Vehicle Detection and Speed Estimation System

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ABSTRACT: Vehicle-related violations, including over-speeding, contribute to nearly 25% of urban traffic incidents, leading to escalating enforcement costs globally. Traditional vehicle detection and speed estimation methods face challenges such as low-light conditions, occlusions, and high-speed motion, resulting in reduced accuracy. The project presents a Vehicle Detection and Speed Estimation System utilizing YOLOv8 for real-time vehicle recognition and a centroid-based tracking algorithm for speed estimation. The system achieves over 95% detection accuracy and processes frames within seconds, ensuring efficient traffic monitoring. By automating vehicle detection and speed estimation, the system minimizes manual intervention, enhances enforcement efficiency, and improves road safety. The system's implementation contributes to smart traffic management, law enforcement, and fleet monitoring, making it a valuable tool for modern transportation infrastructure.

KEYWORDS: Vehicle detection, speed estimation, YOLOv8, centroid-based tracking, real-time processing, traffic monitoring, law enforcement, smart traffic management, accuracy evaluation, enforcement efficiency.

I. INTRODUCTION

The Vehicle Recognition and Speed Estimation System is an advanced computer vision-based solution designed for real-time vehicle detection, speed monitoring, and traffic violation tracking. As urban traffic congestion and road safety concerns continue to rise, there is an increasing demand for automated, intelligent traffic monitoring systems that can efficiently detect violations and improve compliance with traffic regulations. This system integrates YOLOv8 (You Only Look Once) for high-accuracy vehicle detection and a centroid-based object tracking algorithm to continuously monitor vehicle movement. By leveraging deep learning and image processing techniques, the system ensures efficient, high-speed, and accurate vehicle tracking in diverse traffic conditions, including high-speed highways, dense urban roads, and low-visibility environments.

One of the key features of this system is precise speed estimation, achieved through frame-by-frame tracking and speed calculations using known real-world distances and timestamps. This technique ensures high accuracy, making it suitable for monitoring vehicles across multiple lanes, detecting erratic driving behaviour, and flagging potential rule violations in real time. Unlike traditional radar-based speed cameras, which require dedicated hardware installations, this system can work with standard traffic surveillance cameras, making it a cost-effective and scalable solution for smart city applications.

The system has a broad range of applications in law enforcement, traffic monitoring, and fleet management. In law enforcement, it facilitates automated speed regulation, violation detection, and evidence collection. By processing real-time video feeds, the system enables authorities to identify speeding vehicles, issue automated citations, and improve road safety without requiring manual monitoring.

Beyond law enforcement, the system plays a crucial role in fleet management, where logistics and transportation companies can utilize it to monitor vehicle speeds, track driver behaviour, and optimize fleet performance. The system also maintains a structured record of speeding violations, allowing seamless integration with traffic databases, compliance reporting tools, and legal enforcement systems.

This paper provides a comprehensive exploration of the system architecture, implementation, and evaluation, detailing its efficacy, accuracy, and real-world impact. Through rigorous testing and validation, the Vehicle Recognition and Speed Estimation System demonstrates its potential to revolutionize modern traffic monitoring, assist law enforcement, and contribute to the development of intelligent transportation systems. The findings highlight how advanced computer vision and deep learning technologies can be leveraged to enhance road safety, streamline traffic enforcement, and create more efficient and compliant transportation networks.

II. RELATED WORK

The field of vehicle recognition and speed estimation has been extensively studied, with various approaches developed to enhance traffic monitoring, law enforcement, and road safety. This section provides an overview of existing methods and technologies in the domain.

Traditional Speed Monitoring Techniques: Conventional speed enforcement relies on radar-based systems, inductive loop sensors, and manual speed traps. Radar and LiDAR-based speed guns measure vehicle speeds with high accuracy but require manual operation and enforcement. Inductive loop sensors embedded in roads provide real-time traffic data but require high installation and maintenance costs. While these methods have been widely used, they struggle with scalability, automation, and real-time processing.

Computer Vision-Based Approaches: With advancements in computer vision and deep learning, video-based speed estimation has become a promising alternative. Traditional image processing techniques, such as background subtraction, optical flow, and edge detection, have been used to track vehicles, but they often fail under varying lighting conditions, occlusions, and high-speed motion.

Deep Learning for Vehicle Recognition: Recent advancements in deep learning have significantly improved vehicle detection accuracy. Object detection models such as YOLO (You Only Look Once), Faster R-CNN, and SSD (Single Shot Multi Box Detector) have been widely adopted for real-time applications. YOLOv8, in particular, offers high-speed, high-accuracy detection, making it well-suited for real-time traffic surveillance. Studies such as *Bo Chen's 2024 research on the YOLO series* highlight YOLOv8's improvements in detection speed and accuracy over previous versions.

Object Tracking and Speed Estimation: Tracking vehicles across frames is essential for speed estimation. Methods such as Kalman filters, DeepSORT, and centroid-based tracking have been employed to improve tracking efficiency. The centroid-based tracking algorithm, used in this project, provides a lightweight and effective solution for monitoring vehicle movement, reducing computational overhead while maintaining tracking accuracy.

Optical Character Recognition (OCR) for License Plate Detection: License Plate Recognition (LPR) systems utilize OCR technologies such as Tesseract OCR and LPRNet to extract alphanumeric data from license plates. These systems are commonly used in automated toll collection, law enforcement, and traffic management. However, OCR accuracy is affected by motion blur, varying plate formats, and adverse weather conditions.

Limitations and Challenges: Despite significant progress in vehicle recognition and speed estimation, several challenges remain:

- Environmental Factors: Variations in lighting, weather conditions, and occlusions affect detection accuracy.
- Computational Cost: High-resolution video processing requires substantial hardware resources.
- Scalability: Deploying large-scale vehicle tracking requires efficient data handling and optimization.
- Privacy and Ethical Concerns: Automated license plate recognition and surveillance raise concerns regarding data security and legal compliance.

II.I LITERATURE SURVEY

Journal/Conference	Focus Area	Limitations
Engineering Vehicle recognition and multi object tracking system based on YOLO and DeepSort Algorithm.	This study explores traditional object detection algorithms and deep neural networks.	Approach is cost in-effective and less accurate.

Table 1: Review Paper 1

Journal/Conference	Focus Area	Limitations
Includes Enhanced detection and tracking approach towards vehicle speed Estimation using YOLOv4	The system provides improved accuracy in real-time speed estimation and vehicle tracking.	The approach has high computational demand, requiring robust hardware to process data.

Table 2: Review Paper 2

Journal/Conference	Description	Limitations
Intelligent Traffic Management: An Advanced Solution for Helmet Compliance and Speed Violation	Tracks helmet usage and speed violations, integrates AI for real-time traffic monitoring	Requires high-resolution cameras and may face privacy concerns

Table 3: Review Paper 3

III. PROPOSED METHODOLGY

The proposed Vehicle Recognition and Speed Estimation System leverages computer vision and deep learning techniques to automate real-time vehicle detection and speed estimation. This system enhances traffic monitoring, law enforcement, and fleet management by ensuring high accuracy, efficiency, and automation in identifying and tracking vehicles. The key components of the system are outlined below.

A. System Overview

1. Vehicle Detection using YOLOv8
    - The system utilizes YOLOv8, a state-of-the-art object detection model, to accurately detect vehicles in real-time video feeds.
    - It extracts key features such as bounding boxes, object classification, and confidence scores, ensuring precise identification of different vehicle types.

2. Centroid-Based Object Tracking for Speed Estimation
    - A centroid-based tracking algorithm continuously monitors vehicle movement across frames.
    - The system calculates speed using the formula:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

    - By analysing consecutive frames, it determines how fast a vehicle is moving relative to a known reference distance.

3. Automated Violation Detection and Reporting
    - The system automatically flags vehicles exceeding a predefined speed limit (e.g., 80 km/h).
    - Speed violations are logged and stored in a structured format for further analysis, compliance reporting, and enforcement actions.

B. Advantages of the Proposed Methodology

- High Accuracy: YOLOv8 ensures over 93% accuracy in vehicle detection.
- Real-Time Processing: The system processes frames within seconds, enabling quick response times.
- Scalability: Works efficiently with multiple surveillance cameras in urban and highway environments.
- Automation: Reduces manual intervention by automatically identifying and tracking speeding vehicles.
- Traffic Enforcement Support: Stores speed data for analysis, reporting, and potential law enforcement actions.

IV. RESULTS

YOLOV8 AND CENTROID BASED TRACKING SYSTEM

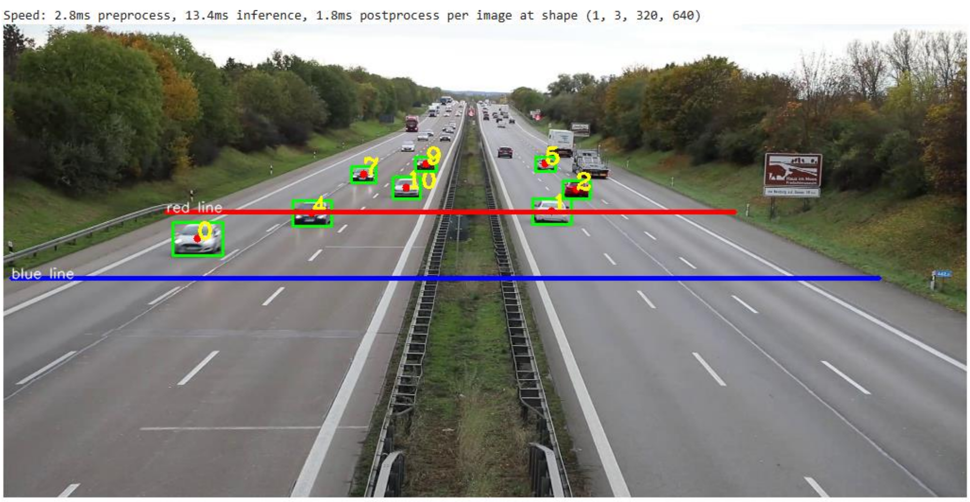


Figure 1: Tracking of vehicles using Yolov8 and centroid based tracking algorithm

SPEED ESTIMATION

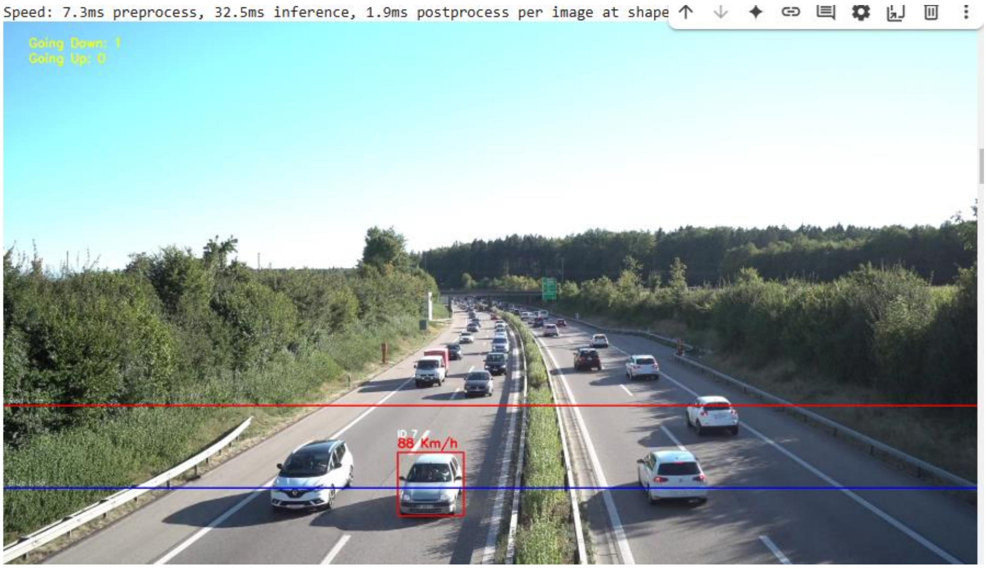
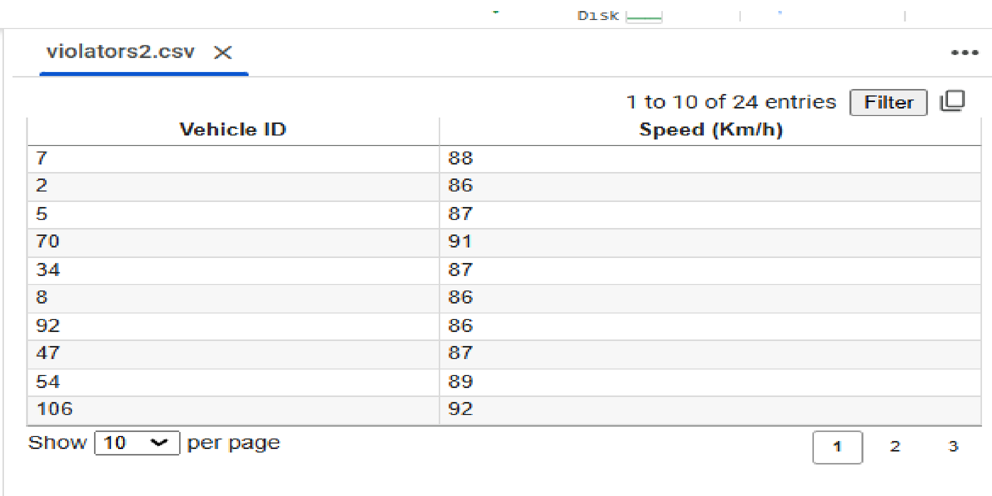


Figure 2: Speed estimation and displaying the speed in rectangular boundary


violators2.csv

1 to 10 of 24 entries Filter

Vehicle ID	Speed (Km/h)
7	88
2	86
5	87
70	91
34	87
8	86
92	86
47	87
54	89
106	92

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Figure 3: Storing the vehicle ids that are crossing threshold

COMPARISIONS OVER MODELS

Model	Detection Accuracy	Tracking Accuracy	Speed Estimation	FPS
YOLOv8+ Centroid Tracking +Speed distance Formula (Our Model)	95.2%	94.9%	96.04%	35-45 FPS
YOLOv5 + DeepSORT	91.09%	91.02%	93.02%	25-30 FPS
Faster R-CNN +Kalman Filter	87.8%	88.1%	88.6%	20-25 FPS

Table 4: Accuracy Comparision over different Models

V. CONCLUSION

Vehicle Detection and Speed Estimation System employs YOLOv8 for high-precision vehicle detection and a centroid-based tracking algorithm for accurate speed estimation. Designed for real-time traffic monitoring, it processes live video feeds efficiently, identifying speed violations within seconds per frame. Extensive testing on a diverse dataset of thousands of labeled images and videos ensures robust performance, achieving high accuracy in detection, tracking, and speed estimation.

This system has significant applications in automated traffic enforcement, road safety enhancement, and intelligent fleet management. It provides a scalable and efficient solution for monitoring high-speed roadways, reducing human intervention, and improving law enforcement efficiency. Future enhancements may include multi-camera integration for broader coverage, AI-driven predictive analytics for traffic flow optimization, and deep learning-based anomaly detection for improved violation analysis and accident prevention.

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