Automated Traffic Ticket Generation System for Speed Violations using YOLOv9 and DeepSORT

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Abstract—This paper introduces an Automated Traffic Ticket Generation System for Speed Violations, leveraging cutting-edge technologies to enhance the enforcement of traffic regulations. The system employs YOLO (You Only Look Once), a robust deep learning-based object detection algorithm, for accurate and real-time vehicle detection. It integrates Deep SORT for multi-object tracking, ensuring consistent identification of vehicles across video frames. To reliably extract vehicle identity, OpenALPR (Automatic License Plate Recognition) is incorporated, offering superior performance in recognizing license plates under diverse conditions, such as varying speeds, lighting, and camera angles. The system processes real-time video feeds from traffic surveillance cameras, detecting and tracking vehicles as they pass through predefined reference lines. By measuring the time taken for a vehicle to cross these lines, the system calculates its speed. If the speed exceeds the specified limit, an automated traffic ticket is generated. This ticket includes key details such as the vehicle type, speed, license plate number, and the exact timestamp of the violation. Experimental results demonstrate the system's high accuracy and efficiency in detecting violations, tracking vehicles, and recognizing license plates. By automating traffic law enforcement, this solution reduces human errors, enhances accuracy, and provides a scalable approach to managing traffic violations.

Keywords—YOLOv9, DeepSORT, OpenALPR, Vehicle Detection, Speed Violation Detection, License Plate Recognition, Traffic Law Enforcement, Real-Time Traffic Monitoring

I. INTRODUCTION

With the exponential increase in urbanization and the growing number of vehicles on the road, managing traffic flow and ensuring compliance with speed regulations have become crucial challenges for city planners and law enforcement agencies worldwide. Traditional methods of traffic enforcement, such as radar guns and manual speed checks, while useful, are limited by various factors including their dependency on human operators, limited coverage area, and potential for human error. As the need for more efficient and reliable traffic management systems rises, intelligent systems driven by advanced technologies such as computer vision, machine learning, and automation offer promising alternatives to overcome these challenges.

This research introduces an Automated Traffic Ticket Generation System designed to significantly streamline the process of monitoring and enforcing speed limits in real-time. The core objective of this system is to leverage state-of-the-art technologies to automatically detect traffic violations, particularly speeding, without the need for human intervention. The proposed system integrates multiple cutting-edge technologies, including YOLO (You Only Look Once) for vehicle detection, DeepSORT for object tracking, and OpenALPR (Automatic License Plate Recognition) for license plate identification, to create an efficient and effective solution to enforce traffic rules and improve road safety.

At the heart of the system is YOLO, a real-time object detection algorithm that quickly identifies vehicles within a video frame and generates accurate bounding boxes around each vehicle. YOLO's high-speed processing capability allows for near-instantaneous vehicle detection, even in busy or dynamic traffic conditions. YOLO's precision ensures that the vehicles are identified correctly, reducing the likelihood of false positives or missed detections.

Building upon YOLO, DeepSORT (Deep Learning-based Sort) is employed to enhance the tracking performance of the system. DeepSORT is a robust tracking algorithm that assigns unique identifiers to detected vehicles and maintains these identities across multiple frames. This is particularly useful in complex traffic situations where vehicles may overlap or occlude each other. By tracking the movement of each vehicle across frames, DeepSORT ensures that the system can accurately monitor the trajectory of each vehicle, even in scenarios with high traffic congestion.

To estimate vehicle speeds, the system employs a novel approach based on central coordinates and predefined reference lines in the video footage. The speed estimation method works by calculating the distance a vehicle travels between reference points within a fixed time frame. This provides an accurate estimation of the vehicle's speed, which is then compared against predefined speed limits to determine whether a violation has occurred.

Once a speed violation is detected, the system utilizes OpenALPR technology to capture and read the vehicle's license plate number. OpenALPR, a widely used optical character recognition (OCR) system, extracts the alphanumeric characters of the license plate with high accuracy, even in low-light conditions or when the plate is partially obscured. The integration of OpenALPR into the system enables seamless ticket generation, automatically associating the detected violation with the corresponding vehicle's registration details.

This research aims to demonstrate the feasibility and effectiveness of this fully automated system for traffic enforcement. By automating vehicle detection, tracking, speed estimation, and ticket generation, the system eliminates human errors, reduces administrative workload, and enhances the overall efficiency of traffic monitoring. Additionally, it offers the potential to improve road safety by ensuring consistent and objective enforcement of speed regulations, thereby contributing to reduced traffic accidents and safer roadways. The system's ability to function in real-time, with minimal manual intervention, represents a significant advancement in traffic enforcement technologies, paving the way for smarter and more reliable urban traffic management solutions.

 This research introduces an Automated Traffic Ticket Generation System designed to streamline the process of monitoring and enforcing speed limits. By leveraging cutting-edge technologies, the system efficiently detects vehicles, tracks their movement, estimates speed, and generates tickets for violations in real time.

At its core, the system employs YOLO for rapid vehicle detection, providing accurate bounding boxes around each vehicle in the captured video footage. Deep SORT enhances tracking performance by maintaining vehicle identities across frames, even in congested conditions. To accurately estimate vehicle speeds, a novel approach utilizing central coordinates and predefined reference lines is implemented. Once a speed violation is confirmed, OpenALPR is employed to extract license plate information, allowing for seamless ticket generation.

This research aims to demonstrate the feasibility and effectiveness of an automated approach to traffic enforcement, highlighting its potential to improve compliance with speed regulations and contribute to safer roadways.

II. LITERATURE REVIEW

In recent years, the rapid advancements in deep learning have revolutionized the field of computer vision, significantly improving object detection capabilities for applications such as traffic surveillance. One of the most widely used techniques for vehicle detection is YOLO (You Only Look Once), a real-time object detection model that has demonstrated remarkable performance in various applications. D. Balakrishnan et al. [2] introduced an improved version of YOLOv3, enhancing its real-time vehicle detection ability by optimizing the balance between speed and accuracy. Their model excels at detecting vehicles even in dense traffic, offering high frame processing rates and good detection accuracy. However, while YOLOv3 performs exceptionally in vehicle detection, it primarily focuses on identifying objects in the frame and does not address the additional requirements of tracking or speed estimation, which are critical for automated traffic violation detection. This gap in the model's capabilities highlights the need for an integrated solution that combines vehicle detection with tracking and speed estimation, which is precisely what this research aims to address. By incorporating DeepSORT for tracking and a speed estimation mechanism, this study aims to create a more comprehensive end-to-end solution for automated traffic violation detection.

Vehicle tracking is another critical component in building a robust traffic monitoring system. DeepSORT is one of the most reliable objects tracking algorithms available, known for its ability to maintain vehicle identities across video frames in dynamic environments. S. A. U et al. [4] present a robust system for urban traffic management that combines YOLOv5 for real-time vehicle recognition and DeepSORT for vehicle tracking, with a focus on alleviating traffic congestion through direction analysis. Their system, applied to Hyderabad's complex road network, categorizes vehicles into four types (bike, car, bus, and truck) and achieves an accuracy of 87.93% in vehicle tracking and direction analysis. While their approach significantly enhances traffic flow and congestion management, it primarily focuses on movement direction and vehicle classification. In contrast, our research provides a more comprehensive solution by extending beyond traffic flow optimization to include automated detection and enforcement of speed violations. Leveraging YOLOv9 for higher detection accuracy, DeepSORT for precise tracking, and OpenALPR for license plate recognition, our system not only monitors traffic but also ensures compliance with speed regulations. This added functionality addresses a critical aspect of road safety, offering a more holistic and scalable framework for intelligent traffic management in smart cities.

T. Thapliyal et al. [5] present a promising approach to Automatic License Plate Recognition (ALPR) by utilizing the YOLOv5 model for vehicle and plate detection and Tesseract OCR for extracting text from license plates. While their system addresses the challenges of high vehicle speed, non-uniform plate designs, and multilingual text, its reliance on Tesseract OCR limits its accuracy in handling distorted or low-resolution plates, especially under challenging lighting conditions. In contrast, our research leverages YOLOv9 for enhanced detection accuracy and OpenALPR, which is better optimized for real-world scenarios, providing more reliable license plate recognition even in high-speed traffic or poor-quality video feeds. Additionally, our system integrates functionalities for speed violation detection and automated ticket generation, making it a more comprehensive and scalable solution for traffic law enforcement. This positions our work as an advancement over T. Thapliyal et al.'s ALPR framework, addressing broader traffic management challenges while maintaining robust performance in diverse environments.

P. N. Huu et al. [6] proposed a robust system for tracking and calculating the speed of mixed vehicles using YOLOv4 for vehicle detection and DeepSORT for object tracking. Their algorithm demonstrated impressive accuracy, achieving up to 95%, and proved its potential for real-world applications in urban traffic management. However, their focus was limited to speed tracking without addressing other critical aspects, such as vehicle identification for traffic violation enforcement. Our research advances this framework by adopting YOLOv9 for improved detection accuracy, integrating OpenALPR for seamless license plate recognition, and incorporating automated ticket generation for speeding violations. This end-to-end system not only monitors and tracks vehicles but also provides actionable outputs for traffic law enforcement, making it a more comprehensive and practical solution for real-time traffic management challenges.

III. METHODOLOGY

This section outlines the structured methodology used in the development of the Automated Traffic Ticket Generation System designed to detect and enforce speed violations using YOLOv9, DeepSORT, and OpenALPR. The system integrates multiple technologies to ensure a seamless workflow from vehicle detection to the generation of traffic tickets.

A. System Architecture

The architecture of the Automated Traffic Ticket Generation System is designed to handle the complex tasks involved in detecting, tracking, and penalizing vehicles that violate speed regulations using real-time video surveillance. This system is a multi-module, integrated solution that processes video frames to monitor traffic, detect violations, and generate automated tickets for offenders.

- Input Module: The system starts by capturing live video footage from traffic surveillance cameras. These cameras are strategically positioned along roads to provide continuous coverage of traffic flow. The video feed is processed frame by frame to detect vehicles, track their movement, and analyze their speed. The system ensures that no vehicle is overlooked, and violations are detected promptly.
- YOLOv9 Vehicle Detection: The YOLOv9 (You Only Look Once) algorithm is used for real-time, high-accuracy vehicle detection. YOLOv9 is designed to identify and classify objects within video frames with remarkable speed and precision, making it ideal for traffic monitoring tasks where quick processing is essential. The algorithm detects vehicles in each frame and creates bounding boxes around them, marking their positions for further analysis. YOLOv9's efficiency enables it to handle large amounts of video data and detect vehicles even in congested traffic scenarios.
- Deep SORT Tracking: After detecting the vehicles, the system employs the Deep SORT (Simple Online and Realtime Tracking) algorithm to track each vehicle across successive frames. Deep SORT ensures that each vehicle is assigned a unique identifier and maintains this identity across the video stream, even when vehicles overlap, change lanes, or are momentarily obscured. Deep SORT uses Kalman filters to predict the movement of vehicles and correct any tracking errors. This continuous tracking is crucial for calculating the vehicles' speed and ensuring accurate identification throughout the video sequence.
- Speed Estimation Module: The Speed Estimation Module calculates the speed of each vehicle based on its displacement across frames and the known frame rate of the video. By utilizing the vehicle's position at two different points in time and the distance between those points (which can be inferred from the camera's field of view and calibration), the system estimates the vehicle's speed. The system accounts for factors such as camera calibration and frame rate to ensure that the speed estimates are accurate. If a vehicle exceeds the predefined speed limit for that road segment, it is flagged for a violation.
- OpenALPR License Plate Recognition: For vehicles that exceed the speed limit, the system uses OpenALPR (Automatic License Plate Recognition) technology to capture and recognize the vehicle's license plate number. OpenALPR uses advanced optical character recognition (OCR) techniques to accurately read and decode license plates, even under challenging conditions such as low light or motion blur. This process allows the system to associate the speeding vehicle with a specific registration number, ensuring that the violator is correctly identified for ticketing.
- Violation Detection and Ticket Generation: When the system detects a speeding violation, it records key details about the offense, including the vehicle's speed, license plate number, time of the violation, and location. This information is stored in a secure database, which can be accessed for later reference or legal action. The system can automatically generate a traffic ticket based on the stored data, complete with relevant information such as the violation type, the violator's details, and the fine amount. This automated process eliminates human error and speeds up the enforcement of traffic regulations, making the system more efficient and reliable than traditional manual ticketing methods.
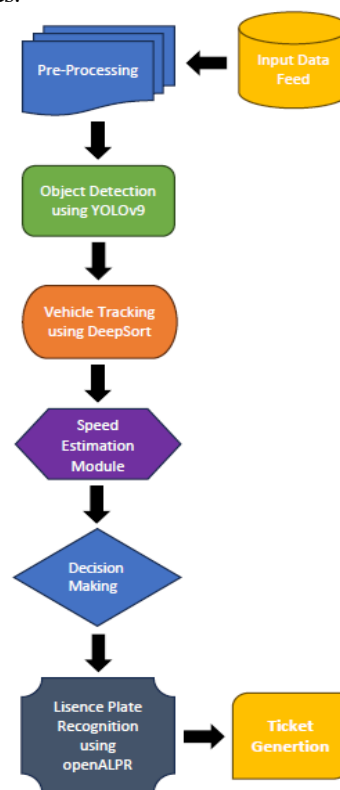

Fig. 1. Flowchart illustrating proposed methodology

This modular approach ensures that each aspect of the violation detection and ticketing process is handled efficiently, from vehicle identification to final ticket generation. The use of advanced detection, tracking, and recognition technologies ensures high accuracy and reliability in traffic monitoring and enforcement.

B. Vehicle Detection

The initial phase involves the detection of vehicles in real-time using YOLOv9. The detection process is as follows -

- Input Preparation: This phase begins with capturing video frames from traffic surveillance cameras, which are then resized and normalized to meet the input requirements of the YOLOv9 model. The frames are resized to ensure they

match the resolution expected by YOLOv9, which is crucial for maintaining optimal detection accuracy. The resizing process ensures that the video can be processed efficiently, balancing detail with computational performance. Additionally, the frames are normalized, adjusting pixel values to a standard range to eliminate discrepancies caused by varying lighting conditions and camera settings. This step is essential for ensuring consistent and accurate vehicle detection, which is key to the overall effectiveness of the system.

- Bounding Box Generation: After the video frames are processed and prepared, YOLOv9 generates bounding boxes around each detected vehicle. A bounding box is a rectangular frame that identifies and isolates the location of a vehicle within the image frame. Each bounding box is represented in the format *(xmin,ymin,xmax,ymax),* where:

xmax, xmin: The x-coordinate of the bottom-right corner and the top-left corner of the bounding box respectively.

ymax, ymin: The y-coordinate of the bottom-right corner and the top-left corner of the bounding box respectively.

This rectangular box allows the YOLOv9 model to localize the detected vehicle precisely within the frame. The bounding box is essential for the subsequent steps in the system, such as vehicle tracking and speed estimation, as it helps to define the region of interest (ROI) for further analysis.

Central Coordinate Calculation: Once the bounding boxes are generated around the detected vehicles, the central coordinates of each bounding box are calculated to aid in tracking and speed estimation. The center coordinates are essential for maintaining accurate vehicle tracking over time and for calculating the vehicle's movement across frames.

The center of the bounding box is computed using the following formula:

$$centre\_cord\_x = \frac{xmax + xmin}{2}$$

$$centre\_cord\_y = \frac{ymax + ymin}{2}$$

C. Continuous Vehicle Tracking using DeepSORT

After the initial vehicle detection, the next step is the continuous tracking of vehicles across video frames. This is achieved through the DeepSORT algorithm, which significantly improves the tracking performance by integrating both appearance and motion information. DeepSORT is widely used for robust object tracking in dynamic environments like traffic monitoring.

D. Speed Estimation

The Speed Estimation phase is crucial for determining whether a vehicle is exceeding the established speed limit. This process involves calculating the time it takes for a vehicle to traverse a known distance between two predefined reference lines placed in the field of view of the camera. Typically, these reference lines are set 10 meters apart, providing a standardized measurement for speed calculation.

To improve the accuracy of detection and reduce errors caused by vehicles moving at different angles or speeds, the reference lines are not defined as narrow lines but as broader stripes. This approach ensures that vehicles passing through the reference area are detected reliably, even if their bounding boxes only partially intersect the lines. The broader stripes help accommodate slight misalignments and ensure that the system captures the vehicle's motion more accurately.

When the vehicle crosses the first reference line, the system logs the current timestamp as t_{start}. Then, as the vehicle crosses the second reference line, the timestamp t_{finish} is recorded. The time difference between these two timestamps, time_diff, given as, $t_{finish} - t_{start}$, is calculated, and the vehicle's speed is estimated using the formula:

$$Speed = \frac{Distance}{time\_diff}$$

Where, the distance is set to 10 meters. The resulting speed is expressed in meters per second, providing a clear measure for evaluating compliance with speed regulations.

This speed estimation process allows the system to determine whether a vehicle is violating speed regulations. If the estimated speed exceeds the speed limit, the system triggers a violation detection, which is crucial for the automatic generation of a traffic ticket.

Fig. 2. Illustration of vehicle detection, from video frame capture to bounding box generation

Fig. 3. Representation of the reference lines and the vehicle's path, illustrating how intersections are detected

E. License Plate Recognition

License Plate Recognition (LPR) is a key element of automated traffic monitoring systems, designed to identify vehicles exceeding predefined speed thresholds. When a vehicle's speed surpasses the input threshold set for the road, the system triggers a camera to capture an image of the violating vehicle. This image is processed to extract the portion containing the license plate ensuring precise localization even under varied environmental conditions.

The isolated license plate is then analyzed using Optical Character Recognition (OCR) technology, such as OpenALPR, to convert the visual characters into machine-readable text. The recognized license plate number is linked to violation data, including the timestamp, location, and recorded speed. This automated approach enables accurate, real-time enforcement of speed regulations, providing reliable evidence for issuing digital traffic tickets. The system is designed to handle diverse license plate formats and ensures consistent performance across different lighting and weather scenarios. illustration of OpenALPR in action

Fig. 4 Illustration of OpenALPR in action

F. Automated ticket generation using OpenALPR

The final phase of the proposed methodology is the automated generation of a digital ticket. This process leverages OpenALPR, a robust license plate recognition system, to efficiently identify vehicles involved in traffic violations. When a vehicle is detected exceeding the predetermined speed limit, the system captures a high-resolution image of the vehicle at the precise moment of the violation.

The bounding box coordinates isolate the segment of the image containing the vehicle's license plate. This cropped section is processed by OpenALPR, which extracts the alphanumeric license plate number with high accuracy. The recognized number is then linked to the violation details recorded by the system, including the timestamp of the violation and location coordinates.

To generate a complete and reliable ticket, the system compiles all the violation data into a structured digital format. The ticket includes essential fields such as:

- Ticket Number: A unique identifier for each violation.

- Violation Date and Time: The exact moment the incident occurred.

- Vehicle Number: The extracted license plate details.

- Violation Penalty: The monetary fine associated with the offense.

- Location Coordinates: GPS data pinpointing where the violation took place.

- Offense Description: A summary of the violation (e.g., overspeeding).

- Evidence: The image(s) of the vehicle captured during the violation.

The digital ticket serves as official documentation for the traffic violation, ensuring the enforcement process is transparent and supported by verifiable data. Furthermore, the cropped image of the license plate and supporting evidence are stored securely for future verification, should any disputes arise. By automating ticket generation, the system streamlines traffic law enforcement, reduces human error, and enhances overall compliance with speed regulations.

Violation Details

Ticket No.	TCKT1121240001
Date	11/21/2024
Time	20:23:11
Vehicle No.	212___
Violation Penalty	200
Location	39.2904 76.6122
Offence	Overspeeding
Evidence	Test1.img Test2.img

Fig. 5 Sample Digital Ticket generated

This comprehensive methodology integrates advanced technologies in object detection, tracking, speed estimation, and license plate recognition to create an efficient and automated traffic violation detection system. By leveraging YOLOv9, DeepSORT, and OpenALPR, the proposed system not only enhances traffic monitoring but also streamlines the process of ticket generation, contributing to improved traffic regulation compliance.

IV.   RESULTS AND ANALYSIS

The Table 1 presents a detailed analysis of the performance metrics for the Automated Traffic Ticket Generation System across multiple video feeds. The metrics include the number of actual violations, detected violations, violations where the number plate was successfully detected, and the error rates in violation detection and number plate recognition.

A. Violation Detection Accuracy

The system demonstrated varying levels of accuracy across different videos. For instance:

- In Video 1, all 5 actual violations were accurately detected, resulting in a 0% error rate.

- In Video 6, only 3 out of 4 violations were detected, leading to the highest error rate of 25.00% in violation detection.

B. Number Plate Detection Accuracy

Similar to violation detection, the performance of number plate recognition varied. For example

In Video 4, number plates for all violations were detected, achieving a 0% error rate.

- In Video 3, out of 20 detected violations, number plates for 18 vehicles were accurately recognized, resulting in a 10.00% error rate.

C. Correlation Between Frame Rate and Performance

- Higher frame rates (e.g., Video 8, with 56 FPS) appear to improve detection and recognition capabilities, as evidenced by relatively lower error rates in both violation detection (13.64%) and number plate recognition (11.11%).

- Lower frame rates (e.g., Video 2, with 24 FPS) correspond to higher error rates, indicating that frame rate plays a critical role in ensuring the system captures sufficient data for accurate analysis.

D. Efficiency Overall System Performance

- Across all videos, the system recorded 93 actual violations, out of which it successfully detected 83 violations. This corresponds to a detection success rate of approximately 89.25%.

- For number plate detection, out of the 83 detected violations, the system accurately recognized the number plates for 79 vehicles, achieving a recognition success rate of approximately 95.18%.

These results indicate that the proposed methodology significantly enhances the capabilities of traditional traffic enforcement systems, ensuring accurate detection, reliable tracking, and efficient ticket generation, ultimately contributing to improved road safety and compliance with traffic regulations.

TABLE I.   VIOLATIONS AND NUMBER PLATE DETECTION FEED   RESULTS

Video	fps	Actual Violat-ions	Detec-ted Viola-tions	No. Plate Detected	Error in Violation Detecti-on (%)	Error in Plate Detecti-ons (%)
Video 1	24	5	5	5	0	0.00
Video 2	24	13	11	10	15.38	9.09
Video 3	24	22	20	18	9.09	10.00
Video 4	36	36	1	1	1	0.00
Video 5	34	3	3	3	0	0.00
Video 6	44	13	11	11	15.38	0.00
Video 7	43	14	14	13	0	7.14
Video 8	56	22	18	13	13.64	11.11
Total		**93**	**83**	**79**		

V. CONCLUSION

The increasing complexities of urban traffic management necessitate innovative and efficient solutions to ensure road safety and enforce compliance with speed regulations. This research presents a comprehensive Automated Traffic Ticket Generation System, leveraging advanced technologies such as YOLOv9 for real-time vehicle detection, DeepSORT for robust tracking, and OpenALPR for accurate number plate recognition. By integrating these components, the system addresses key challenges in traffic enforcement, including real-time detection of speed violations and automated ticket generation, with minimal human intervention.

The results of this research highlight the effectiveness and feasibility of the proposed system. The system demonstrated a high degree of accuracy in violation detection (89.25%) and number plate recognition (95.18%), showcasing its potential for deployment in real-world scenarios. Error rates observed in specific instances were primarily attributed to factors such as low frame rates, complex traffic conditions, and motion blur. These findings underscore the importance of optimizing camera hardware to enhance the system's reliability further.

One of the significant contributions of this research is the use of broader reference lines for speed estimation, which improves detection accuracy by reducing false negatives in intersection detection. Additionally, the adoption of bounding box technique mitigates inaccuracies caused by bounding box variations in speed calculations, ensuring consistent and reliable performance.

In conclusion, this research demonstrates that the proposed system can significantly streamline traffic enforcement by automating violation detection and ticket generation processes. Its deployment in urban settings can lead to improved compliance with traffic laws, reduced human workload, and ultimately safer roadways. This study lays a strong foundation for future advancements in intelligent traffic management systems.

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