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AI-Based Car Parking Communication System for Enhancing Urban Traffic Management in Erbil, Kurdistan

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Abstract: Urban traffic congestion and inefficient parking management remain pressing challenges in rapidly developing cities such as Erbil, Kurdistan. A common issue arises when parked vehicles block others, causing unnecessary delays, frustration, and potential conflicts. This study presents an AI-based car parking communication system designed to enable seamless interaction between vehicle owners in such situations. The proposed system integrates YOLOv8 for real-time license plate detection and Tesseract OCR for character recognition, while a Firebase database cross-reference detects plates to identify the corresponding vehicle owners. Once identified, the system automatically sends an in-app and email notification to the blocking vehicle's owner, facilitating quick resolution. Developed using Flutter, the mobile application provides a multilingual, user-friendly interface supporting Kurdish, Arabic, and English. Experimental results demonstrate high detection accuracy and rapid response time, confirming the system's effectiveness in reducing parking-related conflicts and improving overall urban traffic management in Erbil.

Keywords: *Parking Management, Artificial Intelligence, License Plate Recognition, YOLOv8, OCR, Smart City, Erbil*

1. Introduction

Over the past decade, the capital city of the Kurdistan Region, Erbil, has experienced rapid urbanization accompanied by a substantial rise in vehicle ownership. This growth has exerted significant pressure on the city's transportation and parking infrastructure, leading to persistent issues such as traffic congestion, inefficient parking utilization, and frequent vehicle blockages [1][12]. In many instances, vehicles parked along busy streets or in crowded areas obstruct others, resulting in wasted time, driver frustration, and occasional conflicts [2][13].

Despite these recurring challenges, traditional parking management systems in Erbil lack technological integration and real-time communication mechanisms that could enable drivers to resolve such blockages efficiently. The absence of an automated communication channel between vehicle owners forces drivers to rely on ineffective, time-consuming, and often uncoordinated solutions—such as searching for the vehicle owner in person or waiting indefinitely for the car to be moved. These manual processes not only increase traffic congestion but also contribute to fuel wastage and stress among drivers [4][14].

To address this gap, the present research introduces an AI-based car parking communication system that leverages artificial intelligence (AI) and mobile technologies to facilitate direct and instant interaction between drivers in parking obstruction scenarios [5],[6][15]. The proposed system employs YOLOv8 for license plate detection and Optical Character Recognition (OCR) using Tesseract to extract plate numbers, which are then matched with a Firebase database containing registered user information. Once a match is found, the system automatically sends in-app and email notifications to the vehicle owner, allowing rapid communication and problem resolution.

Beyond its core functionality, the proposed system is designed with user accessibility and localization in mind, offering multilingual support in Kurdish, Arabic, and English, ensuring inclusivity for the Erbil community. Additionally, the system aims to improve urban traffic management by reducing unnecessary congestion and enabling better organization of parking spaces [7][16].

The main objectives of this study are to:

Develop a real-time mobile communication system for managing blocked vehicle incidents in Erbil.

Apply and evaluate deep learning models (YOLOv8 and OCR) for accurate Kurdish license plate recognition.

Enhance user experience through an intuitive, cross-platform mobile interface built with Flutter.

Contribute to the modernization of Erbil's urban infrastructure by integrating AI-driven parking management solutions.

The outcomes of this research highlight the potential of AI-powered communication systems to reduce parking-related conflicts, improve citywide traffic flow, and serve as a model for other rapidly developing urban centers facing similar challenges [8][9][17].

2. Literature Review

Efficient parking management has become a central concern in modern urban planning due to the rapid expansion of cities and the continuous growth of vehicle ownership. The absence of smart and data-driven parking solutions contributes significantly to traffic congestion, wasted time, and increased fuel consumption, thereby reducing urban sustainability and mobility [1][18]. Recent advancements in Artificial Intelligence (AI), Internet of Things (IoT), and Deep Learning have opened new possibilities for developing intelligent parking management systems that enhance real-time decision-making and optimize urban traffic flow.

Poorly managed parking systems have been identified as one of the key contributors to congestion in densely populated cities. They not only reduce the availability of parking spaces but also increase environmental pollution through prolonged idling and vehicle circulation [1][19]. The COVID-19 lockdowns provided evidence of how reduced traffic volumes can improve air quality and overall urban livability. Consequently, there is an urgent need for sustainable and smart parking systems capable of dynamically managing parking demand and mitigating the adverse impacts of urbanization [1][20].

IoT has been widely utilized to modernize parking management by providing real-time data collection and analysis capabilities. IoT-based smart parking systems often employ sensors, cameras, or RFID technology to detect vehicle presence and availability of spaces. For instance, Al Mamari et al. [2] demonstrated an IoT-based system using Wi-Fi–connected sensors to monitor vacant spots in a university setting, effectively reducing congestion within institutional parking zones. These systems provide essential insight into parking availability, though they require costly hardware installation and maintenance, making them less practical for large-scale deployment in developing urban regions.

Wireless Sensor Networks (WSN) have further improved parking management by enabling low-power communication between sensing units. Gu et al. [3] proposed a Street Parking System (SPS) utilizing 3-axis magnetic sensors to accurately detect parked vehicles. The system's adaptive drift correction enhanced detection accuracy to nearly 99%, with battery lifespans exceeding seven years. Despite these advances, WSN-based approaches remain limited by hardware dependency and environmental interference, reducing their scalability for complex, unstructured parking environments.

The integration of cloud computing with mobile applications has been another major step toward intelligent parking management. Alkheder et al. [4] developed a mobile-based parking system in Abu Dhabi that connected users to real-time parking data through cloud services, helping drivers reduce the time spent searching for spaces. These solutions significantly improve user convenience but often depend on high data connectivity and infrastructure investment, which may not be readily available in developing regions such as Erbil.

Recent research has increasingly focused on AI-based and computer vision approaches that can automate detection, monitoring, and vehicle identification without heavy physical infrastructure. YOLO-based deep learning architectures (e.g., YOLOv4, YOLOv5) have achieved strong accuracy in detecting vehicles and recognizing parking occupancy in real time [5][6]. Such vision-based systems are more flexible, cost-effective, and scalable than sensor-based systems.

In the domain of license plate recognition, Neupane et al. [7] introduced the "Shine" system, which utilized object detection algorithms to verify the rightful use of parking spaces and achieved an impressive mean average precision (mAP) of 92.16%. Similarly, Jyothi et al. [8] and Lina and Shaokun [9] used Optical Character Recognition (OCR) combined with Convolutional Neural Networks (CNNs) for accurate real-time plate identification, supporting automated gate access and digital payment systems.

Further, advanced hybrid models have been developed to predict parking slot availability using deep learning. Jakkaladiki et al. [10] proposed an Ensemble CNN–Boosted Graph LSTM (ECNN-BGLSTM) model that integrates IoT, cloud computing, and sensor data to enhance prediction accuracy. Likewise, Chai et al. [11] presented a Recurrent Deep Neural Network (RDNN)-based control model for autonomous parking, improving trajectory planning and adaptability under various conditions.

While prior studies have made significant progress in improving parking detection and management, most existing systems emphasize slot availability or parking optimization rather than direct driver-to-driver communication. Moreover, few solutions are tailored to developing cities with limited infrastructure and unique linguistic or regional requirements. Current AI-based parking frameworks also struggle with inconsistent results under varying environmental conditions, such as low lighting or partially obscured license plates.

To address these gaps, the present research introduces an AI-driven parking communication system specifically designed for Erbil's urban context. Unlike conventional models, the proposed approach integrates YOLOv8 and Tesseract OCR to detect and recognize Kurdish vehicle license plates and establish real-time communication between drivers via a mobile application. This system not only contributes to the advancement of smart parking research but also provides a practical and accessible solution for traffic improvement in developing urban regions.

3. Methodology

3.1 Introduction

The proposed system was designed to automatically identify vehicle license plates and notify car owners, thereby enabling fast and efficient communication between drivers in cases of parking obstruction. The system comprises three major components: The dataset, used to train the object detection model; the AI-driven backend, responsible for license plate detection, recognition, and notification delivery; and the mobile application, serving as the user interface.

The implementation integrates several technologies, including Flutter for mobile development, YOLOv8 for object detection, Tesseract OCR for text extraction, and Firebase for cloud-based data storage and notification management. This section outlines each component of the system — from data collection and processing to deployment and mobile application integration — as illustrated in Figure 1.

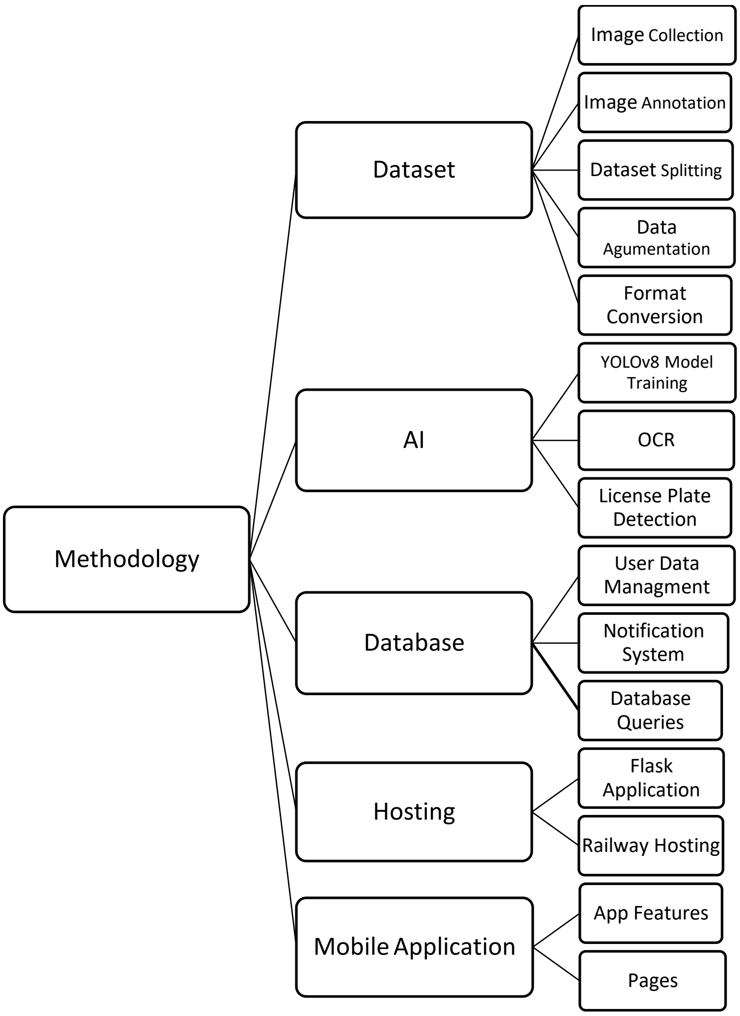

Figure 1: The full flowchart of the system component

3.2 Data Collection (Dataset)

To ensure reliable training of the object detection model, a comprehensive dataset of Kurdish vehicle license plates was created. The dataset preparation process involved several key stages, summarized below and illustrated in Figure 2.

Image Collection: A total of 748 images of vehicle license plates were captured using a smartphone camera under diverse conditions, including variations in lighting, distance, and viewing angle.

Data Augmentation: To improve model robustness and generalization, data augmentation techniques such as rotation, scaling, and brightness/contrast adjustment were applied. This expanded the dataset to 3,876 images, significantly improving the variety of training samples.

Image Annotation: Each image was manually annotated using the LabelImg tool, which generates XML files containing bounding-box coordinates corresponding to the license plate region.

Format Conversion: Since YOLOv8 requires a specific annotation format, the XML files were converted into TXT files containing class IDs and normalized bounding-box coordinates.

Dataset Splitting: The dataset was divided into three subsets:

- Training set: 80% of the data for model training.
- Validation set: 10% for fine-tuning parameters.
- Test set: 10% for final performance evaluation.

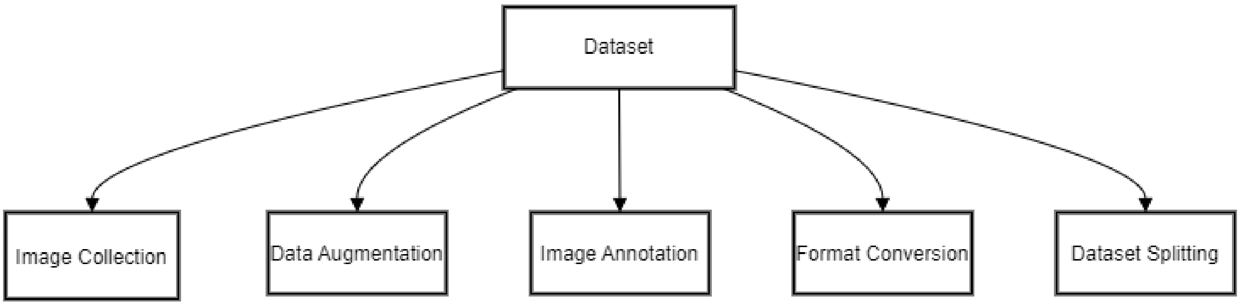

Figure 2: A flowchart of the dataset preparation.

3. Data Processing (AI and OCR)

The detection and recognition pipeline was implemented using YOLOv8 for object detection and Tesseract OCR for text recognition.

YOLOv8 Model Training: YOLOv8, a state-of-the-art deep-learning model for object detection, was trained on the prepared dataset for 100 epochs. The training process optimized the model's weights to minimize detection errors, and the best-performing model was retained for deployment.

License Plate Detection: After training, the YOLOv8 model was integrated into the backend to detect license plates from user-submitted images. The model returns bounding boxes around detected plates, which are then cropped for text extraction.

Text Recognition (OCR): The Tesseract OCR library was used to extract alphanumeric characters from the cropped plate images. Post-processing filters removed non-relevant symbols, ensuring that recognized text matched the Kurdish Regional Government (KRG) license plate format:

- Part 1: City code (21–24)
- Part 2: Letter (A–Z)
- Part 3: Five-digit numeric sequence (1–9)

Regular expressions were applied to validate recognized patterns and ensure formatting consistency.

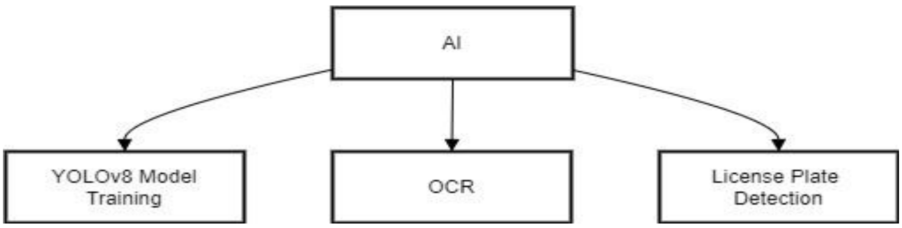

Figure 3: A flowchart of the Data Processing process.

3.4 Database (Firebase Integration)

A Firebase Firestore database serves as the backbone for user management and notification delivery.

User Data Management: The database stores user information, including car details, license plate numbers, email addresses, and Firebase Cloud Messaging (FCM) tokens for notification purposes.

Database Querying: When a license plate is detected and recognized, the backend queries Firebase to check whether the plate number is registered. If a match is found, the system retrieves the corresponding user's contact information.

Notification System: The application uses FCM to send real-time push notifications and SMTP to send email alerts to the identified vehicle owner. If the detected plate number is not registered, the user is promptly informed that the vehicle's owner is unregistered.

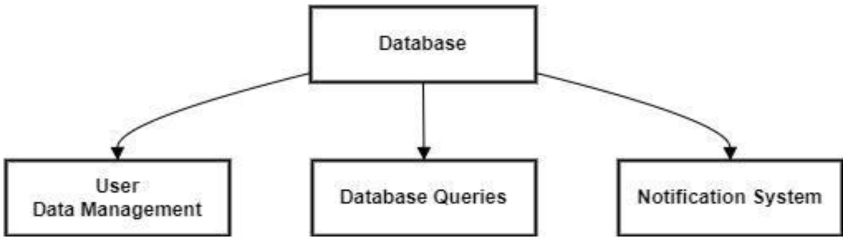

Figure 4: A flowchart of the Database creation parts

3.5 Hosting and API (Railway)

The system's backend was implemented in Python (Flask framework) and deployed using the Railway cloud platform to ensure reliable access and continuous deployment.

Flask Application: The backend provides an Application Programming Interface (API) that receives images from the mobile app, processes them using YOLOv8 and Tesseract OCR, and returns detection results to the client.

Railway Hosting: Deployment on the Railway allows the API to be publicly accessible, enabling seamless communication between the mobile app and the backend. This configuration ensures real-time response, scalability, and reliable integration across platforms.

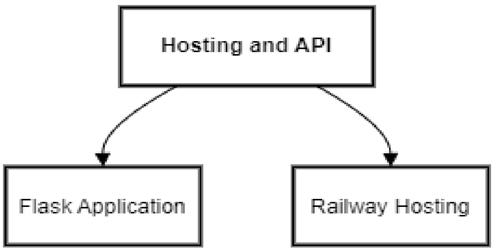

Figure 5: A flowchart of the Hosting and API parts

3.6 Mobile Application (Flutter)

The mobile application, developed using the Flutter framework and Dart programming language, acts as the primary interface for end-users. Flutter was chosen for its cross-platform compatibility (Android / iOS) and responsive design capabilities.

Key Features:

Account Creation and Login: Users can create accounts and register vehicle information, including license plate numbers. Data is securely stored in Firebase.

Home Page: Displays key functionalities, such as:

- Parking Timer: Reminds users to move their vehicles.
- Tips and Advice: Provides guidance on proper parking etiquette and traffic safety.

Camera Page (Main Feature): Enables users to capture an image of a blocking vehicle. The photo is uploaded to the backend for plate detection and recognition. If the vehicle owner is registered, a notification and email are sent automatically. Otherwise, the user is informed that no match was found.

Chat Page: Allows temporary in-app messaging between drivers for quick coordination when a blocking event occurs.

Settings Page: Supports multilingual functionality (English, Arabic, Kurdish) and light/dark themes.

Account Management: Users can update personal information, modify notification preferences, and log out.

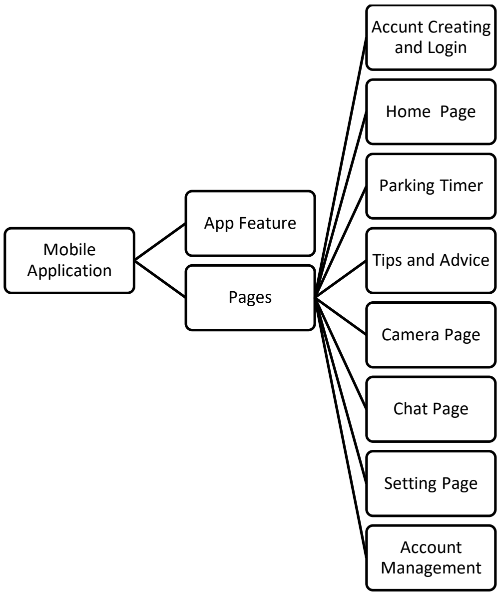

Figure 6: A flowchart of the stages of the creation of the Mobile application

4. Results

4.1 App Appearance and Features

The developed mobile application aims to reduce parking-related conflicts, particularly situations where one vehicle blocks another — a frequent problem in Erbil (Figure 7).

Figure 7: Overview of parking challenges in Erbil City

To access the system, users must first create an account by entering an email, username, and password, followed by registering their vehicle's license plate number and model (Figure 8).

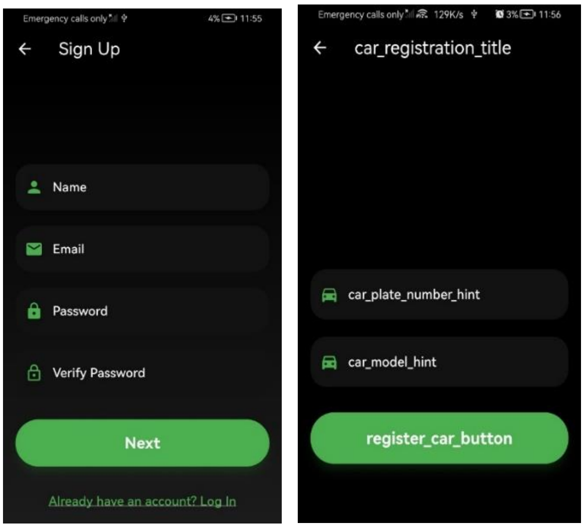

Figure 8: The app's user registration.

After successful login, users are directed to the Home Page, which includes essential features such as Parking Timer, Tips and Advice, Camera Page, Chat Page, and Settings Page (Figure 9). The Tips and Advice section provides useful guidance on safe and efficient parking practices. The Parking Timer (Figure 10) allows users to set reminders for moving their cars, helping prevent prolonged occupation of parking spots.

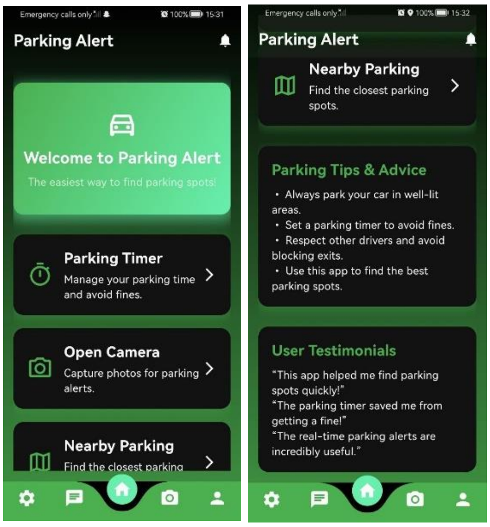

Figure 9: home page after logging in.

Figure 10: Setting the timer for car parking

The Camera Page represents the main functionality of the app. Users can capture an image of a blocking vehicle, which is automatically uploaded to the backend for license plate detection and OCR recognition (Figure 11). If the detected plate number matches an existing record in Firebase, the car owner immediately receives both an in-app notification and an email alert (Figure 12). If no match is found, the system informs the user that the vehicle is not registered in the database.

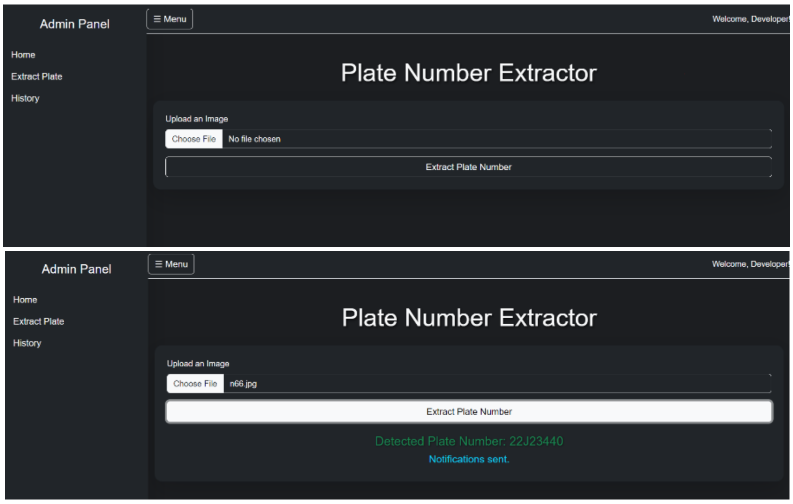

Figure 11: Backend Part of the Application

If the plate number is discovered in the Firebase database, the car owner will receive a notification and an email, as illustrated in Figure 12. Otherwise, the user will be told that the owner is not logged in.

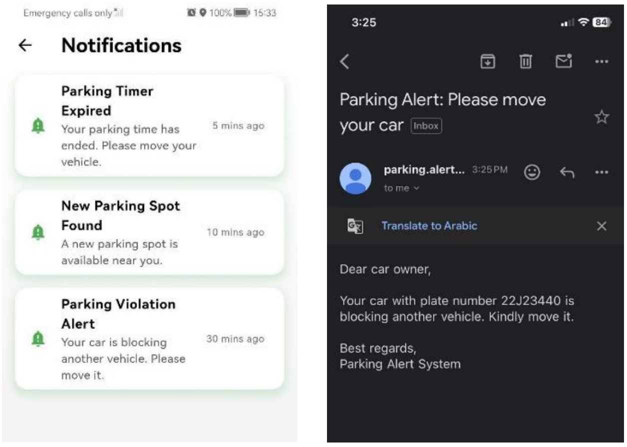

Figure 12: The car owner gets a notification through the app and the email.

Additionally, users can locate nearby parking areas through an integrated map interface, avoiding the need to switch between multiple applications (Figure 13).

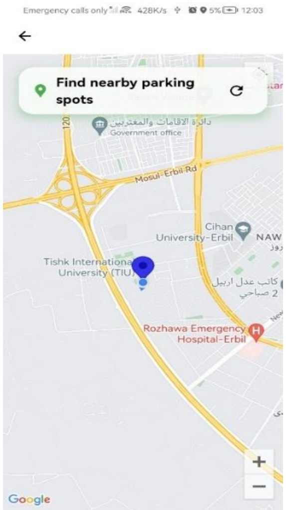

Figure 13: Process of finding nearby parking spaces in Erbil City

When both drivers are registered in the system, a temporary chat channel can be established between them to coordinate vehicle movement more efficiently (Figure 14).

Figure 14: In-app communication between users

The Settings Page enables users to adjust language preferences (English, Arabic, and Kurdish) and toggle between light and dark modes. Furthermore, an Account Management page allows users to update their personal data, modify notification preferences, and log out when needed (Figure 15).

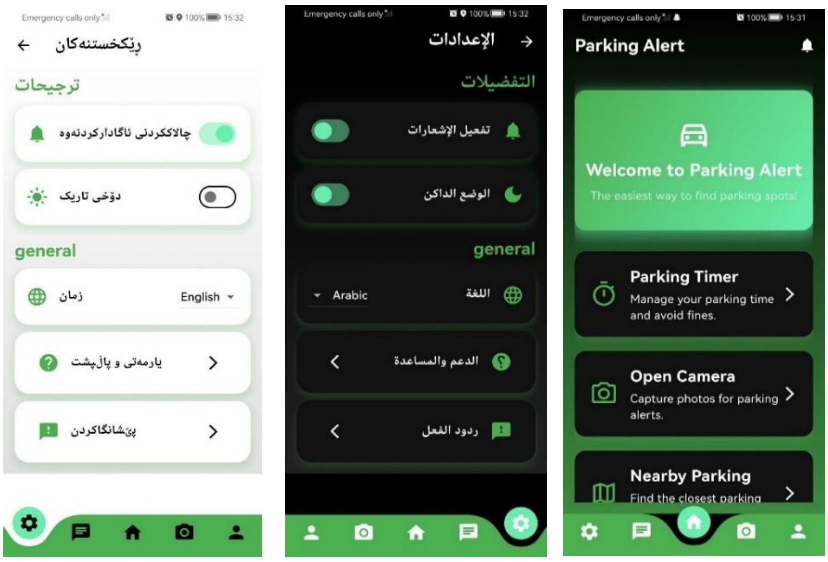

Figure 15: Interface showing language and mode customization options

4.2 Plate Recognition Model:

The YOLOv8-based detection model achieved outstanding performance in recognizing vehicle license plates. As shown in Figure 16, the model attained an accuracy of 99.23% at an Intersection over Union (IoU) threshold of 0.5, with a precision and recall of 99.5% and an F1 score approaching 1.0. Out of 1,664 tested license plates, 1,651 were correctly identified, with only minor misclassifications.

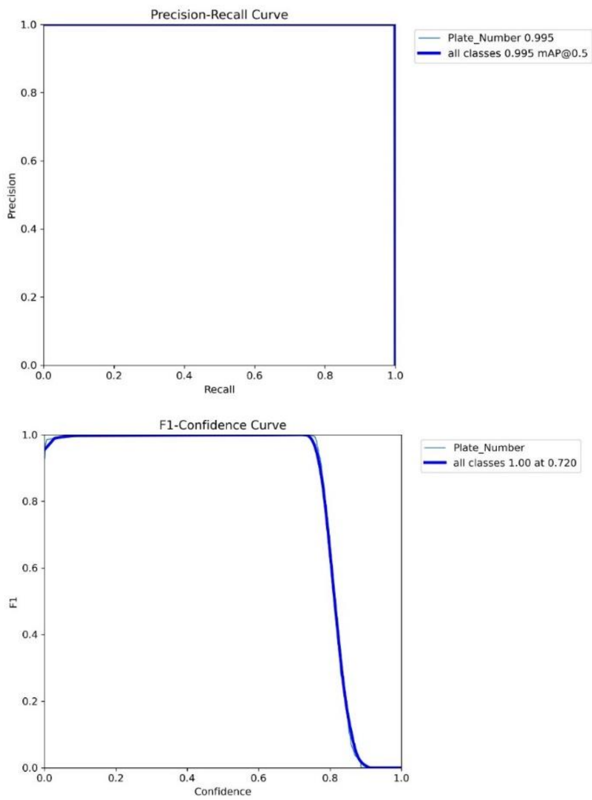

Figure 16: Evaluation metrics (Precision, Recall, and F1 Score) of the plate recognition model

The system was further evaluated across multiple environmental conditions — including daytime, nighttime, and varying viewing angles — demonstrating high stability and adaptability (Figure 17).

Figure 17: Evaluation of the model's performance in different scenarios

The bounding box prediction accuracy was also verified through visualization of spatial coordinates (x, y) and dimensions (width, height), confirming reliable plate localization in most cases (Figure 18). The training and validation curves (Figure 19) reveal consistent model convergence, indicating successful learning without significant over-fitting.

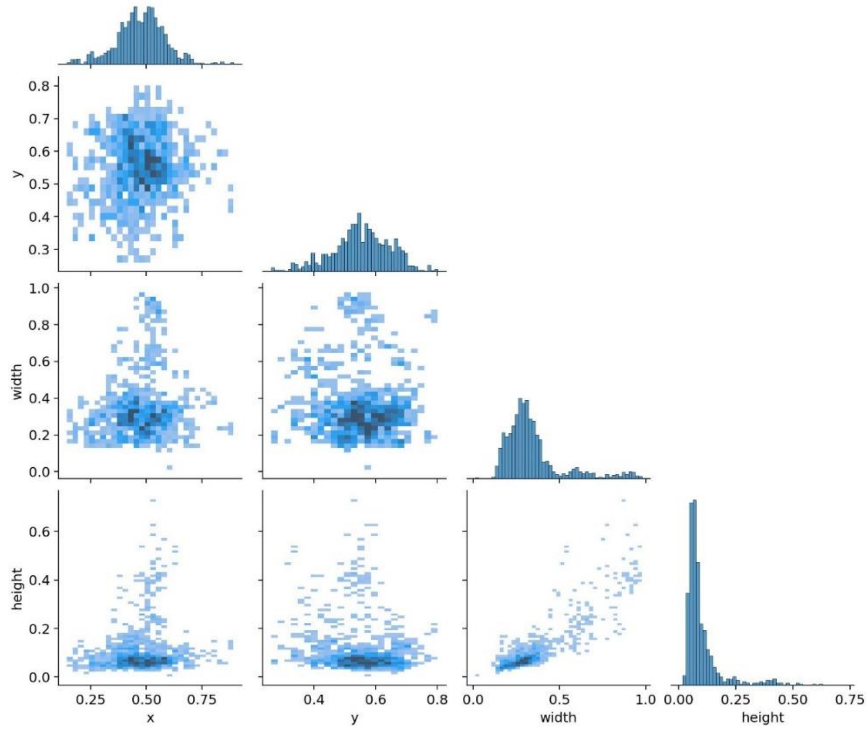

Figure 18: Detecting bounding boxes for license plates in terms of their position (x, y) and size (width, height).

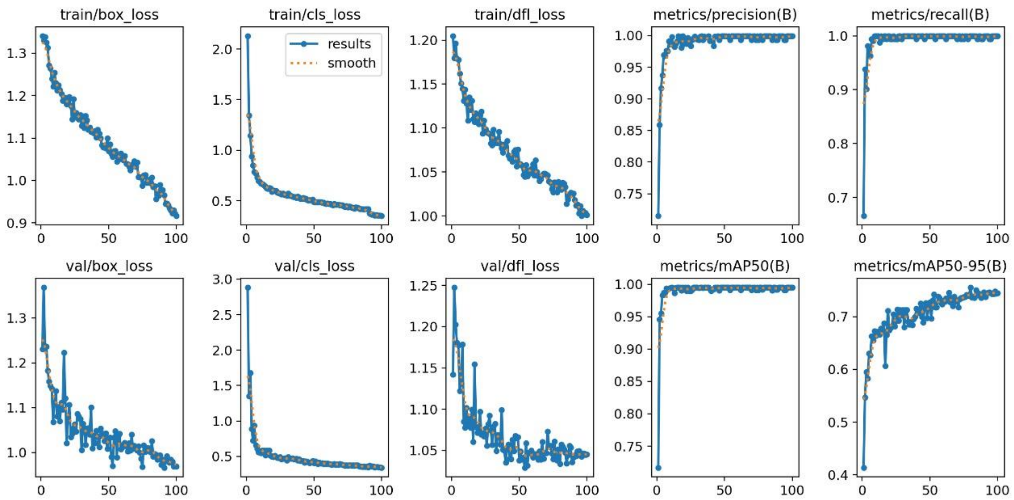

Figure 19: Model performance on training and validation data

On average, the system required less than 15 seconds to process an image, perform detection, recognition, and send notifications. The model was executed on an NVIDIA Quadro P620 GPU with 4 GB of VRAM, ensuring efficient computational performance.

5. Discussion

The results obtained confirm the effectiveness and reliability of the proposed AI-based car parking communication system. With an F1 score near 1.0 and detection accuracy exceeding 99%, the system demonstrates strong robustness under various lighting conditions and viewing angles, which are common challenges in real-world parking scenarios. This performance significantly enhances the practicality of the mobile application for everyday use in Erbil.

One of the main challenges encountered during implementation was the presence of older Kurdish vehicle plates that still contain Arabic characters, which occasionally caused OCR misreads. Future updates will include a hybrid recognition approach to support both Kurdish and Arabic alphanumeric patterns. Another limitation concerns driver responsiveness; some users may overlook text notifications. To overcome this, upcoming versions will incorporate audio-based alerts to ensure accessibility and faster response.

Compared with existing smart parking systems [2][3][4], which mainly focus on detecting empty spaces or optimizing parking allocation, the current system directly addresses the communication gap between drivers, a problem particularly relevant to Erbil's urban environment. Furthermore, this study employs YOLOv8, a more advanced and efficient deep-learning model than the older YOLO versions used in prior works [5][6], enabling faster and more accurate detection with lower computational cost.

In summary, the integration of AI, OCR, and mobile-based communication provides a scalable, multilingual, and community-oriented solution that goes beyond traditional parking management. Future research will focus on enhancing the app's response time, expanding dataset diversity, and integrating the system into broader smart city traffic management frameworks.

6. Conclusions

The current system demonstrates significant progress in addressing one of the most common urban mobility problems—vehicles blocking one another in crowded parking areas. By combining Artificial Intelligence (AI) and Optical Character Recognition (OCR) technologies within a mobile application, the project effectively bridges the communication gap between drivers and provides a practical solution for daily parking challenges.

The successful integration of YOLOv8 for license plate detection and Tesseract OCR for character extraction highlights the technical strength and reliability of the developed system. The use of Firebase enables real-time comparison of detected plate numbers with a registered vehicle database, ensuring accurate identification of blocking car owners. Furthermore, the inclusion of a temporary in-app chat feature enhances user engagement and enables quick, direct communication between affected drivers, significantly reducing the time required to resolve parking disputes.

Overall, the system offers a user-friendly, time-saving, and scalable solution for managing parking issues in densely populated cities like Erbil. It exemplifies how cloud-based architecture and AI-driven recognition technologies can be integrated to solve real-world problems efficiently.

Despite its success, certain limitations must be acknowledged. The system's recognition accuracy depends heavily on the quality and diversity of the training dataset, and external factors such as damaged plates or poor lighting can reduce reliability. These challenges open avenues for future research and improvement, including continuous dataset expansion and refinement to enhance model robustness, integration of parking-space management and location-tracking features, collaboration with governmental parking authorities to unify data management, development of a user accountability and feedback system, and optimization for varied environmental conditions and plate formats.

In conclusion, the current system showcases a tangible example of how AI-based solutions can improve urban living conditions and mobility efficiency. As cities continue to expand, such intelligent applications will play an increasingly important role in promoting sustainability, convenience, and smarter urban infrastructure. This research contributes meaningfully to the growing body of work in smart parking systems and underscores the value of applying AI to address community-focused challenges.

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Conflict of Interest

The authors declare no conflict of interest related to this publication.

Author contribution

The study was jointly conceptualized by Saia Hasan. Slvar Abdulazeez and Ahmed Shwan were responsible for developing the experimental methodology and performing the formal data analysis. Ahmed Shwan executed the data collection. Saia Hasan and Slvar Abdulazeez prepared the initial draft of the manuscript, and all authors collaborated on reviewing and editing the final document.

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