signal Control
Author: Gartner N. H.
Description

Gartner proposed the OPAC (Optimized Policies for Adaptive Control) system, which is the earliest adaptive traffic control strategies. This method dynamically adjusts signal timings based on real-time traffic demand using mathematical optimization techniques. The study demonstrated significant reduction in vehicle delays and waiting time the system requires complex computations and is difficult to implement in low-cost.

2. Title: Review of Road Traffic Control Strategies

Author: Papageorgiou M.

Description

Papageorgiou provided a comprehensive review of traffic control strategies. The study compares three major types of systems:
1.Fixed-time systems
2.Actuated systems (sensor-based)
3.Adaptive systems (real-time control)
The research clearly shows that adaptive systems perform better because they respond to real-time traffic conditions. However, they require advanced infrastructure such as sensors, communication networks, and centralized control systems.
This study is important because it establishes that while intelligent systems are efficient, they may not always be practical due to high cost and complexity.

3. Title: Adaptive Traffic Light Control System Using Artificial Intelligence

Author: .Khamis M. A.

Description

Khamis proposed a traffic signal control system based on Artificial Intelligence. The system uses algorithms to analyze traffic conditions and make decisions about signal timing.The key feature of this system is its ability to "learn" from traffic patterns and improve over time. It can prioritize lanes with higher traffic density and reduce congestion effectively.
However, the limitation is that AI-based systems require powerful processors, large datasets, and continuous training. This increases both cost and system complexity, making it difficult to implement in real-world conditions without strong infrastructure.

4. Title: Multi-Agent Reinforcement Learning for Traffic Light Control.

Author: Wiering M.

Description

Wiering introduced the concept of Multi-Agent Reinforcement Learning (MARL) for traffic control. In this approach:
Each traffic signal acts as an "agent" Agents learn from their environment using trial-and-error
The system improves its performance over time
This method is highly effective in handling dynamic and unpredictable traffic conditions. It can adapt automatically without human intervention.
However, the major challenges include:
1.Long training time
2.Need for simulation environments
3.Difficulty in real-world implementation

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assigned to corresponding edges of traffic network graph. The Dijkstra algorithm is introduced to achieve the solution of the model built in this paper. Finally, a supposed traffic network is used to conduct a simulation, and the results show that the proposed optimization model of reserving charging for electric vehicles can satisfy users' different demands.

System Design and Block Diagram:

1. **Input Section**

The input section consists of:
IR Sensors placed on each lane to detect vehicle density
RFID Module to detect ambulances equipped with RFID tags
The IR sensors continuously monitor traffic and send signals based on vehicle presence, while the RFID reader detects emergency vehicles approaching the intersection.

2. **Processing Section**

At the core of the system is the ESP32 microcontroller, which acts as the brain of the system.
It receives input from IR sensors and RFID module
It analyzes traffic density on each lane
It makes decisions based on programmed logic
If normal traffic is detected, the controller selects the lane with the highest density and assigns a longer green signal time.
If an ambulance is detected, the system immediately overrides normal operation and gives priority to that lane.

3. **Output Section**

The output section includes:
Traffic Signal LEDs (Red, Yellow, Green)
LCD Display for status monitoring
The LED s indicate signal changes, while the LCD displays information such as active lane and emergency detection status.
Working Summary
Under normal conditions, signals are controlled based on traffic density In emergency conditions, RFID detection ensures instant

Working Principle -

1. Traffic Density Detection

Traffic density detection is the primary function of the system.

- ✧ IR sensors are installed on each lane at the intersection.
- ✧ These sensors emit infrared rays and detect reflected signals when a vehicle is present.
- ✧ When a vehicle passes or stops near the sensor, it generates a digital signal (HIGH/LOW).

How it works:

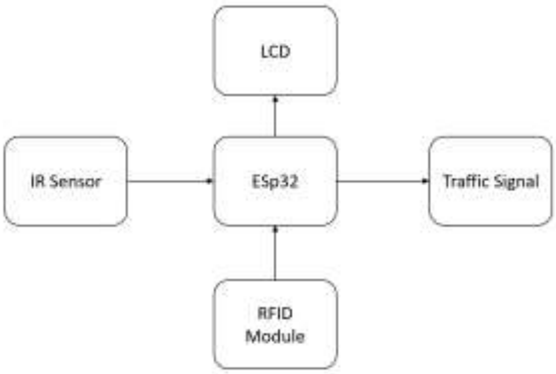
- ✧ Each lane has multiple IR sensors placed at fixed distances. When vehicles occupy a lane, more sensors get activated.
- ✧ The ESP32 reads the number of active sensors from each lane.
- ✧ Based on this input, it calculates the traffic density level (low, medium, high).

Decision Making:

- ✧ The controller compares density across all lanes.
- ✧ The lane with the highest number of vehicles is given priority.
- ✧ That lane receives a longer green signal duration.
- ✧ Lanes with fewer vehicles receive shorter green time.

Result:

Reduces waiting time
Prevents unnecessary signal delays
Improves traffic flow efficiency.



2.Ambulance Detection (Priority Control System)

This is an important feature designed for emergency handling.

- ✧ Each ambulance is fitted with an RFID tag.

An RFID reader is placed near the traffic signal junction.

How it works:

When an ambulance approaches the signal, the RFID reader scans for nearby tags.
If a valid RFID tag is detected:

- ✧ The reader sends a signal to the ESP32
- ✧ The microcontroller immediately recognizes it as an emergency condition

System Response:

Normal traffic operation is temporarily stopped

- ✧ All other lanes are switched to RED signal
- ✧ The ambulance lane is given instant GREEN signal

After Ambulance Passes:
The system waits until the ambulance clears the junction
Then it returns to normal density-based operation

Result:

Faster emergency response
Reduces risk to life
Eliminates dependency on manual traffic control .

3. Signal Control Mechanism

The output of the system is controlled using LED traffic lights.

Signal Representation:

- ✧ Red LED → Stop
- ✧ Yellow LED → Prepare/Wait
- ✧ Green LED → Go

Control Logic:

The ESP32 controls LEDs through its GPIO pins
It switches signals based on:

- ✧ Traffic density data
- ✧ Emergency detection

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Operation Flow:

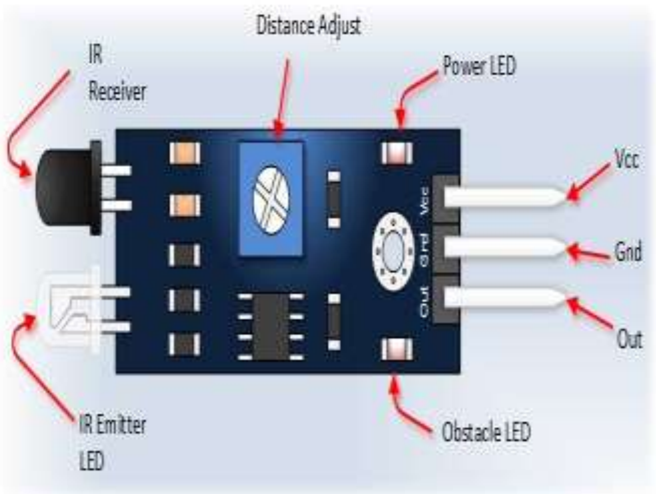
1. Green signal is given to selected lane .
2. Other lanes remain in red
3. Before switching, yellow signal is activated for safety

Then next lane gets green signal

Key Feature:
Smooth transition between signals
Prevents accidents at intersections

4. Overall System Operation
Normal Mode:

IR sensors detect traffic
ESP32 calculates density
Signals are adjusted dynamically
Emergency Mode:
RFID detects ambulance

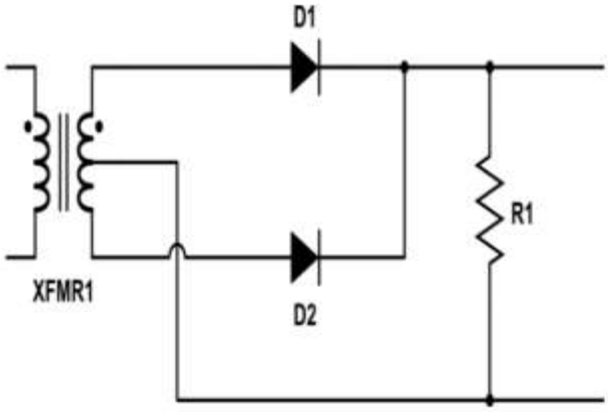


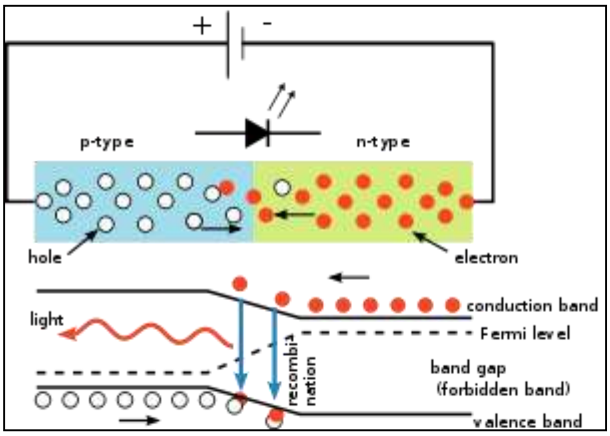
System overrides normal logic
Instant green signal for ambulance lane

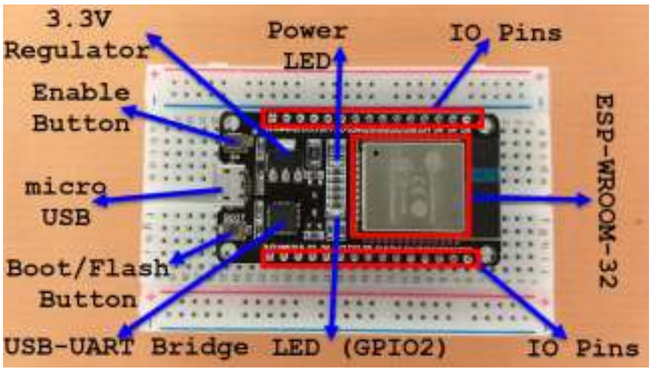
Automatic Control:
No human intervention required
Fully automated decision-making

5. Advantages of This Working System
Real-time traffic control

1.Reduced congestion and waiting time
2.Fuel saving and pollution reduction
3.Emergency vehicle prioritization
4.Low-cost and scalable.
5.Adaptive signal control based on real-time data.
6.Automatic clearance for emergency vehicles.
7.Reduction in congestion and pollution.
8.Low cost and scalable for urban areas.
9.Can be integrated with IoT for future expansion.







FUTURE SCOPE

The proposed Sub-Smart Traffic Signal Control System provides a strong foundation for intelligent traffic management; however, it can be further enhanced with the integration of advanced technologies and modern communication systems. In the future, the system can be upgraded by incorporating Internet of Things (IoT) capabilities using controllers like the ESP32, enabling real-time data transmission to a centralized server. This would allow traffic authorities to monitor and control multiple intersections remotely, improving overall traffic coordination. Additionally, the implementation of Artificial Intelligence (AI) and Machine Learning algorithms can significantly enhance system performance by enabling predictive analysis of traffic patterns. The system can learn from historical data and adjust signal timings more efficiently, reducing congestion during peak hours.Another major improvement can be achieved by replacing IR sensors with camera-based image processing systems. This would provide more accurate vehicle detection, lane monitoring, and even identification of traffic violations such as signal jumping. Integration of GPS technology in emergency vehicles can further improve ambulance prioritization by creating a “green corridor” across multiple signals, ensuring faster response times during critical situations. The system can also be extended to support Vehicle-to-Infrastructure (V2I) communication, where vehicles can directly communicate with traffic signals to share real-time information such as speed and position, enabling smarter decision-making.Furthermore, the development of a centralized allow synchronization of multiple junctions, leading to smoother traffic flow across entire city networks. Mobile application integration can also be introduced to provide real-time traffic updates, congestion alerts, and alternative route suggestions to users. From an energy perspective, the system can be powered using renewable energy sources such as solar panels, making it more sustainable and cost-effective. Cloud computing can also be utilized to store and analyze large volumes of traffic data for better planning and optimization.

CONCLUSIONS

The Sub-Smart Traffic Signal Control System with RFID-based Ambulance Detection presents an effective and practical solution to the growing problem of traffic congestion in urban areas. Traditional traffic signal systems operate on fixed time intervals, which often lead to inefficient traffic management and unnecessary delays. The proposed system overcomes these limitations by introducing a dynamic and automated approach based on real-time traffic conditions.In this project, traffic density is monitored using IR sensors installed on each lane. These sensors provide continuous input to the central controller, which is implemented using the ESP32 microcontroller. Based on the data received, the system intelligently allocates green signal time to the lane with the highest vehicle density. This ensures optimal utilization of road space and significantly reduces waiting time at intersections.

A key feature of this system is the integration of RFID technology for ambulance detection. Emergency vehicles equipped with RFID tags are identified by the RFID reader at the junction. Upon detection, the system immediately overrides normal operation and provides a green signal to the ambulance lane, ensuring quick and safe passage. This feature plays a crucial role in improving emergency response time and can potentially save lives.The system operates automatically without the need for manual intervention, making it more reliable and less prone to human error. The use of LEDs for signal indication and LCD for monitoring enhances the usability and effectiveness of the system. Additionally, the design is cost-effective and scalable, making it suitable for implementation in developing regions and small cities.

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