Development of Adaptive Traffic Signal Control System for Pune City

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***Abstract*—Traffic congestion has become a major challenge in urban transportation systems due to the increasing number of vehicles and inefficient fixed-time traffic signal operations. Conventional traffic signals provide equal signal durations irrespective of traffic density, resulting in unnecessary delays and increased fuel consumption. This paper presents an adaptive smart traffic signal control system based on ESP32 microcontrollers and infrared (IR) sensors for real-time traffic density monitoring. The proposed system dynamically allocates signal timings according to vehicle density at multiple junctions. Two master ESP32 controllers process the sensor data and determine appropriate signal durations to improve traffic flow efficiency. Experimental analysis demonstrates that the proposed system reduces waiting time and congestion while providing better utilization of road infrastructure. The system offers a low-cost and scalable solution for intelligent transportation and smart city applications.**

***Index Terms*—Smart Traffic System, ESP32, Infrared Sensors, Intelligent Transportation System, Adaptive Traffic Control, IoT.**

I. Introduction

Rapid urbanization and increasing vehicle populations have led to severe traffic congestion in metropolitan areas. Conventional traffic signal systems generally operate with fixed timing sequences that do not adapt to changing traffic conditions. As a result, roads with lower traffic density receive the same signal duration as highly congested roads, causing unnecessary delays and inefficient traffic movement.

Recent developments in intelligent transportation systems have enabled the implementation of adaptive traffic management techniques. IoT-based traffic systems provide real-time monitoring and dynamic signal control, thereby improving traffic flow and reducing congestion.

This paper proposes an adaptive smart traffic signal control system using ESP32 microcontrollers and IR sensors. The system continuously monitors vehicle density at two junctions and allocates signal timings dynamically according to traffic conditions. The proposed approach aims to minimize waiting time, improve traffic throughput, and provide an economical solution for urban traffic management.

II. Literature Survey

Several traffic management techniques have been developed to overcome the limitations of conventional fixed-time traffic signals. Camera-based systems provide accurate vehicle detection but require significant computational resources and are affected by environmental conditions. Sensor-based systems using ultrasonic and infrared sensors have emerged as cost-effective alternatives for traffic density estimation.

IoT-enabled traffic control systems have gained considerable attention due to their ability to provide real-time monitoring and intelligent decision-making. ESP32-based systems offer wireless connectivity, low power consumption, and efficient processing capabilities, making them suitable for smart traffic applications.

Despite these advancements, many existing systems are expensive and difficult to implement on a large scale. Therefore, a simple and economical adaptive traffic control system is required.

III. Proposed Methodology

The proposed system consists of two junctions equipped with infrared sensors and ESP32 microcontrollers. Multiple IR sensors are installed along the lanes to detect the presence of vehicles. Sensor data are continuously monitored by the master ESP32 controller, which determines the traffic density at each junction.

Based on the detected traffic conditions, the controller dynamically allocates green signal durations. Junctions experiencing higher traffic density are given higher priority, thereby reducing congestion and improving vehicle movement. LEDs are used to represent traffic signals, and the entire system is designed to operate efficiently with minimum hardware requirements.

The major contribution of the proposed work is the development of a low-cost and scalable adaptive traffic signal control system for urban intersections. The system employs ESP32 microcontrollers and infrared sensors to acquire real-time traffic density information and dynamically allocate signal timings according to traffic demand. A Master–Slave architecture based on the ESP-NOW communication protocol enables synchronization between adjacent traffic junctions, thereby improving traffic flow continuity and reducing unnecessary delays. The integration of the Blynk IoT platform provides real-time monitoring, remote supervision, and data visualization capabilities. Additionally, the proposed framework incorporates traffic engineering principles such as Peak Hour Factor analysis and Webster's optimization method to improve signal timing efficiency. The overall architecture offers a practical solution for intelligent traffic management and can be extended to larger smart city transportation networks.

IV. System Design

Initially, the IR sensors detect the presence of vehicles at each lane. The corresponding traffic density information is transmitted to the master ESP32 controller. The controller compares the traffic conditions of both junctions and determines which junction requires priority.

The signal timing is then adjusted dynamically according to the detected traffic density. Once the allocated signal duration is completed, the system switches to the next junction and continuously repeats the process. This adaptive mechanism helps in reducing unnecessary waiting time and improving traffic efficiency.

As per case study of central pune and roads it has in busy areas we have built general arrangement of signals and sensors along with measurements as prototype scale which further can be implemented in real world model. As per case study of Central Pune we have consider road of 10 meter wide for our model with planting sensor at 5 meter distance at each lane of road. Distance between both junction is about 50 meter. According to road we have 7 meter signal height which will aceesible for everyone to follow signal.

V. Results and Discussion

Based on real-time traffic density sensed by infrared sensors at two interconnected junctions, the experimental findings demonstrate how well the suggested system adjusts green signal durations. In order to improve overall traffic flow, lanes with higher traffic density were given longer green times, while lanes with lesser traffic were given shorter green durations. The Master–Slave ESP32 setup and ESP-NOW communication were successfully used to synchronize the two junctions, guaranteeing coordinated signal operation and removing conflicting green signals. Smoother vehicle circulation between intersections and fewer stop-and-go delays were made possible by the synchronized operation.

The suggested adaptive and synchronized strategy greatly decreased waiting times, enhanced overall traffic management efficiency under various traffic situations, and improved traffic continuity between intersections when compared to traditional fixed-time traffic signal systems. Real-time traffic condition display was made possible by cloud-based monitoring, which made the system appropriate for smart city applications.

For our model we have to operate it remotely from control room so we are using Blynk dashboard where we can have real time status of all signal model and here it become accessible to check which lane is more dense as per requirement we able to change signal time of that lane.

Here we design small prototype model for 2 Junction of traffic signal which are togetherly co-ordinated and also sensor on each lane considering ideally 4 lane for each signal. The experimental results demonstrate the effectiveness of the proposed adaptive traffic signal control system under varying traffic conditions. Traffic density information collected through infrared sensors was processed in real time by the ESP32-based control unit, enabling dynamic adjustment of signal timings according to traffic demand. Lanes with higher vehicle density were allocated longer green signal durations, while lanes with lower traffic density received shorter green durations, resulting in improved utilization of available road capacity. The implementation of ESP-NOW communication successfully established synchronization between two adjacent traffic junctions and prevented conflicting signal operations.

VI. Conclusion and Future Scope

Paper presents an adaptive smart traffic signal control system based on ESP32 and infrared sensors for real-time traffic density monitoring. Unlike conventional fixed-time traffic signals, the proposed system dynamically allocates signal durations according to traffic conditions, thereby reducing congestion and improving traffic flow efficiency. The developed system offers a cost-effective, reliable, and scalable solution for intelligent transportation systems and smart city applications. Future enhancements can further improve system performance by incorporating advanced technologies such as artificial intelligence and cloud connectivity.

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