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Enhancing Traffic Management with Deep Learning Based Vehicle Detection and Scheduling Systems

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***Abstract*—Traffic congestion is an inescapable issue in contemporary urban life, leading to time wastage and increased accident risks. This paper presents an innovative approach that harnesses machine learning and computer vision to monitor vehicle density on roads and optimize traffic signal timings at intersections. With the escalating number of vehicles on the roads, traffic congestion has become a critical problem. Queue lengths at intersections surge with rising traffic flows, rendering traditional traffic system inefficient. In response, this paper introduces a real-time traffic light control algorithm that adapts to traffic flow. utilizing computer vision and machine learning to discern traffic flow characteristics at signalized road intersections, employing state-of-the-art real-time object detection using a deep Convolutional Neural Network known as YOLO. YOLOcan be implemented on embedded controllers through Transfer Learning, enabling deep neural network capabilities even on limited hardware resources. The proposed system comprises a camera system capturing real-time video feeds of roads, which are then processed by a machine learning model to detect vehicle density. The scheduling system dynamically adjusts traffic signal green times based on observed vehicle density. Furthermore, we conduct an in-depth analysis using various machine learning models to predict traffic patterns. This analysis encompasses a performance comparison of models like K-Nearest Neighbor, random forests, and decision trees to forecast traffic volume with respective accuary of 53.43%, 98.88%, 99.09%. The study also investigates the influence of parameters such as time of day, weather and temperature conditions. The primary objective of our system is to optimize traffic flow by minimizing waiting times at traffic signals, thereby reducing congestion and enhancing the overall commuting experience for drivers.**

Keywords—Intelligent Transport System, Machine Learning, CNN – Convolution Neural Network, Reinforcement Learning, You Only Look Once - YOLO, Deep Learning.

I. Introduction

Traffic congestion presents a major challenge in urban areas worldwide, including the United States. While previous studies have assessed the economic costs of congestion, such as wasted fuel and time, fewer have delved into quantifying the associated public health impacts. Furthermore, understand-ing the relative magnitudes of economic and public health consequences and their variations across different urban areas remains largely unexplored. These variations are likely influenced by factors such as road infrastructure, popula- tion density, and atmospheric conditions affecting pollutant formation[1][2]. A three-tier solution taxonomy: traffic data collection tools, machine learning algorithms for analyzing traffic patterns, and traffic police scheduling strategies. The survey showcases case studies to demonstrate the applica-bility of these strategies in different domains. The survey includes case studies to illustrate the practical implementation of these strategies in different domains, offering a comprehen- sive overview of state-of-the-art approaches to enhance traffic discipline and efficiency [3][4][5].

various machine learning approaches for network traffic analysis, highlighting the importance of traffic analysis for network performance and security evaluation. With the growing network traffic and the rise of artificial intelligence, new methods are needed to detect intrusions, analyze malware behavior, and categorize Internet traffic. The paper presents a review of techniques used in traffic analysis [6][7]. Intelligent Transport System (ITS) plays a crucial role in achieving accurate and advanced traffic predictions, aiming to enhance commuting experiences and administrative efficiency. Extensive research and continuous evolution in the field have resulted in a substantial body of literature on traffic prediction, spanning several decades[8][9].

The mechanism, called MSR2C-ABPNN, which utilizes Artificial Neural Networks (ANN) to predict and control traffic congestion, thereby enhancing the efficiency of road traffic. By employing the backpropagation algorithm to train the neural network, the system aims to improve the comfort of travelers and facilitate intelligent transportation decision-making. The use of neural networks offers a promising approach to address traffic situations [10][11].

A deep CNN counts vehicles on a road segment using video images collectively, without individual detection, replicating human-like counting methodology [12][13]. An automated traffic light system that utilizes image processing and machine learning techniques to optimize green signal timing based on the number of vehicles detected in each lane. The system employs YOLO darknet weights and labels with categorized classes for vehicle identification. Implemented using Raspberry Pi 3B+ and a rotatable webcam, the system achieves 100% accuracy in vehicle counting and optimally setting green signal time to minimize waiting time [14][15]. RL algorithm for Partially Detected Intelligent Traffic Signal Control (PD-ITSC) systems addresses scenarios where only a small portion of vehicles are detected by the ITSC system. The system effectively reduces average waiting time and travel time for vehicles at intersections, even with low detection rates, across different car flows and road network types [16][17][18][19]. New algorithm leveraging image processing is proposed for accurate vehicle detection during night-time conditions. The RGB image is segmented into individual channels and converted to binary images using different thresholds. Traffic density is estimated and compared to a reference value, determining the optimal green light duration based on traffic density [20].

The proposed system combines the advantages of machine learning, open computer vision, and a convolutional neural network (CNN) to create an efficient traffic management app. By accurately detecting real-time vehicle density through the CNN's analysis of video feeds, the app optimizes green light timings at intersections, reducing wait times and improving traffic flow. Furthermore, by utilizing various machine learning models and considering factors like time of day, weather,and traffic conditions, the system enhances traffic volume predictions and fine-tunes signal timing optimization. Overall, this integrated approach aims to significantly alleviate traffic congestion, providing drivers with a smoother and more pleasant commuting experience.

II. DATA COLLECTION AND PROCESSING

In the process of collecting data on traffic volume and density, two main approaches can be utilized: past traffic data and real-time image data. Past traffic data, obtained from sources like traffic sensors, GPS data, and social media feeds, offers reliability and accuracy but may not capture dynamic changes due to external factors.The dataset also includes various parameters such as time of day, weather and temperature conditions. On the other hand, real time image data acquired through CCTV cameras, drones, or satellite imagery allows for responsiveness to immediate traffic patterns, although it may have limitations in accuracy. Following data collection, statistical methods and machine learning algorithms, such as K-Nearest Neighbors, Random Forest, Decision Trees, and Convolutional Neural Networks (CNNs), can be employed for data processing, analysis, and prediction of real-time traffic patterns and vehicle density. CNNs, specifically, excel in estimating vehicle density by leveraging large datasets of traffic images and can provide improved accuracy and efficiency. However, challenges like the requirement for high-quality training data and potential biases in the network should be taken into consideration when utilizing CNNs for this purpose.The integration of these approaches offers valuable insights for traffic management, monitoring, and studying the impact of congestion on the environment and human health.

III. METHODOLOGY

To effectively manage traffic flow, a systematic approach can be adopted as shown in figure 1. It starts with obtaining a comprehensive traffic dataset that includes relevant information such as vehicle counts and congestion levels. Thisdata is then processed to clean and organize it, preparingit for analysis. Next, a suitable machine learning model is selected and trained using the processed data to predict traffic patterns and estimate vehicle density. The trained model is evaluated for its accuracy and performance. Based on the predictions, the appropriate green time for traffic signals is calculated, considering factors like vehicle density and traffic flow. Threshold times are checked to ensure optimal signal timings, with adjustments made if necessary. Finally, traffic lights are scheduled according to the determined green times, either through synchronized signals or adaptive control sys- tems. This data driven approach allows traffic management systems to make informed decisions, optimize signal timings, and ultimately improve traffic flow and reduce congestion on road networks.

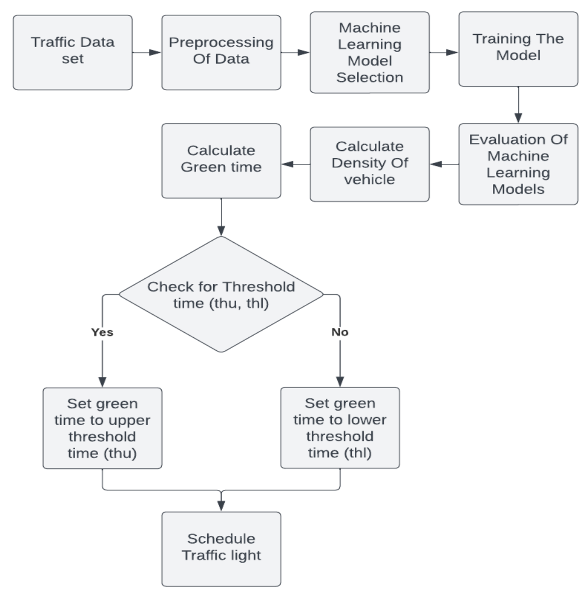

Fig. 1. Flow Chart for scheduling algorithm

IV. System Architecture

1) Develop a mobile app that uses a convolutional neural network (CNN), specifically YOLO, to detect the number of cars from the image captured by a camera mounted near the traffic signal as shown in figure.
2) Once the app detects the number of cars, a mathematical equation 1 is used to calculate the optimal green signal time for the traffic signal using equation 4.1. convert

green signal time into millisecond as required by micro-controller.

$$GT = \frac{VC1}{VCT} \times (4 \times AGT) \quad (1)$$

where,
GT = Green Time
VC1 = Vehicle Count of One Road
VCT = Total Vehicle Count of All Roads
AGT = Average Green Time

3) Retrieve the data from Firebase using a NodeMCU, an open-source firmware and development kit that is used for building IoT (Internet of Things) devices.
4) Use the NodeMCU to activate the traffic signal light by sending the updated green signal time to the traffic signal
5) Continuously monitor and adjust the green signal time based on real-time traffic conditions.

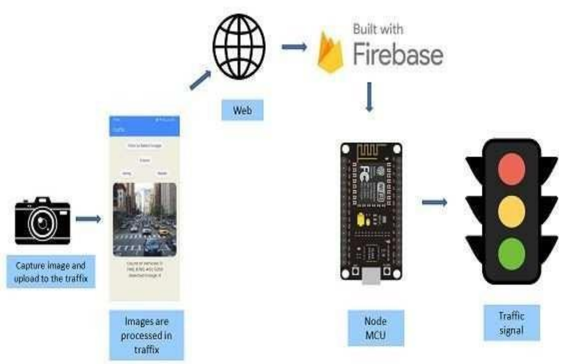

Fig. 2. System Architecture for traffic light signal

V. Results and Analysis

The paper aimed to predict traffic density using three algorithms: Random Forest, K-Nearest Neighbor, and Decision Tree and a Comparison of Performance of Machine Learning Algorithm is shown in figure 3. The results showed that the Decision Tree algorithm had the highest accuracy rate of 99% as shown in Table 1 and figure 4 shows the confusion matrix for Decision Tree.

TABLE I
Performance Of Machine Learning Algorithm

Sr.No	Algorithm	Accuracy in percentage
1	K-Nearest Neighbour	53.43
2	Random Forest Algorithm	98.88
3	Decision Tree Classifier	99.09

Using a Convolutional Neural Network (CNN) for vehicle counting provides real-time analysis of images or video frames captured from road cameras, allowing immediate and accurate counting of vehicles. With its ability to detect and localize vehicles, CNNs can handle varying conditions, making them

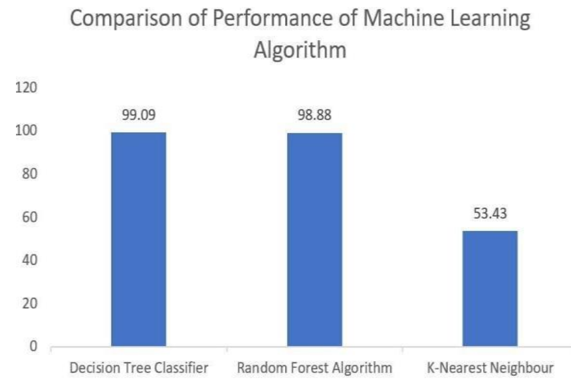

Fig. 3. Comparison of Performance of Machine Learning Algorithm

robust for vehicle counting tasks. The scalability of CNN-based systems allows for efficient monitoring of high traffic areas using multiple cameras, while the flexibility in deployment enables customization based on specific monitoring needs.This data-driven approach directly observes and analyzes real-time vehicle movements, offering valuable insights for dynamic traffic management and infrastructure planning.

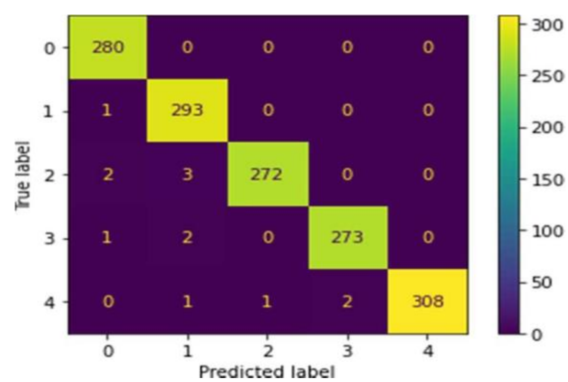

Fig. 4. performance analysis Decision Tree algorithm

considering the above observation, the YOLOv5 convolutional neural network is used to detect the number of vehicles in each image as shown in figure 6 in the Flutter based mobile application, which then calculated the green time (mileseconds) for each traffic light. The green time was then sent toFirebase, which in turn passed it to the NodeMCU. The trafficlights were then scheduled based on the green time calculated by the app as shown in figure 7.

TABLE II
Time Generation And Scheduling Of Green Signal Using YOLOv5 for moderate traffic

Lane	No. of Vehicles	Predicted No. of Vehicles	Green Time (sec)	Wait Time (sec)
1	26	26	63	0
2	30	30	74	63
3	28	28	73	136
4	14	14	38	209

The implementation is carried out in real time for cap-turing the number of vehicle in the lane and the perfor-

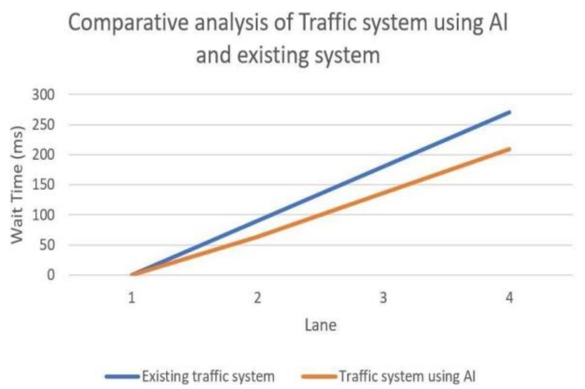

Fig. 5. Comparative analysis of Traffic system using AI and existing system

TABLE III
TIME GENERATION AND SCHEDULING OF GREEN SIGNAL USING YOLOV5 FOR LOW TRAFFIC

Lane	No. of Vehicles	Predicted No. of Vehicles	Green Time (sec)	Wait Time (sec)
1	6	6	40	0
2	7	7	46	40
3	8	8	53	86
4	15	15	90	139

mance measures are tabulated in table 2, 3 and 4. The table presents essential traffic data for an intersection, including the number of lanes, current vehicle count, predicted vehicle count, green time for each lane, and wait time experiencedby vehicles. This information allows traffic engineers and planners to analyze the traffic flow, identify congestion, and optimize signal timings. By adjusting the green times based ontraffic volume and predictions, authorities can enhance traffic efficiency, reduce wait times, and improve overall intersection safety for drivers and pedestrians. The Comparative analysis of Traffic Flow AI with existing system as show in figure 5. The graph compares the wait times at an intersection between the existing traffic flow system and the implementation of a traffic flow AI system. The x-axis represents the number of lanes, and the y-axis shows the corresponding wait times in seconds. The graph demonstrates that the traffic flow AI system significantly reduces wait times compared to the existing system across all lane counts. By dynamically adjusting signal timings based on real-time data and traffic patterns, the AI system improves traffic efficiency, minimizes congestion, and provides a smoother driving experience for commuters. Overall, this paper successfully utilized machine learning algorithms to predict traffic density, detect vehicles in images and effectively manage traffic lights. The use of YOLOv5 and Flutter allowed for efficient and accurate counting of vehicles

TABLE IV
TIME GENERATION AND SCHEDULING OF GREEN SIGNAL USING YOLOV5 FOR HEAVY TRAFFIC

Lane	No. of Vehicles	Predicted No. of Vehicles	Green Time (sec)	Wait Time (sec)
1	30	30	45	0
2	36	36	55.03	45
3	42	42	64	100.03
4	49	49	74	164.03

and calculation of green time, respectively. The integration of Firebase and NodeMCU ensured smooth communication between the various components of the system.

Figure 8 shows the Traffic Light setup where live demo for traffic light scheduling has been implemented with the help of machine learning algorithms.

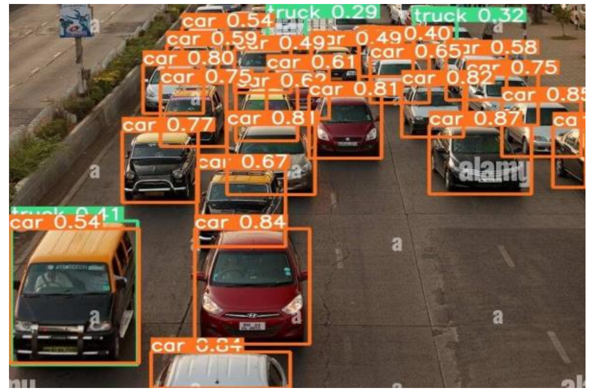

Fig. 6. Vehicle Detection using yoloV5

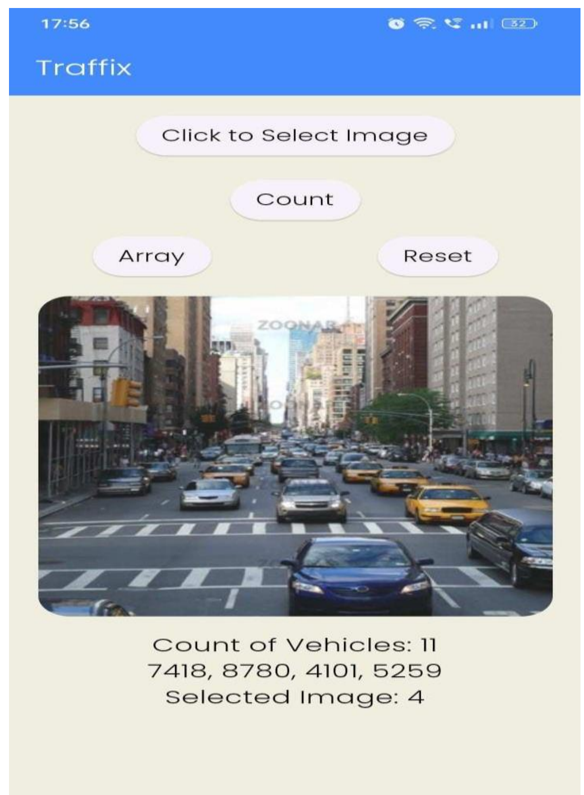

Fig. 7. Calculation of green time using mobile application

VI. CONCLUSION

The suggested system, that employs machine learning and open computer vision to determine the number of vehicles on the road and modify the green light period of the traffic

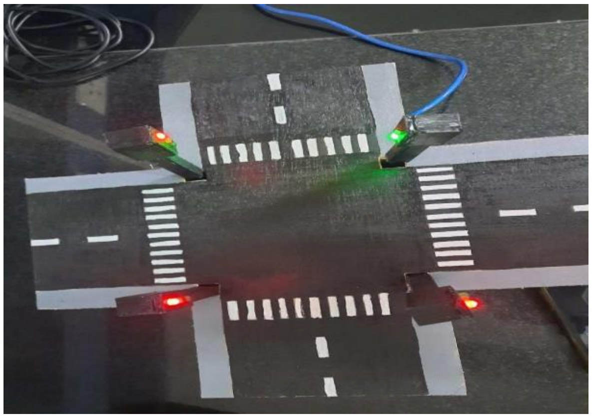

Fig. 8. Implementation of traffic light setup

signal appropriately, has proved to be efficient in increasing traffic flow and decreasing congestion. The live demo of the system showcased its ability to accurately detect the number of vehicles and adjust the traffic signal's green light time, leading to a reduction in waiting times and improved traffic flow. The analysis of different machine learning models for traffic prediction also provided valuable insights into the factors that influence traffic flow, which could be used to further enhance the system's accuracy. Overall, this research presents a promising solution to the problem of traffic congestion and highlights the potential of machine learning and computer vision in improving transportation systems.

VII. FUTURE SCOPE

Generative AI, such as GANs and VAEs, can enhance research on traffic congestion and commuting experiences. It enables data augmentation for robust machine learning models, simulates diverse traffic patterns for system evaluation, detects anomalies for adaptive signal control, creates predictive models for congestion mitigation, and generates interactive visualizations for analysis and communication. By leveraging generative AI techniques, researchers can improve data quality, optimize traffic management strategies, and provide valuable insights for stakeholders and policymakers to enhance traffic flow and the overall commuting experience.

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