Development of a Smart System for Detecting Illegal Parking Violations in Nigeria

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ABSTRACT
This study develops a smart system for detecting illegal parking violations in Nigeria. The system is designed to automatically detect, identify, and report parking violations using computer vision, Internet of Things (IoT) and cloud technologies. To obtain photos of the vehicles that are parked in the area where parking is prohibited, the system is equipped with an ESP32-CAM. These photos are then sent to a cloud-based Flask server, which runs a YOLOv8 model for vehicle and plate detection and Tesseract OCR for license plate recognition. The detected plates are cross-checked with a Supabase database to find vehicles that are not registered, annotated results along with the description of the violations are sent to the police (law enforcement agents) as an alert on a web dashboard in real-time. The system was evaluated with performance metrics which include accuracy, precision, and reliability under different lighting and environmental conditions. The results obtained from the evaluation process demonstrate the potential of the system to be implemented as a scalable and cost-efficient solution for urban traffic enforcement in Nigeria.

Keywords
Smart system, illegal parking violations, urban traffic enforcement, Nigeria

1. INTRODUCTION
Unauthorized parking has emerged as a persistent and escalating challenge to urban traffic management in Nigeria, driven largely by rapid urbanization and sustained population growth across major cities. As urban centers continue to expand, the demand for limited road and parking infrastructure has intensified, resulting in widespread traffic congestion, increased crash risk, and reduced efficiency of the road transportation system [1], [2]. Empirical evidence indicates that illegal parking particularly in high-traffic commercial zones significantly contributes to travel delays, excessive fuel consumption due to prolonged idling, and elevated levels of air pollution from vehicular emissions [3]. Beyond mobility concerns, these effects translate into broader public health and safety risks, positioning unauthorized parking as a critical urban governance issue in Nigeria. Recent studies highlight notable regional disparities in the severity of this problem. According to [4], the South-South and South-East regions record disproportionately high traffic crash rates, with illegal parking frequently acting as a contributing factor to road obstruction, collisions, injuries, and premature loss of life. In response, several intervention strategies have been explored in the literature. For example, [5], [6] applied the Six Sigma DMAIC framework to identify traffic violations, including improper parking and over speeding, while studies conducted in Aba, Nigeria, demonstrate that on-street parking bans can significantly alter driver behavior and congestion patterns. However, despite these efforts, enforcement outcomes remain limited. Prior research attributes this persistence to weak regulatory enforcement, chronic traffic congestion, and frequent conflict between drivers and traffic authorities [7], [8], [9]. In practice, parking regulation in Nigeria is still predominantly enforced through manual patrol methods, which are inherently slow, resource-intensive, and prone to human error. Law enforcement officers are required to physically monitor restricted zones, identify violations, and apply sanctions often with significant delays. Limited manpower and logistical constraints further hinder comprehensive coverage, allowing many violations to go undetected. This manual approach not only reduces enforcement efficiency but also introduces subjectivity, bias, and inconsistency in decision-making. National statistics underscore the gravity of the issue: reports from the Nigerian Bureau of Statistics indicate that road obstruction offenses including illegal parking accounted for 187 traffic crashes nationwide in the third and fourth quarters of 2021 alone, resulting in congestion, vehicle damage, and serious public safety concerns, [10]. These figures highlight the urgent need for more effective, automated, and scalable enforcement mechanisms. Against this backdrop, emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and computer vision have demonstrated significant potential in transforming parking management systems and improving operational efficiency in urban environments [11]. Recent studies show that intelligent parking solutions can enable real-time detection of violations, reduce enforcement costs, and support data-driven decision-making for traffic authorities [12]. The motivation for this research therefore stems from the growing global shift toward smart, energy-efficient, and technology-driven parking systems. This study seeks to contribute to this paradigm by developing an intelligent parking management solution tailored to the Nigerian context, aimed at mitigating the long-standing problem of unauthorized parking in urban car parks while enhancing safety, efficiency, and regulatory compliance.

2. LITERATURE REVIEW
The development of intelligent transportation systems (ITS) has become central to addressing traffic congestion and enforcement challenges in rapidly urbanizing cities. ITS integrates sensing technologies, real-time communication, and intelligent data processing to enhance traffic efficiency, safety, and environmental sustainability. Recent studies emphasize that ITS architectures enable automated traffic monitoring, mobility prediction, and decision support, forming the backbone of modern smart city initiatives. However, issues

such as data privacy, infrastructure standardization, and deployment cost continue to affect large-scale implementation, particularly in developing countries [13], [14] . Within the ITS framework, smart parking and parking violation detection systems have emerged as effective tools for reducing traffic congestion and improving road safety. These systems typically combine sensors, image processing techniques, and automated enforcement mechanisms to monitor parking behavior in real time. [15] report that such systems improve parking compliance and traffic flow, although many existing solutions rely on costly infrastructure or centralized sensing units, making them unsuitable for low-resource urban environments. Additionally, several implementations remain limited by slow response times and inadequate integration with enforcement workflows, reducing their practical effectiveness. Automatic Number Plate Recognition (ANPR) has become a core technology in intelligent traffic enforcement due to its ability to identify vehicles from still images or video streams. ANPR systems are widely used in applications such as toll collection, access control, and traffic law enforcement. Traditional ANPR approaches relied on edge detection and rule-based Optical Character Recognition (OCR) techniques, which performed poorly under varying lighting and environmental conditions. To address these limitations, recent studies have increasingly adopted deep learning–based models for license plate detection and recognition [16], [17]. Deep learning architectures, particularly convolutional neural networks and transformer-based models, have significantly improved the robustness and accuracy of ANPR systems. [18] demonstrate that lightweight yet high-performance models can achieve reliable plate detection even in complex outdoor environments. YOLO-based object detection frameworks have gained popularity due to their real-time performance and ability to detect small objects, such as license plates, in unconstrained scenes. These characteristics make YOLO models well-suited for real-time traffic monitoring and embedded or cloud-assisted enforcement systems. Optical Character Recognition remains a critical component of ANPR pipelines, enabling the extraction of alphanumeric characters from detected license plates. Tesseract OCR continues to be widely used because of its open-source nature and acceptable recognition accuracy when combined with appropriate image preprocessing techniques [19]. Although more advanced OCR frameworks such as PP-OCRv3 and other deep learning–based recognizers offer improved performance, they often require higher computational resources, which may limit their deployment on low-cost or resource-constrained platforms[20] [21]. Consequently, the choice of OCR technology often represents a trade-off between accuracy and system complexity. Several recent studies have explored the integration of computer vision, IoT, and cloud computing for traffic monitoring applications. IoT-enabled cameras provide flexible and scalable data acquisition, while cloud-based processing enables centralized model execution and real-time notification services. However, many existing systems focus on vehicle counting or parking availability rather than automated enforcement of illegal parking violations. Furthermore, limited attention has been given to designing systems tailored to the infrastructural and operational constraints of developing urban environments, such as those found in Nigeria.

In summary, existing literature demonstrates the effectiveness of intelligent transportation systems, deep learning–based ANPR, and smart parking solutions for traffic management. Nevertheless, gaps remain in the development of affordable, scalable, and enforcement-oriented systems that integrate low-cost IoT hardware, real-time violation detection, and cloud-based reporting. This study addresses these gaps by proposing a smart illegal parking violation detection framework that combines embedded imaging, deep learning–based detection, and automated enforcement visualization, specifically designed for deployment in Nigerian urban contexts.

3. METHODOLOGY

Figure 1 shows the system architecture while Figure 2 shows the system flowchart. Figure 3 also shows the ESP32CAM used for the image capturing of the illegally parked vehicles.

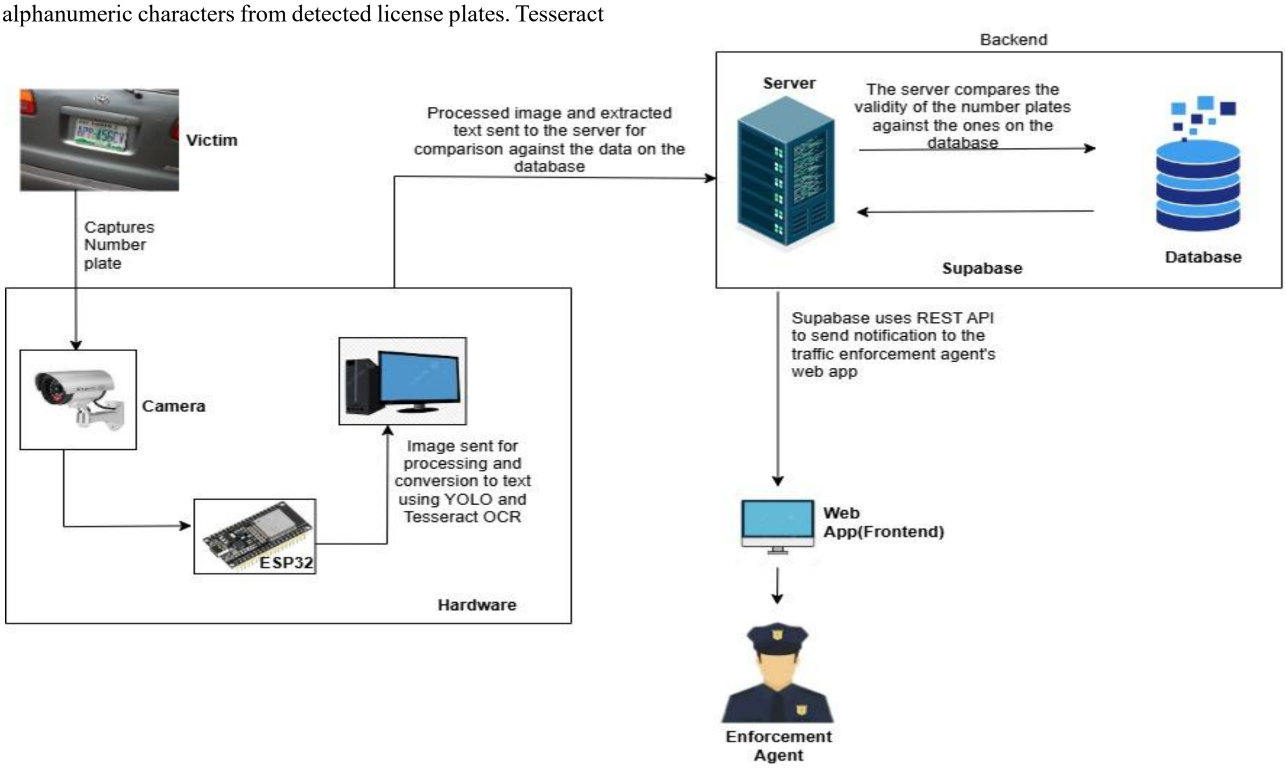

Figure 1: **The Proposed Smart Illegal Parking Violation Detection System.**

Figure 1 illustrates the procedure from image capturing, vehicle detection, time monitoring, license plate recognition, data verification, and the sending of a notification to the police officer, all of which are responsible for the automatic implementation of the illegal parking rules.

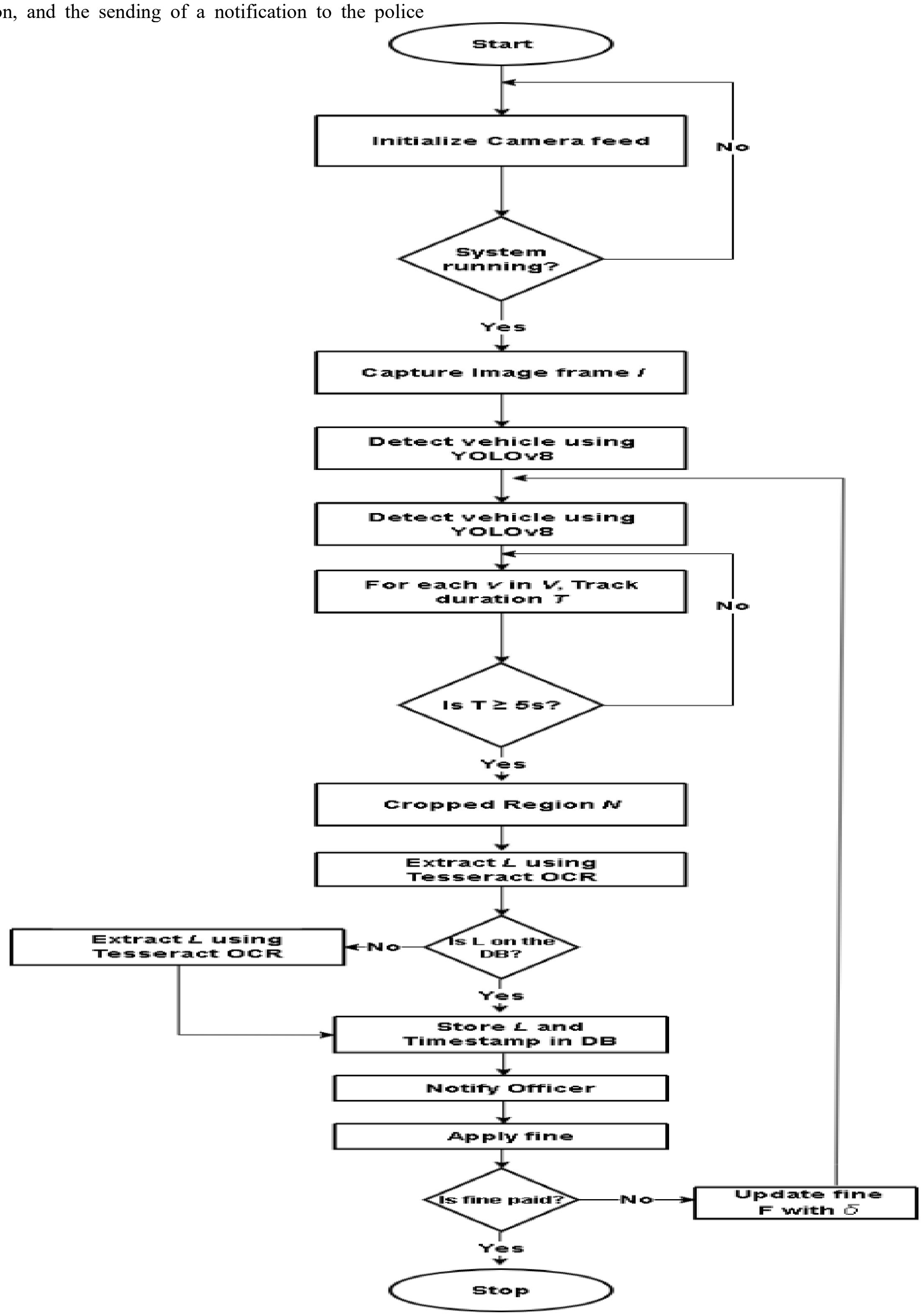

Figure 2: The Proposed system flowchart

3.1 System Algorithm

Algorithm: Smart Illegal Parking Violation Detection System Using Computer Vision

Input: Real-time camera feed

Step 1: Start camera feed

Step 2: While the system is running:

Step 3: Capture image frame *I*

Step 4: Use YOLOv8 to detect vehicles *V* in frame

Step 5: For each vehicle v in *V:*

Step 6: Track duration *T* of stationary position

Step 7: If $T \geq 5$ seconds:

Step 8: Crop plate region *N*

Step 9: Use Tesseract OCR to extract *L*

Step 10: Validate L against the ones on the database

Step 11: If valid:

Step 12: Store L and timestamp in database

Step 13: Notify officer via Supabase

Step 14: Apply fine *F* and update with δ if unpaid

Step 15: Else:

Step 16: Discard or flag for manual review

Step 17: GOTO Step 4

Step 18: Stop

3.2 Experimental Setup

The following tools and technologies were used:

i. ESP32-CAM: IoT camera module for image capturing
ii. Python: Primary programming language for server and model integration.
iii. Flask: Lightweight web framework handling ESP32 image uploads.
iv. C++ and Arduino: Programming language and IDE used to integrate capturing function into ESP32-CAM and uploading functions the captured image to the server.
v. YOLOv8 (Ultralytics): Deep learning object detection model; it does the main work
vi. Tesseract OCR: OCR engine that Extracts plate characters
vii. Supabase: Backend database and real-time notification platform
viii. Railway: Cloud hosting service for deploying Flask backend with public endpoint.
ix. Typescript and React.js: Used in developing the frontend Dashboard for monitoring and reporting violations

Figure 3: ESP32CAM

3.3 Training model on Google Colab

The object detection model used for identifying license plates was trained using the YOLOv8 framework from Ultralytics as indicated in Figures 4 and 5. The dataset used was obtained from Roboflow which provides pre-annotated datasets for machine learning applications. The dataset contained images of vehicles with labelled license plates captured under varying lighting and weather conditions. The [redacted] training was performed using Google Colab due to its GPU acceleration support and compatibility with YOLOv8.

```
# Install YOLOv8
!pip install ultralytics

# Import libraries
from ultralytics import YOLO
import os
```

Figure 4: Installing YOLO on Colab

```
# Install Roboflow
!pip install roboflow

# Download dataset
from roboflow import Roboflow
rf = Roboflow(api_key="BA[illegible]BQwDwSm6453J4")
project = rf.workspace("smartparking-hegbm").project("smart_parking_project-jo2o2")
dataset = project.version(1).download("yolov8")
```

Figure 5: Installing Roboflow

4. RESULTS AND DISCUSSIONS

The confusion matrix in Table 1 indicates that the classifier correctly predicted 879 instances as class '0' and only 7 instances were misclassified as '0' when their actual class was 'background.' The model is very accurate in separating the '0' class from the 'background,' as there are only a handful of false positives and no predictions for the 'background' class can be seen. Such a high-performance level implies that the classifier can be trusted for the existing dataset and the classification task.

Table 1: Confusion Matrix

	Predicted: 0	**Predicted: background**
True: 0	879	7
True: background	0	0

4.1 Performance Evaluation

The YOLOv8 model was trained through the use of annotated license plate datasets. As the training went on, the model exhibited quick convergence, which is evident in Figures 6 and 7. The final evaluation metrics brought out a precision of 99.66%, recall of 99.99%, and mAP@50 = 99.49%, thus, the detection pipeline's stability is what is being confirmed here. The inference time was an average of 270ms per frame, which is almost real-time detection can be used for embedded systems like ESP32-CAM. Table 2 shows the object detection performance metrics.

Table 2: Object Detection Performance Metrics

Metric	**Value**
Precision (B)	0.9966
Recall (B)	0.9999
F1-Score	0.9982
mAP@50	0.9949
mAP@50–95	0.8443
Fitness	0.8593
Speed (inference)	≈270 ms/image

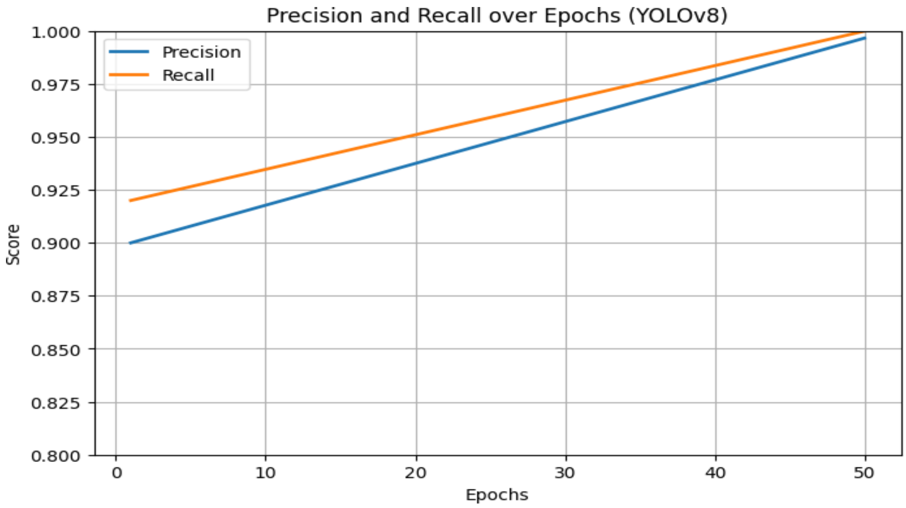

Figure 6: Precision and Recall Curve

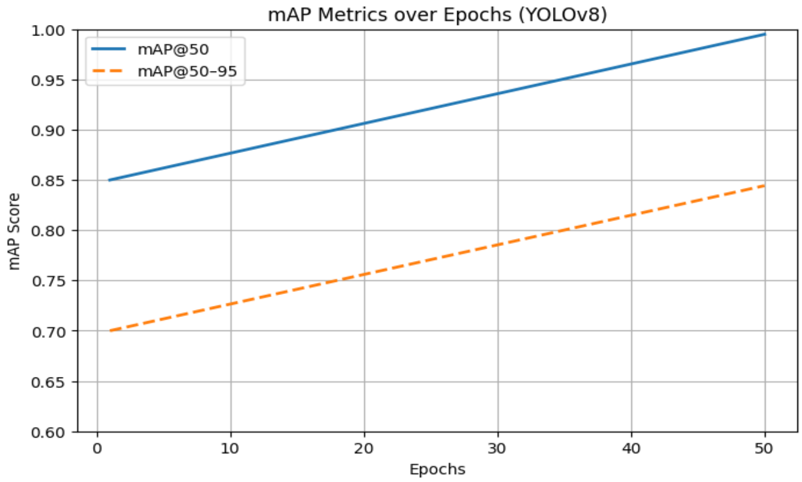

Figure 7: mAP Curve

The system was also tested on different lightning conditions such as daylight, night and low light. The results of the different testing conditions are depicted in Table 3 and Figure 6 respectively.

Table 3: System Performance across different lighting

Condition	**Detection Accuracy (%)**	**OCR Accuracy (%)**	**Average Latency (s)**	**Observations**
Daylight	98.7	96.4	0.8	Very clear images, stable detection
Night	41.2	25.0	1.2	Very poor image visibility
Low-Light (Artificial light)	78.9	65.3	0.9	Detection works, OCR errors common

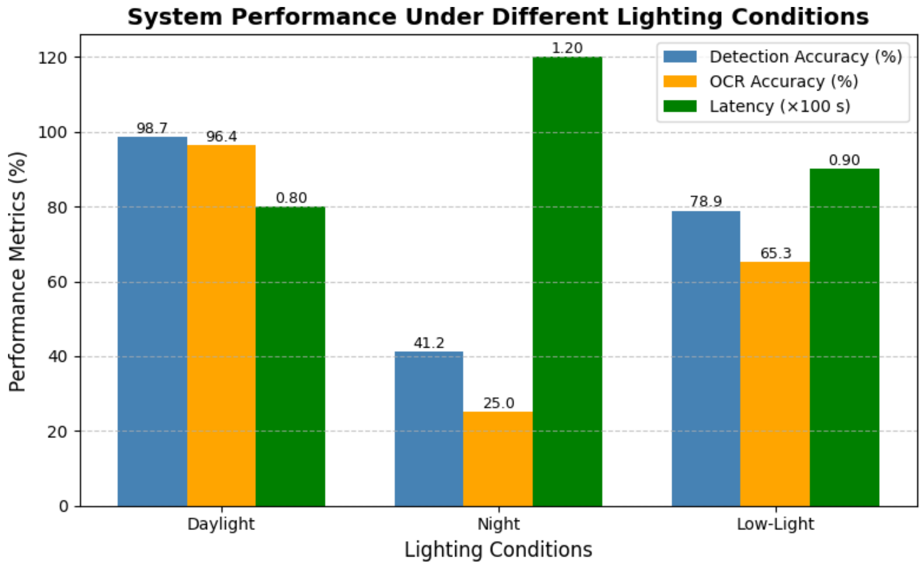

Figure 8: System Performance across different lighting

4.1.1 Dashboard Interface

Figure 7 shows the web-based dashboard developed for monitoring violations. The dashboard displays key details such as the captured vehicle image, new alerts, plate detected and total violations. It allows law enforcement officers to view real-time alerts and track violation records stored in Supabase

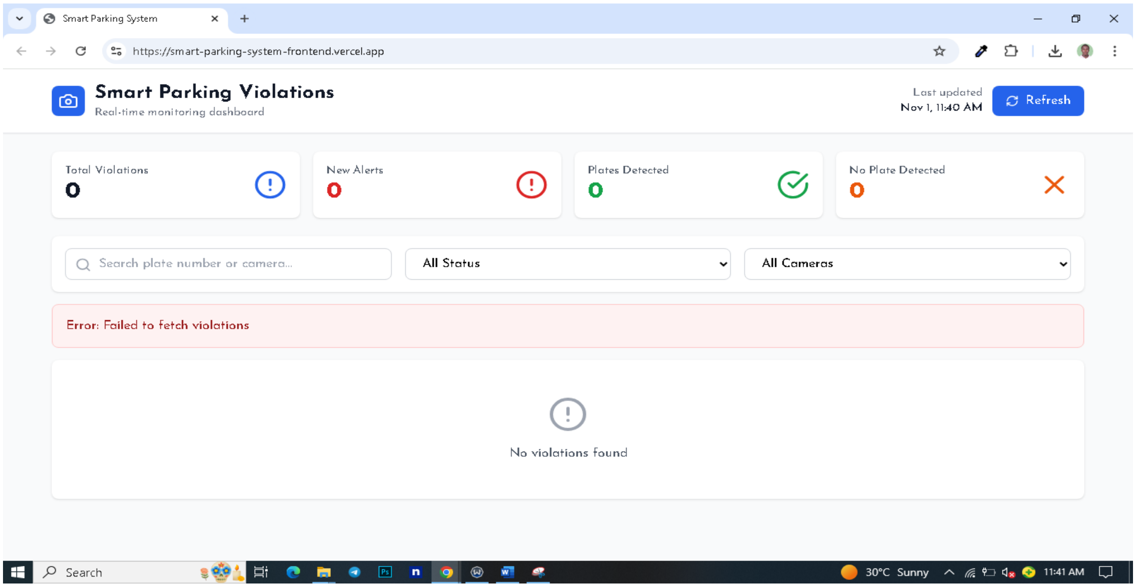

Figure 7: Dashboard Interface

4.2 Discussion on Evaluation Scope and Generalizability

While the experimental results demonstrate strong detection and recognition performance under the evaluated conditions, the current evaluation was conducted using a limited set of datasets and deployment scenarios. Specifically, the training and testing data were primarily composed of vehicle images obtained from publicly available datasets and controlled real-world captures under selected lighting conditions. Although this approach provides a reliable baseline assessment, broader evaluations across multiple datasets, urban layouts, camera viewpoints, and environmental conditions would further strengthen the generalizability of the proposed system.

Future evaluations should incorporate cross-dataset testing, including data collected from different Nigerian cities, road configurations, and traffic densities, as well as varying weather conditions such as rain, fog, and heavy dust. Such comprehensive evaluation would enable a more robust assessment of system scalability, robustness, and transferability to diverse urban contexts.

5. CONCLUSION AND RECOMMENDATION

This study developed and evaluated a smart illegal parking violation detection system designed for deployment in Nigerian urban environments using low-cost and scalable technologies. By integrating ESP32-CAM–based image acquisition with YOLOv8 deep learning–based vehicle and license plate detection, Tesseract OCR for character recognition, and cloud-based validation and reporting, the system demonstrates the practicality of automating parking enforcement in resource-constrained settings. Experimental results show high detection accuracy and near real-time performance under daylight and moderate lighting conditions, confirming the system's suitability for operational use. Performance degradation under poor illumination highlights the critical influence of hardware limitations on intelligent traffic enforcement systems, emphasizing the need for careful hardware–software co-design in real-world deployments. From a broader perspective, this work contributes to intelligent transportation systems research by bridging the gap between smart parking studies and actionable traffic law enforcement. The proposed framework prioritizes automated violation detection, evidence generation, and real-time reporting rather than parking availability alone, making it particularly relevant for urban traffic governance. Future improvements should focus on enhancing low-light performance through auxiliary illumination and diversified training datasets, integrating advanced deep learning–based OCR models to improve character-level accuracy, and enabling edge-based inference using lightweight frameworks such as TensorFlow Lite or OpenVINO to reduce latency and network dependency. Additional extensions may include tighter integration with official vehicle registration databases and more advanced dashboard functionalities to support fine management and enforcement transparency, thereby strengthening the system's readiness for large-scale deployment.

Although the system achieved strong performance under the evaluated scenarios, more comprehensive evaluations across multiple datasets, geographic locations, traffic patterns, and environmental conditions are required to further validate robustness and large-scale applicability. Future work will therefore focus on multi-city deployments, cross-dataset validation, and long-term field testing to strengthen the empirical foundation of the proposed framework.

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