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Green Lane - Smart Signal with Emergency Priority

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Abstract: ***Traffic congestion and delayed emergency response remain major challenges in urban transportation due to the limitations of conventional fixed-time traffic signal systems. These systems operate with predefined signal duration and failed to adapt to real-time traffic density or provide automatic priority to emergency vehicles. This paper presents "Green Lane – Smart Signal with Emergency Priority", an intelligent traffic signal system that dynamically controls signal timing based on real-time vehicle density while enabling priority passage for emergency vehicles. The proposed system integrates camera-based vehicle detection using Python and Open CV with an ESP32 microcontroller for adaptive traffic signal control. Emergency vehicle detection triggers an immediate signal override to create a dedicated green lane, ensuring faster clearance. Experimental results obtain from a prototype implementation show reduced waiting time improve traffic flow efficiency and quicker emergency vehicle movement compared to traditional fixed time systems. The system is low-cost, scalable, and suitable for smart city traffic management applications.***
Keywords: Smart Traffic Signal, Green Lane, Emergency Priority, ESP32, IoT.

I. INTRODUCTION

Urban traffic systems face increasing congestion due to rapid vehicle growth Fixed-time traffic signals operate with predefined timings and cannot respond to real-traffic conditions, leading to long waiting times and inefficient traffic flow. Emergency vehicles often get delayed at intersections, increasing response time.

The proposed Green Lane system addresses these issues by dynamically controlling traffic signals based on vehicle density and automatically prioritizing emergency vehicles. This improves traffic efficiency and enhance public safety.

A. Relevance of the Study

The Green Lane system plays a crucial role in modern smart city development by addressing two major challenges: traffic congestion and emergency response delay. By combining computer vision, embedded systems, and automation, the system improves traffic flow efficiency while ensuring faster emergency vehicle movements. The low cost and scalable design make it suitable for urban, semi-urban and developing regions. The system also contributes to fuel efficiency, reduced emissions, and improved road safety making it highly relevant for intelligent transportation systems.

B. Feasibility Study

1) Technical Feasibility: The system uses widely available components such as ESP32 microcontroller, USB camera, LEDs, and Python-based image processing. Vehicle detection using OpenCV is well-established and reliable under normal lighting conditions. Emergency priority logic is implemented using simple sensor-based detection, making the system technically feasible.

2) Economic Feasibility: The proposed system is cost-effective as it uses affordable hardware components. The absence of expensive infrastructure such as radar or LiDAR makes it suitable for budget-constrained traffic authorities. Maintenance cost is minimal due to simple electronic components.

3) Operational Feasibility: The system operates automatically without human intervention. Once deployed, it continuously monitors traffic density and emergency conditions, ensuring reliable and smooth traffic control with minimal operational effort.

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II. LITERATURE SURVEY

1) Paper title: Smart Navigation system for Emergency Vehicles
Author: Fatma M. Talaat & Samah A. Gamel (2025)
Abstract and relevance: Uses IoT and cloud computing for emergency vehicle routing but lacks optimization of normal traffic flow.
2) Paper title: AI – Driven Real-Time Traffic and Emergency Management using YOLO
Author: Preethi Harris et al. (2025)
Relevance: Applies AI-based vehicle detection but is sensitive to lighting and network conditions.
3) Paper title: Intelligent Traffic Management systems
Author: Hesham A. Sakar & Magda I. EI-Afifi (2023)
Relevance: Reviews modern ITS technologies but does not provide an integrated low-cost implementation.
4) Paper title: IoT Based Road Traffic Management Systems
Author: Pendurthy Bhavana et al. (2023)
Relevance: Uses IR sensors for density-based control but lacks emergency vehicle prioritization.
5) Paper title: Smart Traffic Management System
Author: Ninad Lanke & Sheetal Koul (2013)
Relevance: The approach is outdated and limited to RFID based identification without intelligent sensing capabilities. It does not incorporate machine learning or dynamic timing adaptation according to congestion changes. Deployment and maintenance challenges of RFID tagging on every vehicle are not discussed. Modern smart city requirements like pollution reduction, real-time dashboards, and emergency routing are missing.

III. EXISTING AND PROPOSED SYSTEM

A. *Existing System*

Most urban traffic intersections operate using fixed-time traffic signal systems, where red, yellow, and green signals follow predefined durations irrespective of real-time traffic conditions. These systems do not consider variations in traffic density and depend on manual intervention by traffic police during congestion or emergency vehicles such as ambulances and fire trucks often experience delays due to absence of automatic priority mechanisms

Disadvantages of Existing System

1) Fixed signal timings cause unnecessary waiting and congestion.
2) No real-time traffic density monitoring.
3) Emergency vehicles do not receive automatic priority.
4) Increased fuel consumption and air pollution.
5) Manual control reduces efficiency and reliability.
6) Not suitable for smart city and intelligent traffic systems.

B. *Proposed System*

The proposed Green Lane – Smart Signal with Emergency Priority system dynamically controls traffic signals based on real-time vehicle density using camera-based detection. An ESP32 microcontroller processes traffic data and allocates green signal duration according to congestion levels. Emergency vehicle detection triggers an immediate signal override, creating a dedicated green lane for fast clearance. The system is fully automated, low-cost, and suitable for smart city traffic management.

IV. OBJECTIVES AND METHODOLOGY

A. *Objectives*

The main objective of the Green Lane – Smart Signal with Emergency Priority system is to develop an intelligent traffic signal mechanism that dynamically controls signal timing based on real-time vehicle density while ensuring immediate priority for emergency vehicles. The system aims to reduce traffic congestion, minimize waiting time at intersections, improve emergency response, and enhance overall traffic flow efficiency.

B. *Methodology*

The methodology begins with capturing the real-time traffic video using a camera installed at some corner from where it can capture video.

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The video feed is processed using Python and OpenCV to detect and count vehicles in each lane, which represents traffic density. This density data is transmitted to an ESP32 microcontroller that dynamically allocates green signal duration based on congestion levels. Emergency vehicle detection logic continuously monitors for priority conditions and immediately overrides the normal signal cycle to provide a green signal for emergency lane. The entire system operates in a continuous loop, enabling real-time adaptation to changing traffic conditions with minimal human intervention.

Algorithm

- Start
- Initialize webcam, Python environment, and ESP32 microcontroller.
- Capture real-time traffic video using the camera(webcam).
- Process the video in Python using OpenCV and NumPy.
- Detect and count vehicles in each lane from the processed video.
- Send the vehicle count data to the ESP32 microcontroller through serial communication.
- ESP32 analyzes the received vehicle count and determines traffic density for each lane.
- In normal mode, allocate green signal to create a green lane.
- In emergency mode, use simulated for system testing.
- ESP32 controls the LED traffic lights.
- Update real-time traffic data and signals on Streamlit dashboard.
- Repeat continuously traffic control.
- Stop.

V. DESIGN CONSIDERATION

The system design integrates a USB webcam for traffic monitoring, ESP32 microcontroller for decision-making, and LED signals to represent traffic lights. Python-based vehicle detection ensures accurate density estimation. The design supports future upgrades such as IoT cloud monitoring and AI-based prediction.

A. Software Components

1) Python for traffic processing
2) OpenCV for vehicle detection
3) Arduino IDE for ESP32 programming
4) Streamlit dashboard for visualization

VI. MATERIAL IDENTIFICATION AND SPECIFICATIONS

Table -1: Components and Specifications

Component	Specification	Purpose
ESP32 Dev Kit	Bulit-in Wi-Fi	Main controller
USB Webcam	720p/1080p	Vehicle detection
LEDs	Red, Yellow, Green	Traffic signal
Jumper wires	20-22 AWG	Circuit connection
Breadboard	840 points	Mounting LEDs for traffic signal

VII. WORKING PRINCIPLE

The working of the Proposed Green Lane -Smart Signal with Emergency Priority system begins with a webcam at the traffic intersection, which continuously capture real-time video of vehicle movement. This video feed is processed using Python with OpenCV, Pyserial, and Numpy to detect and count vehicle count, representing traffic density, is transmitted to the ESP32 microcontroller via serial communication and it as four modes.

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1) Normal Traffic Mode: In this mode, the ESP332 dynamically controls traffic signals based on real-time vehicle density. Lanes with higher vehicle count are given longer green signal duration, while low-density lanes receive shorter green time. The relay module drives the LED traffic lights to regulate traffic flow efficiently.
2) Emergency Vehicle Priority Mode: When an emergency vehicle is detected, the ESP32 immediately interrupts the normal signal cycle and activates a green signal for corresponding lane. This creates a dedicated green lane for emergency vehicle clearance. Once the emergency vehicle passes, the system safely resumes normal traffic operation.
3) Simulation Mode: Simulation mode is used to test and validate system behaviour without physical traffic conditions. Traffic scenarios such as low, medium, and high congestion are simulated vehicles count, allowing verification of signal timing, emergency response logic, and overall system performance.
4) Analytics Mode: In this mode, real-time traffic data, signals status, and vehicle count are sent to dashboard display. A streamlit-based dashboard visualizes traffic density, signal timing, and system performance, enabling effective monitoring and analysis.

By operating through these four modes, the system ensures adaptive traffic signal control, reliable emergency prioritization, effective simulation testing, .and real-time traffic monitoring.

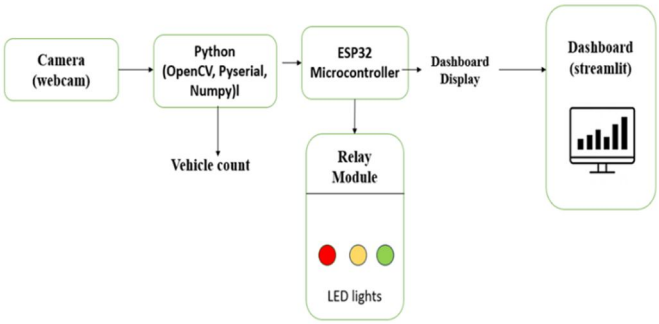


Fig -1: Block diagram of Green Lane-Smart signal with Emergency priority

VIII. RESULTS & DISCUSSION

The prototype demonstrated efficient adaptive traffic control, with reduced congestion and waiting time. Emergency vehicle priority was successfully implemented, resulting in immediate signal clearance. The system operated reliably without signal conflicts and showed improved traffic efficiency compared to fixed -time systems.

IX. CONCLUSION

The Green Lane-Smart Signal with Emergency Priority system provides an effective solution for intelligent traffic management. By combining real-time vehicle detection, adaptive signal control, and emergency priority handling, the system improves traffic flow efficiency and emergency response performance. The low-cost makes it suitable for smart city deployment.

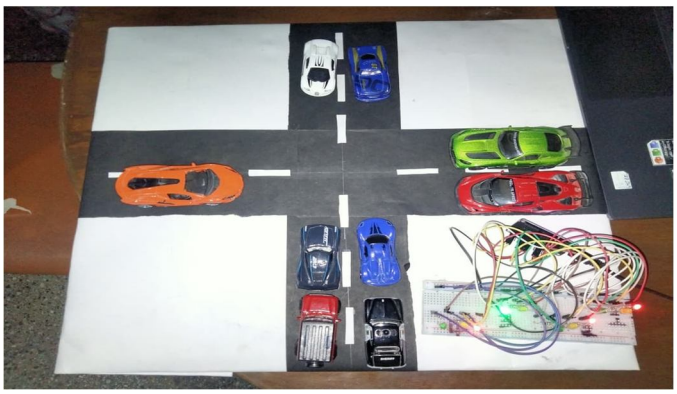
X. FUTURE ENHANCEMENT

1) AI-based traffic prediction
2) Inter-signal communication
3) Solar-powered traffic signals
4) Integration with GPS-based emergency tracking

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Appendix- Photographs of Prototype





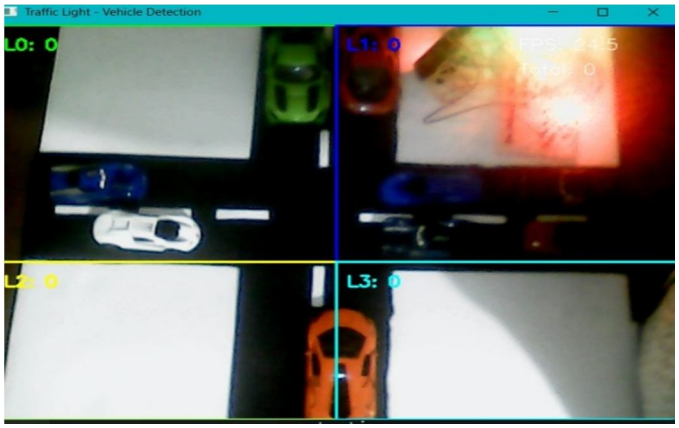


Fig-2: Prototype of Green Lane-Smart Signal with Emergency Priority

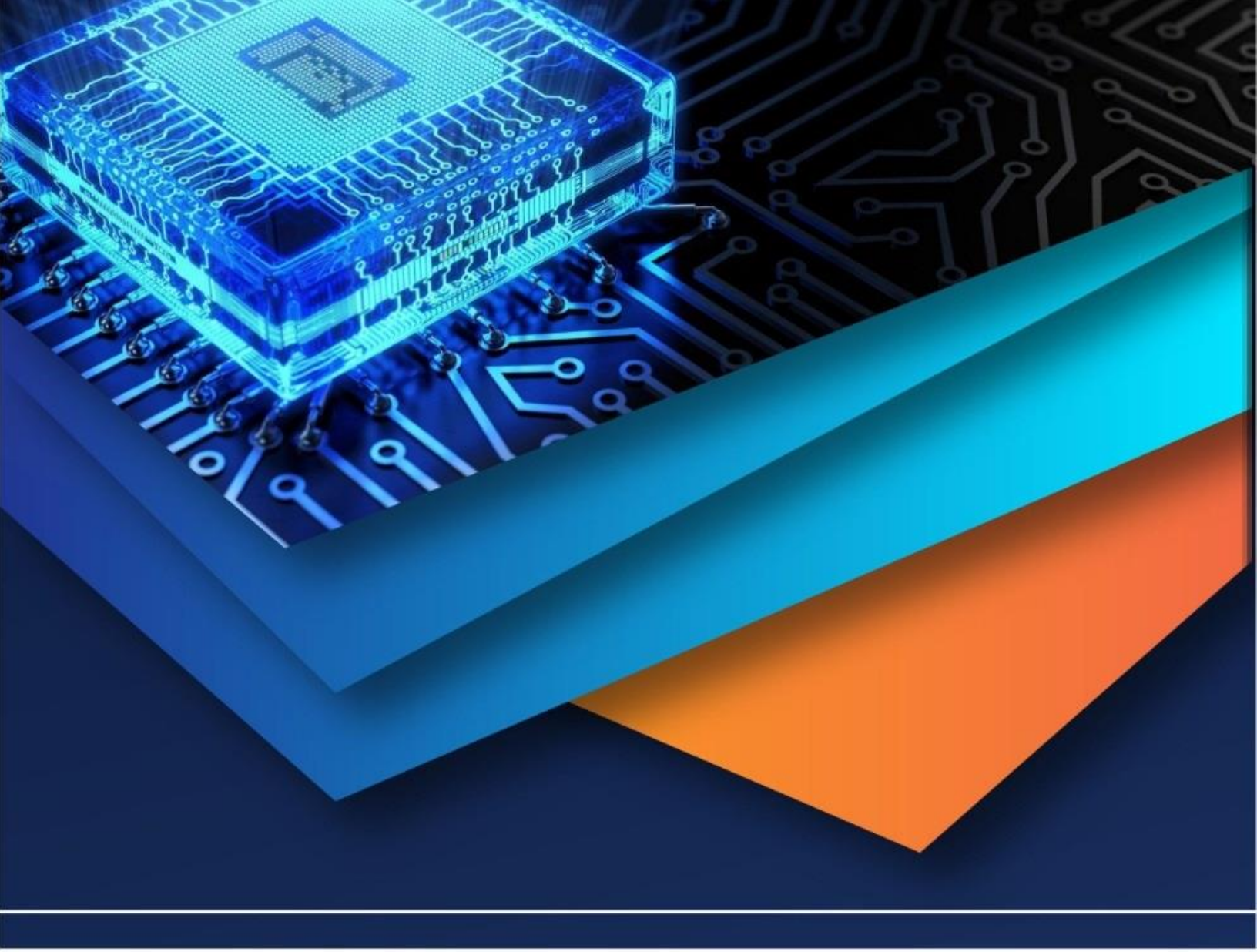


Fig-3: Webcam view picture

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Fig-4: Streamlit dashboard results



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