Adaptive IoT-Based Traffic Signal Control Using Micro-congestion detection

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Abstract

Traffic congestion is a major issue in urban areas due to the increasing number of vehicles and inefficient fixed-timer traffic signal systems. This paper proposes an Adaptive IoT Based Traffic Signal Control System using Micro-Congestion Detection to improve traffic management efficiency. The system utilizes six Infrared (IR) sensors, with three sensors installed on each road, to detect real-time vehicle density. A microcontroller such as ESP32 or Arduino processes sensor data and dynamically adjusts the green signal duration based on congestion levels. Traffic data is transmitted to the ThingSpeak cloud platform via Wi-Fi for real-time monitoring and analysis. Additionally, manual signal override is enabled using the Blynk mobile application during emergency situations. The proposed system reduces waiting time, optimizes traffic flow, minimizes fuel consumption, decreases air pollution, and enhances road safety. This intelligent approach contributes significantly toward smart city infrastructure development.

***Key Words*:** IoT, Traffic Signal Control, IR Sensor, Microcontroller, ThingSpeak, Blynk.

1. INTRODUCTION

The rapid growth of the internet has significantly transformed communication, business, and information access. Email remains one of the most widely used digital communication tools, with billions of active users and massive daily message exchanges, demonstrating its continued importance in personal and professional interactions. However, accessing email services remains challenging for individuals with visual impairments. Most email platforms rely on graphical user interfaces that require visual perception and manual input. Although assistive technologies such as screen readers provide partial support, they often demand memorization of keyboard shortcuts and complex navigation patterns, increasing cognitive effort and reducing usability. As a result, many visually impaired individuals rely on third-party assistance to manage emails, which compromises privacy and limits independence. To overcome these challenges, the proposed Voice-Based Email System offers a fully speech-driven interface that allows users to send, receive, and manage emails using voice commands alone. By integrating Speech-to-Text (STT) and Text-to-Speech (TTS) technologies with standard email protocols, the system eliminates the need for visual interaction and keyboard usage, enabling secure, independent, and efficient digital communication for visually impaired users.

2. EXISTING SYSTEM

Most existing traffic signal systems operate on a fixed timer-based mechanism with predefined intervals for red, yellow, and green signals. These timings remain constant and do not adjust according to real-time vehicle density at the intersection. As a result, the green signal duration does not change even when traffic conditions vary, highlighting the need for an adaptive IoT-based traffic control system like our project.

Disadvantages:

- Fixed signal timing without considering real-time traffic density
- Increased waiting time on highly congested roads
- Unnecessary green signal duration for less crowded roads
- Higher fuel consumption due to long idling periods
- Increased air pollution and carbon emissions
- No real-time traffic monitoring or data analytics

3. PROPOSED SYSTEM

The proposed Adaptive IoT Based Traffic Signal Control System provides an intelligent, congestion-aware traffic management solution. The system dynamically adjusts signal timing based on real-time vehicle density, eliminating the limitations of fixed-timer control.

- Utilizes Infrared (IR) sensors to detect real-time vehicle density on each road.
- Employs a Microcontroller Unit (MCU) to analyze congestion levels and automatically adjust green signal duration.
- Prioritizes the lane with higher traffic density to reduce waiting time and improve flow efficiency.
- Integrates Internet of Things (IoT) technology to transmit traffic data to the ThingSpeak cloud platform via Wi-Fi.

4. SYSTEM ARCHITECTURE

The proposed Adaptive IoT Based Traffic Signal Control System follows a modular and intelligent architecture designed to monitor real-time traffic density and dynamically control signal operations. The workflow begins with vehicle detection using Infrared (IR) sensors installed at the traffic junction. Three sensors are placed on each road to measure congestion levels accurately. The sensor data is processed by the Microcontroller Unit (MCU), which analyzes traffic density and dynamically adjusts the green signal duration to prioritize the congested lane. The traffic lights are automatically controlled by the MCU, while an I2C LCD displays real-time traffic status and countdown information. Traffic data is transmitted via Wi-Fi to the ThingSpeak cloud platform for monitoring and analysis, and a Blynk-based manual override feature allows emergency control. This architecture ensures adaptive and efficient traffic management.

Algorithm:

A. Traffic Density Detection

The The system begins by continuously monitoring vehicle presence using six Infrared (IR) sensors installed at the junction. Three sensors are placed on each road to detect congestion levels. When a vehicle interrupts the IR beam, the sensor generates a digital signal. The Microcontroller Unit (MCU) reads the sensor inputs and counts the number of active sensors on each road. Based on the count, traffic density is categorized as low, medium, or high.

B. Congestion Analysis and Decision Making

After collecting sensor data, the MCU compares congestion levels between both roads. If one road has a higher number of triggered sensors, it is identified as the high-density lane.The controller then calculates the appropriate green signal duration dynamically. If both roads have equal congestion, a predefined timer logic is applied to ensure fairness and balanced traffic flow.

C. Adaptive Signal Control

Based on the decision-making process, the MCU activates the Traffic Signal Control Module. The green signal is extended for the lane with higher congestion, while the opposite lane remains in the red state. If traffic density decreases, the system automatically reduces green signal duration to optimize overall intersection efficiency. This adaptive switching minimizes unnecessary waiting time and improves traffic flow.

D. IoT Data Transmission and Monitoring

Once signal decisions are executed, traffic data such as vehicle density levels and signal timing duration are transmitted via Wi-Fi to the ThingSpeak cloud platform.The cloud system stores real-time data and generates graphical representations for monitoring and analysis. This enables traffic authorities to observe congestion patterns and make data-driven decisions for long-term planning.

E. Manual Override Mechanism

The Manual Override Module allows authorized users to control traffic signals through the Blynk mobile application. In emergency situations such as ambulance movement or VIP convoy clearance, the automatic logic can be temporarily overridden. The selected lane is immediately granted green signal priority, ensuring faster response during critical conditions.

F. Display and System Feedback

The I2C Liquid Crystal Display (LCD) continuously updates real-time information, including traffic density level, active green signal lane, countdown timer, and system mode (Automatic/Manual).This visual feedback ensures transparency, simplifies monitoring at the junction, and assists during system testing and maintenance.

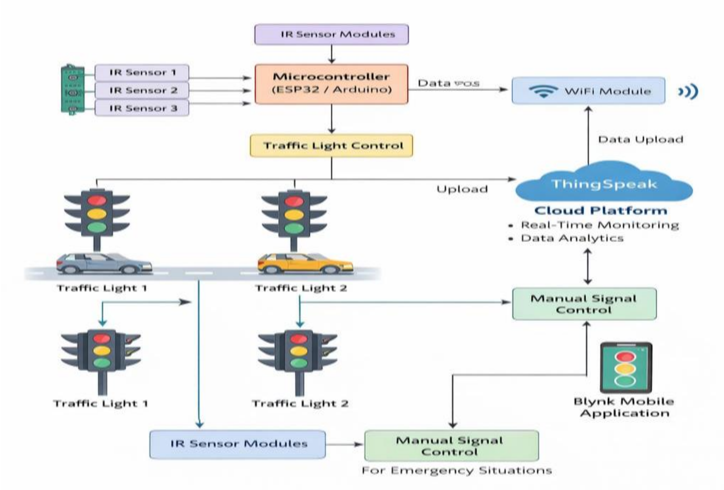

Figure -1: System Architecture

DATAFLOW DIAGRAM

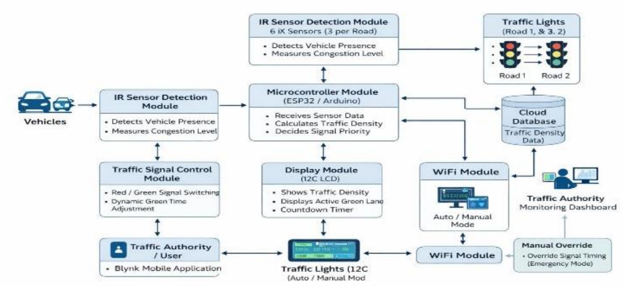

Figure -2 : Dataflow digram

RESULT AND DISCUSSION

A. Hardware and Software Components Utilized

The proposed system integrates both hardware and software components to achieve adaptive traffic control. The hardware setup includes Infrared (IR) sensors for vehicle detection, a Microcontroller Unit (MCU) such as ESP32 or Arduino for processing, traffic signal LEDs, an Inter-Integrated Circuit Liquid Crystal Display (I2C LCD) for output display, and a Wi-Fi module for IoT connectivity. On the software side, embedded C/C++ programming is used for microcontroller logic implementation. The ThingSpeak cloud platform is used for real-time data visualization and storage, while the Blynk mobile application enables manual override functionality.

B. Real-Time Traffic Density Detection– Proposed Approach

The IR sensors successfully detect vehicle presence by sensing beam interruption. The system continuously monitors sensor activation and categorizes traffic density as low, medium, or high based on the number of triggered sensors. Experimental testing shows that the sensors respond accurately under normal lighting conditions and effectively detect vehicle movement at the junction. This real-time detection forms the basis for adaptive signal timing.

C. Adaptive Signal Timing Performance

The microcontroller dynamically adjusts green signal duration according to congestion levels. During testing, the lane with higher vehicle density consistently received extended green time, reducing waiting periods significantly compared to fixed-timer systems. When both lanes had similar traffic conditions, the system followed predefined timer logic to maintain fairness. This adaptive mechanism improved traffic flow efficiency and minimized unnecessary delays.

D. IoT Cloud Monitoring Results

Traffic data, including vehicle density levels and signal timing duration, was successfully transmitted to the ThingSpeak cloud platform via Wi-Fi. The platform displayed real-time graphs representing traffic patterns at the junction. Historical data analysis showed clear peak-hour congestion trends, demonstrating the system's capability for long-term traffic monitoring and smart planning applications.

E. Manual Override Performance

The Manual Override Module, implemented using the Blynk application, functioned effectively during simulated emergency scenarios. When activated, the selected lane immediately received green signal priority. This feature ensures faster emergency response and enhances road safety by combining automation with human intervention.

F. Overall System Performance Analysis

The proposed system demonstrated improved traffic management efficiency compared to traditional fixed-time models. Key observed improvements include:

* Reduced average vehicle waiting time
* Smoother traffic flow during peak hours
* Lower fuel consumption due to minimized idling
* Decreased air pollution levels
* Reliable real-time cloud monitoring

The system operated efficiently using standard hardware components and maintained stable Wi-Fi connectivity for IoT data transmission. Overall, the results confirm that the Adaptive IoT Based Traffic Signal Control System provides a practical, scalable, and intelligent solution for modern urban traffic management.

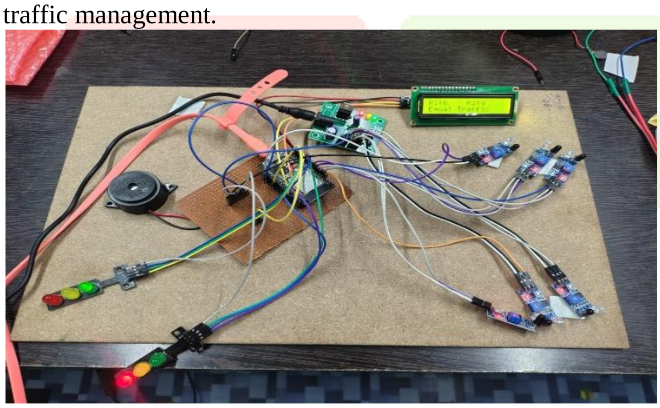

Figure -3:

The hardware setup shows IR sensors installed on both roads, connected to the microcontroller and traffic signal module.

3. CONCLUSION

The Adaptive IoT Based Traffic Signal Control System using Micro-Congestion Detection provides an intelligent and dynamic solution to modern traffic management challenges. By eliminating dependency on fixed-timer mechanisms and incorporating real-time vehicle density detection through IR sensors, the system ensures efficient and responsive signal control. The integration of a Microcontroller Unit (MCU), IoT cloud monitoring via ThingSpeak, and manual override functionality using the Blynk application enhances system flexibility, reliability, and smart connectivity. The adaptive signal timing mechanism reduces traffic congestion, minimizes waiting time, lowers fuel consumption, and decreases air pollution levels. The proposed architecture demonstrates how IoT technology combined with real-time sensing and automated decision-making can significantly improve urban traffic efficiency and contribute to the development of smart and sustainable city infrastructure.

FUTURE ENHANCEMENT

The proposed system can be further improved by The proposed Adaptive IoT Based Traffic Signal Control System can be further enhanced by integrating Artificial Intelligence (AI) and Machine Learning (ML) algorithms for predictive traffic analysis. Instead of relying only on IR sensors, future versions can incorporate camera-based vehicle detection using computer vision techniques. This would allow accurate vehicle counting, classification, and movement tracking. The system can also be expanded to manage multiple intersections through centralized cloud coordination. Integration with GPS-based emergency vehicle tracking can enable automatic signal priority without manual intervention. Advanced data analytics can be applied to historical cloud data to predict peak traffic hours and optimize signal timing proactively. The use of solar-powered modules can improve energy efficiency and sustainability. Enhanced cybersecurity mechanisms can be implemented to protect IoT communication from unauthorized access. Future upgrades may include a dedicated mobile dashboard for traffic authorities to monitor and control multiple junctions in real time. Vehicle-to-Infrastructure (V2I) communication can also be introduced for smarter traffic interaction. These enhancements would make the system more scalable, intelligent, secure, and suitable for large-scale smart city deployment.

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