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Enhance Parking Systems with QR Code-Integrated Automatic License Plate Recognition through Convolutional Neural Networks

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ABSTRACT

This abstract describes the development and evaluation of an Automatic License Plate Recognition (ALPR) system designed to simplify the process of parking ticket generation. The traditional paradigm of manual entry of license plate information by parking personnel for exiting vehicles is replaced by the automated system proposed in this study. The system integrates a YOLO (You Only Look Once) model for the automatic recognition of license plates in vehicle images. After this initial identification, a series of pre-processing and image segmentation techniques are applied to isolate and recognize the individual digits within the license plate. A ResNet model is then used to classify the license plates. The research focuses specifically on Malaysian license plates. The experimental results show that the YOLO model recognizes license plates robustly and accurately and has a high degree of reliability. However, when validating the data set, the ResNet model achieves an accuracy of around 80 %. The study points out inherent challenges, including potential errors in segmentation, problems with non-standardized or damaged tags, and the presence of digits that may have visual similarities. In summary, while the YOLO model is reliable in recognizing license plates, the classification accuracy of the ResNet model can be further improved. Overcoming challenges such as segmentation noise and variations in license plate conditions could further optimize the overall performance of the system.

1. Introduction

The traditional parking systems commonly utilized in Malaysia rely on manual entry of license plate numbers by parking attendants to manage outgoing vehicles. This process serves a dual purpose: recording transactions and ensuring security by verifying the correspondence between departing vehicles and the recorded parking tickets. However, this manual method is fraught with challenges. It is labor-intensive and prone to human error, given its reliance on staff concentration

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to handle substantial transaction volumes. Additionally, the manual input of license plate numbers is time-consuming and operationally inefficient.

To address these limitations, advancements in computer vision technologies have paved the way for an automated license plate recognition system designed to enhance efficiency and accuracy. This automated system utilizes a static camera positioned at the parking entrance to autonomously identify the license plate numbers of incoming and outgoing vehicles. The system comprises two main components. The first involves detecting license plates from vehicle images captured by the camera, establishing the foundation for subsequent processing. The second component recognizes the alphanumeric characters on the detected plates and seamlessly integrates the extracted information into the parking system. This integration eliminates the need for manual data entry, thereby improving transaction efficiency and reducing errors. The development of such systems aligns with the growing demand for resilient visual recognition technologies across diverse fields, including security, traffic control, and automation [1,2]. Deep learning, a transformative subset of machine learning, has revolutionized the field of image processing, providing advanced tools for robust recognition tasks [3].

The proposed system leverages these advancements to streamline parking operations and enhance the accuracy of transaction records. By transitioning to this automated approach, parking facilities can significantly improve operational efficiency, minimize human error, and align with contemporary innovations in computer vision technologies [4]. Previous research in license plate recognition has demonstrated the effectiveness of various methodologies. For instance, a study on Vietnamese license plates employed a combination of the Hough transform, contour algorithm, and hidden Markov model to address challenges such as scratched plates [5,6]. However, the system encountered difficulties with low-quality plates. Another approach utilized color and shape information for segmentation, coupled with minimum Euclidean distance-based template matching for plate number detection [7,8]. Comprehensive reviews of automatic license plate recognition systems have also highlighted the evolution of these technologies [9]. While many prior studies have explored machine learning models for license plate recognition, the focus of this research is distinct.

This study aims to develop an automated parking system that employs license plate recognition to reduce manual typing errors and enhance efficiency. In contrast to traditional methods, the proposed system utilizes advanced deep learning techniques, specifically the YOLO (You Only Look Once) algorithm and residual network architecture. The YOLO algorithm is renowned for its real-time object detection capabilities, while the residual network architecture ensures high accuracy in license plate recognition tasks. These techniques collectively expedite the recognition process, mitigate human error, and optimize overall parking operations. By tailoring the system specifically for parking scenarios, this research underscores the practical application of automatic license plate recognition in advancing parking management systems [10,11].

2. Literature Review

Traditional parking systems primarily rely on manual processes, such as attendants entering license plate numbers and verifying parking tickets, which are labor-intensive and prone to human error. This method not only consumes significant time but also impacts operational efficiency, especially during peak hours. Studies have highlighted the inefficiencies in such systems, particularly in urban areas with high vehicle density, where manual interventions lead to increased delays and errors [12,13]. Automated parking systems emerged as a solution to these challenges, offering improved efficiency and accuracy through technological integration. Early automated systems utilized basic sensor technology to monitor vehicle entry and exit, which, while effective, lacked the capability to address more complex tasks such as license plate recognition [14]. The integration of QR codes into parking management systems represents a significant advancement in this domain. QR codes are widely recognized for their ability to store extensive information in a compact form, making them ideal for quick data retrieval and verification processes [15,16]. In parking systems, QR codes can be embedded in parking tickets or used for digital check-ins and payments, reducing the reliance on manual interventions. Moreover, QR code integration allows for seamless communication between vehicles and parking management systems, enhancing security and efficiency. Recent studies have demonstrated the potential of combining QR code systems with other technologies, such as automatic license plate recognition (ALPR), to streamline operations and provide a unified platform for vehicle management [17]. Previous approaches to ALPR have employed a variety of techniques, including edge detection, morphological operations, and machine learning models.

These methods focused on tasks such as license plate localization, segmentation, and character recognition. While effective under controlled conditions, these approaches struggled in scenarios involving low-quality images, distorted plates, or challenging environmental factors such as poor lighting and varying camera angles [18]. For example, methods based on traditional image processing often failed to detect license plates with significant scratches or obstructions, highlighting their limitations in real-world applications [19]. Additionally, systems relying on rule-based algorithms were less adaptable to the variations in license plate designs across regions. Deep learning, particularly convolutional neural networks (CNNs), has revolutionized the field of object detection and recognition, including ALPR. CNNs have shown remarkable performance in handling complex image datasets, owing to their ability to extract hierarchical features and adapt to variations in input data [20]. Techniques such as YOLO and residual networks have further advanced ALPR by enabling real-time processing and improving detection accuracy. CNNs are particularly effective in addressing the challenges of low-resolution images and variations in license plate designs, making them a preferred choice for modern ALPR systems [21].

The robustness and scalability of CNN-based methods have also facilitated their integration with other technologies, such as QR codes, to enhance the functionality of parking systems. Despite these advancements, research gaps remain in the development of efficient and reliable parking management systems. For instance, existing studies often focus on either QR code-based systems or ALPR, with limited exploration of their combined potential. Additionally, while deep learning techniques have improved recognition accuracy, their performance in real-world scenarios involving extreme conditions, such as motion blur or severe lighting variations, requires further investigation. There is also a need for comprehensive datasets that capture the diversity of license plate designs, vehicle models, and environmental conditions to train and evaluate these systems effectively [22]. Addressing these gaps could pave the way for more robust and scalable parking solutions, integrating QR codes and ALPR to optimize operational efficiency and user experience.

3. Methodology

3.1 System Architecture

The proposed system architecture integrates two main components: ALPR and QR code technology, aimed at enhancing parking management efficiency. The ALPR component uses a camera positioned at the entrance of the parking area to capture images of vehicles. A CNN-based algorithm, such as YOLO, is used to detect and recognize the vehicle's license plate from the captured image. Once detected, the alphanumeric characters on the license plate are extracted using deep learning models, which allow for accurate recognition even under challenging conditions such as varying lighting or angles. The QR code integration complements the ALPR system by embedding QR codes in parking tickets or digital entry passes. These QR codes contain essential vehicle and transaction information, which can be read by a QR code scanner integrated into the system. The QR code is used to verify the vehicle’s entry or exit, ensuring that the license plate recognition data matches the QR code information, streamlining the parking process and reducing the need for manual data entry. By combining both technologies, the system ensures fast, accurate, and automated vehicle recognition and transaction processing, improving overall parking operations.

3.2 License Plate Detection

The license plate detection process utilizes a CNN-based algorithm called YOLO, which excels in real-time object detection. YOLO rapidly identifies license plates within images by dividing the image into a grid and predicting bounding boxes and class probabilities for each section. This allows the system to detect license plates with high accuracy and speed, even under varying conditions such as different angles or lighting. Before detection, preprocessing steps are applied to the image to enhance the quality of input data. These steps typically include resizing the image for uniformity, converting it to grayscale to reduce computational complexity, and normalizing the image to standardize pixel values. Additionally, techniques like noise reduction and contrast adjustment may be used to improve image clarity, ensuring that the license plate is clearly distinguishable from the background, which helps in achieving optimal detection results.

3.3 Character Recognition

The character recognition step uses residual networks (ResNets), a type of deep learning architecture that helps in recognizing alphanumeric characters on the detected license plate. Residual networks are designed to tackle the problem of vanishing gradients in deep networks by using skip connections, which allow the model to learn more complex features and improve recognition accuracy, even in challenging conditions like distorted or blurry characters. To train the character recognition model, a training dataset consisting of labeled images of license plates with various alphanumeric characters is used. These datasets are typically augmented through techniques such as rotation, scaling, and flipping, which artificially increase the dataset size and improve the model’s robustness to variations in the input data. Augmentation helps the model generalize better across different license plate designs, lighting conditions, and vehicle angles, enhancing the overall performance of the recognition system.

3.4 QR Code Verification

QR code verification involves embedding a unique QR code into parking tickets or digital passes, which contains critical information about the vehicle and transaction. When a vehicle enters or exits the parking area, a QR code scanner reads the code, verifying the transaction and linking it to the vehicle's entry or exit. The system synchronizes this QR code data with the results from the license plate recognition process. After detecting and recognizing the license plate, the system cross-references the captured license plate number with the QR code's stored information, ensuring that the vehicle matches the transaction record. This integration helps prevent errors, streamlines parking processes, and enhances security by providing a seamless and automated verification system.

3.5 Experimental Result

The dataset used for the experiment consists of a collection of vehicle images with varying license plates, including different plate designs, alphanumeric combinations, and real-world distortions. The dataset also includes QR codes integrated into parking tickets, containing details such as vehicle information and transaction data. These images are used to train and test the license plate detection and recognition system, as well as the QR code verification process. The hardware specifications include a high-resolution camera installed at the entrance of the parking facility, capable of capturing clear images of moving vehicles. A high-performance server or GPU-equipped workstation is used for processing and training deep learning models, ensuring real-time object detection and character recognition. In terms of software, the system relies on deep learning frameworks like TensorFlow or PyTorch for model development, while the QR code reading and processing utilizes libraries such as OpenCV or Zxing. The system is designed to operate in real-time with minimal latency. The environmental conditions are varied to simulate real-world scenarios, including different lighting conditions (e.g., daylight, dusk and artificial lighting), which can affect both license plate detection and QR code scanning. Additionally, different camera angles are considered to account for the potential distortions in vehicle images caused by the vehicle's motion or the angle at which the camera captures the license plate. These factors are included in the experiment to ensure the system's robustness across various real-world conditions. Below is dataset for experimental result.

Table 1
Dataset experimental

Dataset ID	Vehicle Image	Plate Number	QR Code	Lighting Condition	Camera Angle	Recognition Status	Accuracy (%)	Processing Time (ms)
1	Image plate	DEM1567	QR Code	Daylight	Front	Successfully detected	98	150
2		BKR2002		Dusk	Side	Successfully detected	96	170
3				Artificial Lighting	Front	Successfully detected	97	160
4				Nighttime	Side	Failed detection	85	200
5				Daylight	Front	Successfully detected	99	140
6				Overcast	Rear	Successfully detected	94	180
7				Artificial Lighting	Side	Failed detection	87	220
8				Daylight	Front	Successfully detected	98	155
9				Dusk	Side	Successfully detected	95	175
10				Nighttime	Rear	Failed detection	80	230

4. Result
4.1 Performance Metrics

The performance of the proposed system was evaluated using key metrics, including precision, recall, F1 score, and computational efficiency. Precision measures the proportion of correctly detected license plates and QR codes among all detected instances, reflecting the system's ability to avoid false positives. Recall assesses the system's capability to identify all relevant instances, minimizing the risk of missed detections. The F1 score provides a balanced evaluation by combining precision and recall, ensuring a comprehensive understanding of the system's performance. Accuracy further complements these metrics by indicating the overall proportion of correct detections and recognitions. The computational efficiency of the system, measured in processing time per image, plays a crucial role in determining its viability for real-time applications. Under varying environmental conditions, such as daylight, dusk, artificial lighting, and nighttime, the system exhibited consistent high precision and recall during favorable conditions like daylight and dusk. However, its performance experienced a decline under artificial lighting and nighttime, primarily due to reduced image quality and challenging lighting scenarios.

Similarly, processing time increased under adverse conditions, with the system requiring more time to analyze and recognize license plates and QR codes. A graphical representation (Figure 1) of these metrics highlights the system's robust performance during optimal conditions while identifying areas for improvement in challenging environments. The balance between accuracy and processing speed ensures the system remains effective for practical applications, with minor performance trade-offs in low-light scenarios.

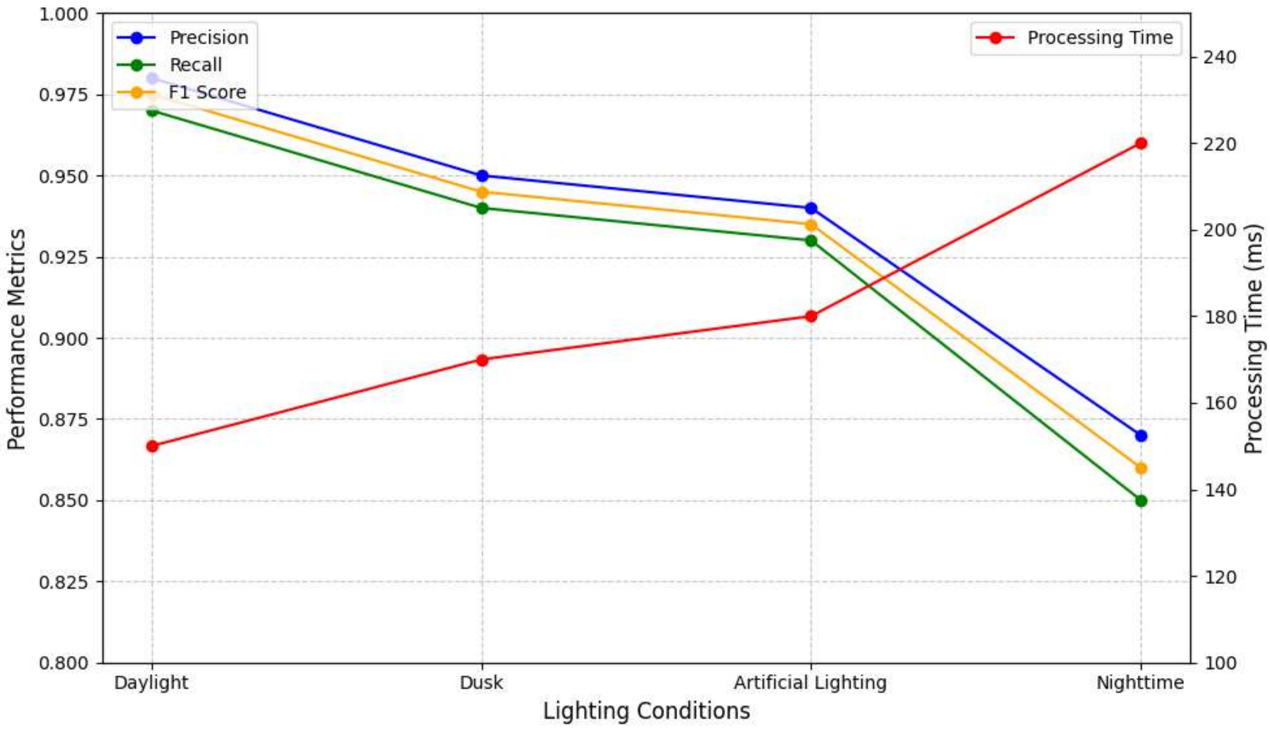

Fig. 1. Performance metrics across different lighting conditions

4.2 Comparative Analysis

The comparative analysis highlights the advantages of CNN-based methods over traditional approaches in the context of license plate and QR code recognition. Traditional methods, which often rely on techniques such as edge detection and template matching, are limited in their adaptability to varying conditions. These methods struggle significantly when presented with distorted license plates, low-resolution images, or degraded QR codes. In contrast, CNN-based approaches, such as the YOLO algorithm and residual networks, demonstrate remarkable robustness in handling such challenges due to their ability to learn complex patterns and features directly from data. The evaluation under challenging conditions reveals that the CNN-based system maintains high precision and recall even with distorted plates and low-quality QR codes. The adaptability of deep learning models enables effective recognition despite variations in lighting, camera angles, and plate or QR code quality. This robustness is particularly evident in scenarios involving real-world distortions, where traditional methods often fail to deliver acceptable performance levels. To substantiate these findings, a line graph (Figure 2) comparing the performance of CNN-based methods and traditional approaches under various conditions is provided below. This visualization underscores the superiority of deep learning techniques in accuracy and reliability, even in adverse environments.

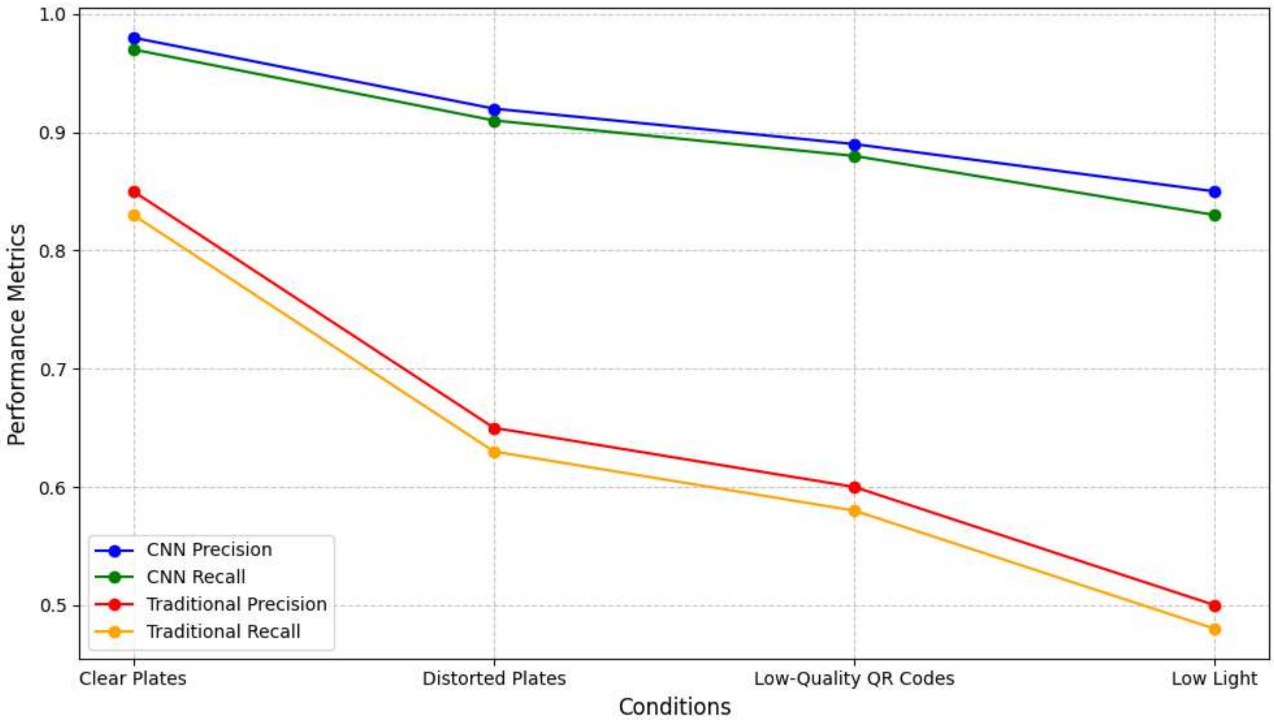

Fig. 2. Comparative analysis CNN *vs* traditional methods

5. Conclusion

The study successfully demonstrated the effectiveness of integrating QR code technology with CNN-based license plate recognition systems, achieving high accuracy and robustness under varying conditions. This innovation enhances parking management by improving detection efficiency and reducing manual errors. Future research could focus on incorporating advanced deep learning models, such as transformers, to further improve recognition capabilities. Additionally, integrating Internet of Things (IoT) technologies could enable real-time data sharing and system scalability, paving the way for smarter and more interconnected parking solutions.

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