Computer Vision-Based Adaptive Traffic Signal Control System

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ABSTRACT:

Urban traffic congestion is increasing rapidly due to the growing number of vehicles and the continued use of fixed-time traffic signal systems. Conventional traffic signals operate with predefined timings and do not consider real-time traffic conditions, which results in longer waiting time and inefficient traffic flow. This paper presents a computer vision-based adaptive traffic signal control system that dynamically adjusts signal timings according to real-time traffic density. Vehicle detection and counting are performed using the YOLO object detection model with OpenCV. Lane-wise traffic density is calculated and used to control signal duration automatically. Experimental observations show that the proposed system improves traffic movement and reduces congestion when compared with traditional fixed-time traffic signal systems.

Keywords — Adaptive Traffic Signal, Computer Vision, YOLO, OpenCV, Traffic Analysis.

I. INTRODUCTION

Traffic congestion has become a serious issue in urban areas due to rapid population growth and increased vehicle usage. Most traffic intersections still operate using fixed-time signal control, where equal green time is assigned to all lanes irrespective of traffic conditions. This approach often leads to unnecessary delays, fuel wastage, and increased air pollution.

With the advancement of artificial intelligence and computer vision, intelligent traffic management systems have gained significant attention. Vision-based systems can analyse traffic conditions using video feeds and estimate traffic density without the need for costly physical sensors. This research focuses on developing an adaptive traffic signal control system that uses vehicle density information obtained through computer vision techniques to optimize traffic signal timings.

II. OBJECTIVES

The key objective of this project is as follows:

- To understand the limitations of traditional traffic signal systems.

- To monitor traffic in real time using computer vision techniques.
- To detect and count vehicles using AI-based models.
- To control traffic signals dynamically based on traffic density.

III. RELATED WORK

Earlier traffic control systems mainly relied on hardware-based sensors such as inductive loops and infrared sensors. Although these systems provide traffic data, they involve high installation and maintenance costs. To overcome these limitations, researchers have explored image processing and video-based traffic analysis methods.

Recent studies have shown that deep learning-based object detection models such as YOLO offer high accuracy and real-time performance for vehicle detection. These models are suitable for traffic monitoring applications due to their fast-processing speed. However, many existing approaches do not effectively utilize lane-wise traffic density for adaptive signal control. This work addresses this limitation by integrating real-time vehicle detection with dynamic signal timing.

IV. PROPOSED SYSTEM

The proposed system makes use of computer vision and AI techniques to regulate traffic signals dynamically. Cameras installed at traffic intersections capture live video streams, which are processed using OpenCV and object detection models such as YOLO to detect and count vehicles in each lane. Based on the calculated traffic density, the system decides the duration of green lights, giving more time to heavily congested lanes while reducing waiting time for less crowded ones. This ensures smoother traffic flow and minimizes delays compared to traditional fixed-time signals.

time limits for each lane. It can also be extended to prioritize emergency vehicles like ambulances and fire trucks by identifying them through specialized detection modules. Since the approach relies only on cameras and software, it is cost-effective and can be easily integrated into existing infrastructure. Overall, the proposed method aims to improve road efficiency, reduce fuel consumption, and contribute to building sustainable smart city traffic management systems.

To ensure fairness, the system is also designed with predefined minimum and maximum green time limits for each lane, so that no direction is neglected. The proposed model can also be extended to provide priority access for emergency vehicles such as ambulances, fire brigades, and police vans by integrating specialized recognition modules.

Since the proposed system is camera and software-based, it can be integrated into existing infrastructure at low cost without the need for extensive hardware changes. It improves road efficiency, reduces fuel wastage, lowers vehicular emissions, and contributes to building a sustainable smart city ecosystem.

Furthermore, the approach can be enhanced by combining data analytics and visualization tools such as Matplotlib and Seaborn to monitor real-time traffic patterns and generate predictive insights. Authorities can use this data for long-term planning, infrastructure upgrades, and adaptive traffic management.

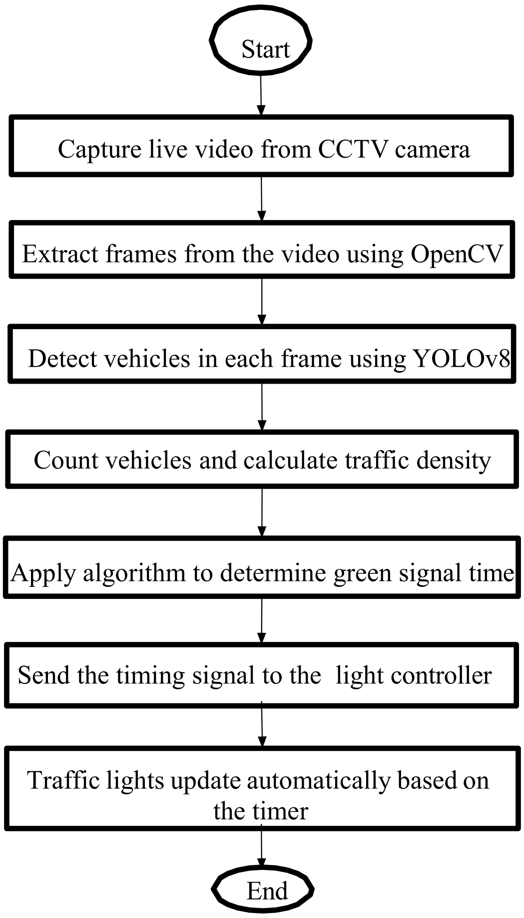

Fig (1). Flow diagram

Step 1: Capturing Images using CCTV at Traffic Signals

CCTV/IP cameras installed at intersections continuously capture live traffic footage covering all lanes. These cameras provide a complete and real-time view of traffic flow and serve as the primary input for further analysis without requiring additional hardware infrastructure.

Step 2: Vehicle Detection and Traffic Density Calculation

The captured images are pre-processed and analyzed using deep learning–based object detection models such as YOLO to detect vehicles. Traffic density is calculated by counting vehicles in each lane, which helps identify congestion levels accurately.

Step 3: Sending Traffic Density to Server for Green Time Calculation

The computed traffic density data is sent to a central server where AI algorithms calculate optimal green signal durations. Signal timings are dynamically adjusted based on real-time traffic demand while maintaining minimum and maximum limits for fairness.

Step 4: Scheduling Based on Computed Green Signal Time

Using the calculated timings, the system schedules signal phases and sequences. The scheduling logic can prioritize emergency vehicles, manage pedestrian crossings, and adapt to peak-hour traffic conditions.

Step 5: Traffic Signal Timer Update

The final signal timings are transmitted to traffic signal controllers, which update the green, yellow, and red phases accordingly. This process is repeated continuously, ensuring real-time responsiveness and efficient traffic management.

V. METHODOLOGY

A. Vehicle Detection

The system uses a convolutional neural network-based object detection model to detect vehicles from live video frames. Each frame is pre-processed and passed to the detection model, which outputs bounding boxes and vehicle counts for each lane.

B. Traffic Density Calculation

Traffic density is calculated by counting the number of vehicles present in each lane during a fixed observation window. Higher vehicle count corresponds to higher traffic density.

C. Intelligent Signal Control Logic

The green signal time is allocated proportionally based on traffic density. Lanes with higher vehicle density are given longer green durations, while lanes with fewer vehicles receive shorter green times. This adaptive logic ensures fair and efficient traffic movement.

VI. RESULTS AND DISCUSSION

The proposed system was tested using recorded traffic video data. Vehicle detection was performed accurately under normal lighting conditions. The adaptive signal control mechanism reduced waiting time during peak traffic hours. When compared with fixed-time traffic signal systems, the proposed approach showed improved traffic flow and reduced congestion.

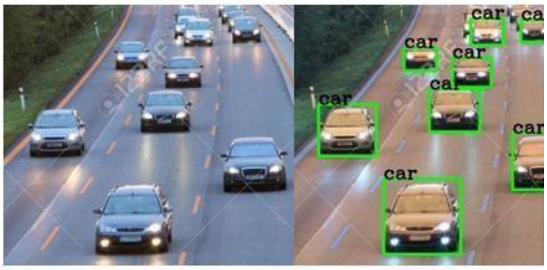

Fig (2). Vehicle Detection

Represent the raw traffic images captured from CCTV cameras at a road intersection, while show the processed output after applying the YOLO-based object detection algorithm. The vehicles in the traffic stream are accurately detected and highlighted with green bounding boxes, which indicates successful identification and classification. This detection process helps in counting the number of vehicles and estimating traffic density, which is later used for dynamically adjusting the traffic signal timings.

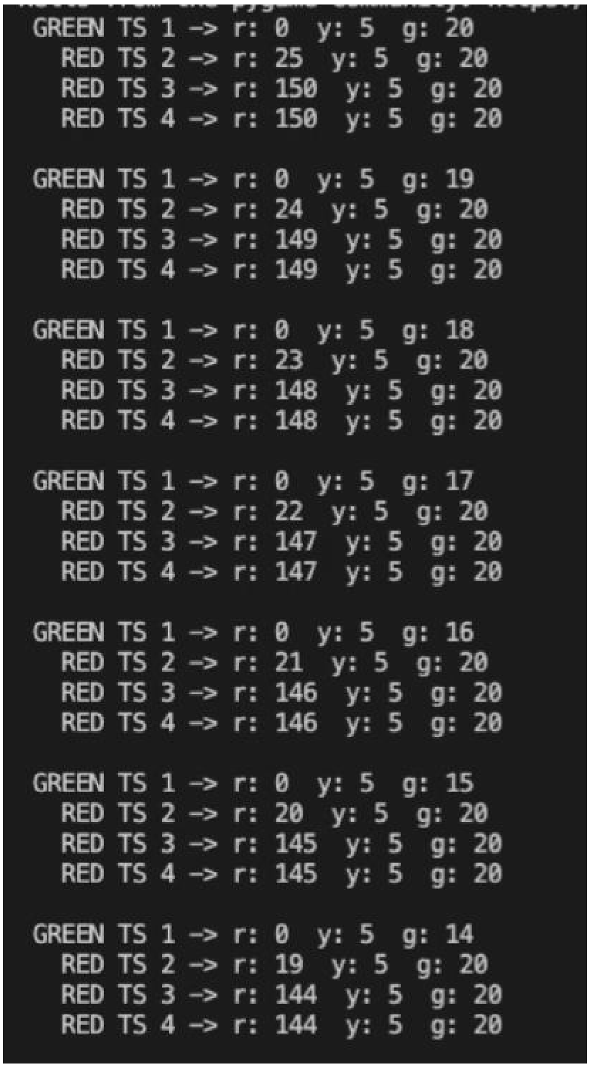

Fig (3). Signal Switching Algorithm

Initially, all signals are loaded with default values, only the red signal time of the second signal is set according to green time and yellow time of first signal.

The above image shows the real-time output of the Signal Switching Algorithm for the 38 proposed AI-Based Traffic Signal Control System. Each block of output represents the current state of all four traffic signals (TS1, TS2, TS3, TS4). For every signal, the three parameters are displayed:

r (Red Time) → Duration (in seconds) for which the signal remains red.

y (Yellow Time) → Fixed duration (generally 5 seconds) for transition between red and green.

g (Green Time) → Duration (in seconds) for which the signal remains green.

VII. CONCLUSION

This paper presented a computer vision-based adaptive traffic signal control system using YOLO and OpenCV. By adjusting signal timings based on real-time traffic density, the proposed system improves traffic efficiency and minimizes congestion. The system provides a practical solution for intelligent traffic management in urban environments.

VIII. FUTURE SCOPE

Future enhancements may include:

- Real-time deployment using live camera feeds.
- Emergency vehicle detection.
- Weather-based signal control.
- Integration with smart city ,infrastructure.

IX. REFERENCES

[1] A. S. Sastry, V. U. K., S. M. S., and S. B. S., "AI-Based Traffic Control System", *Journal of Emerging Technologies and Innovative Research (JETIR)*, vol. 9, no. 7, 2022.

[2] V. Jadhav, V. Ugale, R. Kadam, P. Patil, and T. Ghongade, "Artificial Intelligence Based Smart Traffic Management System using Video Processing", *International Research Journal of Engineering and Technology (IRJET)*, vol. 5, no. 3, 2018.

[3] S. Gong, Z. Huan, M. Ji, X. Chen, and Y. Bao, "ITLCS Based on OpenCV Image Processing Technology", *Journal of Physics: Conference Series*, vol. 2143, no. 1, pp. 012031, 2021.

[4] A. Abbas, U. Sheikh, F. Al-Dhief, and M. N. Haji, "A comprehensive review of vehicle detection using computer vision", *TELKOMNIKA (Telecommunication Computing Electronics and Control*), vol. 19, no. 3, pp. 838-850, 2021.

[5] M. Sharma, A. Bansal, V. Kashyap, P. Goyal, and T. Sheikh, "Intelligent Traffic Light Control System Based on Traffic Environment Using Deep Learning" in *Proceedings of the International Conference on Emerging Technologies*, 2020.

[6] T. Sable, N. Parate, D. Nadkar, and S. Shinde, "Density and Time-based Traffic Control System using Video Processing", *ITM Web of Conference*s, vol. 32, 2020.

[7] V. Zinchenko, G. Kondratenko, I. Sidenko, and Y. Kondratenko, "Computer Vision in Control and Optimization of Road Traffic", *IEEE Third International Conference on Data Stream Mining & Processing (DSMP)*, pp. 249-254, 2020.