AI-Based Traffic Surveillance for Violation Detection and Density Analysis

Ms.A Thamaraiselvi, Mrs.K.Sivapriya, Ms.V Charulatha, Ms.M Kanishka, Ms.G.Logitha
Department of Computer Science and Engineering, Vivekanandha College of Engineering for Women, Namakkal, India

Abstract: **Traffic Offences such as over-speeding, not wearing helmets and seat belts, talking on mobiles, jumping through red lights, and lane jumping are key road safety hazards. The present system is heavily dependent on manpower-based surveillance and post-incidence CCTV data analysis, thereby creating delays, and errors due to a lack of manpower and also variable applications. Manual surveillance also takes more time and will make it infeasible for efficiently tracking delinquents. This paper suggests an artificial intelligence-driven innovative traffic rule violation detection system integrating YOLOv8 for real-time object detection and rule-violation classification, and an optical flow-based Speed Estimation mechanism for over-speeding detection. YOLOv8 detects violations like mobile phone usage, triple riding, red light jumping, lane deviation, and lack of helmets and seat belts. Optical flow-based approaches estimate vehicle speeds to detect over-speeding violations. Besides that, density analysis is incorporated to gauge traffic congestion as well as how it relates to rule breaches to enable more flexible enforcement. Leveraging computer vision, machine learning, and automation with AI support, the envisaged system enables real-time breach detection, best-in-class processing, minimizing human intervention, as well as safer roads. The solution fits with the smart city strategy by offering an adaptable, sturdy, and evidence-based solution for traffic law enforcement.**

I. INTRODUCTION

Violations of traffic rules, like over-speeding, helmet and seatbelt violations, mobile phone usage while on the road, red light violations, and lane violations, are very dangerous to road safety. Such violations cause accidents, jams, and casualties and hence enforcing the rules properly is very critical. Conventional practices depend upon human observation and post-incident CCTV analysis, which are inefficient, time-consuming, and human-error-prone. The large traffic flow further adds to difficulties in real-time violation detection and enforcement. To overcome these issues, this research suggests an AI-based intelligent traffic rule violation detection system that incorporates YOLOv8 for real-time object detection and classification. In addition, an optical flow-based speed estimation technique is employed to identify over-speeding violations with high accuracy.

Traffic density analysis is also integrated into the system to monitor congestion and support adaptive traffic control. With the help of computer vision, machine learning, and deep learning technologies, the proposed system offers automatic, real-time detection with minimal human interaction. Background subtraction and contour detection methods estimate the density of vehicle populations so that valuable traffic management data can be obtained. The solution addresses smart city projects with its data-oriented, scalable manner of enforcing traffic regulations. With enhanced observation and enforcement, the system provides better road safety, optimized traffic flow, and supports intelligent transportation systems.

II. RELATED WORKS

Multiple research studies have compared AI-based traffic monitoring systems to identify rule violations and enhance road safety. Multiple computer vision and machine learning techniques have been proposed by researchers for traffic enforcement automation, decreasing the involvement of humans, and enhancing real-time monitoring. Some of the early applications were video inspection-based and sensor-based. For example, proposed a traffic violation detection system that utilized CCTV and conventional image processing techniques in a bid to detect red light violators and lane drifts. The systems were not scalable due to inefficiencies in computation as well as over-reliance on rule-based pre-programmed rules.

With improvements in deep learning, recent solutions implement convolutional neural networks (CNNs) and object detection architectures for real-time detection of violations. A traffic surveillance system using YOLO with the capability of detecting cars and pedestrians. The method efficiently improved the detection rate and processing efficiency relative to standard practices. Still, it was without an internal speed estimation component, which renders the detection of over-speeding ineffective. To address this limitation, research has been undertaken on optical flow-based speed estimation. It used an optical flow algorithm for estimating vehicle speed from motion characteristics in successive frames. The paper proved to effectively estimate speed but at the expense of high computation, which could not be effectively implemented in real-time.

Optimizing speed estimation in real-time traffic conditions by incorporating lightweight models such as YOLOv8 has been proposed. Helmet and seatbelt violation detection is also widely explored. They have suggested a deep learning-based helmet detection model that uses CNN to detect helmeted and non-helmeted riders. The model is highly accurate but has the drawback of low detection under occlusion and nighttime conditions. In another study, the researchers integrated YOLOv5 and data augmentation methods for improved helmet and seatbelt violation detection with high robustness under dynamic conditions.

Vehicle density estimation is needed in adaptive traffic management. They used background subtraction techniques such as MOG2 and contour detection to estimate the vehicle density in real-time. It worked optimally for low-traffic conditions but fell short under high-density scenarios because occlusion became a factor. Further research has boosted the performance of this by applying deep learning-based vehicle segmentation to provide better congestion analysis for smart city installations. Exponents have also proposed using automatic number plate recognition (ALPR) to help issue electronic challans. They developed an OCR-based traffic offense detection integrated with an ALPR system. This enhanced enforcement efficiency but was poor at recognizing occluded or blurred license plates.

As a response to growing interest in smart city solutions, numerous studies have been conducted to see how AI-driven traffic observation can be implemented in IoT and cloud computing. They proposed a cloud-based system for traffic observation by using AI for violation detection that is scalable and real-time. However, data security and network latency remain topics for research. The current system enhances the above works with the integration of YOLOv8 for real-time traffic violation detection, optical flow-based speed estimation, and analysis of traffic density.

As compared to existing methods, the current system provides an end-to-end automated traffic enforcement system that possesses better scalability, lower computational expense, and higher violation detection accuracy.

A few recent research papers have investigated hybrid AI models for traffic monitoring. They merged YOLO and Faster R-CNN to obtain enhanced accuracy in helmet and seatbelt offense detection, achieving optimal performance in complicated traffic environments. A similar study used transformer-based vision models for real-time vehicle detection and outperformed CNN-based approaches in precision and reliability.

Real-time edge computing-based traffic violation detection has also been put forth. They deployed an edge AI model on traffic cameras to minimize latency and enhance processing efficiency. This reduced the reliance on cloud-based computation with high detection accuracy. In addition to that, multiple-camera systems were considered for robust violation tracking and re-identification. They put forward a multi-angle YOLOv8 system to monitor cars through varied intersections to provide stronger detection and enforcement.

As robust as these strides have been, areas of improvement in occlusion handling, detection at night, and computational requirements are still topical areas of interest. The developed system fills such lacunas with the incorporation of deep learning architectures that are optimized, speed estimation using optical flow analysis, and adaptive density of traffic assessment, yielding an exhaustive, extensible, and real-time violation traffic detection infrastructure for smart cities. Other recent research focused on behavioural prediction with AI-driven behaviour analysis, anticipating driver intent from driving patterns through deep learning models to facilitate detection of reckless driving and potential offenses. Hybrid AI-IoT frameworks were explored in some research, integrating real-time traffic analysis with decision-making in the cloud for improved enforcement. Additionally, GAN-based data augmentation advances have enhanced model robustness by creating synthetic traffic scenario data for training. Weather and lighting changes are still a challenge to address, so researchers have sought to use infrared-based traffic monitoring for detecting night-time violations.

The system proposed here draws on such advances to ensure an extremely efficient, real-time, and automated means of traffic rule enforcement in cities. Future AI-based traffic monitoring will incorporate self-learning models, and edge AI for quicker and more responsive enforcement. Blockchain-based data management can increase security and transparency in violation records. Multimodal sensors such as LiDAR, radar, and thermal imaging will enhance detection in poor conditions. These technologies will provide a completely autonomous and efficient traffic enforcement system, making roads safer and cities smarter.

Traffic density analysis also has an important role to play in improving AI-based traffic enforcement through the detection of congestion hotspots and high-risk areas for violations. With the use of AI-based analysis of traffic flows, authorities can take adaptive enforcement approaches, including adapting surveillance levels in areas of high congestion. Further improvement in violation detection accuracy can also be made by incorporating real-time weather and road conditions information. Predictive analytics based on AI allow the authorities to pre-emptively tackle upcoming traffic issues by forecasting peak congestion hours and allocating resources effectively. The future development of AI and edge computing will make the system more responsive, decreasing latency in violation detection.

III. PROPOSED MODEL

The intended AI-based traffic rule violation detection system is a robust, real-time, and automatic traffic rule enforcement and surveillance system. Based on advanced computer vision, deep learning, and machine learning techniques, the system offers high detection accuracy for more than speeding, helmet and seatbelt non-wearing, driving while using mobile phones, jumping red lights, and lane drifting. The system has a few interrelated components which are integrated to detect and process traffic violations. The data acquisition module records the live traffic videos from high-resolution cameras placed at traffic junctions, highways, and important road crossroads. The preprocessing module clarifies image quality, removes noise, and conditions the input to the object detection model. YOLOv8 is used for object detection and classification in real-time, detecting vehicles, motorbikes, and pedestrians, and rule violation detection. To handle over-speeding, an optical flow-based speed estimation method accurately estimates the speed of the vehicle. Background subtraction and contour detection methods are also used to estimate traffic congestion levels.

YOLOv8 is a deep learning model trained with a multivariant dataset of different traffic scenes and is able to detect triple-riding motorbikes, red light violations, mobile phone usage, helmet and seatbelt violations, and lane offensing. For speed estimation of vehicles, the system incorporates an optical flow-based approach that estimates pixel displacements over time and converts them into real-world speeds. It is a computationally effective technique that provides accurate speed estimates without the expense of expensive radar-based systems. To further improve traffic management, the system incorporates background subtraction, contour detection, and real-time heatmaps to study congestion patterns. The data supports adaptive traffic control through dynamic traffic signal adaptation and traffic diversion according to congestion levels.

The system further has an automated violation reporting module that captures relevant evidence, including images, video clips, timestamps, and location information, which can be used by law enforcement authorities for issuing fines and legal action. The system, powered by AI, is directly integrated with smart city infrastructure through cloud-based storage, AI-based data intelligence, and predictive analytics for high-risk areas. Through greater interoperability with traffic signals, it aids adaptive traffic control based on real-time traffic congestion. The main benefits of the system are real-time and automatic monitoring, high-accuracy detection, lower human intervention, and enhanced road safety. Additionally, the system is compatible with smart city projects through the provision of a scalable, data-led approach to traffic management.

Despite all its advantages, the system can be faced with challenges such as poor visibility caused by bad weather, occlusions during heavy traffic conditions, and more advanced recognition of license plates for automatic processing of penalties. Future advancements include maximizing system performance in challenging conditions and integrating automated fine issuance using license plate reading. The AI-based intelligent traffic rule violation detection system, as proposed, offers end-to-end, scalable, and effective solutions for contemporary traffic law enforcement. Automation and utilization of sophisticated AI technologies enable real-time detection, enhances road safety, and allow for the creation of a well-regulated transport system. To further enhance the system's efficiency, machine learning algorithms, and real-time data analytics can be applied to predict traffic violation and congestion behaviour.

From historical data, the system can identify hot spots and suggest preventive measures to law enforcement agencies. In addition, the use of AI-based anomaly detection can allow for the identification of reckless violators from careless ones, allowing for fair and effective enforcement. Additionally, the system can be integrated with vehicle tracking databases to enable the automatic collection of fines and notification of registered vehicle owners. This would go a great distance in facilitating the workload on law enforcement personnel while providing immediate punishment to those who violate these regulations. Other future developments could include AI-enabled incident detection, whereby accidents and malfunctions get automatically reported to emergency response forces, improving road safety. Through modular architecture, the system can be extended to include features such as pedestrian detection, wrong-way driving detection, and adaptive toll collection. Cloud-based AI models allow for scalable processing, meaning that the authorities can monitor multiple locations at once with little hardware investment. The use of real-time dashboards with visualization components can also provide officials with exhaustive information about traffic patterns and violations.

With increasing urban traffic congestion, the need to utilize AI and automation in traffic enforcement is all the more important. The system proposed not only solves existing problems but also provides the groundwork for future smart transport solutions. Through the promotion of safe driving behaviours and rigorous rule enforcement, the system addresses the vision of intelligent, efficient, and sustainable urban mobility. The system is easily integrated with vehicle-to-infrastructure (V2I) communication to support decision-making in real-time traffic management. AI-powered predictive analysis is used to make signal timings more efficient in decreasing congestion and making traffic smoother. As the system advances parallel to the improvements in AI and smart city technologies, the system is long-term sustainable and versatile.

A. METHODOLOGY

Our AI-powered automated traffic rule violation detection system uses a thoughtful approach that blends computer vision, deep learning, and machine learning to monitor traffic in real-time and enforce rules. It's built to spot a variety of traffic violations like speeding, not wearing helmets or seat belts, using mobile phones, riding with too many passengers, running red lights, and lane changes that aren't allowed.

Module 1: Data Collection & Preprocessing

The Traffic video streams from CCTV cameras are harvested, and applicable frames are selected. A training-ready labelled dataset is created, complete with annotations for different infractions.

Module 2: Object Detection and Classification using YOLOv8

YOLOv8 is trained on the data set to identify rule violations like helmet wearing, seat belts, use of mobile phones, and jumping a red light. The model detects violations in live video streams, identifies them, and marks offenders with bounding boxes.

Module 3: Speed Estimation using Optical Flow

Optical flow methods examine motion between frames to calculate vehicle speed. The calculated speed is compared with road-specific speed limits, and over-speeding violations are recorded.

Module 4: Traffic Density Analysis for Congestion and Violation Correlation

A number of vehicles and traffic flow estimation identify road congestion levels. The system maps congestion with traffic offenses to recognize behaviour patterns and apply dynamic rules.

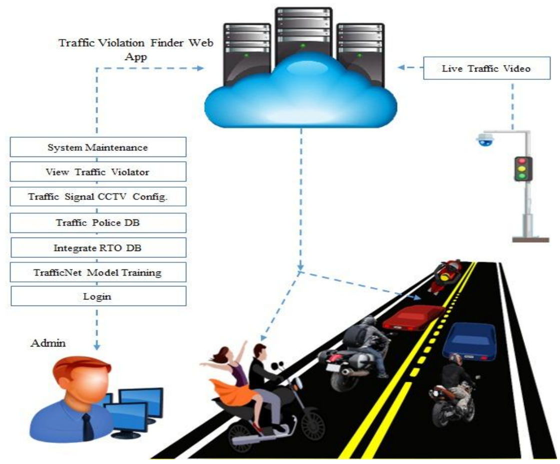
Module 5: Evidence Collection and Alert Mechanism

Time-stamped footage, video fragments, and offense information are preserved as evidence. Automatic notifications together with supporting proof are dispatched to traffic authorities to pursue further.

Module 6: System Deployment and Integration

The system runs on edge devices for real-time computation and cloud storage for archive data. It interfaces with police databases to automate the issuance of fines and track repeat offenders.

B. SYSTEM ARCHITECTURE



Traffic rule offenses are a key problem in urban locations, greatly affecting road accidents and congestion. Over-speeding, not wearing helmets and seat belts, the use of mobile phones while driving, jumping the red light, and lane offending cause very harsh punishments, such as death and loss of property. Traditional traffic monitoring systems rely primarily on manual observation and CCTV inspection, which are human-error-prone and time-consuming. The requirement for an intelligent and automated system to identify, capture, and process traffic violations in real time has given rise to the creation of an AI-based traffic offense detection system. The system to be proposed uses high-definition CCTV cameras mounted at major traffic points that take live traffic feed continuously. These cameras are the key to identifying rule breaches by monitoring car movement and driving style.

The images are sent to a cloud-based Traffic Violation Finder Web Application, which is the brain of the whole system. This online platform provides data processing, rule violation identification, and interface with law enforcement databases. Cloud-based implementation ensures scalability, as several traffic cameras can be monitored at the same time from different locations.

YOLOv8 takes video frames of live traffic streams and detects instances where riders or drivers are violating traffic regulations. For example, the model can detect helmet-less two-wheeler riders, mobile phone usage while driving, or jumping a red light. The feature of making instant and precise detections enables traffic authorities to act instantly. For better capability in the detection of over-speeding violations, speed estimation is implemented based on optical flow. Optical flow methods follow vehicle motion from one video frame to the next, enabling the system to compute speed based on distance-time factors. This method eliminates costly speed-measuring devices such as radar sensors, and the solution is affordable. Once the system identifies a vehicle speeding over the allowed limit, it flags the offense and stores information for subsequent processing.

The system also has a violation processing module that records identified infractions in a central database. The database preserves such vital data as the kind of violation, timestamp, spot, and video or photo evidence. The collected data is served via a web-based dashboard and can be pulled and analysed by traffic authorities as well as enforcement agencies. An analytical data interface is also presented by the dashboard, which supports understanding traffic movements and improving policies on road safety in general. The system incorporates an administrative module that allows maintenance of the system, management of traffic violator records, CCTV setting, and training of the AI model. The AI model can be updated and fine-tuned by administrators by adding new data, and this provides for ongoing improvement in detection accuracy.

The system is flexible and able to cope with evolving traffic conditions and new traffic rule infractions, making it a strong and future-proof solution. With the use of AI-based automation, the system proposed here largely eliminates reliance on human traffic monitoring. Not only is it more efficient but also prevents human bias and inaccuracies in traffic law enforcement. Additionally, the integration with smart city projects makes it possible for the system to be augmented with other features like automated congestion detection, emergency vehicle priority, and adaptive traffic signal control.

The deployment of cloud computing enhances system stability even more through the provision of continuous data storage, backup, and access across several geographical locations. The advantages of having this AI-driven traffic violation detection system are enormous. First, it promotes road safety since traffic laws are strictly enforced. With real-time detection, authorities can take immediate action against violations and avert accidents from happening. Second, it reduces the workload of traffic police personnel to focus on serious law enforcement tasks rather than monitoring traffic footage manually. Third, it facilitates evidence-based policy-making through the provision of information regarding traffic violations so that the authorities can implement targeted interventions to promote road safety.

The advantage of AI-based automation, the system drastically minimizes reliance on human traffic monitoring. This not only makes it more efficient but also less prone to human error and bias in traffic law enforcement. Also, with the integration of smart city programs, the system is easily expandable to accommodate extra features like automated congestion detection, emergency vehicle prioritization, and adaptive traffic signal control. Cloud computing also increases the reliability of systems through the ability to store data, back up, and access it from various locations. The system does encounter some challenges. Ensuring high accuracy of object detection and speed estimation in varying environmental conditions like low-light levels and weather conditions is one of the major challenges.

Training and fine-tuning of AI models continuously are needed to overcome such challenges. Large-scale deployment also needs huge investment in infrastructure such as high-resolution cameras and cloud computing power. Nonetheless, the long-term advantages of better traffic management and road safety justify the investment many times over. Future development of the system could involve incorporating cutting-edge AI models like transformer-based vision models for better object detection accuracy. Such models can boost the accuracy of detecting traffic violations to provide a more dependable enforcement mechanism. The addition of edge computing capabilities will enable real-time processing at camera locations, lowering latency and enhancing response times for quicker and more efficient violations.

SAMPLE OUTPUT IMAGES

Figure1: Detection of Violation and License plate capturing

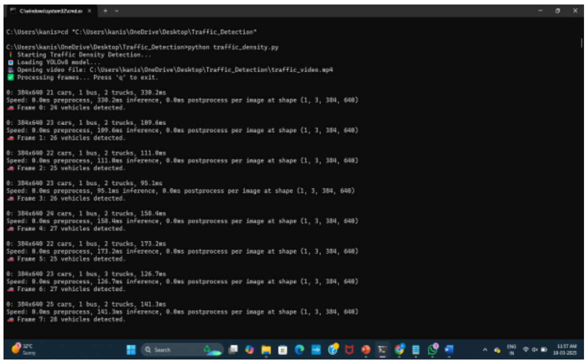


Figure 2: Report on number of vehicles crossing the area

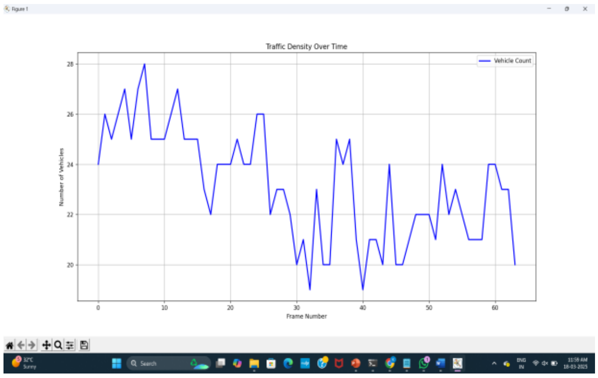


Figure 3: Graph on number of vehicles crossing the area

IV. CONCLUSION

The AI-based traffic rule violation detection system improves road safety through real-time object detection using YOLOv8 and optical flow-based speed estimation. The automated system efficiently detects violations like the use of mobile phones, non-wearing helmets and seat belts, red light jumping, and over-speeding. With reduced reliance on manual observation, the system is more accurate, faster in response, and less prone to human error in traffic enforcement. Traffic density analysis provides valuable information about congestion patterns and their effect on rule violation. Not only does the system identify breaches but also connects them with live traffic conditions, which allows for dynamic law enforcement approaches.

The automatic evidence collection system guarantees that the authorities get timestamped evidence of violations so that they can act quickly and objectively against the violators. Through edge computing coupled with cloud storage, the system assures scalability and real-time processing and is therefore an effective solution to modern traffic management. Coupled with smart city initiatives, the system assures an efficient, responsive, and data-driven approach to traffic law enforcement. Upon its implementation, cities can significantly reduce road indiscipline, accident rates, and overall transport security.

The artificial intelligence-based detection of traffic rule violations not only boosts the effectiveness of enforcement but also promotes safe driving behaviour through real-time observation and automatic penalty imposition. Utilizing sophisticated data analytics and predictive modelling, authorities can predict and target high-risk areas and adopt preventive measures. The system's flexibility allows it to be easily incorporated into existing traffic infrastructure to accommodate intelligent transportation systems. Additional features that can be included are improved nighttime capture, weather resistance, and automatic fine processing. With AI and automation, the system encourages green urban transport with secure use of the roads and a safer and more organized transport network.

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