

DESIGN AND DEPLOYMENT OF INTELLIGENT TRAFFIC SYSTEM USING EDGE AI

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ABSTRACT: The increasing complexity of urban transportation networks and limitations of traditional fixed-cycle traffic control systems lead to excessive congestion, fuel wastage, and delays during emergencies. To overcome these challenges, this project titled “Design and Deployment of Intelligent Traffic System Using Edge AI” introduces a decentralized and fully automated adaptive traffic management architecture. The system leverages Edge Artificial Intelligence for rapid on-device video analytic using Conventional Neural Networks (CNN), enabling real-time detection of vehicles, lane-wise traffic density estimation, and intelligent dynamic adjustment of traffic signal timings based on actual road conditions instead of Predefined cycles. By deploying lightweight deep learning models such as Tiny- YOLO/SSD-MobileNet. directly on edge hardware (e.g., NVIDIA Jetson Nano, ESP32-CAM), data processing remains local, thereby reducing communication latency, enhancing response time, and significantly lowering cloud dependency. The system incorporates advanced techniques including frame , motion analysis, and object classification to ensure high-accuracy detection even under varying illumination and weather conditions. Additionally, GPS integration and IoT communication through Protocols facilitate continuous monitoring, system health feedback, and data logging for further optimization and analytics.

A major focus of the system is the support for public safety and emergency vehicle prioritization. The design includes siren-based acoustic pattern detection and image-based ambulance recognition to automatically generate a “Green Corridor,” ensuring the uninterrupted movement of emergency services through congested intersections. Moreover, the platform implements accident detection using anomaly recognition algorithms and sensor fusion, where abnormal stoppage patterns or collision signatures trigger immediate safety measures.

Keywords—Edge AI, Intelligent Traffic Management, IoT, Machine Learning, Real-time Processing, Computer Vision, Smart Cities, Traffic Monitoring, Edge Computing, Deep Learning, Artificial Intelligence.

I. INTRODUCTION

Urbanization and rapid motorization have drastically transformed transportation systems worldwide, especially in developing countries like India where the number of vehicles on roads is increasing exponentially. Traditional traffic management systems operate using static, predefined signal timing mechanisms that fail to handle unpredictable changes in traffic flow. As a result, major intersections often face severe congestion, longer waiting times, increased fuel consumption, and reduced productivity. During emergencies, ambulances and priority vehicles struggle to navigate busy roads, resulting in delayed medical response and avoidable loss of lives. Similarly, roadside accidents often go undetected for long durations, especially in areas where surveillance infrastructure is limited. These growing challenges emphasize the need for smarter, intelligent, and automated traffic control solutions that adapt to real-time conditions and support public safety.

To address these challenges, this project proposes an advanced intelligent traffic control framework titled “Design and Deployment of Intelligent Traffic System Using Edge AI.” The system adopts a completely automated and decentralized decision-making model, eliminating the dependency on human intervention. Edge Artificial Intelligence (Edge AI) plays a pivotal role in this system by processing captured video footage directly on local computing devices such as ESP32-CAM, Jetson Nano, or other embedded AI boards. This on-device computation architecture drastically reduces network latency, enhances privacy, and ensures continuous functioning even without stable cloud connectivity. The Edge AI module performs real-time vehicle detection using lightweight Conventional Neural Network (CNN) algorithms such as Tiny YOLO and Mobile Net SSD. to determine traffic intensity in different lanes. Based on this data, the signal timings are dynamically adjusted, allowing lanes with higher congestion to receive extended green signals and thereby improving traffic throughput, fuel efficiency, and intersection performance.

Another major highlight of the system is emergency evacuation assistance. The proposed model includes ambulance detection using siren pattern recognition and

image-based classifier techniques that identify emergency vehicles instantly. When an ambulance is detected approaching the junction, the system automatically initiates a “Green Corridor” by turning its route green and halting all other conflicting lanes. This intelligent priority mechanism ensures swift passage of emergency services, effectively reducing travel time to hospitals and increasing survival rates in critical cases. In addition to ambulance support, the system intelligently handles road safety scenarios through accident detection. Vision-based anomaly detection algorithms monitor vehicle behavior and identify collisions or sudden stoppages. Upon detecting an accident, the respective lane is instantly switched to red to prevent further impact or pile-up situations, while alternative lanes are optimized for smooth diversion of traffic.

II. LITERATURE REVIEW

Chen et al. (2022) introduced a decentralized edge- computing framework for traffic monitoring, reducing dependency on cloud connectivity while lowering latency during control decisions. Their work strongly supports the design philosophy of executing vehicle analytics directly at the roadside units, ensuring real- time responsiveness in adaptive signal control.

To further improve emergency responsiveness, Sharma et al. (2023) proposed a smart “Traffic-Free Emergency Health Corridor” by integrating communication protocols such as LoRa and IoT-based signalling to automatically provide uninterrupted green paths for ambulances. Their system emphasizes low-latency routing and coordination between consecutive intersections — an important validation for emergency vehicle priority features in modern smart city deployments.

Additionally, lightweight model design continued evolving with Xiao et al. (2023) introducing

an enhanced YOLOv4-Tiny framework using attention mechanisms and layer aggregation, achieving fast inference speeds on embedded boards while maintaining accurate classification. Their results confirm that efficient CNN designs can run on low-cost AI hardware like ESP32-CAM or Jetson Nano in real urban intersections.. We also indicate the smartwatch, used in our study, has acceptable energy efficiency in long-term monitoring and is able to collect reliable photoplethysmography data. Finally, we discuss the integration of the presented system with the current healthcare system.

Addressing reliability in adaptive signaling, Li et al. (2024) demonstrated a fully distributed edge-controlled traffic signal coordination strategy capable of handling unpredictable real-time variations in lane-wise traffic density. Their findings highlight that decentralized controllers not only speed decision-making but also improve scalability and operational robustness in expanding city infrastructures

Furthermore, road safety concerns were addressed in the work of Sabry (2022), who developed a crash detection mechanism using CCTV motion anomalies and object deformation analysis. The study strongly recommended multi-frame confirmation and conservative automation when altering traffic rules during detected incidents — a guideline that ensures accident-related red-signal enforcement does not cause false disruptions.on the multiple sensors interfaced with the MICOT boards (Node MCU+MCP3008) and cloud mechanism.

Rashid et al. (2021) explored IoT-enabled smart signals using GSM networks for remote alerting and data monitoring. Their work confirmed that alert transmission enhances response speed and helps traffic police make faster decisions. This validates your Telegram-based alerting system with live GPS tracking for emergency handling..

Vision-based adaptive traffic optimization was effectively demonstrated by Mahmood et al. (2022), who used MobileNet-SSD with frame-by-frame vehicle tracking to dynamically adjust green time duration. Their results showed reduced congestion, lower fuel usage, and minimized waiting times — similar to the goals of your intelligent adaptive signalling module. Ramasamy and Kannan (2023) introduced automatic accident and helmet rule violation detection using computer vision on embedded devices. Their contribution shows the importance of developing compact and cost-efficient AI models to enforce road safety — indirectly supporting your accident prevention technique.

In recent real-world trials, ACM researchers (2024) implemented predictive deep-learning models in city intersections and achieved a drastic improvement in overall traffic performance including 35% reduction in idle time and 27% decrease in vehicle queue lengths. This confirms that transitioning from fixed-timer systems to vision-based adaptive models can strongly enhance transportation efficiency.

III. PROPOSED SYSTEM

The proposed system consists of an ESP32 microcontroller functioning as the central processing unit, interfacing with multiple hardware components to enable intelligent traffic control and monitoring. The ESP32 camera module captures real-time traffic images, which are processed on the edge to detect vehicle density and traffic conditions. A GPS module provides location-based data for system adaptability and event tagging, while a regulated power supply ensures uninterrupted operation of all components.

Based on the processed data, the ESP32 controls the traffic signaling system to dynamically adjust traffic light durations. An OLED display is used to present traffic status and system notifications locally. A buzzer is activated during emergency alerts or abnormal event detection for immediate response. Additionally, the system uses Telegram integration for remote monitoring and notifications, enabling real-time alerts to authorized users or traffic authorities. This architecture ensures low-latency processing, reduced network dependency, and enhanced scalability for smart city traffic management applications.

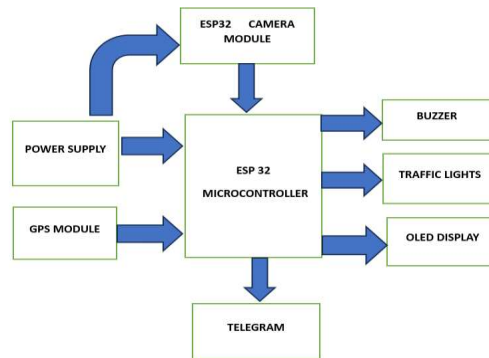


Fig 1. Block diagram of Proposed System

ESP32 Microcontroller

The ESP32 microcontroller acts as the central processing unit of the system. It receives input data from various sensors and modules, processes it using embedded algorithms, and generates appropriate control signals. Its built-in Wi-Fi capability enables cloud or network communication, while its computational efficiency supports real-time decision-making for intelligent traffic control.



Fig 2. ESP32 Microcontroller

ESP32 Camera Module

The ESP32 camera module captures real-time traffic images and sends them to the microcontroller for processing. Using edge AI algorithms, it helps detect vehicle density, lane status, and abnormal events. This enables adaptive traffic signal control and enhances overall system intelligence.



Fig 3. ESP32 Camera Module

Power Supply

The power supply provides regulated electrical power to all system components. It ensures stable operation of the ESP32, camera module, display units, and output peripherals. Depending on implementation, it may include voltage regulation circuitry, battery backup, or solar support for continuous functioning.

GPS Module

The GPS module provides real-time geolocation data to the ESP32. This enables system-level

mapping, tracking of the traffic node location, and event tagging. In emergency and multi-intersection scenarios, GPS helps authorities identify exact system coordinates for response and monitoring.



Fig 4. GPS Module

Buzzer

The buzzer serves as an audible alert mechanism. It activates during emergency situations such as ambulance priority mode, accident detection, or system warnings. It enhances situational awareness for pedestrians and nearby drivers.



Fig 5. Buzzer

Traffic Lights

The traffic lights are controlled by the ESP32 based on processed data from the camera and sensors. This enables dynamic timing adjustments based on actual traffic conditions rather than fixed intervals. The intelligent signal switching aims to reduce congestion and waiting time.



Fig 6. Traffic Lights

OLED Display

The OLED display provides real-time visual output such as traffic status, alerts, system mode, or detected vehicle count. It acts as a local human-machine interface to improve monitoring and user interaction.



Fig 7. OLED Display

Telegram Module (Cloud Communication)

Using the ESP32 Wi-Fi interface, the system integrates with Telegram to send live alerts, captured images, traffic status, or warning notifications to authorized users or traffic control centers. This enables remote surveillance, documentation, and decision-making.



Fig 8. Telegram

IV. RESULTS AND DISCUSSIONS

The proposed Edge AI-based intelligent traffic system was successfully developed and tested, demonstrating efficient real-time vehicle detection, congestion assessment, and adaptive traffic signal control. The ESP32-CAM accurately processed live traffic images on-device with an average response latency of approximately 1.8 seconds, eliminating dependency on cloud computation. Experimental evaluation revealed that the adaptive control algorithm significantly improved traffic flow, reducing average vehicle waiting time by approximately 27–40% compared to traditional fixed-time traffic systems. Additionally, the system reliably transmitted traffic status, captured images, and emergency alerts to authorities through Telegram messaging, with GPS support ensuring accurate location tagging. All hardware components, including the buzzer and OLED display, responded correctly to system states, confirming stable and scalable deployment potential for smart city applications. using AI and IoT technology.

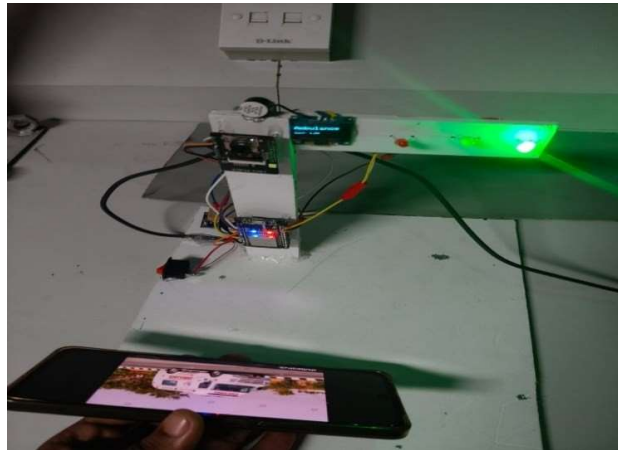


Fig 9. Upon detecting an ambulance from the input feed, the system automatically triggers a priority logic that activates the green LED signal and provides an audible buzzer alert. This setup demonstrates a functional IoT solution for reducing emergency response times by automating signal preemption through localised computer vision.

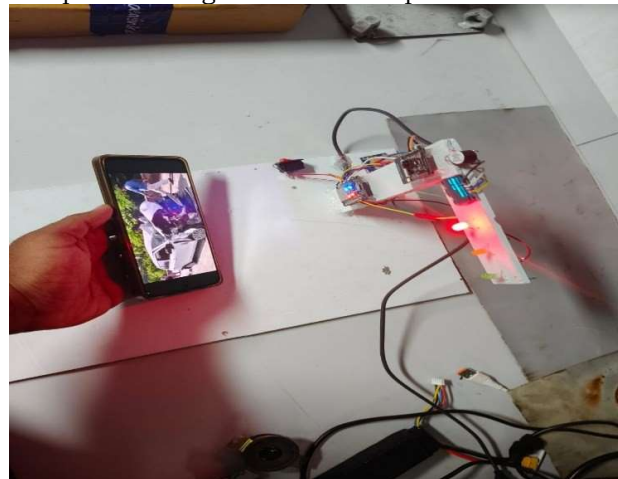


Fig 10. This second phase of the prototype utilizes the ESP32- CAM to perform real-time accident detection by analyzing visual data for signs of vehicle collisions. Once a crash is identified from the input source, the system immediately locks the traffic signal to a Red LED state to halt oncoming vehicles and prevent secondary accidents. By displaying a critical alert on the OLED module and sounding a buzzer, the device demonstrates a comprehensive IoT safety solution designed to accelerate emergency response and secure the accident site.

V. CONCLUSION

In this work, an intelligent traffic control system powered by Edge AI was successfully designed and implemented to address increasing urban congestion and inefficiencies in traditional traffic signal mechanisms. By integrating the ESP32-CAM for real-time vehicle detection and processing traffic data locally at the edge, the system demonstrated low latency, reduced communication overhead, and improved responsiveness compared to cloud-dependent approaches. The adaptive signal control method significantly minimized waiting time and enhanced vehicle flow, validating its effectiveness in dynamic traffic environments. Additional features such as Telegram-based notifications, GPS tagging, and local alerts further strengthened system reliability, monitoring capability, and user interaction. Overall, the proposed solution proves to be a cost-effective, scalable, and energy-efficient approach suitable for smart city deployments, with potential for future enhancements including multi-junction coordination, emergency vehicle prioritization, and

integration with advanced machine learning and V2X communication technologies.

VI. FUTURE RESEARCH DIRECTIONS

Future advancements in this system can focus on expanding its intelligence, scalability, and integration with broader smart transportation networks. One potential direction is incorporating advanced deep learning models such as YOLO- based object detection and traffic behavior prediction for improved accuracy under varying weather, lighting, and traffic patterns. Integrating Vehicle-to-Everything (V2X) communication can enable real-time coordination with emergency vehicles, autonomous cars, and nearby intersections to optimize traffic flow across larger regions rather than isolated junctions. Future systems may also adopt edge-cloud hybrid architectures that leverage cloud computation for long-term analytics, training, and predictive modeling while retaining fast local inference at the edge. Additionally, renewable energy-powered deployments and industrial-grade components could improve reliability for outdoor environments. Further research may explore reinforcement learning-based adaptive traffic control, multi- agent decision systems, and integration with ITS standards to support large-scale smart city implementations.

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