AI-Driven Adaptive Traffic Signal Control System Using Computer Vision and Raspberry Pi for Urban Mobility Enhancement

Saurabh Kedar[1], Kunal Bora[2], Yash Landage[3], Hrishikesh R. Shirke[4]

[1,2,3] Student, Dept. Of Electrical Engineering, PES's Modern College Of Engineering, Maharashtra, India
[4]Professor, Dept. of Electrical Engineering, PES's Modern College Of Engineering, Maharashtra, India

---

Abstract - *Traffic congestion in urban areas is increasing rapidly due to the growing number of vehicles and inefficient traditional signal systems. Fixed-time traffic signals fail to respond to real-time road conditions, leading to delays, fuel wastage, and environmental pollution. This project presents a smart and adaptive traffic signal control system that adjusts signal timings based on actual vehicle density at intersections. The system uses a camera to capture live traffic footage, which is processed on a laptop acting as the main operating system using an object detection model (YOLO) to identify and count vehicles. Based on this analysis, optimized signal timing decisions are generated. A Raspberry Pi is used to receive these decisions and actuate the traffic lights through relay modules. In addition to traffic density control, the system includes features such as emergency vehicle detection and a pedestrian crossing mechanism. These features improve both traffic flow and road safety. Overall, the proposed system provides an intelligent, automated, and efficient solution for traffic management. It helps reduce congestion, saves fuel, improves travel time, and supports the development of smart and sustainable cities by combining AI, IoT, and real-time decision-making.*

Key Words: YOLO, Raspberry Pi, Smart Traffic Signal System, Real Time, IoT

1. INTRODUCTION

This project focuses on developing a smart traffic signal system that can control traffic lights based on real-time vehicle detection. In many places, traffic signals work on fixed timing, which does not change according to traffic conditions. This leads to longer waiting times and traffic congestion. To solve this problem, a camera is used to capture live traffic at the junction. The video is processed using a YOLO-based object detection model to identify and count the number of vehicles in each lane. In this system, the laptop is used as the main processing unit, where the AI model runs and analyses the traffic data. Based on the number of vehicles detected, the system decides which lane should get more signal time. The Raspberry Pi is used to control the traffic lights. It receives commands from the laptop and operates a relay module to switch the signal lights (red, green) ON and OFF. This combination makes the system more efficient, as it adjusts signal timing according to actual traffic conditions instead of using fixed timers. It also helps in reducing congestion and improving traffic flow.

2. PROPOSED SYSTEM

The proposed system is an AI-based smart traffic signal control system that uses real-time traffic analysis to improve the efficiency of road intersections. In this system, a camera is installed at the junction to continuously capture live video of vehicles moving across different lanes. Instead of relying solely on a low-power embedded device, a laptop is used as the main processing unit, providing a more Powerful operating system platform capable of handling complex computations. The laptop runs software tools such as Python, OpenCV, and the YOLO (You Only Look Once) algorithm, which together perform image processing and object detection tasks.

The captured video frames are processed by the YOLO model to accurately detect and classify various types of vehicles, including cars, bikes, buses, and trucks, and then count them in each lane. Based on this data, the system calculates the traffic density dynamically for every lane. Using this information, the laptop determines optimal signal timings, allocating longer green signals to lanes with heavier traffic and shorter durations to those with lower traffic density, thereby improving overall traffic flow.

For hardware execution, a Raspberry Pi is used as a controller that receives commands from the laptop and operates a 4-channel relay module. This relay module is connected to the traffic signal lights red, yellow, and green and switches them according to the instructions provided. The entire system functions automatically without requiring manual intervention, ensuring efficient and intelligent traffic management.

By leveraging the higher processing capability of the laptop for AI computation and using the Raspberry Pi for physical control, the system achieves better accuracy and speed. Ultimately, this smart approach helps reduce traffic congestion, minimizes waiting time, saves fuel, and enhances the overall efficiency of traffic movement at intersections.

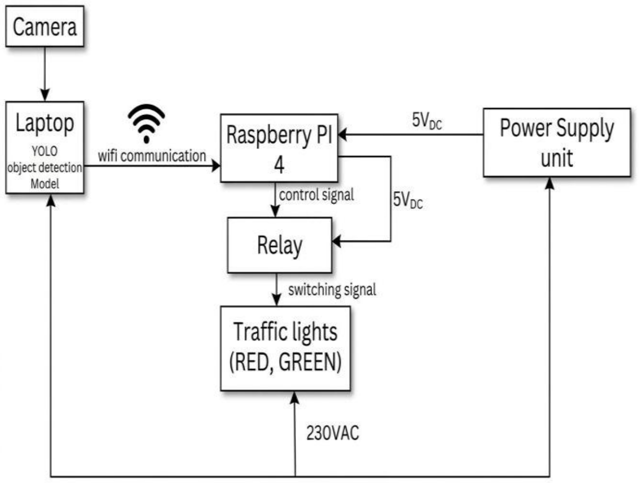

Fig -1: Control system of smart traffic signal system

3. METHODOLOGY

Problem Identification:

Analyse issues with fixed-time traffic signals (e.g., delays, inefficiency). Identify the need for adaptive control based on real-time traffic.

System Design and Planning:
Select hardware: Raspberry Pi, Pi Camera, relays, etc. Plan features like AI vehicle classification, emergency vehicle detection, and pedestrian Integration.

Data Collection & Dataset Preparation:
Capture or source images of various traffic scenarios. Collect images of emergency vehicles, different vehicle types (car, truck, bike), and Pedestrian movement. Label and annotate images for training

Hardware Setup:
Install Pi camera to monitor traffic lanes. Set up traffic lights via relay module.

Software and AI Development:
Train the AI models with collected data.

Integration and Testing:
Combine all modules (camera, sensors, relays) into a working system. Test signal switching under different traffic and pedestrian conditions. Simulate emergency scenarios for priority switching.

Deployment (Prototype Stage):
Implement the system on a scaled down 2-lane intersection model.

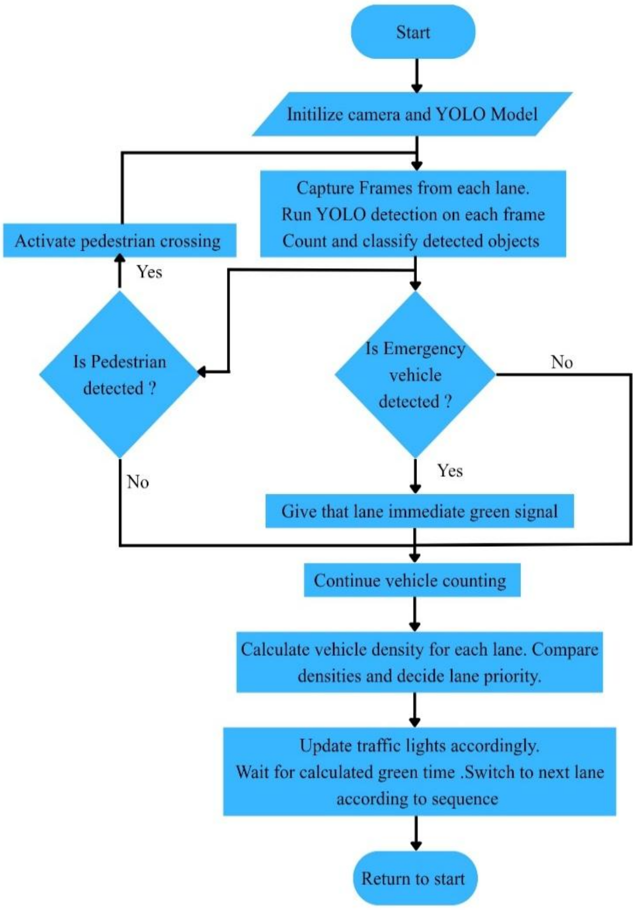

Fig – 2: Flowchart of system

4. EXPERIMENTAL RESULTS

Fig -3: Experimental Setup

Fig -4: Pedestrian Detection

Fig -4 illustrates pedestrian detection using the proposed AI-based system. When a pedestrian is detected for more than 5 seconds, the traffic signal switches to red and remains in that state until the pedestrian leaves the crossing area.

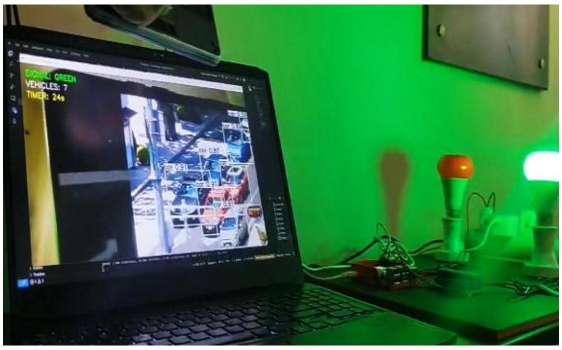

Fig -5: High vehicle density based green signal adjustment

Fig -5 Adaptive green signal control based on real-time vehicle density. The green signal duration is automatically increased when a larger number of vehicles is detected in the lane.

Fig -6: Emergency vehicle based green signal adjustment

Fig-6 Emergency vehicle priority control. When an ambulance is detected, the traffic signal immediately turns green to provide priority passage through the intersection.
Fig -7 Adaptive green signal control for low traffic density. The green signal duration is automatically reduced when fewer vehicles are detected in the lane.

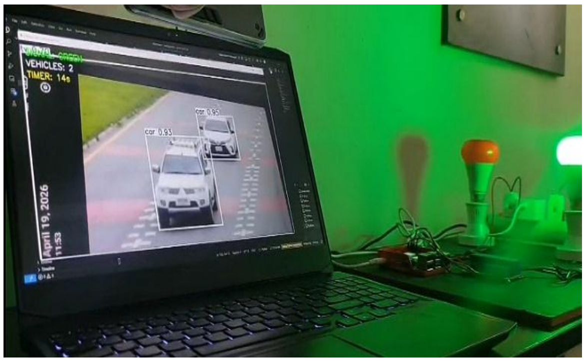

Fig -7: Low vehicle density based green signal adjustment

3. RESULT ANALYSIS

- Reduces waiting time during low traffic conditions.
- Dynamically adjusts signal timing based on vehicle density.
- Provides priority to emergency vehicles.
- Enhances pedestrian safety through real-time detection.
- Utilizes low-cost hardware (Raspberry Pi).
- Suitable for smart city transportation systems.

4. FUTURE SCOPE/ADVANCEMENTS

Future enhancements to the proposed system can include the integration of multiple interconnected traffic junctions for city-wide traffic optimization. The system can be extended using cloud-based monitoring and data analytics to provide real-time traffic insights to traffic authorities. Advanced AI models can be incorporated for improved vehicle classification and traffic prediction. Additionally, the proposed system can be integrated with smart city infrastructure and Vehicle-to-Infrastructure (V2I) communication technologies to further enhance traffic efficiency, road safety, and emergency response management.

5. CONCLUSIONS

The AI-based smart traffic signal system improves traditional fixed-time traffic control by introducing real-time, intelligent decision-making using the YOLO (You Only Look Once) object detection algorithm. It continuously analyzes live video input to detect vehicles, estimate traffic density, and dynamically adjust signal timings to reduce congestion and waiting time. A key feature of the system is its ability to prioritize emergency vehicles such as ambulances, fire trucks, and police vehicles by immediately providing a green signal for faster movement during critical situations. It also enhances road safety by detecting pedestrian presence and allocating appropriate crossing time to prevent accidents. Overall, this project demonstrates an effective AI-driven approach to traffic management that improves efficiency, reduces delays, and increases safety for both vehicles and pedestrians, making it suitable for smart city applications.

REFERENCES

[1] Akash A., Chetan A. B., O. M. Hegde, R. Hosamani, and Vishesh J., “Smart control of traffic light system using artificial intelligence,” Journal of Emerging Technologies and Innovative Research (JETIR), vol. 11, no. 12, pp. c586–c588, Dec. 2024.

[2] S. Mahato, “Smart traffic signals: Comparing MARL and fixed-time strategies,” arXiv preprint arXiv:2505.14544v2, Jun. 2025.

[3] A. N. A. Yusuf, A. S. Arifin, and F. Y. Zulkifli, “Recent development of smart traffic lights,” IAES International Journal of Artificial Intelligence (IJ-AI), vol. 10, no. 1, pp. 224–233, Mar. 2021. Doi: 10.11591/ijai.v10.i1.pp224-233

[4] B. Zhou, Q. Song, Z. Zhao, and X. Liu, “Deep reinforcement learning for smart traffic signal control: A review,” IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 8, pp. 7842–7861, Aug. 2023. Doi: 10.1109/TITS.2023.3264578

[5] W.-H. Lee and C.-Y. Chiu, “Design and Implementation of a Smart Traffic Signal Control System for Smart City Applications,” Sensors, vol. 20, no. 2, p. 508, Jan. 2020, doi: 10.3390/s20020508.

[6] R. Salama and J. B. Idoko, “Design and Implementation of Smart Traffic Light System Using Renewable Energy, Fail-Safe Systems, and Intelligent Sensors,” Research Square, Dec. 2024, doi: 10.21203/rs.3.rs-5542376/v1.

[7] B. Ghazal, K. ElKhatib, K. Chahine, and M. Kherfan, “Smart Traffic Light Control System,” in Proceedings of the IEEE International Conference on Electrical, Electronics, Computer Engineering and their Applications (EECEA), 2016, pp. 161–166, doi: 10.1109/EECEA.2016.7470780.

[8] K. Dharani, D. Sunnyhitha, K. Shirisha, and B. D. Mathews, “Smart Control of Traffic Lights Using Artificial Intelligence,” International Journal of Research and Analytical Reviews (IJRAR), vol. 10, no. 2, pp. 356–357, Jun. 2023.