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Smart Traffic Management System using Image Processing

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Abstract:** Delayed traffic and a rise in fuel contamination in cities happen due to fixed-time traffic signals that do not adapt to demand. As a result, a new traffic control system that combines Deep Learning and Machine Learning has been designed. Using predefined YOLOv8 Nano and EfficientDet-D0 models, the video from surveillance cameras is examined to find vehicles and determine their speed. YOLOv8 Nano was selected because it's fast and accurate which lets us input its predictions into a Random Forest Regressor that controls the green light timing. Because this system focuses on busier places, it decreases wait times and helps signals run more efficiently. Because of this, cities use much less energy and generate less air pollution, contributing to smarter city designs.

***Keywords:** Deep learning, Machine learning, YOLOv8 Nano, EfficientDet-D0, Random Forest Regressor, Traffic congestion, Smart traffic control, air pollution reduction.*

I. INTRODUCTION

With urban areas rapidly expanding, city streets are becoming increasingly packed with vehicles, posing a significant challenge for municipal management. The increase in vehicles triggers environmental issues which generate transportation issues and weaken the operational performance of public transportation. Urban demographics increase the demand for efficient traffic system management of modern city infrastructure. The current traffic control infrastructure deploys fixed signal timing schedules for pre-established protocols in their operation. Previous traffic control strategies once functioned well due to static signal schedules but become insufficient in present times because traffic patterns keep evolving continuously. During some periods roads become heavily congested but many roads remain empty throughout the day. Vehicles face unnecessary wait times at red lights because these systems lack real-time adaptation capability even though there is no cross-traffic present. The delay as well as extra fuel usage and environmental pollution result from these existing rigid systems, as discussed in [1] and highlighted in [4].

Yet, these shortcomings can be solved through Artificial Intelligence (AI) implementation for traffic management. A trained Deep Learning model with image recognition processing on-site at the intersection can accomplish vehicle detection and delay measurement, as shown in [5] ad further supported in [6]. Coupled with a trained Machine Learning model that detects patterns and makes predictions, such programs can dynamically change intersection signal durations based on real-time situations [3].

These AI-enhanced solutions bring traffic-controlling intersections into the new age of urban transportation. As cities expand, the ability to implement solutions such as these into traffic management brings the possibility of more sophisticated systems as a baseline for future transportation efforts [2].

II. BACKGROUND OF THE STUDY

The growth of cities through modern urbanization created an explosive rise in vehicle density which leads to serious levels of traffic congestion throughout urban areas [1]. Longer journeys and higher fuel usage together with growing emissions levels have resulted from modern urban expansion. The expansion of urban areas creates an urgent need for better traffic solutions which can adapt to growing requirements [4]. Traffic control systems operating today function via built-in schedules which do not adapt properly to actual traffic situations in real-time. Vehicle idling grows excessive and waiting periods lengthen because the fixed structure creates inefficient use of road infrastructure [6]. The increasing urban challenges drive cities world-wide to implement innovative traffic solutions which monitor changing conditions [3]. Modern traffic management systems seek to decrease transportation delays as they enhance transit efficiency by producing fewer negative impacts on urban environments [9].

Each advancement in digital technology naturally increases the urgency to perform adaptive traffic control system implementation. Complex transportation demands need to be addressed by such systems for them to establish their role in building sustainable safe transport networks [8].

III. METHODOLOGY

Data collection for the Smart Traffic Management System starts with the use of deep learning models, as illustrated in Fig.1. After that, it implements traffic signal control using an optimal detection algorithm and AI to help the flow and to minimise pollution.

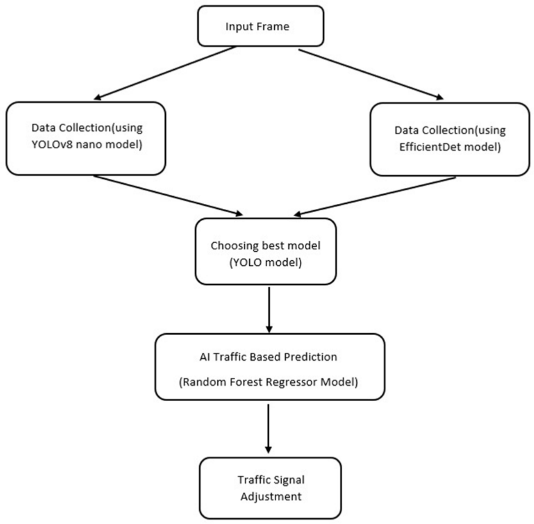

Fig.1 Methodology

A. Data collection using YOLO model

YOLOv8 Nano is an object detection algorithm designed to locate vehicles and people easily in the input frames it receives. It shows bounding boxes, gives each one a classification and gives a score of how confident it is in the label. The fact it takes up little space allows it to run smoothly on devices with basic processors and still find objects accurately.

B. Data collection using EfficientDet model

EfficientDet uses both BiFPN and EfficientNet to achieve accurate detection of objects at several scales. It accurately det ects small and close objects using both their shape and meaning. Results comprise the object type, its location and a confidence rating.

C. Choosing Best Model (YOLO model)

A speed, precision and consistency analysis was carried out for YOLOv8 Nano and EfficientDet. YOLOv8 Nano was chosen because it delivers excellent real-time performance. It has the needed sensitivity for the system's efficiency objectives.

D. AI Traffic Based Prediction (Random Forest Regressor Model)

To decide on the best traffic signal duration, the Random Forest Regressor uses both old and present traffic information. The system uses various decision trees to ensure the right signals are given depending on the number of cars and how jammed the street is. As a result, traffic management can be varied in different situations.

E. Traffic Signal Adjustment

The system alters the duration of traffic lights to solve problems caused by waiting and traffic congestion. When the system sees a group of people, it gives them a green light and changes as needed. It ensures that traffic moves safely and smoothly with only limited supervision.

IV. PROPOSED SYSTEM

The proposed Smart Traffic Management System based upon the use of Artificial Intelligence (AI), Deep Learning (DL) and Machine Learning (ML) with image processing to improve the urban traffic flow. This system then adjusts signal timings dynamically, in real time, using real time congestion data instead. Live video feeds from the surveillance cameras mounted at intersections are analyzed in order to extract traffic variables including vehicle count and speed. Two pre-trained object detection object detection models, YOLOv8 Nano and EfficientDet-D0 pretrained on the COCO dataset were used by the system. For real time deployment YOLOv8 Nano is selected for its high accuracy and low computational requirements. Although fast small object detection, EfficientDet-D0 is slow.

Speed estimation as well as congestion assessment is made possible by vehicle tracking across frames. Historical and current traffic data are fed into a Random Forest Regressor that predicts optimal signal durations given a metric that balances total travel time against maximum queueing time. They then automatically adjust signal phases to create priority for congested lanes and reduce wait time and improve flow.

The system is real time and autonomous, requires no intervention by man, resulting in reducing vehicle idle time, fuel consumption and emissions, increasing traffic efficiency, air quality and road safety.

V. IMPLEMENTATION

The implementation phase ensures intelligent traffic management by integrating three key algorithms. Real-time vehicle detection, estimating vehicle speeds and studying congestion is handled by YOLOv8 Nano and EfficientDet-D0, while a Random Forest Regressor is used to predict the best green light duration for different traffic situations. When combined, these models build an adaptable and responsive control system for signals.

1) Algorithm - 1: YOLOv8 implementation of Vehicle Detection, Speed Estimation and Congestion Level

The real time vehicle detection in this algorithm is performed using a lightweight YOLOv8 Nano model pre trained on COCO dataset. It detects and counts car, bus, truck and motorcycle types per frame of video. Once detection is done, centroids are calculated to track the vehicle movement and speed can be estimated by the use of frame displacement and FPS. The model is efficient for real time deployment on limited hardware in that the congestion level is dynamically determined as a function of vehicle count.

2) Algorithm - 2: EfficientDet-D0 for Vehicle Detection and Congestion Level

To identify vehicles throughout a video frame sequence, this algorithm makes use of the EfficientDet-D0 model which was first pre trained on the COCO dataset. The detection of small objects in different scenes is effective and robust in moderately crowded situations. Congestion is estimated by centroid displacement for vehicle tracking. It’s more computationally intensive then YOLOv8, but works well for detecting various object types in structured scenes.

3) Algorithm - 3: YOLOv8 and Random Forest Regressor for Dynamic Signal Prediction

In this synthesis, the vehicle detection process is leveraged by using YOLOv8, whereas optimal green light duration is predicted by a Random Forest Regressor. The signal timing decisions are made based on features such as vehicle count, congestion level and average speed. The model keeps signal phases dynamic and overlays predicted traffic control instructions over the video stream, providing useful, real time adaptive signal management.

VI. RESULTS

A. Results of YOLOv8 Model

YOLOv8 Nano successfully detected cars, buses and trucks in real time, even when some part of the vehicle was hidden (as shown in Fig. 2). It worked successfully with lots of traffic, requiring almost no resources which was perfect for keeping it on all the time [4].

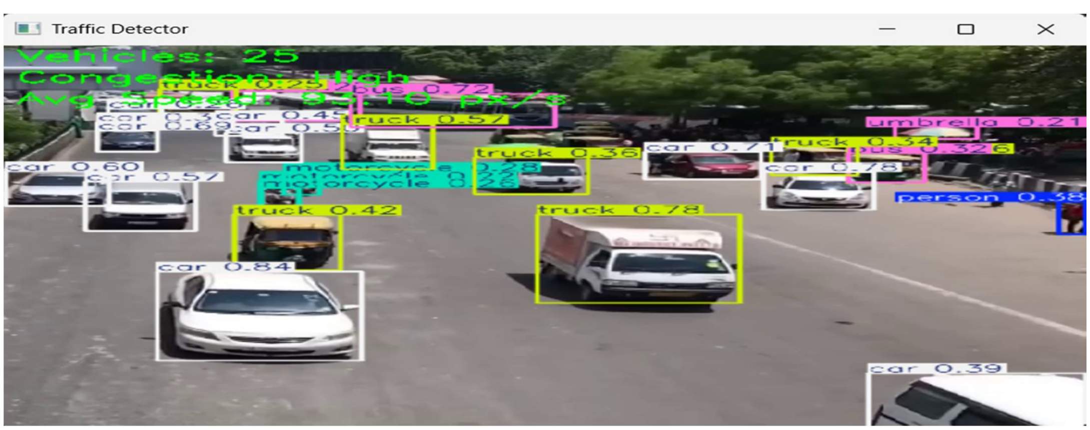

Fig 2 Traffic Detection with YOLO

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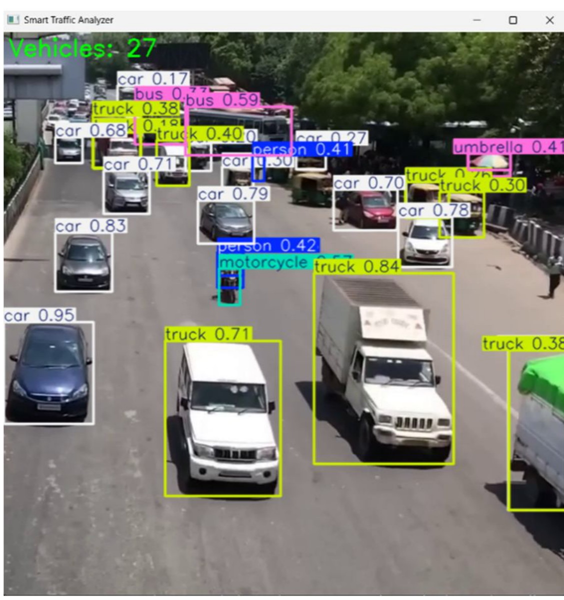
B. Results of EfficientDet-D0 Model

In moderate traffic (as shown in Fig. 3), EfficientDet-D0 spotted motorbikes and bicycles well, yet in really crowded areas, there were missed vehicles due to the congestion [6].

Fig 3 Traffic Detection with EfficientDet

C. Results of YOLOv8 + Random Forest Regressor Models

According to the integrated model, 42 cars were considered and the green light was set for 107 seconds (Fig. 4, Fig. 5). It made changes to traffic patterns real time as needed which supported better operation of the intersection without much involvement from humans [1].



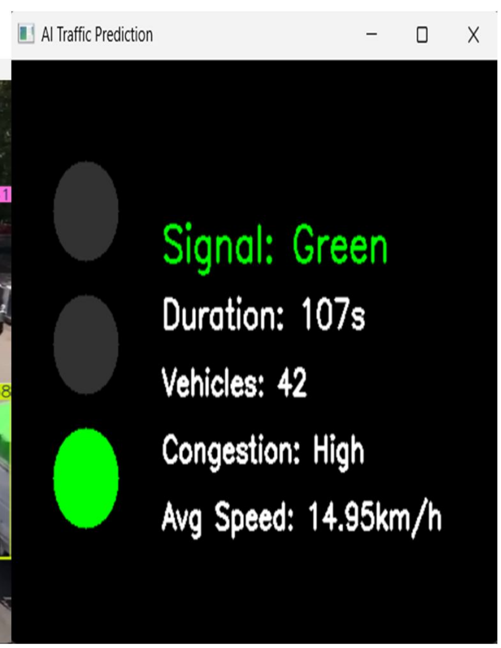


Fig 4 Smart Traffic Analyzer | Fig 5 AI-Based Traffic Signal Control

D. Comparative Analysis of Results for Algorithm 1 and 2 :

The overall results in Fig. 6 reflect that YOLOv8 outperformed EfficientDet when it came to counting accuracy and produced fewer errors and more reliable results in situations with lots of traffic which makes it more suitable for traffic systems used in real time [9].

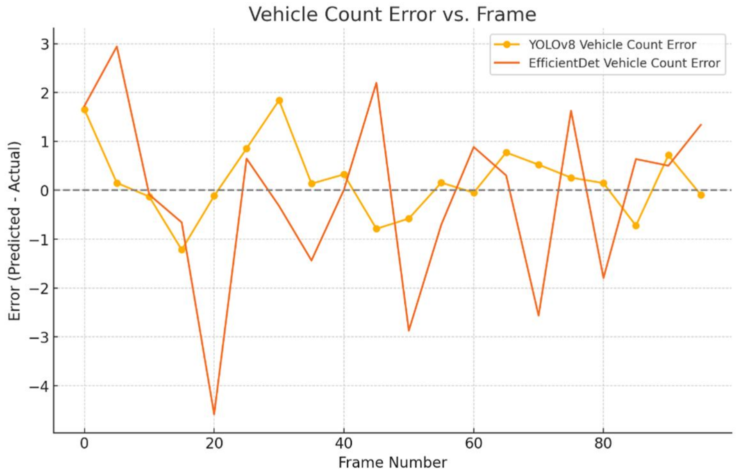


Fig 6 Traffic Error Metrics

VII. CONCLUSION AND FUTURE ENHANCEMENTS

In this study, a smart traffic management system with real time vehicle detection implemented using YOLOv8, EfficientDet and traffic signal optimization utilizing a Random Forest Regressor is presented. Based on live traffic flow and speed the system adapts signal timings, resulting in decreased congestion, less waiting time, less emissions and more traffic efficiency. Future work involves embedding road sensors and IoT devices to improve precision, coordinating multiple intersections for continuous traffic flow, adjusting signal behavior according to weather conditions, giving emergency vehicles the first right of way and designing a decentralized IoT based architecture for smarter traffic control city wide.

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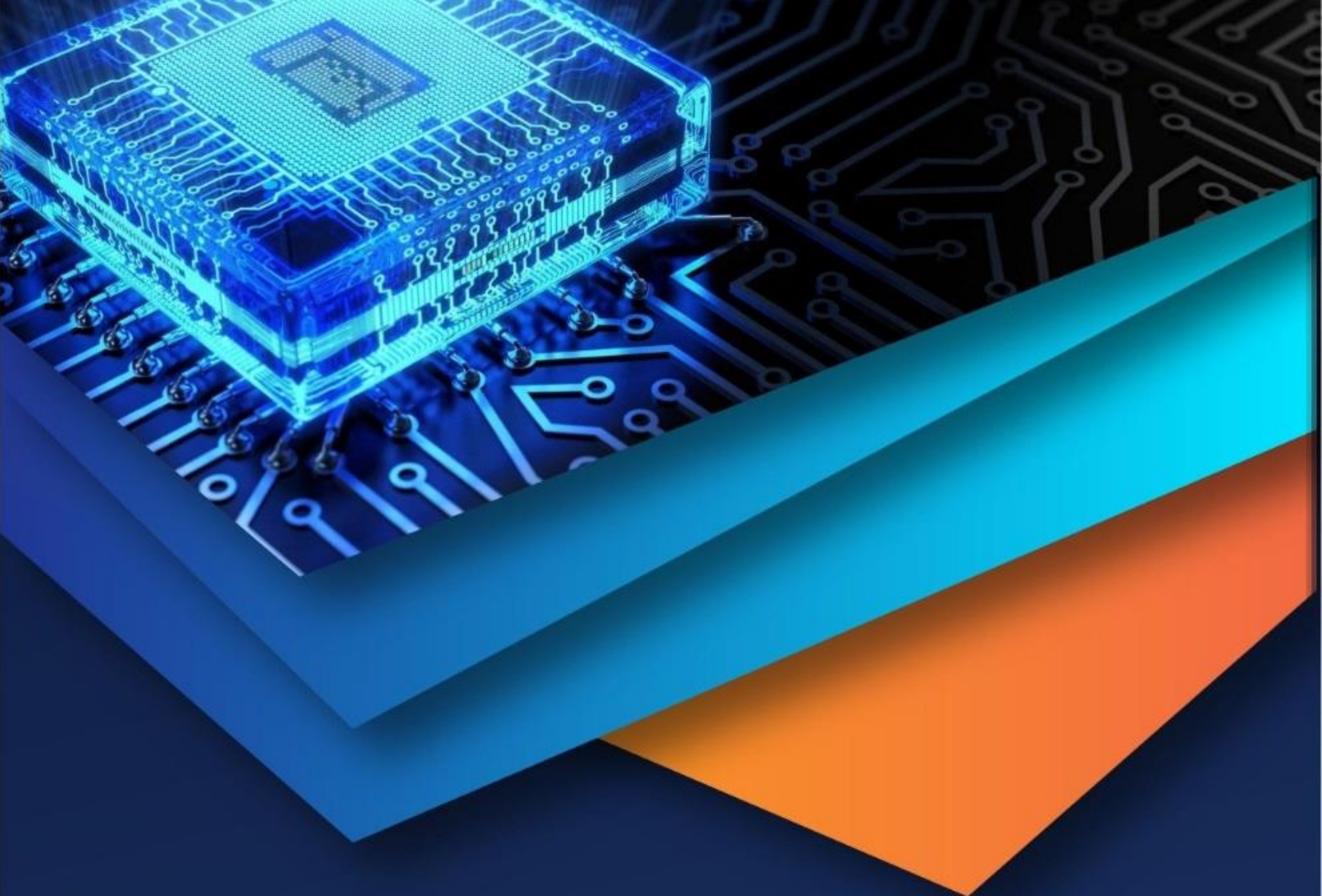

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