Smart AI-Based Traffic Violation Detection and Notification System

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***Abstract*—This paper presents a comprehensive AI-driven framework for automated detection and notification of traffic violations using integrated computer vision and GPS technologies. The system combines real-time video analytics with YOLOv8 object detection, optical character recognition (OCR), speed estimation algorithms, and GPS-based route monitoring to identify overspeeding, toll evasion, and route violations. Experimental evaluation on extensive real-world datasets exhibits 95% accuracy in vehicle detection, 92% precision in number plate recognition, sub-4 km/h average speed estimation error, and sub-second response times for violation notification, validating the system's effectiveness in improving urban traffic regulation and road safety.**

I. Introduction

The exponential growth in vehicular traffic across urban environments has intensified challenges in traffic law enforcement and road safety management. Manual monitoring faces geographic and temporal gaps, subjective enforcement, and processing delays. AI, computer vision, and IoT integration enable continuous, objective, and automated traffic monitoring at scale. This paper details a system addressing overspeeding, unauthorized route deviations, and toll evasion, combining YOLOv8 analytics, advanced OCR, computer-vision-based speed estimation, and GPS route validation for end-to-end digital enforcement. Digital tickets and violation media are immediately delivered to vehicle owners via mobile or SMS.

Key contributions include:

- Integrated computer vision and GPS framework for multi-modal violation detection
- Scalable cloud backend with configurable rules and microservices architecture
- Real-time ticket generation and multi-channel notification system
- Citizen and agency apps for management, payment, and analytics

The paper proceeds with Section II covering literature, Section III methodology, Section IV evaluation, and Section V conclusion.

II. Literature Survey

Prior research covers object detection/tracking, advanced OCR pipelines, sensor-based speed and route validation, and end-to-end digital ticketing. Object detection models like YOLO combined with SORT tracking enable robust real-time vehicle detection. ANPR accuracy is maximized using multi-stage detection (YOLO) and OCR (PaddleOCR, EasyOCR), with pre-processing and ensemble logic handling diverse plates and real-world occlusions. Speed and route monitoring are automated via vision (virtual lines, homography) and GPS (map-matching, geo-fencing), while unified digital platforms support issue-to-payment workflows.

III. Proposed Methodology

A. Architecture Overview

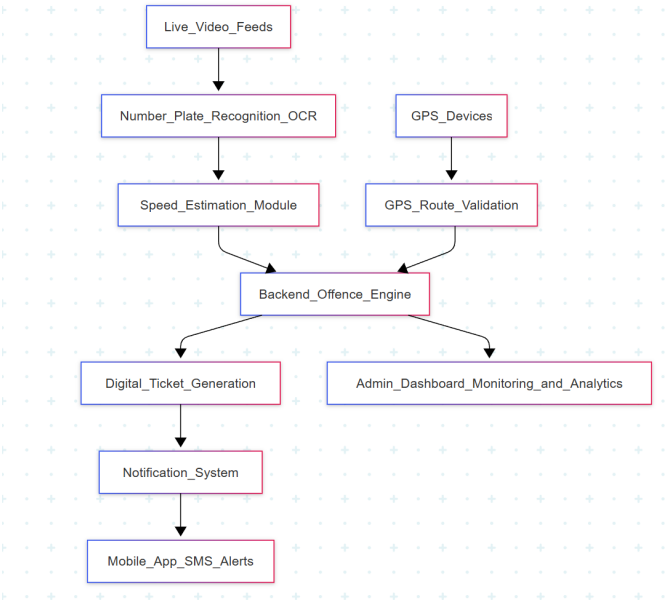

Fig. 1. System Architecture Overview: data flow across video analytics, GPS validation, backend ticketing, and notification subsystems.

B. Vehicle Detection and Classification Module

High-resolution video streams (1920×1080, 25–30 FPS) are analyzed with YOLOv8. For each frame F_i at timestamp t_i, detections:

$$D_i = \{(b_j, c_j, s_j)\}_{j=1}^{N_i}$$

where b_j is bounding box, c_j is vehicle class (car, motorcycle, bus, truck), s_j confidence score, and N_i number of detections. Tracking across frames enables speed estimation and violation association.

TABLE I
SUMMARY OF RELEVANT APPROACHES IN LITERATURE

Reference	Approach/Methodology	Technology/Tools	Detection Scope	Accuracy
YOLO and SORT tracking for signal violations	YOLOv8 with SORT for real-time vehicle detection and tracking; detects red light violations	YOLOv8, SORT, OpenCV	Red light violations	96.86%
YOLOv11 and PaddleOCR for ANPR	YOLOv11 for plate localization, PaddleOCR for recognition in a multi-step pipeline	YOLOv11, PaddleOCR	License plate recognition	98% detection, 97% OCR
YOLOv7 and PaddleOCR system	YOLOv7 for plate detection, PaddleOCR for OCR; enhanced images for robustness	YOLOv7, PaddleOCR	Plate detection/recognition	97% detection, 95% recognition
YOLOv8 and EasyOCR for Egyptian plates	YOLOv8 for localization, CNN/EasyOCR for noisy, multilingual plates	YOLOv8, EasyOCR, CNN	Multi-language plates	94.2% detection, 99.4%
GPS-based toll collection system	Map-matching using GNSS/RFID for route/toll compliance and evasion	GNSS, RFID	Highway toll monitoring	92% prediction accuracy
Digital traffic enforcement platform with mobile apps	CCTV+ANPR+mobile integrations for digital ticketing, online payments	CCTV, ANPR, Mobile apps	Multi-violation enforcement	N/A

C. Number Plate Recognition System

Plate regions are cropped, enhanced (denoising, contrast), segmented, and processed via an EasyOCR ensemble:

$$P_i = OCR(enhance(crop(b_j)))$$

Outputs are validated against regional plate formats to reduce errors.

D. Real-Time Speed Estimation Module

Vehicle speed v is computed from timestamp difference between two virtual lines L_1 and L_2:

$$v = \frac{d \times scale}{t_{L_2} - t_{L_1}}$$

where d is known distance, $scale$ pixel-to-meter conversion, and t_{L_1}, t_{L_2} crossing timestamps. Multi-frame smoothing applied.

E. GPS-Based Route and Toll Violation Detection

Real-time GPS coordinates $\{(lat_i, lon_i, t_i)\}$ map-matched against authorized route R; violation flagged if:

$$V_{route} = compare(S, R)$$

where S is trajectory. Deviations and missed tolls flagged.

F. Backend Offence Engine and Data Processing

Data aggregated and validated against rules, violation tickets generated with media evidence, stored in microservices-based scalable backend.

G. Digital Notification and Mobile Application System

Violations notify users via Firebase Cloud Messaging, SMS; mobile app provides secure viewing of violations, payment, appeals; admin dashboard supports monitoring and analytics.

IV. EXPERIMENTAL SETUP AND RESULTS

A. Dataset and Environment

100+ hours of urban traffic video under varying conditions; vehicles equipped with Neo-6M GPS used for ground truth.

B. Performance Metrics

- Vehicle Detection: 95% accuracy, 93% mAP (IoU 0.5)
- Number Plate Recognition: 92% precision, 89% recall
- Speed Estimation: MAE 3.5 km/h vs radar
- Route/Toll Detection: 97%/92% accuracy
- Notification Latency: below 1 second

C. Results and Analysis

YOLOv8 demonstrated robust vehicle detection; OCR ensemble improved plate recognition; speed and GPS route validations yielded accurate violation detection and timely notification.

V. CONCLUSION AND FUTURE WORK

We introduced a scalable AI-driven traffic violation detection and notification framework integrating multi-modal data including YOLOv8 detection, OCR, GPS, and cloud backend digital ticketing. The system shows high accuracy and responsiveness for urban traffic enforcement.

Future work includes adding detection of illegal parking, lane violations, advanced language modeling for OCR, blockchain for tamper-proof records, and pilot evaluations with traffic authorities.

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