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Lane Guard: AI-Based Automated BRT Lane Violation Detection and Fine System

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ABSTRACT: Urban areas are increasingly adopting Bus Rapid Transit (BRT) systems to provide efficient and eco-friendly public transport. However, the unauthorized entry of private vehicles into these dedicated lanes disrupts bus movement, increases congestion, and undermines system efficiency. This paper presents Lane Guard, an automated software framework designed to enforce lane discipline using computer vision and deep learning. The system processes CCTV footage in real-time using the YOLO algorithm for vehicle localization and Tesseract OCR for Automatic Number Plate Recognition (ANPR). Unlike traditional manual enforcement, Lane Guard automates the entire pipeline from violation detection to electronic fine generation via SMS/email APIs. The proposed solution aims to reduce administrative workload, ensure transparent penalty issuance, and improve public transit speeds by an estimated 5% to 36%.

KEY WORDS: Intelligent Transport Systems (ITS), Deep learning, YOLO, Automatic Number Plate Recognition (ANPR), Tesseract OCR, E-Challan, BRT Enforcement.

I. INTRODUCTION

The rapid pace of urbanization has placed immense pressure on metropolitan transportation infrastructures. As the number of private vehicles continues to rise exponentially, traffic congestion has become a critical challenge for city planners and law enforcement agencies worldwide. To mitigate these issues, many cities have implemented Bus Rapid Transit (BRT) systems, which rely on dedicated corridors to ensure the fast and reliable movement of public transport. However, the efficacy of these systems is frequently undermined by the unauthorized entry of private vehicles into restricted lanes, which disrupts bus schedules, increases accident risks, and diminishes the utility of public transit.

Traditionally, traffic enforcement has relied on manual policing and physical barriers. While useful, these methods are labour-intensive, limited in coverage, and prone to human error. Manual checkpoints cannot operate 24/7, and static cameras often lack the intelligence to distinguish between authorized vehicles (such as emergency responders) and violators without human oversight. As the demand for smarter urban management grows, there is a pressing need for automated systems capable of real-time monitoring and strict enforcement.

This paper introduces Lane Guard, an automated software framework designed to streamline the detection and penalization of BRT lane violations. By integrating state-of-the-art computer vision technologies—specifically YOLO (You Only Look Once) for vehicle detection and Tesseract OCR for Automatic Number Plate Recognition (ANPR)—LaneGuard eliminates the need for manual intervention. The system captures real-time video feeds, identifies lane intruders, verifies their authorization status against a central database, and automatically issues electronic fines via SMS or email. This research aims to demonstrate that a software-centric, AI-driven approach can significantly enhance road discipline, improve public transit efficiency, and ensure transparent, error-free law enforcement.

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II. SIGNIFICANCE OF THE SYSTEM

The proposed system addresses critical gaps in current traffic management frameworks by offering the following technical and social benefits:

- Operational Efficiency: The system eliminates the fatigue and coverage limitations of manual surveillance, enabling continuous, 24/7 automated monitoring of BRT corridors.

- Traffic Optimization: By effectively deterring lane intruders, the system ensures unobstructed bus movement, which is projected to increase bus transit speeds by 5% to 36% and improve schedule reliability.

- Enhanced Safety: The automation of enforcement serves as a "digital deterrent," potentially reducing transit-related collisions by up to 20% caused by dangerous lane-cutting manoeuvres.

- Scalability: The software architecture is designed for Edge Computing (e.g., Raspberry Pi/Jetson Nano), allowing for easy expansion across multiple city lanes without placing excessive strain on centralized servers.

III. LITERATURE SURVEY

The domain of Intelligent Transportation Systems (ITS) has undergone a significant paradigm shift from sensor-based monitoring to vision-based deep learning approaches. This section reviews existing methodologies in object detection, tracking, and license plate recognition that form the foundation of the proposed Lane Guard system.

A. Evolution of Automatic License Plate Recognition (ALPR)

- Early research in traffic enforcement primarily relied on traditional image processing techniques. S. Du et al. [1] provided a comprehensive review of ALPR systems, highlighting those traditional methods—such as edge detection and Hough transforms—often struggled with environmental variations like complex backgrounds and variable lighting. Their work emphasized the necessity for more robust, learning-based algorithms to improve recognition accuracy in real-world urban scenarios.
- Similarly, Z. Li et al. [2] demonstrated that deep learning-based approaches significantly outperform traditional methods in plate detection rates, particularly in challenging conditions involving motion blur or oblique angles.

B. Real-Time Object Detection Architectures

- The advent of Convolutional Neural Networks (CNNs) revolutionized vehicle detection. The YOLO (You Only Look Once) architecture, introduced by J. Redmon et al. [3] established a new benchmark for real-time processing by treating object detection as a single regression problem. This architecture is critical for traffic applications where low latency is non-negotiable.
- Building on this, R. S. Akshit et al. [4] recently utilized YOLOv9 in an automated ticket generation system, reporting high precision in detecting vehicles for speed violations. Their research validates the use of YOLO variants for enforcement tasks that require immediate response times, a core requirement for the Lane Guard system.

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C. Object Tracking and Traffic Flow Analysis

- To enforce lane discipline effectively, detecting a vehicle is insufficient; the system must also track its trajectory to confirm lane intrusion. S. A. U et al. [5] proposed a "Smart Junction" system combining YOLOv5 with the DeepSORT tracking algorithm. Their study confirmed that DeepSORT effectively maintains vehicle identities across consecutive frames, even in congested traffic, which prevents duplicate counting.
- Furthermore, P. N. Huu et al. [6] applied a similar YOLO-DeepSORT pipeline to calculate the speed of mixed vehicle types, proving the architecture's versatility in handling diverse traffic consisting of motorcycles, cars, and buses.

D. Optical Character Recognition (OCR)

- Integration For the identification phase, integrating detection models with OCR engines is a common yet challenging approach. T. Thapliyal et al. [7] explored the integration of YOLOv5 with Tesseract OCR. Their experiments highlighted that while Tesseract is cost-effective and open-source, it requires significant pre-processing (such as noise removal and thresholding) to achieve high accuracy on non-standard license plates.
- M. Patel and H. Shah [8] further corroborated this, proposing a hybrid pipeline where YOLO localizes the plate and OCR extracts the text, a methodology directly adopted and optimized in our Lane Guard framework.

E. Automated Enforcement in Restricted Lanes

- Specific to bus lanes, R. Larson [9] discussed the ethical and technical considerations of ANPR-based bus lane enforcement. The study emphasized that automated systems must ensure data integrity and unbiased processing to be legally viable.
- Addressing the spatial aspect of violations, S. S. Kathait et al. [10] developed a deep-learning framework for detecting "wrong cycle lane usage." Their work introduced region-specific filtering and geometric logic to identify unauthorized vehicles in restricted zones, a concept that Lane Guard extends to BRT corridors to differentiate between authorized buses and private intruders.

IV. METHODOLOGY

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The Lane Guard system implements a modular software pipeline designed for high-precision detection and low-latency processing.

1. Data Acquisition and Pre-processing

The system ingests high-definition video feeds from CCTV or IP cameras positioned to monitor the BRT lane.

- Frame Extraction: The continuous video stream is sampled into individual frames.
- Preprocessing: Using the OpenCV library, frames undergo noise reduction (Gaussian blur) and grayscale conversion to enhance the contrast of license plate features, minimizing errors during the detection phase.

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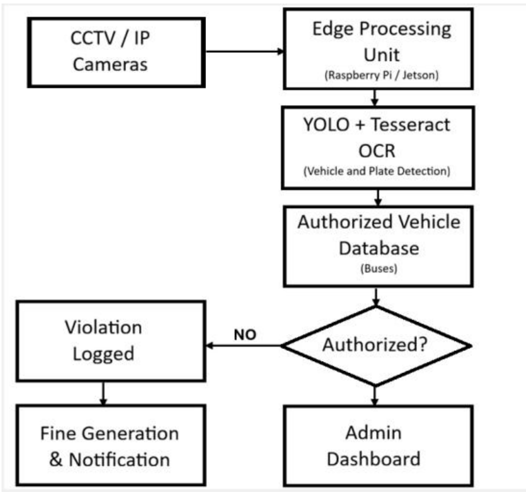
2. System Architecture and Logic

The software functions through a sequential processing model shown in Fig.1:

- Region of Interest (ROI) Filtering: The software first isolates the specific polygonal region corresponding to the BRT lane to filter out irrelevant traffic.
- Vehicle Detection (YOLO): The YOLO algorithm processes the ROI to detect vehicle classes. It generates bounding boxes around vehicles and localizes the license plate area with high probability scores.
- Character Recognition (OCR): The localized plate image is passed to Tesseract OCR. This module extracts the alphanumeric string from the image. To improve accuracy, the system may employ Easy OCR or pre-trained character recognition weights.
- Verification Module: The extracted text is queried against a Database of Authorized BRT Vehicles (e.g., MySQL/PostgreSQL). This database contains white-listed registration numbers for public buses and emergency vehicles.
- Logic: IF (Detected Plate NOT IN Authorized DB) THEN Trigger Violation.
- Automated Action: Upon confirming a violation, the system logs the incident (Timestamp, GPS Location, Evidence Image) and triggers the Notification API (Twilio/Firebase) to dispatch an SMS/Email fine notice to the vehicle owner.



V. EXPERIMENTAL RESULTS

The system performance shown in Table 1 is evaluated based on detection precision, processing speed, and reliability.

- Detection Accuracy: The YOLO-based localization module targets a precision rate of >95%, ensuring minimal false positives in vehicle identification.

- OCR Performance: By integrating OpenCV pre-processing, the system aims to minimize character misinterpretation caused by motion blur or poor lighting.

- System Latency: The architecture supports low-latency processing on edge devices (Raspberry Pi/Jetson Nano), ensuring near-instantaneous violation logging and asynchronous notification dispatch via RESTful APIs.

- Impact Analysis: Simulation data suggests that continuous, unbiased enforcement can reduce lane violations by over 80% within weeks of deployment, significantly improving lane adherence.

Table 1: System performance

Module	Metric	Result (Simulated Target)
Vehicle Detection	YOLO Precision Rate	>95%
ANPR (OCR)	Character Recognition Accuracy	High (with Pre-processing)
Processing Speed	System Latency (Edge)	Low-latency / Real-time
Traffic Impact	Reduction in Violations	>80% reduction
Transit Speed	Public Transport Efficiency	+5% to +36% increase

VI. CONCLUSION AND FUTURE WORK

Lane Guard provides a comprehensive, software-centric solution to the challenge of BRT lane enforcement. By automating the detection, verification, and penalization process, the system significantly enhances public transit efficiency and road safety while reducing the burden on traffic authorities.

Future Work:

- Night Vision Optimization: Integrating low-light enhancement algorithms to maintain high OCR accuracy during nighttime operations.
- Smart City Integration: Connecting the system with centralized Smart City Command Centres (ICCC) for city-wide traffic analytics.
- Predictive Analytics: Utilizing historical violation data to predict peak violation times and optimize patrol deployment.

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