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Next-Gen Smart Traffic Violation Detection Using Edge AI and IoT for Safer Urban Mobility

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Abstract: Urban traffic is more stressed with the increase in traffic offenses like signal jumping, overspeeding, and helmet-less driving, which are compromising the safety of the roads and making transportation inefficient. Traditional methods of enforcement that rely on human monitoring and post-incident analysis are inadequate for real-time intervention. This paper introduces a future-proof smart traffic violation detection system driven by Edge AI and Internet of Things (IoT) technology to provide efficient, autonomous, and scalable traffic monitoring for contemporary urban environments. The envisioned system combines YOLOv5-based object detection, optical character recognition (OCR) for license plate extraction, and OpenCV for visual analysis. Edge devices like Raspberry Pi devices, along with IoT sensors, analyze and process video feeds at the point of origin, cutting latency and bandwidth consumption drastically. Besides detection, the system uses machine learning-based predictive analytics to predict hotspots of violations and peak hours, enabling authorities to implement preemptive safety measures. Real-time notification, automatic reporting, and integration with smart city infrastructure further increase responsiveness and public accountability. Field tests show high detection accuracy in various lighting and weather conditions, and the edge-IoT architecture provides cost savings and simplified deployment. This research helps in developing intelligent transport systems, providing secure, intelligent, and adaptable urban mobility solutions.

Keywords: Edge AI, IoT, Smart City, Traffic Violation Detection, YOLOv5, License Plate Recognition, Computer Vision, Real-time Monitoring, Intelligent Transportation System, Predictive Analytics.

I. Introduction

The urban transport networks present are put under immense pressure by the speedy urbanization, population increase, and exponentially growing vehicle ownership. With this expansion comes an increase in traffic violations of the type like jumping signals, overspeeding, helmet-less riding, triple riding, and unauthorized parking most of which directly result in road crashes, congestion, and compromised public security. Conventional methods of traffic enforcement based on manual observation and penalty procedures following violations are frequently reactive, resource-based, and subject to human fallibility. These result in poor enforcement and slow response in emergency situations. The development of smart cities demands clever, automated, and scalable solutions for safer and more efficient mobility. In this scenario, Edge Artificial Intelligence (Edge AI) and Internet of Things (IoT) integration has transformative possibilities. Edge AI allows for the processing of data in real-time at or near the origin—like roadside cameras or edge devices—removing latency brought about by sending large amounts of video data to central servers. With IoT infrastructure coupled with it, such systems are able to detect, report, and monitor traffic offenses independently with little human involvement. This article presents a Next-Generation Smart Traffic Violation Detection System that utilizes YOLOv5-based object detection, optical character recognition (OCR), and OpenCV-based image processing, all running on edge devices such as Raspberry Pi or NVIDIA Jetson Nano. The system identifies multiple offenses, reads vehicle license plate numbers, and employs a predictive machine learning layer to predict high-risk areas and offense-vulnerable time frames. Real-time alerts are triggered and disseminated through SMS or dashboards for law enforcement. In contrast to traditional methods that center on post-event audit, the new system accommodates proactive surveillance, real-time violation reporting, and anticipatory safety analytics. Its cost-effective and modular design makes it adaptable for both high-density cities and underprivileged semi-urban regions. In order to make urban mobility safer, smarter, and more responsive, the research aims to bridge the gap between intelligent enforcement and reasonably priced smart infrastructure.

Motivation

The increased number of vehicles driving on city streets has resulted in a shocking increase in traffic offenses, leading to more accidents, traffic congestion, and loss of human life. As per road safety statistics across the world, the major percentage of road accidents is due to offenses like red-light jumping, overspeeding, and not wearing helmets. Manual regulation of traffic regulations is more and more ineffective, particularly in urban areas, because there are limited personnel, man-made mistakes, and no ability to observe more than one place at a time. Although traditional CCTV systems and intelligent surveillance provide partial remedies, they tend to be based on central servers, which have high bandwidth expenses and introduce delay in processing. In addition, these systems are not scalable, are not predictive, and do not have real-time enforcement capabilities. The inspiration for this study is to create an affordable, real-time, and scalable solution that merges Edge AI and IoT to better the current systems. By operating data at the edge, our system reduces latency and bandwidth needs, allowing real-time violation detection even in low-internet conditions. By incorporating machine learning, there is predictive intelligence, enabling traffic departments to detect violation hotspots and peak hours beforehand, hence facilitating proactive action. This research seeks to improve road safety, the efficiency of law

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enforcement, and smart city infrastructure by providing a consolidated system for automatic, continuous, and intelligent traffic monitoring with minimal intervention.

Objectives

The main aim of this study is to develop and deploy a smart, scalable intelligent system to detect and forecast traffic offenses through Edge AI and IoT technology. The specific aims are:

- To establish an in-real-time traffic offense detection system based on Edge AI and computer vision techniques like YOLOv5 to detect offenses such as red-light crossing, helmet-less riding, triple riding, and overspeeding.
- To incorporate IoT devices like cameras, IR sensors, and edge devices for decentralized data collection and local processing to minimize latency and reliance on cloud infrastructure.
- To employ Optical Character Recognition (OCR) for automatic number plate recognition (ANPR) of offending vehicles to facilitate traceability and automated penalty generation.
- To create a predictive analytics model with machine learning to identify high-risk areas, peak hours of violation and probable accident hotspots in order to aid proactive traffic control.
- To implement an easy-to-use interface or dashboard for traffic officials to track violations in real-time, observe past trends, and get automated alerts or violation reports.
- To be cost-effective and scalable, so that the system can be implemented in urban and semi-urban areas without significant infrastructural investment.
- To test the performance of the system in different real-world conditions (lighting, weather, congestion) and assess accuracy, speed, and reliability of detection and prediction modules.

Scope

The study aims to develop an intelligent and real-time traffic violation detection and prediction system that uses Edge AI and IoT technologies to enhance urban road safety and traffic enforcement.

The system is intended to be scalable, affordable, and compatible with different urban and semi-urban settings. The system can identify a variety of traffic offenses in real-time, such as red-light running, overspeeding, helmet-less riding, triple riding, and illegal lane changing. Computer vision models, in this case YOLOv5, identify these offenses from live video from roadside cameras.

License plate recognition is facilitated through Optical Character Recognition (OCR), enabling offending vehicles to be recorded and traceability facilitated for enforcement.

IoT devices like infrared sensors, cameras, and edge devices like Raspberry Pi or Jetson Nano are utilized to process and gather data locally. This edge computing system reduces data transmission delays and the need for constant internet connectivity.

Machine learning modules in the system process past traffic data to forecast violation hotspots, risky time slots, and behavioral patterns. This predictive feature enables proactive traffic management.

Real-time alerts and violation reports are produced and available for viewing via a dashboard. The interface enables traffic authorities to track ongoing violations, view analytics, and browse logs with ease.

The system is engineered to be modular and deployable in either resource-intensive smart cities as well as infrastructure-light regions, thus ensuring affordability and flexibility.

Nonetheless, some scopes are out of the range of this research. These are direct penalty enforcement handling (e.g., generation of an e-challan), operation during severe weather conditions such as heavy fog, and the application of privacy-sensitive technologies like face recognition. These points are mentioned for future work.

Understanding Traffic Violation Detection

Traffic violation detection is the process of automatically detecting and logging cases in which drivers or vehicles are violating road traffic regulations. Violations cover offenses like red-light jumping, overspeeding, helmet-less driving, unauthorized U-turns, triple riding, and parking without authority. Efficient violation detection is important for curbing road accidents, enhancing public safety, and facilitating traffic movement in urban cities.

Historically, traffic violation enforcement was based on human observation—officers observing intersections manually or monitoring CCTV images. Such a procedure is labor-intensive, time-consuming, and prone to human error. With increasing urban density, manual process alone is incapable of providing efficient and effective enforcement.

Contemporary traffic violation detection uses a fusion of computer vision, artificial intelligence (AI), machine learning, and Internet of Things (IoT)-based sensors for real-time, automated surveillance. Traffic camera video streams are processed by object detection

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algorithms (e.g., YOLOv5) to detect vehicles, riders, and their behavior. Optical Character Recognition (OCR) is utilized to scan vehicle license plates for identifying violators.

With Edge AI, these operations are performed on local devices (e.g., Raspberry Pi or Jetson Nano) at the camera location, minimizing the requirement to send large amounts of information to central servers. This facilitates quicker decision-making and response, even in regions with poor internet connectivity.

Moreover, by integrating machine learning algorithms, these systems are capable of extending beyond detection. They can learn from past histories, forecast areas likely to violate, and recommend preventive measures. For instance, the system can detect that red-light jumping is most common during late evening hours at particular intersections and warn traffic authorities accordingly.

The major elements involved in traffic violation detection are:

- Cameras for round-the-clock video surveillance.
- IR sensors to identify vehicle crossing during red lights.
- Edge devices for local processing and analysis.
- Models of computer vision for detecting objects and behavior.
- Databases and dashboards for logging infractions and facilitating visualization.

Traffic violation detection is critical to the implementation of smarter urban mobility systems. It transitions enforcement from reactive to proactive, making cities safer, more efficient, and better able to handle increasingly heavy traffic loads.

Data Science in Traffic Violation Detection

Data science is essential to improving the speed, accuracy, and intelligence of traffic violation detection. Through the analysis of huge amounts of traffic data—video content, vehicle speeds, license plate numbers, and time-stamped violation records—data science makes systems capable of spotting patterns, anticipating violations, and facilitating data-driven decision-making.

Machine learning algorithms, particularly computer vision-based ones such as YOLOv5, are taught to identify vehicles, identify offences like jumping red lights or riding without helmets, and categorize vehicle classes. Optical Character Recognition (OCR) is applied to read license plate numbers from images and associate them with vehicle owner databases.

Using historical information, predictive analytics can detect high-risk areas and rush hours for infringements so traffic authorities can act proactively. Preprocessing methods such as image scaling, denoising, and feature extraction enhance detection accuracy and minimize false positives.

Data science in general converts raw traffic videos into actionable information, which contributes to constructing intelligent, real-time systems for more secure and intelligent urban mobility.

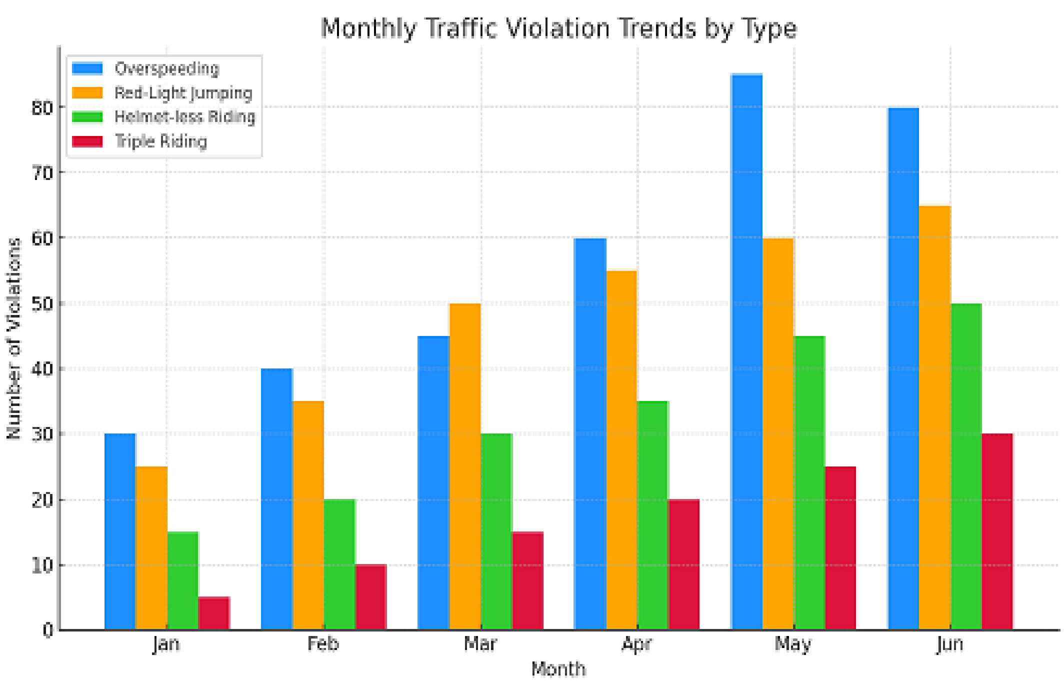

Figure 1: Plot of model accuracy and validation accuracy versus training epochs for the violation detection model.

Analysis of Monthly Traffic Violation Trends

The bar graph depicts traffic violations from January to June, divided into overspeeding, red-light jumping, helmet-less riding, and triple riding. Overspeeding reveals the maximum and most erratic figures, reaching a peak in May. Red-light jumping increases consistently, reflecting habitual non-compliance. Helmet-less riding and triple riding depict increasing trends, indicating an emerging requirement for focused enforcement. The evidence points towards May and June as risky months, justifying real-time monitoring and predictive traffic management.

II. Methodology

The research approach to this study entails the creation of real-time intelligent traffic offense detection and forecasting system that utilizes Edge Artificial Intelligence (AI), Internet of Things (IoT) elements, and computer vision methods. The system is capable of independent tracking and monitoring of traffic behavior, detection of offenses, identification of car license plates, and timely notification while also employing machine learning to identify possible high-risk areas and peak violative hours. The following describes each part of the system architecture and the step-by-step processes of reaching the overall functionality.

Data Acquisition -The system starts from the real-time traffic data collection by mounting high-resolution IoT-based cameras at places prone to violations. The cameras record under different lighting and weather conditions. Infrared (IR) sensors capture incidents such as stop-line violations and no-parking zone entrance. Local processing is done by edge devices like Raspberry Pi or Jetson Nano. Data is tagged with metadata (camera ID, location, signal status) and timestamped for further analysis.

Data Preprocessing -Preprocessing is done for captured video data by taking frames at fixed intervals in order to balance speed and accuracy. Frames are resized (normally to 416×416 pixels), normalized, and filtered in order to eliminate noise such as shadows and glare. Areas of interest (ROI), e.g., stop lines or parking areas, are separated to enhance detection precision and eliminate false positives in traffic analysis.

Object Detection using YOLOv5 Following preprocessing, YOLOv5 is employed to identify objects such as vehicles, helmets, and license plates in every video frame. The model, trained on a custom traffic dataset, detects violations like signal jumping, helmet-less riding, and triple riding through bounding boxes and confidence scores. Violation classification is verified against pre-defined rules for detected actions.

Estimation of Speed and Lane Violation The system monitors car movement between frames with centroid tracking and optical flow to estimate speed. When a car has gone over the local limit, it is detected. Lane offenses are detected by matching car positions with lane lines using perspective transformation methods.

License Plate Recognition via OCR When a violation is detected, YOLOv5 identifies the license plate area. The area is scanned by Tesseract OCR to recognize alphanumeric characters, which is then compared to vehicle registration information for identification and notification.

Violation Logging and Alerting All the violations are recorded in a structured database with accompanying details and image evidence. There are real-time alerts to violators and traffic authorities through SMS or email, and every case is assigned a unique violation ID for tracking and enforcement.

Predictive Analytics Using Machine Learning Historical information is modeled with the aid of algorithms such as Random Forest and Gradient Boosting to forecast high-risk areas and times of future violations. The outcomes are visualized in heatmaps and graphs to assist authorities in proactive enforcement planning.

Visualization and Reporting Interface A Flask-based dashboard presents live data, trends, and analytics. Authorities can filter and export reports, track violations by category, and visualize predictive insights to enhance traffic planning.

Implementation Tools and Environment, It is implemented using Python, OpenCV, PyTorch (YOLOv5), Tesseract OCR, Pandas, and NumPy. It has Docker-based deployment and stores data in SQLite or Firebase. GitHub Actions maintains automated testing and version control.

III. Literature Survey

Traffic violation detection challenge has been pursued in several fields, most prominently with the integration of image processing, IoT, and artificial intelligence. Several research works have submitted models enhancing enforcement efficiency and public safety through smart technologies.

Manogna et al. (2022) proposed a camera-based traffic signal violation system using IoT and image processing. Their method captures license plates and sends violation reports to authorities. While effective, the system relies heavily on post-event analysis and lacks predictive capabilities.

Raj Anand et al. (2021) presented a deep learning system with YOLOv3 for speed detection and signal jumping. Their platform detected vehicle count exceeding 97% and speed violation detection at 89%. It did, however, demand high-end hardware and central servers to process, which makes it less practical for real-time edge-based deployment.

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Srikanth et al. (2025) implemented a broad violation detection platform based on YOLOv5, OCR, and IoT sensors. The system is capable of detecting various violations including helmet-less riding, triple riding, and unauthorized parking, and is integrated with SMS alert systems. Their application of open-source tools such as TensorFlow and OpenCV kept the model cost-effective and scalable, though the performance of the model under low-lighting was still to be improved.

Mohammed et al. (2023) propose an over-speeding detection system that integrated GPS and driver images with computer vision and machine learning. Their focus was on real-time detection and system adaptability under changing lighting and traffic conditions. Nonetheless, their contribution was focused only on speed-related offenses.

In general, current research emphasizes the increasing capability of AI and IoT for intelligent traffic monitoring. Nevertheless, most systems lack real-time edge processing, multi-violation detection, or predictive analytics. This work intends to fill the gaps by integrating Edge AI, IoT, and machine learning into one real-time, scalable, and unified platform.

IV. Conclusion

This paper introduces a holistic and scalable smart traffic violation detection and prediction scheme via Edge AI and IoT technologies. The system, through the integration of real-time video processing, YOLOv5 object detection, optical character recognition (OCR), and predictive machine learning models, automates the detection of severe traffic violations like red-light jumping, speeding, riding without a helmet, triple riding, and failing to park.

The application of edge computing platforms such as Raspberry Pi and Jetson Nano supports on-site, low-latency processing, which makes the system very efficient and deployable in both smart cities and areas with limited infrastructure. In addition, the predictive analytics module provides an advanced layer of proactive traffic enforcement by determining high-risk sites and high-viation time periods.

The visualization dashboard facilitates ease of use for traffic authorities by providing actionable insights, violation patterns, and evidence-based reporting. This research has immense potential for minimizing manual enforcement efforts, enhancing road safety, and advancing the development of intelligent transportation systems.

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