IoT-Driven Smart Car Parking Solution with Automated Entry-Exit and User Reservation App

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Abstract— **The rapid increase in urban populations has intensified parking challenges, as conventional methods of manually searching for parking slots cause congestion, fuel wastage, and delays. This paper proposes an IoT-driven smart parking solution that integrates real-time monitoring, automated entry–exit control, and a mobile reservation application. The system employs an ESP32-CAM module to capture license plate images, with Automatic Number Plate Recognition (ANPR) performed using Google Vision Optical Character Recognition (OCR) for vehicle verification. A servo motor–based gate mechanism regulates access, minimizing manual intervention. To handle scenarios where number plates are unclear or damaged, a geo-fencing–based fallback mechanism allows users to trigger entry via the app, provided their device is within a predefined radius and a valid reservation exists. The system also supports secure digital payments and provides cloud-based dashboards with real-time analytics for operators. By combining automation, accuracy, and user convenience, the proposed solution enhances parking efficiency, reduces congestion, and contributes to sustainable urban mobility.**

Index Terms— **ESP32-CAM, NodeMCU ESP8266, ANPR, Google Vision OCR, Geo-Fencing, Android Application, Smart Parking, IoT, and Intelligent Transportation Systems.**

I. INTRODUCTION

The rapid growth of urban populations has resulted in a corresponding increase in the number of private vehicles, which has intensified challenges related to parking management. Traditional parking practices, where drivers manually search for available spaces, lead to significant issues such as traffic congestion, fuel wastage, and time delays [1]. These inefficiencies not only inconvenience users but also contribute to environmental pollution and deteriorating urban mobility.

To address these issues, smart parking solutions that leverage Internet of Things (IoT) technologies have emerged as promising alternatives. These systems integrate sensors, cameras, and cloud platforms to provide digital reservations via mobile applications, automated entry-exit management, and real-time parking availability monitoring [2]. Users can conveniently check availability, reserve slots in advance, and experience smoother parking operations, while operators benefit from better utilization of space and reduced need for manual intervention.

Recent research has also explored the integration of image processing and sensor-based verification for more accurate parking management. For example, systems combining cameras, infrared (IR) sensors, and database management have been proposed to track multiple parking slots simultaneously, detect vehicle presence, and perform license plate recognition using ANPR techniques [3]. Building upon these advancements, the present work employs the ESP32-CAM module along with Google Vision OCR for license plate text extraction. This approach enhances recognition accuracy while reducing reliance on custom-trained models.

Despite these advances, challenges remain when number plates are dirty, damaged, or unclear. To overcome this limitation, the proposed system introduces a geo-fencing–based fallback mechanism. If ANPR fails, users can request gate access through the mobile application. The system then verifies the request by capturing a real-time image of the vehicle, cross-checking it with pre-booking records, and confirming the user's presence within a 100-meter geo-fenced radius. Once validated, the entry barrier is automatically lifted [4].

In addition to making things more convenient for users, the proposed system provides cloud-based dashboards and real-time analytics for administrators. Parking operators can monitor occupancy patterns, identify peak usage hours, and generate revenue insights, while predictive analytics enable smarter allocation of slots. Furthermore, integration with digital payment gateways ensures secure, cashless transactions directly through the mobile app.

To summarize, the proposed solution addresses the limitations of existing parking systems by combining IoT technologies, ANPR, and geo-fencing into a unified framework. This work's primary contributions are as follows:

- **IoT-enabled smart parking architecture** that integrates sensors, microcontrollers, and a mobile application for reserving and tracking slots in real time.
- **ANPR using ESP32-CAM and Google Vision OCR** for automated vehicle verification at entry and exit points.
- **Geo-fencing–based fallback mechanism** to ensure seamless access when number plates are unclear, damaged, or unreadable.
- **Automated gate control** using servo motors, reducing manual intervention and ensuring efficient vehicle flow.
- **Integration of digital payment methods** within the reservation app for secure and contactless booking.
- **Cloud-based dashboards and analytics** support operators with data-driven decision-making and resource optimization.

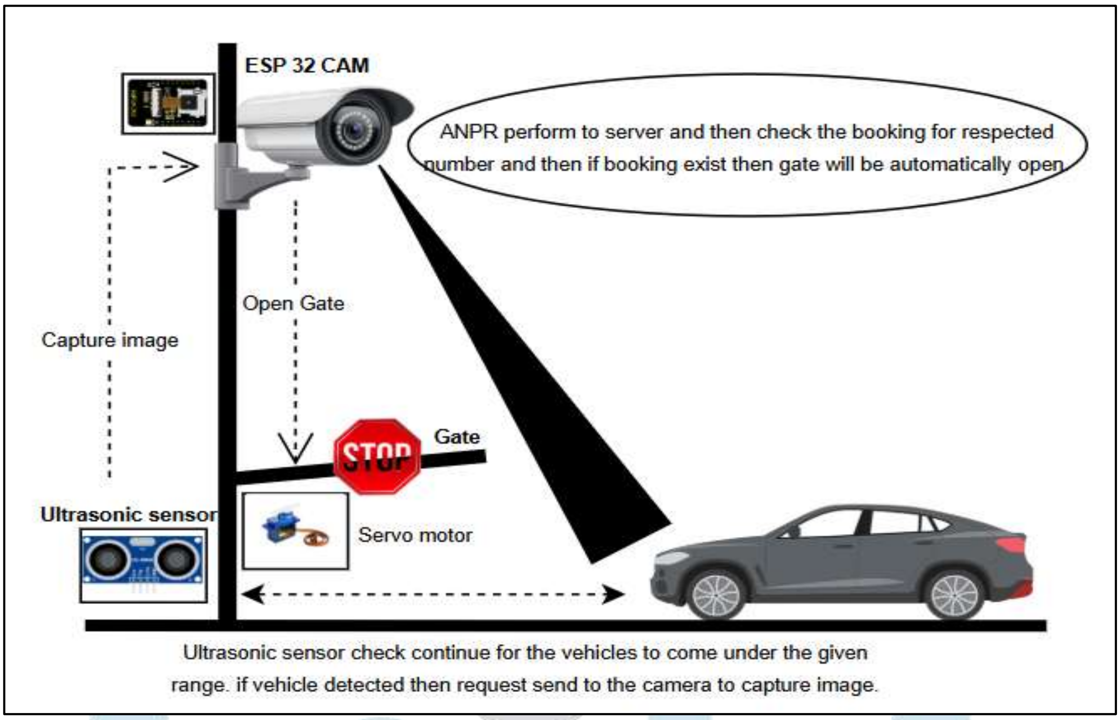

Figure 1. Automatic gate open mechanism

By combining automation, scalability, and sustainability, the proposed hybrid solution improves user satisfaction, enhances operational efficiency, and contributes to smart city initiatives by reducing congestion, fuel consumption, and carbon emissions.

II. LITERATURE REVIEW

To identify cars with English and Hindi license plates, an ANPR system using OCR and template matching techniques has been created, achieving segmentation and recognition accuracies of roughly 96% and 98%, respectively [2]. In addition to covering issues like ambient factors and the broad range of number plate patterns that might lower accuracy, a thorough analysis of ANPR systems identifies the algorithms employed and assesses their performance in real time. The report also looks at how ANPR integration with cutting-edge technologies like deep learning and IoT could greatly increase the security and efficiency of transportation systems in the future [5].

For Indian parking facilities, an ANPR system has been proposed to improve vehicle identification and address the growing challenges of rising vehicle numbers and reliance on manual inspection. This system automates license plate recognition and expedites parking space allocation by utilizing OCR, a Raspberry Pi camera, and the YOLO detection method [6]. Furthermore, video-based sensor systems are emphasized for their role in enhancing traffic management and road planning by generating high-quality data to support intelligent transportation systems (ITS). These systems demonstrate adaptability to changing environments and can meet the demands of automated and connected vehicles [7].

In addition, Deep learning techniques have also been used for ANPR for Indian license plates, using LSTM-based Tesseract for OCR and Faster R-CNN for detection [8]. When used on Indian license plates, template matching and OCR-based techniques have demonstrated accuracy rates ranging from 75% to 85% [9].

With an accuracy rate of 82%, feature-based localization, picture segmentation, and statistical character recognition have been used to address the problem of varying license plate standards in India [10]. A modified YOLO architecture using a sliding-window approach has been developed to improve tiny plate identification. It provides high detection accuracy (98.22%) and recognition efficiency (78%) under a variety of settings, and noise reduction techniques may be used to further improve it [11].

Additionally, a YOLOv4 algorithm-based intelligent parking management system has been created, achieving 100% identification accuracy and connecting with LINE Bot to send automatic parking fee notifications [12]. Additionally, to enhance security, operational effectiveness, and user comfort, a ticketless parking solution that combines facial verification and license plate recognition has been proposed. This solution has applications in toll collection systems and parking facilities [13]. The real-time applicability of a YOLO-based system combined with Tesseract OCR for Pakistani car number plates has been highlighted by its good localization accuracy and robust recognition across a variety of plate forms and ambient situations [14]. In addition to recognition, real-time image processing has been used in intelligent parking systems to identify available and illegally parked cars, show available spots, and direct navigation, all of which increase parking efficiency and support intelligent urban traffic management [15,16].

To enable precise, real-time license plate recognition and tracking, Automatic Number Plate Recognition (ANPR) systems nowadays make use of Deep Learning (DL) algorithms and sophisticated image processing techniques [18]. DL-based sliding window models, including YOLO (You Only Look Once), are used in state-of-the-art Automatic License Plate Recognition (ALPR) techniques, which greatly increase real-time processing efficiency and detection accuracy [19]. Beyond traditional ANPR applications, creative Parking Management Systems (PMS) have been developed using the combination of Raspberry Pi and Internet of Things (IoT) technology. By providing vehicles with dynamic parking availability information, these systems use sensors, cameras, and real-time analytics to improve parking efficiency [20]. As intelligent parking solutions have advanced, ideas such as face-recognition ticketless entrance and adaptive parking space management have been made possible by the Internet of Things, infrared sensors, ESP32 modules, and IP cameras [21,22].

This research explores a fog computing and blockchain-based smart parking architecture designed for self-driving cars. In order to provide a reliable infrastructure for next-generation parking facilities, the goal is to decrease computational delays while strengthening the security, privacy, scalability, and efficiency of IoT–cloud platforms [23]. In a related context, researchers [24] look at the design and implementation challenges of energy control systems in campus microgrids, emphasizing key components of energy management systems to improve functionality and reliability, control mechanisms, and performance optimization techniques. They also examine the changes, integration difficulties, and potential fixes for integrating smart grid technologies, storage systems, and renewable energy into microgrid infrastructures.

In 2016, scholars highlighted that user privacy in smart parking could best be preserved through secure platforms based on elliptic curve encryption [25]. Later, in 2018, a novel computer vision algorithm was introduced for automated detection of parking spaces and vehicle license plates [26]. By 2020, further advancements were proposed for intelligent parking systems through the combination of computer vision technologies with electronic payment mechanisms [27].

Table 1. Comparison between related works and the proposed system

The Work	Pre-booking slot	ANPR	Real-time slot availability	Digital Payment	Geo-Fencing
[2]	✕	✓	✓	✕	✕
[5]	✕	✓	✕	✕	✕
[28]	✓	✕	✓	✓	✕
[29]	✓	✓	✕	✕	✕
[30]	✓	✓	✓	✕	✕
The proposed system	✓	✓	✓	✓	✓

III. METHODOLOGY

The proposed system is an IoT-enabled embedded solution that integrates both hardware and software components. It is programmed using Embedded C for microcontroller operations and Python (Flask framework) for server-side processing, while HTML, CSS, and JavaScript are employed for the web interface. The system leverages image processing libraries such as OpenCV and Google Cloud Vision to implement Optical Character Recognition (OCR) techniques, enabling the extraction of alphanumeric data from vehicle license plates.

At the core of the hardware architecture is the ESP32 microcontroller, which is Wi-Fi enabled to facilitate seamless communication between the ESP32, the Flask backend, and a MySQL database. The hardware setup includes infrared (IR) sensors, ultrasonic sensors, servo motors, OLED display and Node MCU ESP8266, which collectively support real-time interaction with vehicles. The ESP32 communicates with the Flask server via RESTful APIs, while the server performs CRUD (Create, Read, Update, Delete) operations on the MySQL database to manage booking and occupancy records.

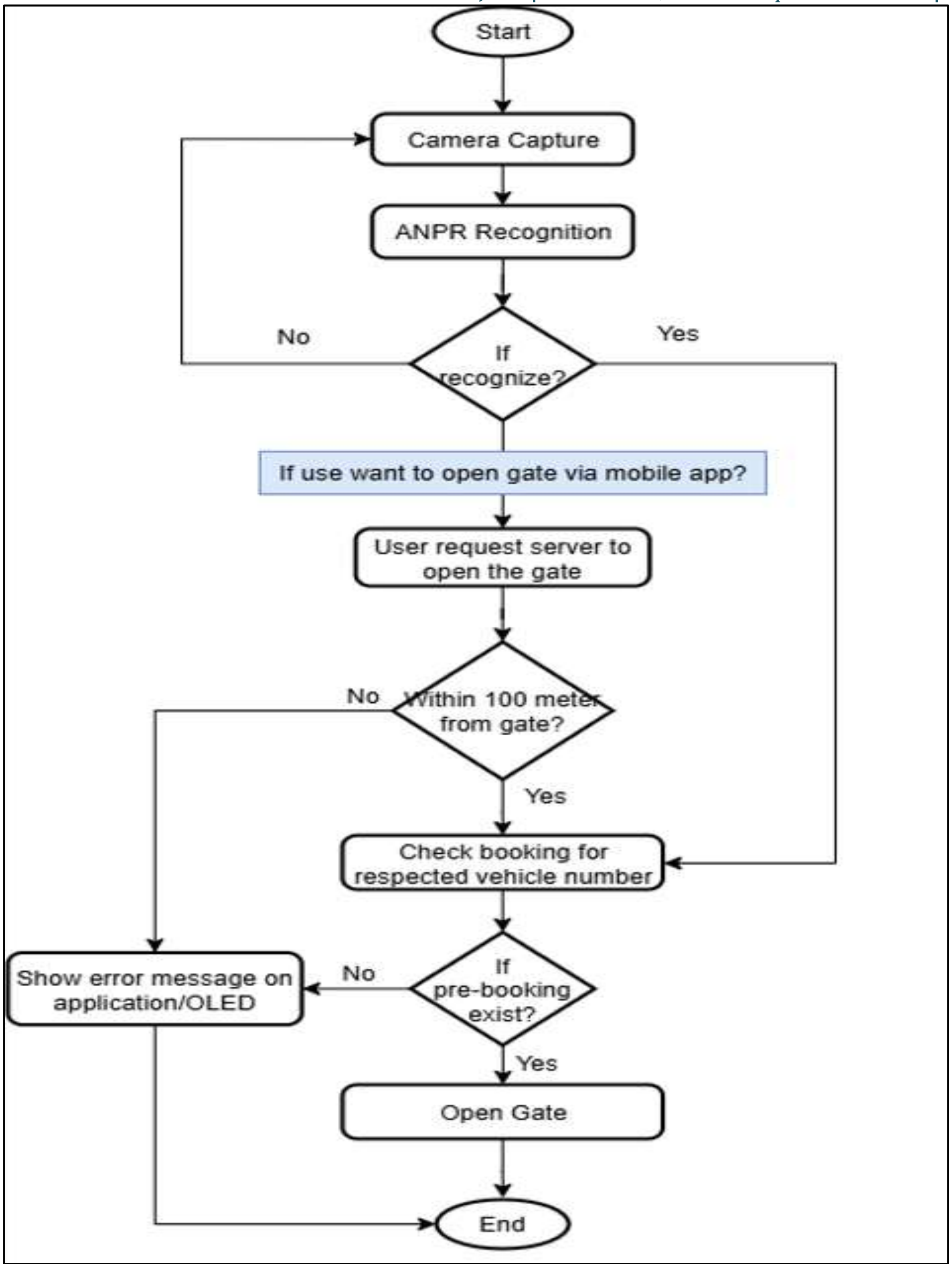

Figure 2. Flow chart of Open Entry/Exit Gate with fallback mechanism

The system integrates a dedicated Android application that allows users to pre-book parking slots remotely. Once a slot is reserved, the booking details are stored in the MySQL database through the Flask backend. Only vehicles with valid pre-booking are granted access to the parking facility, thereby ensuring controlled entry and preventing unauthorized parking.

The circuit incorporates ultrasonic sensors at the entry and exit gates to detect vehicle presence, while each parking slot is equipped with an IR sensor to monitor occupancy status. When a car is parked, the corresponding IR sensor updates the server via Node MCU ESP8266, and the Flask backend broadcasts the updated slot availability to all connected Android applications using Socket.IO in real time.

At the entrance, the ESP32-CAM module captures images of vehicles upon detection by the ultrasonic sensor. The captured image is transmitted to the Flask server running on either AWS EC2 or a local laptop for processing. The system applies OCR using Google Cloud Vision to extract the vehicle's license plate number. The recognized alphanumeric data is then cross verified against the booking table in the database. If a valid pre-booking is found, the gate is automatically opened via a servo motor, and the OLED display provides appropriate messages (e.g., "Image Captured", "Checking Booking Status", "Access Granted"). Vehicles without pre-booking are denied entry, and the display informs the driver accordingly.

To address situations where the Automatic Number Plate Recognition (ANPR) system may fail, such as when number plates are unclear, dirty, or damaged, a fallback mechanism was integrated into the access control system. Using **geo-fencing**, the system detects when a user is within a 100-meter radius of the gate. If the user initiates a gate-open request from the mobile application, the system captures an image of the vehicle and validates the request against the pre-booking records. Once the booking is confirmed, the gate is opened, bypassing the need for successful ANPR detection. This approach ensures uninterrupted and secure gate access even under challenging conditions, thereby improving both reliability and user experience.

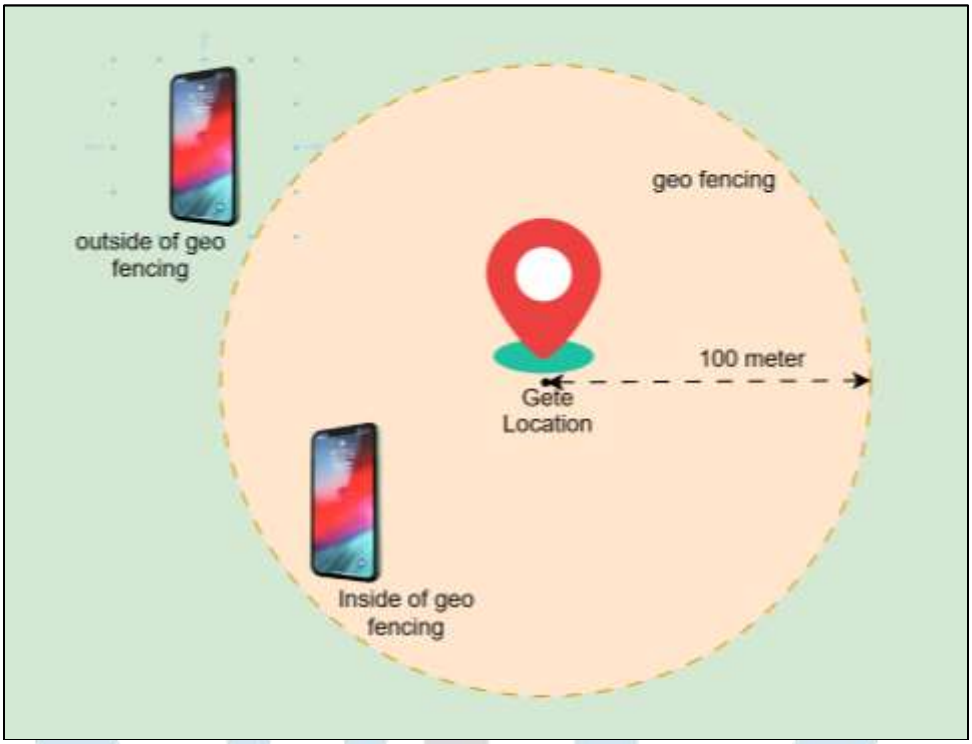

Figure 3. Fallback mechanism (geo-fencing) working

In this study, the YOLOv8 (You Only Look Once, version 8) deep learning model was employed to train and detect vehicle number plates. YOLOv8 was selected due to its high accuracy, real-time performance, and robustness in object detection tasks. A labeled dataset of vehicle images containing annotated number plates was used to train the model, ensuring that the bounding boxes accurately represented the plate regions. The training process involved fine-tuning YOLOv8's pre-trained weights on the custom dataset to improve detection performance in varying lighting, angles, and environmental conditions. Once trained, the model was utilized for inference, where it successfully identified and localized number plates in test images and video streams. This methodology provides a reliable and efficient approach for automatic number plate detection, forming the foundation for further processing such as character segmentation and recognition.

For training the model, we collected the dataset from Kaggle, specifically the *License Plate Dataset* provided by Ronak Gohil, which contains a diverse set of vehicle images with annotated number plates for object detection tasks (Gohil, 2022) [https://www.kaggle.com/datasets/ronakgohil/license-plate-dataset]. This dataset served as the primary source of training images, ensuring that the YOLOv8 model was exposed to sufficient variations in number plate size, angle, and lighting conditions.

In this research, Amazon Web Services (AWS) cloud infrastructure was utilized to support the training and deployment of the license plate detection system. Specifically, Amazon S3 (Simple Storage Service) was used to store and manage the dataset, trained model weights, and experimental outputs in a secure and scalable manner. For model training and inference, Amazon EC2 (Elastic Compute Cloud) instances were employed, providing on-demand high-performance computing resources with GPU acceleration to handle the computationally intensive tasks of YOLOv8 training and real-time detection. The integration of S3 for data management and EC2 for computation ensures scalability, flexibility, and efficient resource utilization, making the system suitable for both research experiments and potential large-scale deployment.

Through this architecture, the proposed system ensures secure and automated access control, real-time parking slot monitoring, and user convenience through mobile-based pre-booking, thereby offering an efficient and intelligent smart parking solution.

IV. RESULTS AND DISCUSSIONS

The proposed license plate detection system was trained using YOLOv8 on the Kaggle dataset (Gohil, 2022). The training process was carried out over 50 epochs, and the performance metrics are presented in **Figure 4**. As shown, both the training and validation losses (box loss, classification loss, and distribution focal loss) consistently decreased, indicating stable convergence of the model. The evaluation metrics further demonstrate high detection performance, with precision and recall values approaching 0.99, and mean Average Precision (mAP) scores of 0.99 at IoU 0.5 (mAP50) and approximately 0.85 at IoU 0.5–0.95 (mAP50–95). These results confirm the effectiveness of the YOLOv8 model in accurately detecting license plates under varying conditions.

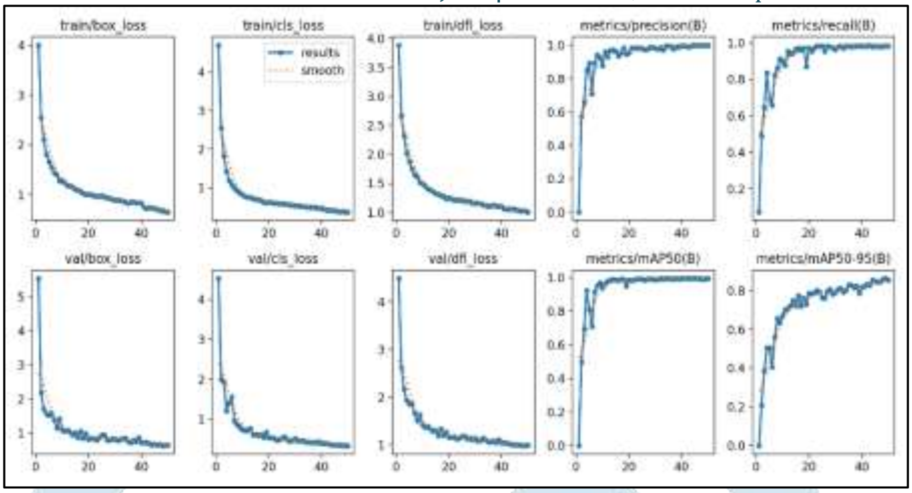

Figure 4. Training and validation performance of YOLOv8 for license plate detection.

The normalized confusion matrix of the trained model, shown in **Figure 5**, further validates the robustness of the system. The model correctly classified 98% of license plates as license_plate and misclassified only 2% as background, while all background regions were correctly identified. This minimal error rate highlights the reliability of the model in distinguishing license plates from non-object areas.

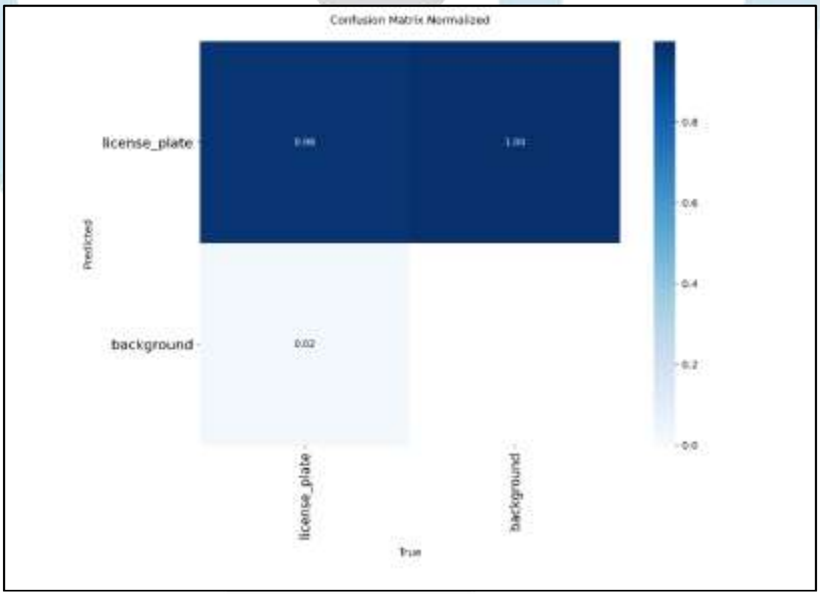

Figure 5. Normalized confusion matrix of the YOLOv8 model for license plate detection

To qualitatively evaluate detection performance, **Figure 6** presents sample detection results on test images. The bounding boxes labeled as license_plate confirm that the system is able to accurately localize plates across different vehicle types, distances, and viewing angles. The detection remained effective even in challenging scenarios such as varying lighting conditions and partial occlusions, which demonstrates the generalization capability of the model in real-world settings.

Despite its strong performance, the ANPR system may encounter limitations when license plates are dirty, damaged, or unclear, leading to detection failures. To address this challenge, a fallback mechanism was integrated. Using geo-fencing, the system detects if a user is within a 100-meter radius of the gate. If a gate-open request is made via the mobile application, the system captures an image of the vehicle and validates it against pre-booking records. Upon successful verification, the gate opens, bypassing the need for ANPR. This ensures uninterrupted and secure gate access, thereby increasing both robustness and user satisfaction.

Figure 6. Example of YOLOv8 license plate detection results on test images.

Overall, the experimental results show that YOLOv8 is highly effective for automatic number plate recognition, and the integration of the fallback mechanism enhances system reliability in real-world deployments.

V. CONCLUSION

In this research, we developed an automatic number plate recognition (ANPR) system using the YOLOv8 deep learning model, trained on a Kaggle dataset, and achieved high performance with a precision of 0.99, recall of 0.98, and mAP scores of 0.99 (mAP50) and 0.85 (mAP50–95). Experimental results, supported by the confusion matrix and detection outputs, confirmed the model's robustness in accurately detecting license plates across diverse conditions. To ensure reliability in real-world deployments, a fallback mechanism was also integrated, where geo-fencing and pre-booking validation enable secure gate access when ANPR fails due to unclear or damaged plates. Overall, the proposed system demonstrates both accuracy and practicality, providing a reliable solution for intelligent access control.

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