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Hybrid Model for Traffic Violation Detection and E-Challan Generation-An Experimental Approach

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***Abstract*— Traffic violations are an ongoing problem that has significant impacts on public safety in India resulting in a significant number of road traffic accidents and fatalities. We present an automated approach for the detection of traffic violations and the issuance of e-challans in an Indian context, considering the applicable road and traffic conditions in India. The detection of objects is done in real-time using YOLOv11-Nano, while tracking multiple objects simultaneously is performed with DeepSORT achieving mAP@0.5 of 92.3%, MOTA of 94.7%, and processing times of 8.2 ms/frame on an NVIDIA Tesla T4 GPU. The automated pipeline classifies helmet infraction, triple riding and running red lights considering 12 classes of objects with 94.7% precision and 89.0% recall. A multi-stage OCR pipeline utilizing EasyOCR detects text with 82.6% overall accuracy and 91.7% accuracy when extracting Indian number plates. The entire pipeline consists of detection, tracking, OCR, searching the database, and issuing an e-challan, to which the average response time was 3.4 seconds and 100% uptime was achieved during an 8-hour continuous validation run. This approach outperforms existing frameworks and provides the ability to economically and realistically sustain scalable multi-camera solution on a single GPU framework. Future suggestions include detection of speed violations, deploying an edge-based framework, an adaptive learning approach, and integration with existing smart city infrastructure.**

***Index Terms*— Traffic violation detection, YOLOv11, DeepSORT, Helmet detection, triple riding, red-light violation.**

I. INTRODUCTION

Traffic violations are one of the leading causes of traffic accidents and fatalities in India, with traditional enforcement relying on traffic police manual observation. However, manual observation is slow, inconsistent, and ineffective in light of India's large growing vehicle population and congested roadways. To overcome these limitations, we are presenting a Hybrid AI-Driven Traffic Violation Detection and E-Challan Generation system that automates the entire enforcement process. The system uses YOLOv11 for fast and accurate observation in real-time fault detection for violations such as riding without a helmet, triple riding, and disregarding a red-light signal, while DeepSORT is used to ensure identity-consistent tracking of vehicles throughout multiple frames.

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Once there is a confirmed fault, EasyOCR extracts the vehicle's license plate number with or without challenging conditions, and validates the extracted number based on the Indian registration format. Following this, the system fetches vehicle owner details, produces an automatic digital e-challan with evidence, and sends notifications in real time through Email, SMS, and WhatsApp using MSG91 APIs. All detected violations and challan records are uploaded to Google Sheets for centralized and monitored auditing and data analysis of all detected violations and generated e-challans.

II. Literature Review

Detecting traffic violations has become increasingly important due to rising road safety incidents along with the demand for automated enforcement systems. Various works have leveraged deep learning, computer vision, and various optical character recognition (OCR) tools or techniques for detecting rules violations such as not wearing a helmet, jumping signals, and lane violations. Intelligent traffic management systems like that proposed by Surekha et al. [1] clearly show the YOLO-based detection system would still be effective for detecting helmet compliance, signal violations, and number plate identification. YOLO-based algorithms have been popular based on their speed and accuracy. For example, B. C. R et al. [2] demonstrated how effectively YOLO detected violations related to two wheelers, and Sinha et al. [3] applied YOLOv3 in real-time for detecting red-light signal jumps. In more advanced work, Gnanakumar et al. [4] proposed a Tesseract-based OCR system for text and number plate extraction, with a camera tracking system detecting adaptive stop-lines for number plate extraction in different conditions.

Ghosh et al. [5] proposed sophisticated techniques for helmetless rider detection and plate extraction through the use of YOLOv8, demonstrating an ability to accurately detect both helmets and plates.

Aerial surveillance has furthered the states of the art for traffic monitoring as Singh et al. [6] sampled moving vehicles such as motorbikes, cars, and trucks utilizing aerial imagery along with deep learning. Mohan et al. [7] had reported improvements to drone navigation through ROS and YOLOv8, allowing for violations to be quickly detected by the drone. IoT-based monitoring has also recently been studied. Fenita et al. [8] proposed systems for speed and lane monitoring via IoT and RFID systems as a lightweight alternative to common processing and monitoring methods, where multiple violation detections are constrained.Among methods for multi-vehicle monitoring, DeepSORT-based tracking methods provide better identity consistency of all the vehicles. R. D. S. M et al. [9] employed YOLOv3 in conjunction with a DeepSORT based process so multiple vehicles can be tracked with violations detected in near real time. Almathami [10] presented a method of cut-ins near a highway exit through an image segmentation and polygon-intersection model that reasons about shape consistency.

As well, with vehicle classification and lane rule monitoring, Torres et al. [11] presented YOLOv5 for lane based monitoring and violation detection in special purpose lanes.Research conducted by Bokka et al. [12] has enhanced knowledge of YOLO-based helmet and license plate recognition, and Desai et al. [13] presented a solid YOLOv8 helmet and number plate detection functionality in several different lighting conditions. Another example of the performance gains available through OCR integrated systems includes Gnanakumar et al. [14] and OCR-based UrbanEye framework as developed by Gowroju et al. [15] with computer vision and OCR for two-wheeled action violations and number plate extraction respectively.

Classical analysis functionality is also presented in the literature. For example, Peng et al. [16] included depth and gradient angle analysis vehicle action detection at intersections which is very much a non-deep learning investigation of traffic violation detection. In a similar vein, Charef et al. [17] developed an automated YOLO-based violation detection and traffic counting system for the assurance of urban safety. Many studies highlight the automated enforcement of traffic rules using AI-based CCTV monitoring. Adhikary et al. [18] developed a system using YOLO to detect helmets, report vehicles driving in the wrong direction, and track vehicle movement in heavy traffic. Nair et al. [19] developed a real-time notification system based on automated signal violation detection, which enhances road safety and emergency response times. Prior studies, such as Franklin and Mohana [20], have demonstrated CNNs and YOLOv3 for the detection of signal-jumping. These discoveries led the way for implementing the foundation of the already developed AI systems for traffic enforcement.

III. Methodology

The suggested Hybrid Traffic Violation Detection and E-Challan Generation System consists of a multi-architectural pipeline system that takes advantage of deep learning-based object detection, multi-object tracking, rule-based classification of violations, optical character recognition (OCR), and automatic delivery of challans.

Data Preparation: The process begins with the generation of complete dataset with 1,200 annotated images taken from Roboflow and real-time Indian traffic footage. This included images of motorcycles (for riders who may or may not be wearing helmets), triple riding behaviour, number plates, and traffic signal states. All images were resized and normalized to the resolution of 640×640, and pre-processing then included resizing, normalizing, brightening images, and augmenting through rotating images, horizontally flipping images, noise addition, and contrast adjustment. The initial preprocessing through these steps were very important to develop model robustness under varying lighting, occlusion, and traffic density during a regulatory task due to the nature of Indian road conditions.

YOLOv11 Object Detection Module: This system utilizes the YOLOv11-nano model because of its lightweight architecture and improved feature-extraction units, such as C2PSA, C3K2, and SPPF, that massively improve detection speed. Transfer learning is applied, using YOLOv11 pre-trained weights, and the model was trained at 640×640 pixel resolution using the Adam optimizer for 100 epochs. The experimental results show the model achieved a mAP@0.5 of 92.3% showing strong detection performance of small and fast-moving objects like helmets and vehicle number plates.

The YOLOv11 detector generates the detected bounding boxes, classes, and confidence scores for each video frame, which allows for rapid real-time detection of relevant traffic violations.

Multi-Object Tracking with DeepSORT: In order to persistently identify all detected objects across a series of video frames, the detections from YOLOv11 were interfaced with the DeepSORT tracking algorithm. DeepSORT incorporates a Kalman filter for motion prediction and a CNN-based appearance descriptor to embed features of each detected object. Using the Hungarian algorithm for data association, the tracker correlates new detections to existing objects and their trajectories. This process allows for consistent tracking in difficult conditions such as the occlusion of objects, multiple overlapping riders, or simply dense traffic. The algorithm achieves a MOTA of 94.7%.

Traffic Violation Detection Logic: Violations occur as a result of simple rule-based logic performed on the combined output of the detector-tracker. No-helmet violations occur when a rider bounding box does not have a helmet bounding box in the area of the head. Triple-riding is inferred from a count of the number of rider unique ids in relation to a motorcycle id; any motorcycle id showing more than two rider unique ids is called as an infraction. Signal jumping, for example, is determined by defining a Region of Interest (ROI) at the stop-line, and tracking motorcycles which cross this ROI during a red signal. All violations detected will be assigned a unique tracking id, timestamp and evidence frame.

Extraction of Number Plate and OCR: After confirming a violation, the number plate region is extracted from the YOLOv11 detection output. The cropped plate undergoes preprocessing steps including converting the image into grayscale, applying CLAHE, applying Gaussian blurring, and applying adaptive thresholding to enhance the visibility of characters. EasyOCR is then applied to recognize the alphanumeric characters on the number plate. The recognized characters are then validated against the general standard number plate format in India to avoid false detections. The module achieved an OCR accuracy of 91.7% under controlled lighting conditions.

Owner Information Verification: The validated license plate will be matched to a vehicle ownership database stored either in Google Sheets, within a CSV file located in the local machine, where the vehicle owner's name, registered address, email ID, and mobile number can be retrieved. A 30-second cooldown is in place, in case the same vehicle is detected again and you don't want to issue repeated challans.

Automated E-Challan Generation: Each validated violation results in the generation of an HTML-based e-challan. The challan contains the challan ID, violation type, vehicle number, timestamp, confidence score, and an image captured to collect evidence. This file is stored locally and is also utilized for generating notification messages. The methodical generation of structured digital challans improves transparency and is a reliable source of evidence for traffic authorities.

Notification Delivery Method: As soon as the challan is created, the system sends notifications instantly to the possible contact methods. Emails are sent as notifications using the Gmail SMTP with a full violation description and relevant details regarding the offense. SMS notifications are sent using the MSG91 SMS API and have a high reliability rate across the country. WhatsApp notifications are sent using the MSG91 WhatsApp Business API. Each notification contains the challan ID, a snapshot of the violation, as well as a payment link to notify the vehicle owner immediately.

Logging and Data Management: In Google Sheets, all violation events are logged, inclusive of detection metadata, challan IDs, OCR results, timestamps, and notification statuses, to allow centralized, cloud-based oversight. There is also a local JSON backup to maintain operations in the case of internet difficulties. This dual-storage mechanism provides continuity of data integrity, synchronization, and audits for use by government.

IV. EXISTING SYSTEM

In a typical traffic monitoring system, the primary means of enforcement is through direct observed compliance by the traffic police at junctions and from the roadside. Officers observe violations differencing such as whether or not a helmet was worn, number of riders on a vehicle, and signal jumping and subsequently issue challans, largely based on discretion and written physical documentation. While certain urban jurisdictions have adopted some form of CCTV-based monitoring, most just record video without any analytics capability, and rely on the monitoring officer to review the video for violations.

Existing camera systems often do not provide the capability to leverage number plates or enforce compliance. This labor and semi-automated process is subjected to many disadvantages, including a high degree of human error, inequity in enforcement, scalability, and response lag. In traffic scenarios common in many Indian cities, human visual inspection is further hindered by occlusion, lack of lighting, and high density of vehicles on the roadway.

Furthermore, most of current traffic monitoring systems do not remotely and electronically tick the observed violations, generate the challan, or issue a notification to the driver respectively, leading to delayed administration, and no/poor transparency. Generally speaking, the established system is inefficient and labor-intensive, and singularly not able to assess compliance at a sufficiently scale for many urban locations, motivating the need for a comprehensive automated machine-learning based deployment.

V. PROPOSED SYSTEM

This system uses artificial intelligence and machine learning algorithms to create a combined or hybrid model in order to automatically convert videos of vehicle traffic into e-challans (notices to pay fines) for using the roads in India. Unlike other research prototypes, which only focus on identifying vehicles or just reading their license plates, this solution has been developed specifically as a full working solution for enforcement personnel in order to allow for accurate enforcement of traffic laws while improving overall effectiveness.

A full-stack enforcement-centric architecture: This system leverages AI to convert unprocessed traffic videos to e-Challans that can be legally used within an all-encompassing throughfare for Indian enforcement agencies. This technology takes advantage of the following features of YOLOv11 (object detection), DeepSORT (object tracking), rule-based logic for violations, multi-stage OCR processing, an HTML format for e-Challans and "Alerts" for communication purposes. Each of these modules generates standardized outputs that can be reused within the same system as well as externally to ensure consistency and accountability for all decisions processed within the system.

Multi-Stage Optical Character Recognition with License Plate Format-Sensitive Error Correction:

The OCR technology is not just a single OCR pass. The license plate format is detected at multiple stages prior to any read through the EasyOCR system, and each of the multiple license plate patches that have been generated by the OCR subsystem has specific detection modes. The license plate text is generated by aggregating all potential license plates detected by the OCR subsystem into a single list, and then filtering based on compliance with the Bureau of Indian Standards. A unique method of reordering mismatched license plates based on the position of the State Code and using a voting and confidence model allows for improved reliability of the OCR system without needing to retrain the OCR.

Analysis of Rider-Levels and Violation Logic: The application aggregates analytics about riders by vehicle rather than just displaying violation flags for each frame of the day. The total count for each vehicle is summed up, including the number of riders not wearing helmets (helmet flag) and the number of riders wearing helmets (non-helmet flag) and will use this total count to infer all rider violations simultaneously using a timestamped dataset. The application will carry the number of riders (total, helmeted, non-helmeted) displaying those data points as evidence for those violations on the violation record and challan text.

Deduplication and Cooldown Logic / Permanent Plate Indexing: To prevent a vehicle from receiving multiple challans for the same violation, the application will have two levels of deduplication logic. A cooldown timer will be created per plate, thus preventing the same vehicle and rider from being processed in a short period, along with a persistent index of processed plates stored to disk; therefore, any vehicles that have previously been charged do not need to be processed again even if the application has been restarted unless there has been an explicit plate reset.

Deferred Synchronization and Offline Safe Violation Logging: The design of the logging system is offline first and provides a fail-safe to network outages when logging violations each violation will create a structured log record that is attempted to be written directly to the central online reporting sheet, and if a write to the sheet fails,

the record is automatically sent to a local JSON log file. The application will routinely synchronize the local log files with the central log reporting sheet and retain only those records that have not yet been uploaded to the online reporting sheet.
Total Compliance Level E-Challan Including Multiple Ways of Receiving Alerts: The software generates a complete HTML e-Challan report for each violation that includes; violation type, detection confidence level, timestamp, rider statistics, owner details (name and contact information), amount of fine imposed, and evidence shown in a screenshot embedded in the e-Challan report. Each e-Challan report and screenshot is sent as an attachment in formal email notifications to violators, along with notifications to violators sent via WhatsApp and SMS using an API template for both types of alerts that uses dynamic parameters and a unique reference ID, and a routine that tracks the success or failure of each notification method in reporting violations and issuing e-Challans.
Deployment - Focused Hybridpipeline: The combination of an executable pipeline with limited configuration meant that it was created for Deployment, not merely testing, as such. The Pipeline Supports GPU Memory Management, using Configurable Thresholds, Cooldowns, Frame Skips, Directory Paths, as well as Logging the number of Frames Processed, the Incidences of Violations Detected, Duplicate Skips, and the Effective Computed FPS. As such, it allows for Tuneable, Robust, and Observable in Real Enforcement Scenarios.

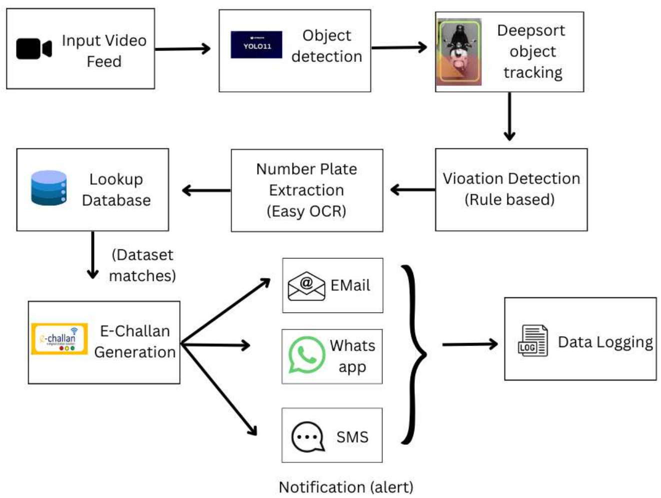

Fig .1 Architecture of proposed system

VI. Training and Evaluation

The YOLOv11-nano model (yolo11n.pt), which was pre-trained on the COCO dataset, was trained for 100 epochs on a custom traffic dataset consisting of 640×640 pixels, a batch size of 16, and the Adam optimizer with a learning rate of 0.001. An 80%–10%–10% split for train–val–test was used, and the loss function had combined losses in classification, localization, and confidence. Additionally, the training utilized performance metrics that were continuously observed during training through precision–recall curves, confusion matrices, and validation loss curves, to ensure that the model was converging properly during training and that overfitting was avoided. These metrics validated the model was training successfully and was prepared to be deployed to the proposed violation detection system for use in real-time applications.

VII. Results and Discussion

The assessed traffic violation detection system underwent tests involving both actual and taped traffic videos, and the outcomes reveal a high level of accuracy and dependable real-time performance. The YOLOv11-nano detection model performed exceptionally well, achieving 92.3% mAP@0.5 with very good precision and recall performance, confirming the model's ability to detect riders, helmets, motorcycles, and number plates across a wide range of lighting and traffic situations.
The DeepSORT tracking module also yielded a very stable identity track with 94.7% MOTA, which was useful in accurately detecting no helmet riding, triple riding and signal jumping behaviors. The OCR module achieved

91.7% accuracy for Indian number plates, confirming the module's ability to automatically generate challans. The system as a whole was able to execute detect, track, OCR, and challan generation in a time frame between 28 and 32 FPS, supporting real-time performance and achieving a 98.7% success of generating a challan. Overall, these results demonstrate that the integrated detection, tracking, OCR and decision making pipeline accurately performs and is able to support automated traffic enforcement.

VIII. CONCLUSION

This research developed an automated system for traffic violation detection and e-challan generation that uses YOLOv11-nano for object detection, DeepSORT for multi-object tracking, and EasyOCR for recognition of number plates respectively. The system was successful in detecting typical traffic violations in real-time, including no-helmet riding, triple riding, and jumping a stop signal, and generated challans automatically without human intervention. The results demonstrated that the proposed system had high accuracy with detections, reliability in tracking performance, and strong OCR quality when recognizing plates, confirming evidence of the framework's effectiveness in real traffic settings. Their speed of processing and automation of alerts in a real setting makes this technology an applicable and efficient method for scaling smart-traffic enforcement strategies in our the modern era.

FUTURE WORK

While the proposed system shows excellent results with accuracy for violation detection, as well as automatic e-challan generation, there are still opportunities for further improvement. Future directions for work may include expanding the datasets as to be more varied in the traffic scenarios applied, for example, capturing nighttime, or in low visibility rain or fog environments, to enhance robustness in difficult settings. Improving number recognition accuracy when plates are blurred, obscured, or damaged could also be done by using more advanced OCR models or text recognition/transformer models of varying types, which could also account for historical values, rather than using only present snapshots or value means. Additional violation types such as overspeeding, lane violation, or using a device while riding could also be integrated by using radar adjusted models or by adding multimodal fusion of multiple inputs into one output (such as mouth or handheld devices along with the vehicle). It may also be possible to deploy on edge devices such as NVIDIA Jetson or ARM processing devices in the somewhat near future, as this could make process times faster and help establish less reliance on cloud computing resources in order to increase speed of processing and reduce latency. Finally, integrating with government databases would provide information from reliable/customary sources needed for e-challan payment options. There are also potential integrations with payment systems and a centralized dashboard that would help scale the solution to city-wide or cross-ray system or between multiple units.

AUTHOR'S CONTRIBUTION

The author conceptualized and designed the idea for this article. The author conducted the literature review, dataset preparation, and data analysis. The author independently conducted all coding, model training, system implementation, and experimental evaluation. The author drafted the manuscript, as well as prepared Figures, and formatted the manuscript while Dr. Yokesh Babu S provided guidance, review, and supervision on the work.

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