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Smart Traffic Signal Control System Using Vehicle Detection and Machine Learning

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Abstract:
Traffic congestion is a major problem in urban areas due to the rapid increase in vehicles. Traditional traffic signal systems use fixed time intervals, which lead to inefficient traffic flow and increased waiting time. This paper proposes a Smart Traffic Signal Control System that dynamically adjusts signal timing based on vehicle density. The system uses video input to detect vehicles and applies a machine learning-based approach to predict the green signal duration. A rule-based model is used to calculate optimal signal timing. The system improves traffic efficiency, reduces congestion, and minimizes waiting time. The implementation is carried out using Python, and results show better performance compared to conventional systems.

Keywords —**Traffic Management, Machine Learning, Vehicle Detection, Smart Signal, Python**

I. INTRODUCTION

Traffic congestion has become a significant issue in modern urban areas due to rapid population growth and the increasing number of vehicles on roads. Traditional traffic control systems are based on fixed-time signals, which are not efficient in handling real-time traffic conditions. These systems often result in unnecessary delays, increased fuel consumption, and environmental pollution [1].

To address these challenges, smart traffic management systems have been developed using advanced technologies such as Machine Learning, Computer Vision, and the Internet of Things (IoT). These technologies enable real-time monitoring and analysis of traffic conditions, allowing for dynamic control of traffic signals and improved traffic flow [3][8].

Machine learning techniques play a crucial role in predicting traffic patterns and optimizing signal timings. Various approaches have been proposed for traffic signal optimization using intelligent algorithms, which significantly improve system efficiency [4]. Additionally, deep learning methods are widely used for real-time traffic flow prediction, helping authorities take proactive decisions [5].

Computer vision techniques are extensively used for vehicle detection and tracking. Modern object detection algorithms such as YOLO provide high accuracy and speed, making them suitable for real-time applications in traffic monitoring systems [2][6]. These methods help in identifying vehicle density and adjusting traffic signals accordingly.

Furthermore, adaptive traffic signal control systems dynamically adjust signal timings based on current traffic conditions, reducing congestion and improving road utilization [7]. By integrating these technologies, smart traffic systems aim to enhance transportation efficiency and support the development of smart cities.

This research paper focuses on the design and implementation of a smart traffic management system that utilizes machine learning and computer vision techniques for efficient traffic control. The proposed system aims to reduce traffic congestion, minimize delays, and improve overall traffic management

II. LITERATURE REVIEW

Several studies have been conducted in the field of smart traffic management systems using advanced technologies. A machine learning-based approach is used to improve traffic flow by dynamically adjusting signal timings [1]. Computer vision techniques are applied for vehicle detection and counting, which helps in estimating traffic density [2].

Intelligent traffic systems for smart cities use IoT and data analytics for better traffic control and monitoring [3][8]. Machine learning models are also used for optimizing traffic signals and reducing waiting time at intersections [4]. Deep learning techniques enable real-time traffic flow prediction for efficient decision-making [5].

Advanced object detection methods such as YOLO are used for accurate and fast vehicle detection in real-time applications [6]. Adaptive traffic signal control systems adjust signal timings based on current traffic conditions to reduce congestion [7].

Overall, these studies indicate that integrating machine learning, computer vision, and IoT improves traffic management, but there is still a need for a more efficient real-time adaptive system.

III. OBJECTIVE

The main objectives of the proposed smart traffic management system are as follows:

- To develop an intelligent traffic control system using machine learning and computer vision techniques.
- To detect and count vehicles in real-time using video input.
- To analyze traffic density at road intersections accurately.
- To dynamically adjust traffic signal timings based on traffic conditions.
- To reduce traffic congestion, waiting time, and fuel consumption.
- To improve overall traffic flow and road efficiency.
- To support the development of smart and sustainable cities.

IV. PROPOSED SYSTEM

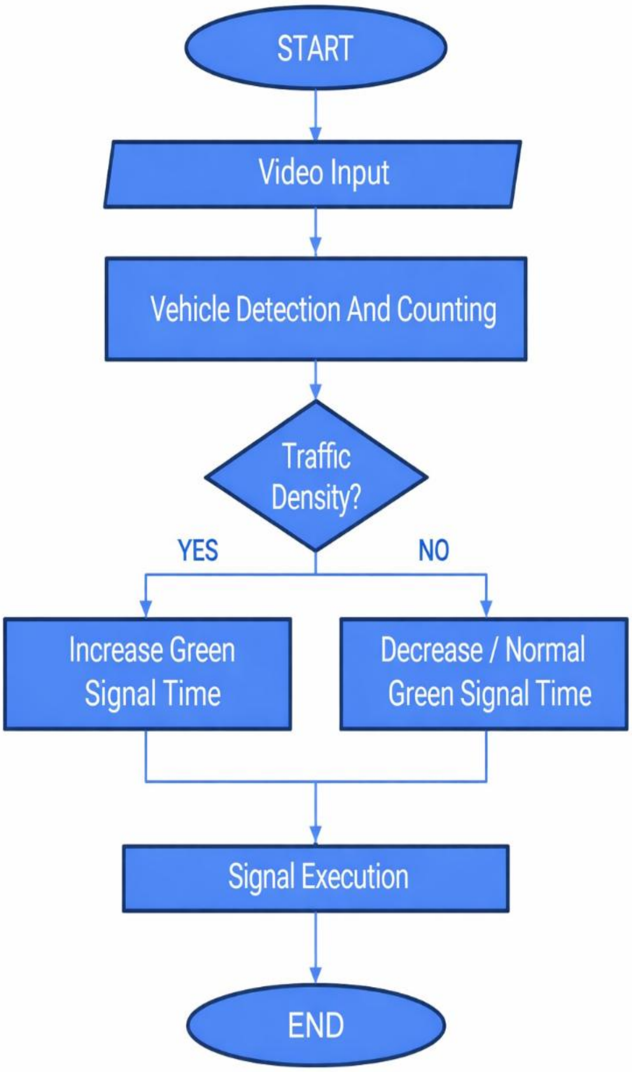


Fig. 1 Work Flow of Proposed System

The proposed system is an intelligent traffic management system that dynamically controls traffic signals based on real-time vehicle density using computer vision techniques. It aims to reduce congestion, waiting time, and improve overall traffic efficiency.

The system starts with capturing real-time video input from cameras installed at traffic intersections. The video is processed frame by frame to detect vehicles using object detection algorithms such as YOLO. The detected vehicles are counted to estimate traffic density on each road.

Based on the vehicle count, the system analyzes traffic density and makes decisions for signal control. The decision-making process is illustrated in the flowchart, where the system checks whether the traffic density is high or low. If the traffic density is high, the green signal duration is increased to allow more vehicles to pass. If the traffic density is low, the signal timing is reduced or maintained at a normal level.

After determining the appropriate signal timing, the system executes the signal control and updates the traffic lights accordingly. This process is repeated continuously, making the system adaptive to real-time traffic conditions.

The flowchart begins with the **START** node, followed by **Video Input**, where real-time traffic video is captured. The next step is **Vehicle Detection and Counting**, where vehicles are identified and counted using computer vision techniques.

After this, a **decision block (Traffic Density?)** is used to check the level of congestion. If the answer is **YES (high density)**, the system increases the green signal time. If the answer is **NO (low density)**, the system decreases or maintains normal signal timing.

Both decision paths then merge into **Signal Execution**, where the calculated signal timing is applied. Finally, the process reaches the **END** node. This flow ensures efficient and adaptive traffic signal control.

V. SYSTEM ARCHITECTURE

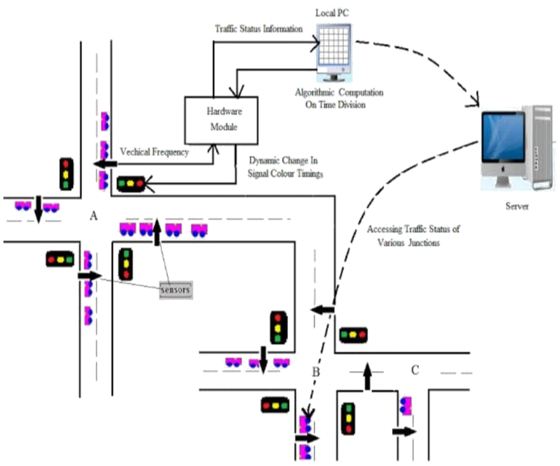


Fig. 2 .Traffic light signal control system

The system architecture of the proposed smart traffic management system is designed to process real-time traffic data and dynamically control traffic signals using computer vision and intelligent decision-making.

The architecture consists of multiple interconnected components that work together to ensure efficient traffic flow at intersections.

1. Video Capture Unit

Cameras are installed at different road intersections to continuously capture real-time traffic video. These cameras monitor vehicle movement from multiple directions and provide input data to the system.

2. Input Processing Module

The captured video is sent to the processing unit, where frames are extracted and pre-processed. This includes noise removal, resizing, and enhancement to improve detection accuracy.

3. Vehicle Detection Module

In this stage, computer vision algorithms such as YOLO are used to detect vehicles from the video frames. The system identifies different types of vehicles and tracks their movement.

4. Vehicle Counting & Density Estimation

After detection, the system counts the number of vehicles in each lane. Based on this count, traffic density is calculated for each direction of the intersection.

5. Decision-Making Module

The decision module analyzes traffic density data and determines signal timing. It applies logic such as:

- High density → Increase green signal time
- Low density → Decrease or maintain normal signal time

This module acts as the core controller of the system.

6. Signal Control Unit

The calculated signal timing is sent to the traffic signal controller. This unit updates the traffic lights (red, yellow, green) accordingly for each lane.

7. Monitoring System

A central monitoring system (computer/server) is used to supervise the entire process. It displays real-time traffic conditions and allows manual intervention if required.

VI. METHODOLOGY

The proposed smart traffic management system utilizes computer vision and machine learning techniques to dynamically control traffic signals based on real-time traffic conditions. The overall methodology is designed to ensure efficient traffic flow and minimize congestion at intersections.

Initially, traffic data is collected through surveillance cameras installed at junctions. The captured video stream is divided into frames and pre-processed to enhance image quality and remove noise. This step ensures better accuracy in subsequent processing.

Next, vehicle detection is performed using advanced object detection algorithms such as YOLO (You Only Look Once). The model identifies and classifies vehicles in each frame. Based on the detected objects, the system calculates the number of vehicles present, which is used to estimate traffic density.

The calculated traffic density is then analyzed to determine the level of congestion. A decision-making module classifies traffic conditions into categories such as high or low density. Based on this classification, the system dynamically adjusts the traffic signal timing. If the traffic density is high, the green signal duration is increased to allow more vehicles to pass. Conversely, if the traffic density is low, the signal timing is reduced or maintained at a normal level.

Finally, the optimized signal timing is executed at the traffic junction. This adaptive approach ensures better utilization of road infrastructure, reduces waiting time, and improves overall traffic efficiency. The methodology follows a systematic flow consisting of data acquisition, pre-processing, vehicle detection, density analysis, decision-making, and signal execution, resulting in an intelligent and real-time traffic management system.

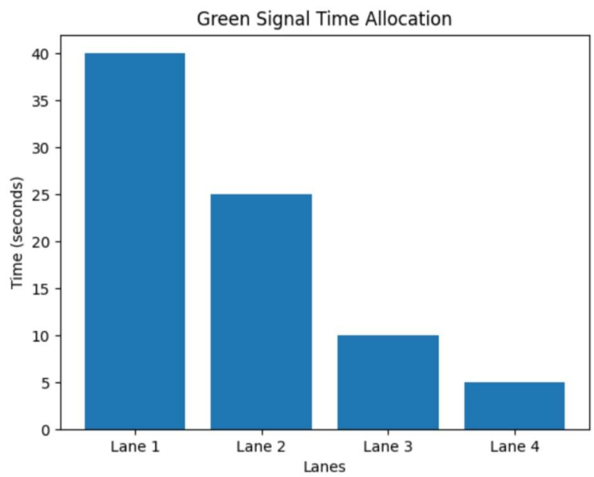
VII. IMPLIMENTATION

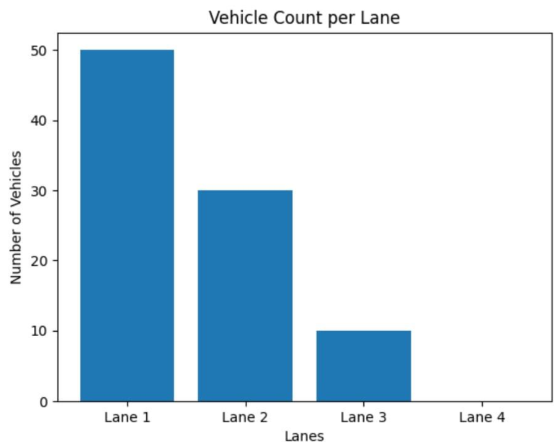
The proposed system is implemented using cameras, computer vision, and machine learning techniques. Traffic video is captured through cameras installed at intersections and processed using Python and OpenCV. A YOLO-based model is used to detect and count vehicles in real time.

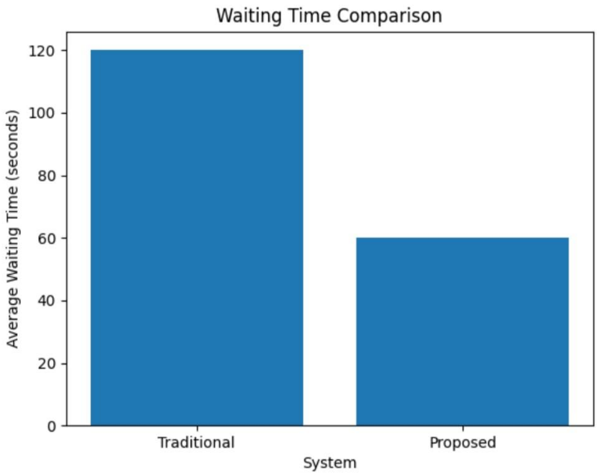
Based on the vehicle count, traffic density is calculated. A decision algorithm then adjusts the green signal timing dynamically—longer duration for high traffic and normal or shorter duration for low traffic. The updated signal timing is sent to the traffic controller for execution.

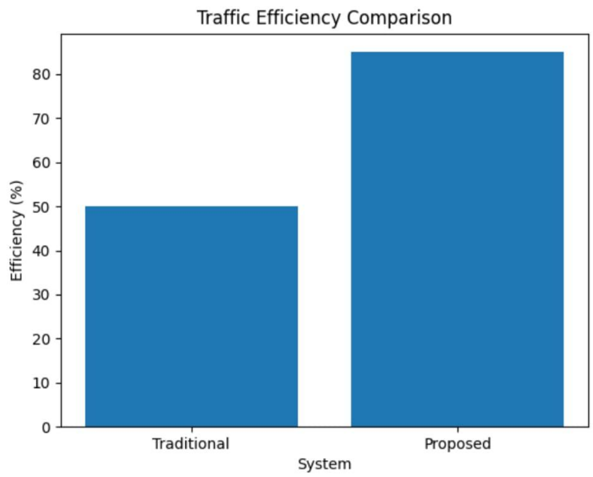
The system runs continuously to ensure real-time adaptive traffic management.

VIII. RESULT









The proposed intelligent traffic signal control system was tested under different traffic conditions with varying vehicle densities across multiple lanes. The system successfully detected vehicles in real time and adjusted signal timings dynamically based on traffic load. Lanes with higher vehicle density were allocated more green signal time, while lanes with fewer or no vehicles received minimal time, reducing unnecessary delays and improving traffic flow.

The performance of the system was compared with traditional fixed-time traffic signal systems. The results showed a significant reduction in average waiting time, as the adaptive approach minimized idle time at intersections. Additionally, the system demonstrated better utilization of available road capacity by distributing signal time efficiently according to real-time conditions.

Overall, the results indicate that the proposed system improves traffic efficiency and reduces congestion. The dynamic allocation of signal timings and the ability to respond to real-time traffic conditions make the system more effective than conventional methods, making it suitable for implementation in smart city environments.

IX. CONCLUSION

Smart Traffic Signal Control System provides an efficient solution for managing traffic based on real-time vehicle density. By dynamically adjusting signal timings instead of using fixed intervals, the system reduces waiting time and improves overall traffic flow.

The integration of vehicle detection, a rule-based machine learning model, and signal control demonstrates a simple yet effective approach to intelligent traffic management. The system is cost-effective, scalable, and can be further enhanced for real-world smart city applications.

X. ACKNOWLEDGMENT

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XI. REFERENCES

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