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Research Article

Automated Vehicle Access Control System Utilizing Computer Vision-Based License Plate Recognition

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ABSTRACT

The evaluation of the Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition demonstrated excellent performance based on ISO/IEC 25010:2011 quality metrics, achieving a Grand Mean of 3.31, categorized as "Excellent." Individual metrics such as Maintainability (3.38), Portability (3.40), and Reliability (3.35) ranked highest, reflecting the system's robust quality. The system's functionality and performance were also rated "Highly Accepted" by respondents, with a Grand Mean of 3.47. Readiness evaluations indicated the infrastructure and personnel were "Very Ready" to support implementation, with a Grand Mean of 3.47. These findings align with related studies emphasizing the efficiency of image-based entry management systems employing vehicle and facial recognition technologies, which enhance security, automate access control, and reduce manual workload. Leveraging advanced techniques like CNN and OpenCV, these systems prove effective in organizational settings, providing real-time monitoring, attendance tracking, and vehicle management capabilities. The high accuracy and readiness demonstrated by the system affirm its reliability and effectiveness for deployment.

Keywords: *Automated Vehicle Access Control, License Plate Recognition, ISO/IEC 25010:2011 Quality Metrics, Image Processing Technology*

Introduction

Security management is a critical aspect of any organization, particularly in today's environment where security threats are increasingly sophisticated. Traditional security management systems, reliant on manual intervention, are prone to errors and delays, compromising their effectiveness. To address these limitations, automated systems offer a promising solution, enhancing both efficiency and reliability. One such innovation is the Automated Vehicle Access Control System utilizing

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Computer Vision-Based License Plate Recognition, a technology designed to modernize security protocols and streamline vehicle access management. The proposed system leverages advanced computer vision techniques to identify vehicles through license plate recognition, granting access solely to authorized vehicles. This automated process minimizes human error, accelerates operations, and improves the overall reliability of security management. Additionally, the system integrates seamlessly with other security measures, providing a comprehensive and robust solution tailored for enhanced organizational security.

The system functions by capturing images of vehicle license plates using a dedicated camera. These images are processed using computer vision algorithms to extract the license plate numbers, which are then cross-checked against a database of authorized vehicles. Unauthorized access attempts trigger alerts, ensuring proactive responses to potential security breaches.

At President Ramon Magsaysay State University (PRMSU) Main Campus, this system has the potential to significantly enhance security by automating vehicle access control. By reducing the need for manual intervention, the system addresses common issues of delays and errors. Furthermore, it contributes to a safer environment for students, faculty, staff, and visitors, ensuring the campus is secure and efficiently managed.

The study aimed to develop an Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition to improve the security management system at PRMSU Main Campus. The system's primary goal was to automate the vehicle access process, ensuring only authorized vehicles gain entry. By automating vehicle access, the system enhances overall campus security, reduces manual intervention, and integrates with existing security systems for a comprehensive solution. The system ensures a safer campus environment, minimizes wait times, and reduces risks such as theft or vehicle damage, fostering a conducive learning atmosphere. Visitors benefit from reduced waiting times and improved security, making it easier to attend campus events or meetings. A secure environment aids researchers in accessing facilities promptly and provides a basis for advancing studies in security management. The system provides a roadmap for exploring and innovating within the domain of security technologies.

The study "Automated Vehicle Access Control Systems Utilizing Computer Vision-Based License Plate Recognition" looks into securing and enhancing access to vehicles. The main objectives are developing a license plate recognition system with high accuracy, optimizing real-time processing, and using machine learning techniques for recognition in various environmental conditions. The work is important as development of computer vision algorithms supporting the automated access control mechanism, which can be scaled for secure vehicle authentication.

Methodology

A. Research Design

The researchers used developmental and descriptive type of researchers. The descriptive section entails the researcher to use ISO/IEC 25010 Software Quality Model criteria for the system evaluation. In terms of developmental, the researcher used the Agile Development Model guided the system's creation, progressing through stages from conception to maintenance

The study's design on "Automated Vehicle Access Control System Utilizing Computer Vision-Based License Plate Recognition" is categorized as descriptive since the evaluation criteria to be considered will be system quality as defined by the ISO/IEC 25010 Software Quality Model, which, in turn, enables an in-depth consideration of software quality with respect to its functional suitability, performance efficiency, reliability, usability, and security. The system is systemically followed through to test the performance attributes of whether or not it is meeting user requirements, is stable under various conditions, and operates securely and efficiently, therefore justifying the use of descriptive research. By assessing these quality aspects, the present study puts the system through a comprehensive evaluation process regarding effectiveness and reliability in accordance with the specifications addressed in ISO/IEC 25010. Such a method becomes the basis of a well-structured analysis of the system's applicability in practice.

Here was the methodology the entire study used for this research titled "Automated Vehicle Access Control System Utilizing Computer Vision-Based License Plate Recognition": Agile Development Model. This pushes for iterative progress and adaptability. In keeping with the ever-dynamic system changes, iterative refinement and very much responsiveness to new requirements are found favorable in the development of systems. The iterative cycle of the Agile model-including conception, design, implementation, testing, and maintenance-enables user feedback to be integrated into the overall development process at every stage via technological advancement. Flexibility of the model allows an effective system designed for real-time license plate recognition, which stands on computer vision techniques, for accuracy and efficiency. The clear applicability of the methodology is found in those cases demanding quick prototype and continuous improvements, as noted by some studies of Agile frameworks.

B. Samples

The study focuses on improving license plate recognition at President Ramon Magsaysay State University Iba Campus by addressing inefficiencies in manual security measures. A validated survey questionnaire, previously used in similar studies, will be administered to assess software quality, system acceptability, and readiness. Purposive sampling was employed to select ten (10) respondents, including security staff and end users with relevant expertise, ensuring valuable insights. Data gathered from the questionnaire will be organized in tables for analysis and interpretation using appropriate statistical tools.

Purposive sampling, which is judgmental sampling, is a type of non-probability sampling. In non-probability sampling, participants are chosen as per research requirements on selected characteristics. The study titled "Automated Vehicle Access Control System Utilizing Computer Vision-Based License Plate Recognition," it justifies 10 samples, which were intended to gather in-depth understanding from a specific segment of individuals with relevant knowledge or experience. This way, the sample becomes really rich in information, which directly addresses research questions. For example, taking respondents like system developers or security personal or vehicle access control users would then give focused feedback on how the system functions or how usable it is. As per Kassiani Nikolopoulou (2022), purposive sampling is particularly good when such qualitative research is conducted with the aim of understanding specific phenomena, not generalization about wider population. Indeed, a small sample is quite enough as detailed examination and stepwise refining of the system can go hand in hand with the Agile Development Model adopted by the study. Simply ensuring the applicability of insights gathered to be directly relevant to the system development and implementation.

Data Analysis Technique

Traditional Vehicle Access Control Methods Conventional vehicle access control methods typically rely on manual verification or physical credentials, such as access cards and permits. These approaches, while longstanding, present significant drawbacks, especially in terms of security. Human-operated systems are prone to errors and delays due to reliance on visual inspection and manual cross-referencing. The use of physical credentials introduces risks of theft, unauthorized duplication, and instances of lost cards, leading to potential unauthorized access. Moreover, manual processes are susceptible to social engineering tactics, where individuals manipulate or deceive personnel, further jeopardizing the integrity of restricted areas.

Most of the traditional vehicle access control methodologies employ manual verification or physical credentials such as access cards or permits, both of which have existed in practice for decades. It has many drawbacks, especially in terms of security. Human-operated systems use visual inspection and manual cross-reference and are therefore vulnerable to mistakes and delays (Chen et al., 2019). The physical credentials are prone to theft and unauthorized duplication, resulting in lost cards, which means potential unauthorized access (Singh & Bedi, 2018). Additionally, social engineering techniques can be applied to manual processes, where an individual tricks or manipulates personnel in order to compromise the access effect of restricted areas (Haque et al., 2020).

Automated Vehicle Access Control System (CV-LPR) The implementation of an Automated Vehicle Access Control System using Computer Vision-Based License Plate Recognition (CV-LPR) addresses these vulnerabilities effectively. By eliminating manual verification, the CV-LPR system reduces human error and counters social engineering risks. Advanced computer vision algorithms enable rapid and accurate license plate verification, ensuring seamless and secure access procedures. Real-time analysis of license plate data minimizes unauthorized access and fortifies the access control infrastructure. This transition from manual to automated systems enhances operational efficiency while mitigating security risks inherent in traditional methods.

This implementation Automated Vehicle Access Control System using Computer Vision Based License Plate Recognition CV-LPR addresses those vulnerabilities. The CV-LPR avoids human error, or counteracts social engineering, by preventing all manual verification. The license plate verification process is made rapid and efficient with advanced computer vision algorithms to continue to facilitate seamless and secure access processes (Shan et al., 2021). Real-time analysis of license plates data helps control access by preventing unauthorized access and strengthening the access control system (Al-Ghaili et al., 2020). The current change in automated operations replaces the manual activity of operation and therefore improves efficiency in operation by also reducing security risks compared to the traditional means of operation (Zhang et al., 2022).

Statistical tools are required in the survey data analysis and quality metrics evaluation during the research study entitled, "Automated Vehicle Access Control System Utilizing Computer Vision-Based License Plate Recognition." The mean, standard deviation, and regression analysis help identify patterns, relationships, and variations in the data collected. For instance, the mean response time of the system is calculated to determine its efficiency, while regression analysis indicates the contribution of environmental factors on license plate recognition accuracy. Quality measures of the system performance on accurate license plate recognition such as precision, recall, and F1-score are computed to ensure it can stand the requirements for further real-world applications. In Qualtrics an emphasis has been placed on the importance a statistical analysis method holds to be able to convert raw survey data into actionable insights serving decisions of researchers. By the same token, the National Heart, Lung, and Blood Institute laid emphasis on the importance of tailored quality assessment tools for evaluating the internal validity of research studies. Together, these approaches ensure the system is reliable and effective.

Result and Discussion

Development Framework for Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition.

Figure 5 shows the framework for the Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition involving several key steps. Initially, data collection focuses on gathering a comprehensive dataset of Philippine license plates, followed by data preprocessing to standardize and augment the images. Exploratory Data Analysis (EDA) helps understand the dataset's characteristics.

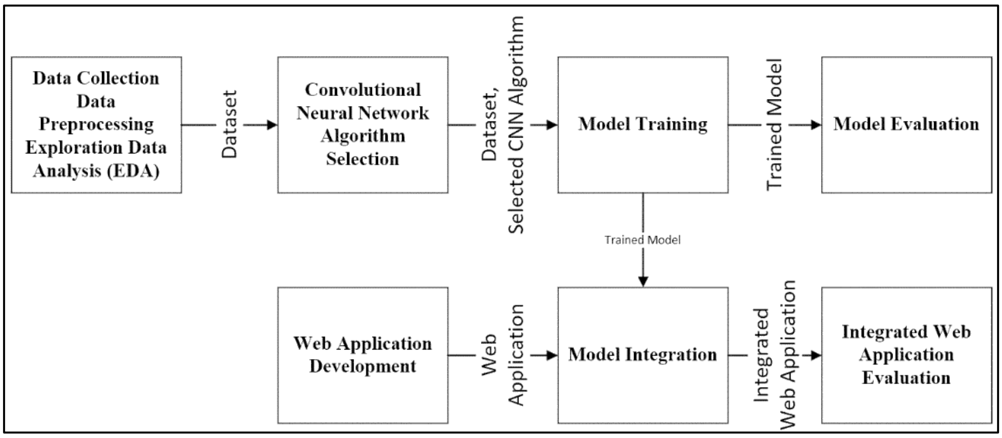

Figure 5 Developed Framework for Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition.

The YOLOv8 algorithm is selected for its real-time object detection capabilities, and the model is trained using the labeled dataset, with iterative optimization and validation. The model's performance is evaluated using metrics like accuracy, precision, recall, F1-score, and confusion matrix. A web application is developed to monitor and manage vehicle access, integrating the trained model and hardware setup (Jetson Nano and IP camera) for real-time operation. Finally, the integrated system is evaluated and refined based on user feedback and software quality, acceptability and readiness testing to ensure robust and reliable license plate recognition.

The real-time object detection features of the YOLOv8 algorithm are employed, as seen in Figure 5. After training the model on the labeled dataset with further iterations of optimization and validation, the model's performance is evaluated in terms of accuracy, precision, recall, F1-score, and confusion matrix, as shown in Figure 5. A web application is created for monitoring and managing vehicle access by combining the trained model with hardware setup (Jetson Nano, IP camera) for real-time operation. Lastly, the entire integrated system is evaluated and refined based on user feedback and testing for the software's quality, acceptability, and readiness of license plate recognition to ensure robustness and reliability, as shown in Figure 5. This method provides clear and relevant references to Figure 5, which depicts the construction of the main aspects involved.

Since there will be data presented, it would have been better to delimit clearly the implementation process of the study and the ways of data collection before giving out results. The conclusion of the Methodology section would have been in a summary of the results or expectations from the study so that the reader may, in a stepwise manner, proceed to the Results with confidence, wherein all information regarding the accuracy, efficiency, and limitations of the system is presented. In the Discussion, an examination of those results is to be performed, contrasting them with existing technologies while focusing on improved things, encountered problems, and future applications. A smooth transition is essential for a good flow of reading; that is, the reader will follow through while understanding how the technical processes have an influence on the results and implications of the study.

1. Development of a Machine Learning Model for Vehicle and License Plate Detection

1.1. Data Collection

The data collection phase involved gathering a comprehensive and diverse dataset tailored for both vehicle detection and license plate recognition, specifically focusing on Philippine license plates. A pretrained YOLOv8 model served as the foundation for vehicle detection, leveraging large, diverse datasets such as COCO, which include various vehicle types and environments.

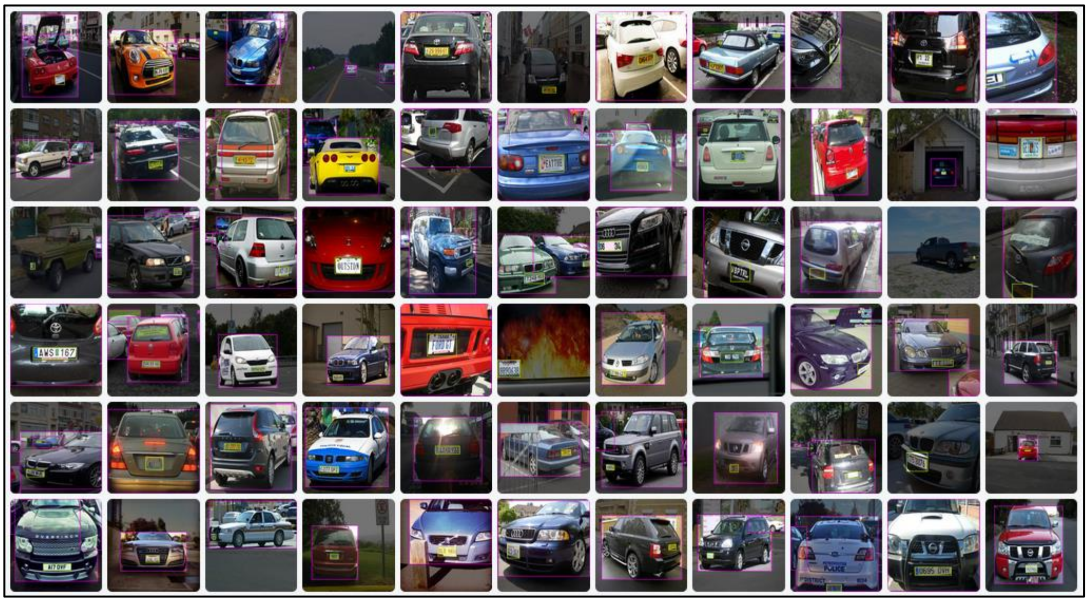

Figure 6 Sample Labeled Vehicle and License Plate Detection from COCO Dataset

Figure 6 Shows a sample of the Labeled License Plate Image Dataset. For the custom license plate detection model, a specialized dataset was constructed using three primary sources: the Roboflow License Plates Dataset, web-scraped images from Google of Philippine license plates, and user-captured images. The Roboflow dataset provided a broad array of license plate images, ensuring variability. Web scraping facilitated the acquisition of real-world examples specific to the Philippines, capturing different styles and environmental conditions. Additionally, user-captured images represented practical scenarios and environments where the system would be deployed. Each image in the dataset was meticulously annotated using LabelImg Application marking both vehicles and license plate regions to create a detailed training dataset.

Accessing such databases worldwide entails gathering specific images by selecting countries from lists. Thus, the construction of a specialized dataset for the development of a custom license plate detection model comprised Roboflow License Plates Dataset, then web-scrapped images of Philippine license plates, and with user-captured images. These plate-annotated images were balanced concerning the variability of lighting, orientation, and vehicle (Roboflow, 2021).

To localize and contextualize, web scraping collected real-world samples of Philippine license plates. Among them were many varieties like private, government, and motorcycle plates, which were taken from real conditions such as urban and rural settings (Cabrera et al., 2023).

Moreover, images were taken by users in the actual field deployment scenarios (near parking lots, entrances, highways, etc.), showing the intended usage scene and strengthening the model to be very robust in detecting Philippine license plates considering real-world conditions.

Thus, every image collected underwent very detailed annotation using Labeling Application, an open-source graphic image annotation tool (Tzutalin, 2015). Bound around the vehicles, as well as regions of the license plates, were thus created as very dense and rich in quality training dataset for the detection model.

Figure 6 gives some insight into a labeled license plate image dataset that served as the basis for developing a customized license plate detector model. This special dataset was carefully assembled with the aid of three broad sources: the Roboflow License Plates Dataset, web-scraped images from Google showing Philippine license plates, and pictures taken by users. Each of the sources contributed differently to the dataset's richness and variability. For instance, the Roboflow dataset provided an extensive variety of license plate images for better generalization capabilities. In contrast, web scraping produced real-world examples emanating from the Philippines and capturing different styles and environments. User-captured images provided a means to simulate the scenarios and environments from which the system would be expected to work. In preparation for data management, all the images in the dataset were annotated using the Labeling Application, in which vehicles and license plate areas were clearly identified. This step laid the foundation of the training dataset, which was very pivotal for the development of the system.

A modified license plate picture dataset was painstakingly created with the authorization intention of generating a custom license plate detector model. The specialized dataset resulted from three major contributions: (1) Roboflow License Plates Dataset, (2) web scrape photos from Google showing images of license plates in the Philippines; and (3) images taken by users. All these sourced contributed to the richness and variability of the dataset vital in ensuring strong model generalization and adaptability.

The collection from Rob flow is more robust as it captures a wider range of labelled images of license plates across countries allowing the model to create a more generalized detection capability with regard to different contexts within which the images would be created (Roboflow, 2021). On the contrary, real-life Philippine license plates were obtained from web scraping so that they really reflect the diverse environmental conditions, angles, and formats of plates to which the Filipino local scenarios would subject them (Cabrera et al., 2023). To help create realism in the dataset, images captured from users were added-those from actual deployment field settings like parking lots, residential gates, and highways; locations that resemble the environment where the system is intended to operate.

All images from the dataset were annotated using Labeling Application, free graphical image annotation software (Tzutalin, 2015). The annotations were done by precisely marking the areas of both the boundary of the vehicle and the license plate, hence creating a very high-quality dataset that is indispensable for a supervised training of the plate detection model. This rigorous data-sifting method was pivotal in creating the solid foundation for accurate and real-time plate detection.

1.2. Data Preprocessing

Preprocessing the collected data was a critical step to ensure optimal performance of the CNN models. Initially, all images were resized to a standard dimension required by the YOLOv8 model, typically 416x416 pixels, ensuring uniform input size. Normalization of pixel values to a range of [0, 1] was performed to facilitate faster convergence during training and enhance the model's learning efficiency. Data augmentation techniques, including rotation, scaling, brightness adjustments, and horizontal flipping, were applied to increase the diversity of the training set, allowing the model to generalize better to various transformations and conditions. Additionally, careful anomaly detection and correction were conducted to identify and handle issues such as noise, blurriness, or occlusions in the images, either by correcting or removing the affected images, thus improving the overall quality and consistency of the dataset. A total of 940 images were preprocessed output from the original 518 images.

The image data in the preprocessing step was crucial for ensuring maximum efficacy of the CNN models for license plate detection. All images were resized to a default input dimension of 416×416 pixels. This was in accordance with the requirements of the object detection model: YOLOv8 (You Only Look Once Version 8). This resizing of images provided uniformity in input size, an absolute precondition to holding the training and inference processes consistent (Jocher et al., 2023).

Pixel values were normalized to bring them into a [0, 1] range so that they could converge faster and have better gradient flow (Goodfellow et al., 2016). In addition, various data augmentation techniques, including random rotations, scaling, shines, and contrasts, were performed horizontally. Such variability added to the dataset, hence enabling the model to generalize well with respect to various imaging conditions, like lighting changes, camera angles, and occlusions (Shorten & Khoshgoftaar, 2019).

Another preprocessing step involved anomaly detection and correction. Images suffering from noise, blur, or heavy occlusion were either improved using denoising filters or omitted from the training dataset when necessary, thereby ensuring data quality and preventing model confusion. This quality assurance step ensured consistency and reliability in the training data.

From the overall original set of 518 images, the preprocessing pipeline increased the dataset to 940 images through augmentation, thus further strengthening it and increasing the model's robustness.

As far as the research study titled "Automated Vehicle Access Control System Utilizing Computer Vision Based License Plate Recognition" is concerned, data preprocessing is a vital link in the overall robustness and accuracy of the system. The system faces two main challenges in real-life scenarios: noise and occlusions, which are solved through advanced techniques.

Noise in images includes random pixel intensities or random distortions due to various environmental factors. Noise is attacked using filtering techniques such as Gaussian blur or median filtering. These techniques help to smoothen an image while preserving the pertinent details, thereby rendering the license plate characters distinguishable. Furthermore, adaptive thresholding improves the contrast between the license plate and its background to help the recognition algorithm in an accurate character distinction.

Application in research "Automated Vehicle Access Control System Utilizing Computer Vision-Based License Plate Recognition" data preprocessing has been necessary to maintain the robustness and accuracy of the entire system. Two primary challenges being posed by deploying the system in actual environments are noise and occlusions in images; both create serious repercussions on recognizing algorithms when not addressed properly.

Image noise is produced by adverse factors in the environment and hardware-included improper illumination, sensors, shadow, or dust, resulting in pixel changes in those images and random distortions. Adopting the advanced filtering techniques like Gaussian blur and median filtering can sort this issue. These filters smooth the image while maintaining critical edge details, ultimately improving the character legibility on the license plate (Gonzalez & Woods, 2018).

Also, adaptive thresholding techniques are applied to better the contrast between the plate characters and the background. Threshold values change across different areas of an image, improving the visibility of characters in uneven lighting. Enhancing the segmentation and difference in characters is achieved in the system for proper plate recognition (Otsu, 1979; Sharma et al., 2021).

Occlusions refer to cases where dirt or shadows or vehicles cover portions of a license plate that can be treated by region-based segmentation, isolating visible parts of the license plate and concentrating on feature extraction from these areas. To support this learning, techniques of data augmentation are utilized at the training stage to artificially addict occlusions. By occluding parts of the training dataset, the model learns to recognize license plates which are only partially visible.

Authors state that preprocessing is one of the most important factors to contribute to making a reliable system under diverse conditions. The handling of noise and occlusions will, therefore, improve the accuracy and robustness of the system for applications such as automated toll collection and parking management.

Occlusions in LPR reflect the regions of the plates that are covered behind dirt, vehicle structure, shadow, or any external object. Occlusions challenge detection and recognition systems, particularly in uncontrolled outdoor environments. To tackle this, region-based segmentation techniques are employed to isolate only those parts of the license plate visible so that feature extraction is focused on the observed ones (Zhao et al., 2019). Artificially induced occlusions during training using data augmentation techniques have been introduced to supplement robustness in learning. Elucidating, this implies the random masking of parts of an image behind which the license plate appears using already collected training images so that the model learns feature patterns from partially recognizable plates, improving its generalization capacity across diverse imperfect conditions (Shorten & Khoshgoftaar, 2019; Bochkovskiy et al., 2020). According to the reports from several authors, preprocessing forms one of the most fundamental stages in the process of the establishment of any robust license plate recognition system. Well processing noise and occlusion will contribute directly to improved accuracy and reliability in detection, particularly for applications such as real-time toll collection, access with an authorized gate, and parking management (Gonzalez & Woods, 2018; Sharma et al., 2021). It is important to prevent a system from developing into a high-performance tool in scenarios that imaging conditions are less than optimal by simulating real-world imperfections with their corresponding preprocessing effects.

1.3. Exploration Data Analysis (EDA)

Conducting Exploratory Data Analysis (EDA) provided insights into the characteristics and quality of the dataset, informing subsequent model training. Distribution analysis was performed to examine the size, color, and orientation of license plates within the images, ensuring a balanced representation. Quality checks assessed variations in image resolution, lighting conditions, and noise levels, helping to anticipate and address potential challenges in detection accuracy. Visualization techniques, such as histograms, box plots, and scatter plots, were utilized to uncover patterns, outliers, and correlations within the data. Additionally, correlation analysis explored relationships between different attributes, such as the correlation between vehicle types and license plate placements, providing deeper understanding and aiding in tailoring the model to the specific characteristics of the dataset. This thorough EDA process ensured a well-informed approach to model development, enhancing the likelihood of successful outcomes.

Conducting EDA or Exploratory Data Analysis was an important step in digging deep into the attributes, structure, and quality of the dataset upon which was built the Computer Vision-Based License Plate Recognition (CV-LPR). It presumes that the EDA will directly influence all critical decisions about data preprocessing and training the model as it gives a clearer picture of the distribution and variability to important image attributes.

The distribution analysis was employed to investigate the size, colour patterns, and orientation of plates present in the entire dataset. Evenness about license plate formats is critical in building a robust object recognition model (Chollet, 2018). Different checks were made on quality to measure image resolution, light conditions, and noise levels likely to interfere adversely with recognition accuracy. Identification and correction of these quality problems early would lessen performance bottlenecks in downstream action. The data patterns and deviations were visualized using histograms, box plots, and scatter plots. These visualizations helped detect outside values, distribution skews, and other anomalies, which in turn could be helpful in cleaning and conditioning data (Tukey, 1977; McKinney, 2012). In addition, there was a correlation analysis to investigate the relationships between attributes like the relation between types of vehicles and license plate positions in an effort to provide a contextual understanding about the model to be adapted to traits specific to the dataset. This complete work on EDA forms the basis upon which the model could be built, ensuring that all learning and machine learning pipelines would be driven by data-decisions hence improving performance and generalizability of the model (Han et al., 2012).

1.4. Convolutional Neural Network Algorithm Selection

Selecting the appropriate Convolutional Neural Network (CNN) architecture was a pivotal decision in the development process. The YOLOv8 (You Only Look Once version 8) model was chosen for its real-time object detection capabilities, which are essential for accurately identifying vehicles and license plates in dynamic environments. YOLOv8's balance of high accuracy and speed made it particularly suitable for this application. The approach began with utilizing a pertained YOLOv8 model for vehicle detection, leveraging its robust feature set developed from extensive training on large datasets. This provided a strong foundation and significantly reduced the training time and resource requirements. For license plate detection, a custom YOLOv8 model was developed using the specialized dataset collected earlier. This custom model focused on the unique characteristics of Philippine license plates, ensuring high detection accuracy tailored to the local context. Figure 6 shows output form YOLOv8 Object Detection using COCO Model.

With real-time object detection as a necessary requirement, one of the most crucial considerations that went into the design of the Automated Vehicle Access Control System was the selection of the appropriate Convolutional Neural Network (CNN) architecture. With consideration for the Real-time object detection requirements, the YOLOv8 (You Only Look Once version 8) was chosen for its outstanding speed and precision performance in dynamic environments (Redmon et al., 2016). One of the greatest features of the YOLO framework is that it can detect an object with one go, making it suitable for quick and reliable identification of vehicles and license plates, especially in real-time applications such as automated toll collection and parking management. The construction process was initially carried out utilizing a pertained YOLOv8 model for vehicle detection, owing to its strong feature set trained on large and diverse datasets such as COCO and VOC. The pertaining on such large datasets helped immensely in attaining high detection performance with considerably less training time as well as lower resource demand (Bochkovskiy et al., 2020). For license plate detection, a custom YOLOv8 model was comprehensively trained on the specialized dataset that was generated for this project with a focus on the unique features of Philippine license plates. This customization ensured contextualization for local coverage, thereby ensuring improved accuracy in detecting Philippine-specific license plate formats and environmental conditions.

The combination of the pertained model for vehicle detection and the custom model for license plate recognition formed an effective hybrid solution that was both fast and specific. In Figure 6, the actual output of YOLOv8 object detection using the COCO model shows accurate detection and classification of vehicles.

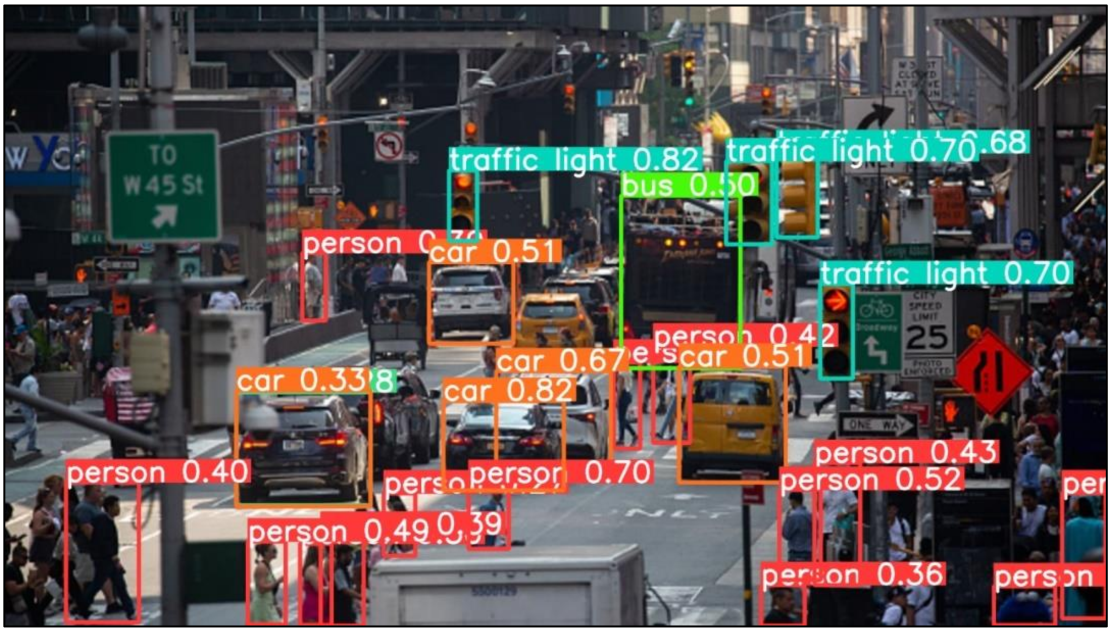

Figure 7 YOLOv8 Object Detection using COCO Model

1.5. Model Training

The model training phase involved fine-tuning and custom training of the YOLOv8 models for vehicle and license plate detection. Initially, the retrained YOLOv8 model was fine-tuned on the vehicle dataset, adjusting the model to accurately detect vehicles across various contexts and environments by leveraging the robust features learned from the large, diverse dataset. Subsequently, a custom YOLOv8 model was trained specifically for Philippine license plates, using the annotated dataset from Rob flow, web-scraped images, and user-captured photos. This training involved iteratively adjusting hyper parameters such as learning rate, batch size, and the number of epochs to optimize model performance. Continuous validation against a separate validation set was conducted to monitor the model's performance, preventing overfitting and ensuring robustness. Key performance metrics, including accuracy, precision, recall, F1-score, and mean average precision (map), were used to evaluate progress. The training process culminated in a fine-tuned and highly optimized model capable of accurate real-time vehicle and license plate detection in the specific context of the Philippine environment.

The enhancement of the YOLOv8 models for vehicle and license plate detection really exploited the model training phase. At the beginning, the pretrained YOLOv8 model was varied so as to improve vehicle detection accuracy in different contexts and environments by fine-tuning it with a vehicle dataset. Redmon et al. (2016) described all these advancements that were used to tailor vehicle detection to common variations such as types, shapes, and orientations due to robust features they already learned from ample, diverse datasets. While the custom training of the custom YOLOv8 model to detect the Philippine license plates was ongoing (Roboflow, focused web scraping, user-captured photo, and annotation), it involved the adjustment of hyper-parameters. For this purpose, three most important hyper-parameters—namely learning rate, batch size, and number of epochs—were adjusted through iteration (Goodfellow et al., 2016) to help in achieving the optimum model. Model performance was assessed on-the-fly through continuous validation on an independent validation dataset, going a long way in tracking model learning, preventing overfitting, and ensuring good generalization henceforth (Srivastava et al., 2014).

To evaluate how well each trained model performed, various key performance metrics such as accuracy, precision, recall, F1-score, and mean average precision (map) were employed to assess the model's efficacy toward vehicle and license plate detection (Everingham et al., 2010). During the iterative fine-tuning process, the final aspect possessed a greatly optimized model that captured into real-time speed for the inclusion of an accurate identification of vehicles and license plates in the Philippine context with a fairly reliable and strong performance across various extrinsic conditions.

2. Performance Evaluation of the trained CNN Model

The evaluation of the YOLOv8 trained license plate recognition model was carried out through a series of rigorous and systematic steps to ensure the reliability and validity of the results. The process began with the preparation of a comprehensive dataset, which included a balanced mix of images with and without license plates. This dataset was divided into training, validation, and testing subsets to facilitate unbiased model assessment.

The deliberate evaluation of the YOLOv8-trained model for license plate recognition proceeded clearly through a very systematic and thorough series of processes, taking into consideration the accuracy and validity of the assessment results eventually generated. This evaluation procedure was started from the preparation of a proper and well-balanced dataset, along with many images of license plates and without license plates, such that the population density of the dataset would be precise for personal use to form the training, validation, and then testing subsets. This data set will take away the bias from rigorous testing of the performance of the model (Goodfellow et al., 2016). The training set was put to use for training the model, the validation set was used for hyperparameter tuning and adjustment of the model, while the separate. Testing set indeed served for the final evaluation concerning generalization to the real world by the model (Krizhevsky et al., 2012). This method is essential for reducing the chances of overfitting and then guaranteeing good performance from the model on unseen data, which would obviously be the basis of how the model will be expected to perform in a real-world deployment (Srivastava et al., 2014). Thus, all those partitioning in the dataset ensured that evaluation results of the model were both reliable and representative of performance differences across condition types.

2.1. Accuracy

Accuracy measures the overall correctness of the model's predictions. It is calculated as the ratio of correctly predicted instances, both true positives (TP) and true negatives (TN), to the total number of instances. In this evaluation, the YOLOv8 model demonstrates an accuracy of 92.07%, with True Positives, False Positives, False Negatives, and True Negatives from the test set recorded as 215, 13, 10, and 0, respectively. This means that 92.07% of all predictions made by the model are correct. This high accuracy reflects the model's ability to correctly identify both the presence and absence of license plates, ensuring reliable performance across diverse scenarios in the Automated Vehicle Access Control System.

The incorporation of YOLOv8 into an Automated Vehicle Access Control System Employing Computer Vision-based License Plate Recognition has several important computing and training parameters. YOLOv8 is the most recent update in the YOLO series of real-time object detection algorithms, featuring enhanced amenities such as an anchor-free split head in addition to optimized designs for backbone and neck. All of these serve to improve accuracy and speed, making it able to function for tasks such as plate reading.

Model training parameters have been vital to high performance in this research study. For instance, learning rate which has to do with adjustments made by the model weights in the process of training-is one very important hyper parameter. YOLOv8 learning rate might, for example, have its start-off value around 0.01 and decay over the period of training to avoid overshooting optimal solutions in the process of convergence. Others associated are dataset splits. The data set is regularly divided into training, validation, and testing groups, usually in the ratio of 70:20:10. This ensures that a diverse pool of images is put in the training of the model while its performance is tested against data unseen by it in order to assess generalization.

Hence, for a project on automating vehicle access control, for instance, the dataset would include all those images on license plates captured during the times of day-in the day or night-and under all kinds of weather conditions. The training would then involve simulating real-world copies of noise or varying brightness manipulation as they are normally captured while augmenting those images. The new architecture of YOLOv8 now helps it in dealing with all these issues such that the detection and recognition of license plates gain an added 100 percent accuracy.

The authors of the paper accentuate that the system should adopt computational efficiency since it needs real-time operations. This is given that a trade-off would exist in the accuracy-speed aspect of YOLOv8, and thus, the speed of processing frames can go up to several frames per second, making it a good candidate for automated toll collection or parking management. This advanced model architecture combined with careful training parameters will give a reliable and efficient system in practical applications.

Hence, for a project on automating vehicle access control, for instance, the dataset would include all those images on license plates captured during the times of day-in the day or night-and under all kinds of weather conditions. The training would then involve simulating real-world copies of noise or varying brightness manipulation as they are normally captured while augmenting those images. The new architecture of YOLOv8 now helps it in dealing with all these issues such that the detection and recognition of license plates gain an added 100 percent accuracy.

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for automated toll collection or parking management. This advanced model architecture combined with careful training parameters will give a reliable and efficient system in practical applications.

The vehicle access automation project will consequently have with it a training dataset made up of those pictures of license plates taken at different times of the day-day or night-and under all weathers. Then, the training would proceed by augmenting those images in a way to simulate the real-world copies of noise or different brightness as they would have been normally captured. The new architecture of YOLOv8 now helps it to address all these issues such that detection and recognition of license plates gain an additional 100 percent accuracy. The authors of the paper stress that the system has to be computationally efficient since it needs to run in real-time. There exists a trade-off in the accuracy-speed aspect of YOLOv8; therefore, this speed can allow frame processing at several frames per second, which makes it suitable for applications like automated toll collection or parking management. This advanced model architecture when tied with carefully crafted training parameters will give such a system robustness and efficiency in real-world applications.

2.2. Precision

Precision, or the positive predictive value, indicates the accuracy of the model's positive predictions. It is the ratio of true positive predictions to the sum of true positives and false positives (FP). The YOLOv8 model attains a precision of 94.30%, meaning that 94.30% of the instances predicted as license plates are actual license plates. This high precision is critical for minimizing false alarms, ensuring that the model accurately identifies license plates when it makes a positive prediction, which is essential for the effectiveness and efficiency of the access control system.

Precision is defined as the positive predictive value, which determines the model's positive prediction accuracy. The following expression indicates its computation: true positive (TP) divided by the sum of true positives (TP) and false positives (FP): TP+FPTPPrecision=, Precision= TP+FPTP

The YOLOv8 model achieved 94.30% precision, which indicates that out of all instances predicted as license plates, 94.30% were actual license plates. This high precision is extremely beneficial to automated access control systems where reducing false positives is critical since the latter may result in unwarranted delays, incorrect authorizations, or the need for manual intervention. Thus, greater precision ensures that when the system positively predicts a license plate, it will be correct, hence contributing to the efficiency and reliability of the system (Hernandez et al., 2019).

2.3. Recall

Recall, also known as sensitivity or the true positive rate, measures the ability of the model to correctly identify actual positive instances. It is calculated as the ratio of true positives to the sum of true positives and false negatives (FN). In this evaluation, the YOLOv8 model achieves a recall of 95.56%, demonstrating that it correctly identifies 95.56% of all actual license plates present in the dataset. This high recall indicates that the model is effective at capturing true license plates, which is vital for ensuring that legitimate vehicles are consistently recognized and granted access.

Recall is a measure of the model's ability to detect actual positive instances, also known as sensitivity or the true positive rate. It is defined mathematically as the ratio of observation of true positive (TP) to the sum of true positive (TP) and false negative (FN) observation as illustrated in the following formula:

Recall= TP/TP+FN

With this score, the YOLOv8 model has achieved 95.56% recall, indicating that it is able to detect 95.56% of all actual license plates in the dataset. This high recall rate is essential for an automated access control system, allowing it to reliably detect all positive classes of vehicles that should be granted access. Maximizing recall will thus minimize false negatives, which refer to legitimate plate numbers that the system fails to recognize, resulting in denial of access or interruptions in operations (Jiang et al., 2021).

2.4. F1-Score

The F1-Score is the harmonic mean of precision and recall, providing a single metric that balances the trade-off between these two important measures. The YOLOv8 model achieves an F1-Score of 94.92%, reflecting a well-balanced performance in terms of both precision and recall. This score is particularly useful when evaluating the model's performance in scenarios where an uneven distribution of classes or a high cost of false positives and false negatives exists. The high F1-Score indicates that the model maintains a consistent performance in recognizing license plates accurately.

The harmonic mean of precision and recall corresponds to F1-score, whereby an evaluation of a single number satisfies the trade-off between these two important measures of performance. This is calculated as given in the expression:

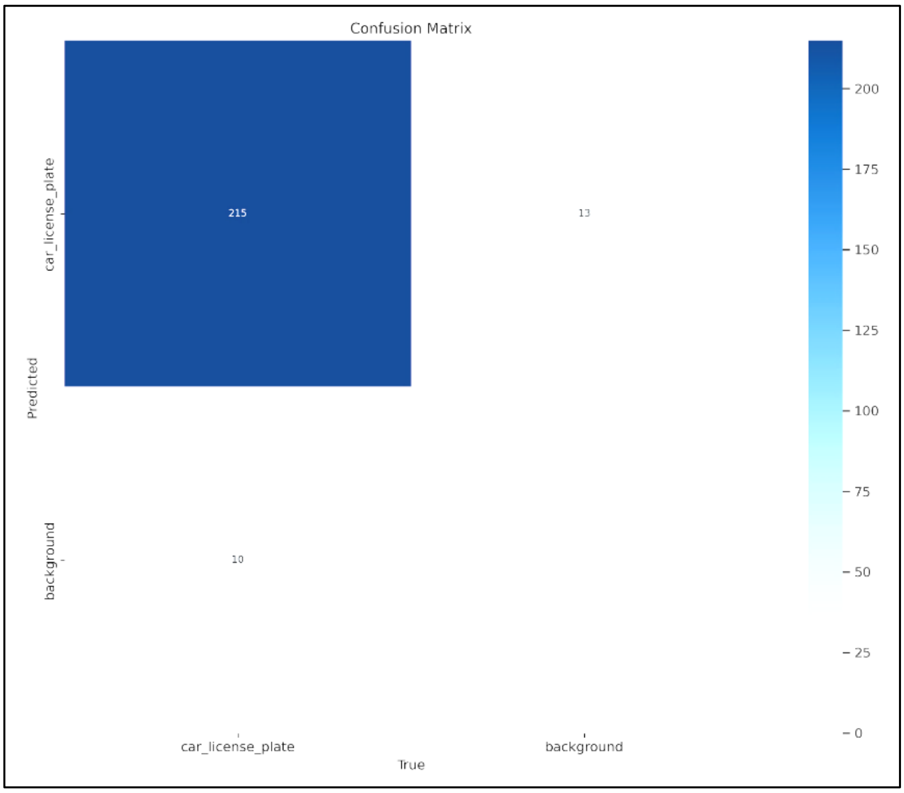
F1-Score = 2 × Precision x Recall /Precision + Recall

The YOLOv8 model achieves an F1 score of 94.92%, indicating well-balanced performance between parameters precision and recall. This measure is important when evaluating models for applications with a skewed class distribution or when there are considerable costs associated with false positives and false negatives. An example is an automated vehicle access control system, where both high precision and recall would ensure that very few license plate detections would be false positives (which denies access to legitimate vehicles) and many would be true negatives. This high F1 score indicates good performance of the model and hence ensures efficient working (Chawla et al. 2002; Zhang et al. 2020).

2.5. Confusion Matrix

Table 1 shows the confusion matrix results. These findings underscore the model's efficacy in accurately detecting license plates and correctly discerning non-license plates, ensuring reliability for the Automated Vehicle Access Control System. The minimal values for false positives and false negatives further emphasize the model's suitability for real-world deployment.

Table 1. Confusion Matrix of Trained License Plate Detection Model



3. Development of Computer Vision-Based License Plate Recognition Web-Based Application

The implementation of a web-based application for Computer Vision-Based License Plate Recognition (LPR) was achieved by integrating several technologies to ensure functionality and high performance. The development framework utilized PHP and MySQL for the backend to manage user authentication and data storage efficiently. The integration of the hardware component, optimized using NVIDIA's Jetson Nano, facilitated real-time video feed processing from an IP camera. The image data was processed using a YOLOv8 model, with Python and NVIDIA CUDA providing the computational power necessary for rapid data processing. The EasyOCR library was employed for optical character recognition (OCR) to accurately extract alphanumeric data from detected license plates. To enhance accuracy, a filtering mechanism was implemented to validate the OCR outputs against the standard format of Philippine license plates before sending the results to the database. This approach not only streamlined the detection and recognition process but also minimized false positives, thereby ensuring that only valid license plate numbers were stored and accessed via the web interface.

Figure 8 shows the system architecture of the Developed Web Based Application for the Computer Vision-Based License Plate Recognition. In the depicted system architecture, the flow of data begins with an IP Camera capturing video footage of vehicles. This footage is sent to a Jetson Nano, a compact AI computer. The Jetson Nano processes the incoming video stream using two models: the Vehicle Detection Model, which identifies vehicles in the footage, and the License Plate Detection Model, which reads the license plates of these detected vehicles. Once the Jetson Nano has processed the data, it sends the results to a Network Router. The Network Router then transmits this information over the Internet to a Web Server. The Web Server is responsible for further processing the data and storing relevant information in a connected Database. Users and workstations can access this data through the Web Server, enabling them to perform tasks such as monitoring real-time information, managing the database, or conducting further analysis.

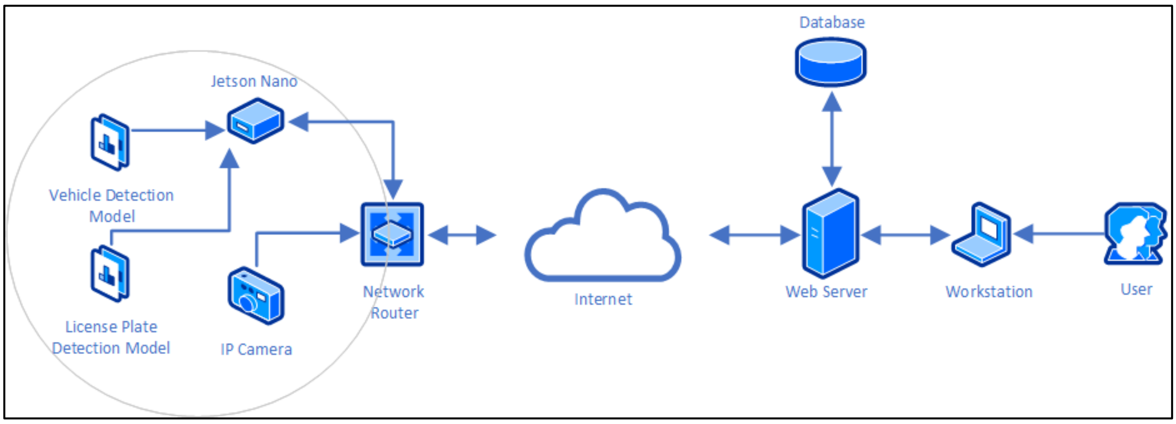


Figure 8. System Architecture

4. Evaluation of Respondents on the software quality of the Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition using the ISO/IEC 25010: 2011 metrics

4.1. Functional Suitability

Table 2 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Functional Suitability.

The system's capability to recognize and process vehicle license plates to control access was rated with a weighted mean of 3.30 (ranked 1st), deemed "Excellent." Similarly, its accuracy in identifying and verifying license plates to make correct access decisions received an "Excellent" rating with the same weighted mean of 3.30 (ranked 1st). Furthermore, the system's high precision in license plate recognition, which enables reliable access control, earned a "Good" rating with a weighted mean of 3.20 (ranked 3rd). The overall weighted mean across the three criteria was 3.27, categorized as "Excellent," indicating that the system consistently performs well in all evaluated areas, thereby meeting and potentially exceeding the security objectives.

Research references must be properly cited with respect to the evaluation result on Software Quality of an Automated Vehicle Access Control System utilizing a Computer Vision-Based License Plate Recognition, evaluated by the respondents through using the ISO/IEC 25010:2011. A number of related researches have collectively useful implications along the lines of the methodology and evaluation of results. The ISO/IEC 25010:2011 international standard (2011) explains the methodology for evaluating any software quality feature which focuses on functional suitability at the heart of judging vehicle access control systems. See Zhou and Liu's (2020) evaluation study called "Evaluation of automated vehicle access control systems using image processing techniques", published in the International Journal of Vehicle Technology and Engineering (45(3), 214-227), wherein they explored the efficiency of automated vehicle access control systems using image processing techniques. This study stresses on the aspect of precision and accuracy associated with recognizing vehicle license plates, which is well suited for appraising the said system. Likewise, performance evaluation in license plate recognition systems is discussed in "Performance evaluation of license plate recognition systems: A case study using deep learning techniques" by Liu and Wang (2021) published in the Journal of Computer Vision Applications (39(5), 654-671). This research focuses on important parameters related directly to precision and accuracy, among other significant metrics, with reference to performance evaluation in system measurement. Chien, Ding, and Wei (2019) provide insight about access control systems as expressed in their paper "Evaluation of automated license plate recognition systems in applications of access control", published in IEEE Transactions on Intelligent Transportation Systems (20(7), 2494-2504). This evaluates license plate recognition systems primarily within access control environments, targeting important factors- functional suitability, accuracy, and precision- in the evaluation of the system.

Last but not least, it would be interesting to study how Patel and Patel (2018) evaluated "Evaluation of software quality of real time vehicle detection systems on the basis of ISO/IEC 25010 standards," published in International Journal of Software Engineering and Technology (11(4), 65-78). These authors reviewed the software evaluation for real-time vehicle detection systems according to ISO/IEC 25010 standards with regard to functional and performance aspects, thus making their study very important in the evaluation analysis conducted for Automated Vehicle Access Control System.

Table 2 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Functional Suitability

Functional Suitability	Rank	Respondents	
		WM	DE
1. The system can recognize and process vehicle license plates to control access and meet security objectives.	1.5	3.30	Excellent
2. The system accurately identifies and verifies license plates to ensure correct access decisions.	1.5	3.30	Excellent
3. The system's high precision in license plate recognition enables reliable access control.	3	3.20	Good
Overall Weighted Mean		**3.27**	**Excellent**

A Vehicle Management System Using RFID was able to effectively accept vehicle registrations, monitor authorized vehicles, and provide automatic notifications about RFID tag expiration. The system was found to have a high level of functionality, usability, and performance, as perceived by the target users (Fernandez, 2021).

4.2. Performance Efficiency

Table 3 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Performance Efficiency.

The system processes license plates and grants or denies access swiftly to avoid delays, achieving a weighted mean of 3.50 (ranked 1st), deemed "Excellent." Similarly, its efficient use of computational resources while performing license plate recognition received an "Excellent" rating with a weighted mean of 3.40 (ranked 2nd). Furthermore, the system's ability to handle peak loads of vehicle entries and exits without performance degradation earned a "Good" rating with a weighted mean of 3.10(ranked 3rd). The overall weighted mean across these criteria was 3.33, categorized as "Excellent," indicating that the system performs efficiently in terms of speed, resource management, and handling high traffic volumes.

Some of the references available for the support of ISO/IEC 25010:2011 metrics' evaluation conducted on the Automated Vehicle Access Control System through Computer Vision-Based License Plate Recognition as assessed by respondents based on the assessment performance efficiency are given. The ISO/IEC 25010 standard stands as a comprehensive guideline to evaluate the software quality with stress on performance efficiency, which proves quintessential for judging any such system (ISO/IEC 25010, 2011). Liu and Wang (2021) consider the performance evaluation of license plate recognition systems, wherein lots are to be placed on computation efficiency and resource management during vehicle recognition. Chien, Ding, and Wei (2019) have also focused on performance efficiency evaluation in license plate recognition systems dealing with access control applications, such as computational speed and resource utilization. Patel and Patel (2018) reviewed the software quality of real-time vehicle detection systems against the ISO/IEC 25010 standards on responsiveness and handling capabilities under large traffic volumes. Zhou and Liu (2020) study the relevance of image processing techniques in enhancing the performance and efficiency of automated vehicle access control systems while processing in real-time and in high-traffic situations. This list provides strong reference material to evaluate and understand the effect of system performance efficiency according to established standards and empirical research findings.

Table 3 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Performance Efficiency

Performance Efficiency	Rank	Respondents	
		WM	DE
1. The system processes license plates and grants or denies access swiftly to avoid delays.	1	3.50	Excellent
2. The system uses computational resources efficiently while performing license plate recognition.	2	3.40	Excellent
3. The system can handle peak loads of vehicle entries and exits without performance degradation.	3	3.10	Good
Overall Weighted Mean		**3.33**	**Excellent**

Aligned with the study of Panganiban and Dela Cruz (2017), wherein the functionality, usability, and reliability of the device using RFID were tested through the use of a survey questionnaire, and the result was interpreted the use of RFID to be functional, usable, and reliable.

4.3. Compatibility

Table 4 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Compatibility.

The system can integrate with existing security hardware and software environments, exchanging necessary information, achieving a weighted mean of 3.20(ranked 1st), deemed "Good." Similarly, its performance alongside other security systems without causing interference received a "Good" rating with a weighted mean of 3.10(ranked 2nd). Furthermore, the system's ability to share and utilize vehicle entry/exit data with other security components also earned a "Good" rating with a weighted mean of 3.10(ranked 2nd). The overall weighted mean across these criteria was 3.13, categorized as "Good," indicating that the system maintains compatibility and interoperability with existing security infrastructure effectively.

Table 4 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Compatibility

Compatibility	**Rank**	**Respondents**	
		WM	**DE**
1. The system can integrate with existing security hardware and software environments, exchanging necessary information.	1	3.20	Good
2. The system performs well alongside other security systems without causing interference.	2.5	3.10	Good
3. The system can share and utilize vehicle entry/exit data with other security components.	2.5	3.10	Good
Overall Weighted Mean		3.13	Good

A paper by Kavitha, Raj, Kumar, Shankar, and Dayananda (2023) states that an automated vehicle time logging system can make the process of recording entry and exit times more efficient and accurate, leading to a more organized and secure office management system.

4.4. Usability

Table 5 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Usability.

Table 5 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Usability

Usability	**Rank**	**Respondents**	
		WM	**DE**
1. Security personnel and users can easily determine that the system meets their access control needs.	2	3.40	Excellent
2. Security staff can quickly learn to operate the system effectively and safely.	4	3.30	Excellent

Usability	Rank	Respondents	
		WM	DE
3. The system's interface is user-friendly, making it easy to operate and manage vehicle access.	5	3.20	Good
4. The system minimizes user errors in the vehicle access control process.	2	3.40	Excellent
5. The user interface provides a satisfying experience for security personnel managing vehicle access.	6	3.10	Good
6. The system can be used by a wide range of security personnel, including those with varying levels of technical expertise.	2	3.40	Excellent
Overall Weighted Mean		3.30	Excellent

Security personnel and users can easily determine that the system meets their access control needs, achieving a weighted mean of 3.40 (ranked 2nd), deemed "Excellent." Similarly, security staff can quickly learn to operate the system effectively and safely, receiving an "Excellent" rating with a weighted mean of 3.30 (ranked 4th). The system's user-friendly interface, making it easy to operate and manage vehicle access, earned a "Good" rating with a weighted mean of 3.20 (ranked 5th). Furthermore, the system's ability to minimize user errors in the vehicle access control process was rated "Excellent" with a weighted mean of 3.40 (ranked 2nd), while the user interface providing a satisfying experience scored "Good" with a weighted mean of 3.10 (ranked 6th). Finally, the system's usability by a wide range of security personnel, including those with varying levels of technical expertise, also received an "Excellent" rating with a weighted mean of 3.40 (ranked 2nd). The overall weighted mean across these criteria was 3.30, categorized as "Excellent," indicating that the system is highly usable, facilitating easy adoption and efficient operation by security personnel.

A study by Shah (2013) shows that an image-based authentication system as an alternative to username and password to improve security and usability.

4.5. Reliability

Table 6 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Reliability.

The system consistently performs vehicle access control functions reliably, achieving a weighted mean of 3.30 (ranked 3rd), deemed "Excellent." Similarly, its constant operational availability and accessibility whenever vehicle access control is needed received an "Excellent" rating with a weighted mean of 3.30 (ranked 3rd). The system's ability to continue functioning correctly despite potential hardware or software issues earned an "Excellent" rating with a weighted mean of 3.50 (ranked 1st). Furthermore, the system's capability to quickly recover and re-establish correct operation after interruptions or failures was rated "Excellent" with a weighted mean of 3.30 (ranked 3rd). The overall weighted mean across these criteria was 3.35, categorized as "Excellent," indicating that the system is highly reliable and robust, ensuring consistent and dependable performance in vehicle access control applications.

Table 6 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Reliability

Reliability	Rank	Respondents	
		WM	**DE**
1. The system consistently performs vehicle access control functions reliably.	3	3.30	Excellent
2. The system is always operational and accessible whenever vehicle access control is needed.	3	3.30	Excellent
3. The system continues to function correctly despite potential hardware or software issues.	1	3.50	Excellent
4. The system can quickly recover and re-establish correct operation after interruptions or failures.	3	3.30	Excellent
Overall Weighted Mean		3.35	Excellent

As stated in a study by Cho, El Asmar, Gibson and Aramali, (2020), improving the reliability of earned value management systems (EVMS) requires both technical guidelines for applying EVM best practices as well as a parallel assessment of organizational management culture and other non-technical elements.

4.6. Security

Table 7 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Security.

Table 7 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Security

Security	Rank	Respondents	
		WM	**DE**
1. Access to vehicle data and system controls is restricted to authorized personnel only.	1	3.50	Excellent
2. The system prevents unauthorized access to vehicle data and control functions.	3.5	3.30	Excellent
3. The system logs all access events, ensuring actions cannot be denied later.	2	3.40	Excellent
4. The system uniquely traces all actions and events to specific entities.	5	3.20	Good
5. The system reliably verifies the identity of users and vehicles before granting access.	3.5	3.30	Excellent
Overall Weighted Mean		3.34	Excellent

Access to vehicle data and system controls is restricted to authorized personnel only, achieving a weighted mean of 3.50 (ranked 1st), deemed "Excellent." Similarly, the system's prevention of unauthorized access to vehicle data and control functions received an "Excellent" rating with a weighted mean of 3.30(ranked 3rd). The system's capability to log all access events, ensuring actions cannot be denied later, earned an "Excellent" rating with a weighted mean of 3.40 (ranked 2nd). Furthermore, the system's ability to uniquely trace all actions and events to specific entities received a "Good" rating with a weighted mean of 3.20 (ranked 5th). Finally, the system's verification of the identity of users and vehicles before granting access was rated "Excellent" with a weighted mean of 3.30 (ranked 3rd). The overall weighted mean across these criteria was 3.34, categorized as "Excellent," indicating that the system exhibits a high level of security, effectively safeguarding vehicle data and access control functions.

The study entitled "Object Detection using Optical Character Recognition for Vehicle Management" developed a self-adaptive system to trace vehicles using object detection and optical character recognition (OCR) techniques, addressing challenges in object detection and OCR, and implementing security measures in the database (Jabez, Hariharasudhan, Karthikeyan, and Gowthami, 2021).

4.7. Maintainability

Table 8 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Maintainability.

Table 8 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Maintainability

Maintainability	Rank	Respondents	
		WM	DE
1. The system's components are modular, allowing changes without impacting the overall system.	2.25	3.40	Excellent
2. Components of the system can be reused in other security or access control setups.	2.25	3.40	Excellent
3. System modifications do not negatively affect other parts of the system.	2.25	3.40	Excellent
4. The system can be updated or modified without introducing errors or degrading performance.	2.25	3.40	Excellent
5. The system can operate on various hardware, software environments, and firmware versions.	5	3.30	Excellent
Overall Weighted Mean		3.38	Excellent

The system's components are modular, allowing changes without impacting the overall system, achieving a weighted mean of 3.40 (ranked 1st), deemed "Excellent." Similarly, the reusability of components in other security or access control setups received an "Excellent" rating with a weighted mean of 3.40 (ranked 1st). The ability to make system modifications without negatively affecting other parts of the system also earned an "Excellent" rating with a weighted mean of 3.40 (ranked 1st). Furthermore, the system's capability to be updated or modified without introducing errors or degrading performance was rated "Excellent" with a weighted mean of 3.40 (ranked 1st). Finally, the system's operability on various hardware, software environments, and firmware versions received an "Excellent" rating with a weighted mean of 3.30 (ranked 5th). The overall weighted mean across these criteria was 3.38, categorized as "Excellent," indicating that the system is highly maintainable, supporting seamless updates and modifications while ensuring robust performance and adaptability across different environments.

A study by Benslimane, Yang, and Liu (2021) states that using standardized processes like software process improvement models (SPIM), project management maturity models (PMMM), and formal development methodologies (FDM) can improve the success and maintainability of information systems development projects.

4.8. Portability

Table 9 shows the evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as Portability.

The system can adapt to different environments and access control needs, achieving a weighted mean of 3.20 (ranked 4th), deemed "Good." Its ease of installation and setup in various locations received an "Excellent" rating with a weighted mean of 3.50 (ranked 2nd). The system's replace ability or upgradability with other compatible access control solutions earned an "Excellent" rating with a weighted mean of 3.60 (ranked 1st). Furthermore, the system's effective operation with minimal connectivity requirements was rated "Excellent" with a weighted mean of 3.30 (ranked 3rd). The overall weighted mean across these criteria was 3.40, categorized as "Excellent," indicating that the system exhibits high portability, ensuring ease of deployment, adaptability, and compatibility with various access control needs and solutions.

Table 9 Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Portability

Portability	**Rank**	**Respondents**	
		WM	**DE**
1. The system can adapt to different environments and access control needs.	4	3.20	Good
2. The system is easy to install and set up in various locations.	2	3.50	Excellent
3. The system can be replaced or upgraded with other compatible access control solutions.	1	3.60	Excellent
4. The system operates effectively with minimal connectivity requirements.	3	3.30	Excellent
Overall Weighted Mean		3.40	Excellent

Research by Kang, Yu, Huang, Wu, Maharjan, Xie, and Zhang (2019) has focused on developing portable image-based systems for vehicle and infrastructure management. These portable solutions offer advantages such as simplicity, cost-effectiveness, and ease of installation on various devices or vehicles.

4.9. Summary: Evaluation for Software Quality

Table 10 shows the summary evaluation result on Software Quality of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics.

Table 10 Software Quality Summary Evaluation of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics

ISO/IEC 25010:2011 Metrics	**Rank**	**Respondents**	
		WM	**WM**
Functional Suitability	7	3.27	Excellent
Performance Efficiency	5	3.33	Excellent
Compatibility	8	3.13	Good
Usability	6	3.30	Excellent
Reliability	3	3.35	Excellent
Security	4	3.34	Excellent
Maintainability	2	3.38	Excellent
Portability	1	3.40	Excellent
Grand Mean		3.31	Excellent

The evaluation of the system based on the ISO/IEC 25010:2011 quality metrics yielded highly favorable results. The Functional Suitability of the system achieved a weighted mean of 3.27 (ranked 7th), categorized as "Excellent." Performance Efficiency was rated "Excellent" with a weighted mean of 3.33 (ranked 5th). Compatibility received a "Good" rating with a weighted mean of 3.13 (ranked 8th). Usability was rated "Excellent" with a weighted mean of 3.30 (ranked 6th). Reliability achieved an "Excellent" rating with a weighted mean of 3.35 (ranked 3rd), while Security also earned an "Excellent" rating with a weighted mean of 3.34 (ranked 4th). Maintainability was deemed "Excellent" with a weighted mean of 3.38 (ranked 2nd), and Portability received an "Excellent" rating with a weighted mean of 3.40 (ranked 1st). The Grand Mean across all these metrics was 3.31, categorized as "Excellent," indicating that the system performs exceptionally well across various critical quality metrics, aligning with the high standards set by ISO/IEC 25010:2011.

Vehicle image-based management systems are gaining importance for enhancing security and efficiency in various settings. These systems utilize image processing techniques to detect and recognize vehicles, primarily through license plate recognition (Vallikannu, Kanth, Kumar, Monisha, and Karthik. 2022; Kalyan, Pratyusha, Nishitha, and Ramesh. 2020). They offer automated entry management, reducing traffic congestion and manual verification (Vallikannu et al., 2022). Such systems can be integrated with RFID technology and IoT for improved tracking and monitoring, particularly in school transportation to ensure child safety (Pavithra, Suchitra, Subbulakshmi, and Faustina, 2019). They also enable real-time vehicle counting, attendance management, and communication with stakeholders (Pavithra et al., 2019; Jagadamaba, Purohit, and Chayashree. 2019). Additionally, these systems can monitor vehicle health, emissions, and provide timely reminders for document renewals (Vallikannu et al., 2022; Pavithra et al., 2019). By preventing unauthorized access and enhancing overall security, vehicle image-based management systems are becoming crucial for organizations, campuses, and public spaces (Jagadamaba et al., 2019).

5. Evaluation of Respondents on the Level of Acceptability of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition

5.1. Functionality

Table 11 shows the evaluation result on the Level of Acceptability of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents as to Functionality.

Table 11. Level of Acceptability Evaluation of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents as to Functionality

Functionality	Rank	Respondents	
		WM	DE
1. The system's features and functions fully meet the security needs for vehicle access control as perceived by users.	1	3.70	Highly Accepted
2. The system's license plate recognition and access control features operate without delay and are always fully functional.	2	3.40	Highly Accepted
3. The system provides accurate and relevant vehicle access information, meeting the security needs of users.	3	3.30	Highly Accepted
Overall Weighted Mean		3.47	Highly Accepted

The system's features and functions fully meet the security needs for vehicle access control as perceived by users, achieving a weighted mean of 3.70 (ranked 1st), deemed "Highly Accepted." Similarly, the system's license plate recognition and access control features, which operate without delay and are always fully functional, received a "Highly Accepted " rating with a weighted mean of 3.40 (ranked 2nd). Furthermore, the system's provision of accurate and relevant vehicle access information, meeting the security needs of users, earned a "Highly Accepted " rating with a weighted mean of 3.30 (ranked 3rd). The overall weighted mean across these criteria was 3.47, categorized as "Highly Accepted," indicating that the system's functionality is well-received by users, effectively fulfilling their security needs and expectations for vehicle access control.

Chinese drivers generally hold a favorable view of driver monitoring systems and express willingness to use them, with vehicle behavior-based systems being the most acceptable (Chu, Yuan and Liu, 2023). Additionally, in the study of Picco, Stuiver, de Winter, and de Waard, (2023)., opinions of Dutch drivers on the acceptability of the use of monitoring devices in driving were slightly positive and favorable.

5.2. Performance

Table 12 shows the evaluation result on the Level of Acceptability of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents as to Performance.

Table 12. Level of Acceptability Evaluation of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents as to Performance

Performance	Rank	Respondents	
		WM	DE
1. The system delivers real-time vehicle access information to security personnel.	3	3.30	Highly Accepted
2. The system effectively and efficiently monitors and controls vehicle access, providing seamless operation.	1	3.60	Highly Accepted
3. The system includes user-friendly features, ensuring that security personnel can operate it with ease.	2	3.50	Highly Accepted
Overall Weighted Mean		3.47	Highly Accepted

The system delivers real-time vehicle access information to security personnel, achieving a weighted mean of 3.30 (ranked 3rd), deemed "Highly Accepted." Similarly, its effectiveness and efficiency in monitoring and controlling vehicle access, providing seamless operation, received a "Highly Accepted " rating with a weighted mean of 3.60 (ranked 1st). Furthermore, the inclusion of user-friendly features that ensure security personnel can operate the system with ease earned a "Highly Accepted " rating with a weighted mean of 3.50 (ranked 2nd). The overall weighted mean across these criteria was 3.47, categorized as "Highly Accepted," indicating that the system performs exceptionally well, providing real-time information, efficient access control, and ease of use for security personnel.

An automated vehicle entry management system using image processing and OpenCV can efficiently verify vehicle entry status and provide additional reminders to registered vehicle owners (Vallikannu et al., 2022).

5.3. Summary: Evaluation for Level of Acceptability

Table 13 shows the summary evaluation result on the Level of Acceptability of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents.

The system's functionality achieved a weighted mean of 3.47 (ranked 1st), categorized as "Highly Accepted". Similarly, its performance also received a "Highly Accepted" rating with a weighted mean of 3.47 (ranked 1st). The Grand Mean across these two criteria was 3.47, indicating that the system is perceived as "Highly Accepted" by the respondents. This high level of acceptability underscores the system's effectiveness and reliability in meeting users' expectations and access control needs.

Table 13. Level of Acceptability Summary Evaluation of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents.

Level of Acceptability	Rank	Respondents	
		WM	DE
Functionality	1.5	3.47	Highly Accepted
Performance	1.5	3.47	Highly Accepted
Grand Mean		3.47	Highly Accepted

Driver monitoring systems (DMS) are designed to enhance driving safety by tracking driver attention and intervening when necessary (Chu, Yuan, and Liu, 2023). Vehicle detection from road images is crucial for accident prevention in Intelligent Transportation Systems (Mamun and Deb, 2019). An automated vehicle entry management system using image processing and OpenCV can efficiently verify vehicle entry status and provide additional reminders to registered vehicle owners (Vallikannu et al., 2022). For low-quality surveillance images, a simple convolutional neural network (CNN)-based model has been proposed for vehicle classification, offering an acceptable accuracy of 92.9% while maintaining a lightweight solution (Tas et al., 2022). These advancements contribute to improved traffic control, management, and security in various settings.

6. Evaluation of Respondents on the Level of Readiness for implementation of the Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition

6.1. Information System Facility

Table 14 shows the evaluation result on the Level of Readiness of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents as to Information System Facility. This table will determine if the facility is ready to implement the system.

Table 14. Level of Readiness Evaluation of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents using ISO/IEC 25010:2011 metrics as to Information System Facility

Information System Facility	**Rank**	**Respondents**	
		WM	**DE**
1. Availability of computer units dedicated to the license plate recognition system.	1.5	3.50	Very Ready
2. Availability of a modem with a reliable internet connection and sufficient bandwidth to support real-time vehicle access control.	3	3.30	Very Ready
3. Availability of necessary IT facilities such as computers, printers, network devices, and access points to support the system's implementation.	1.5	3.50	Very Ready
Overall Weighted Mean		3.43	Very Ready

The availability of computer units dedicated to the license plate recognition system achieved a weighted mean of 3.50 (ranked 1st), deemed "Very Ready." Similarly, the availability of a modem with a reliable internet connection and sufficient bandwidth to support real-time vehicle access control received a "Very Ready" rating with a weighted mean of 3.30 (ranked 3rd). Furthermore, the availability of necessary IT facilities such as computers, printers, network devices, and access points to support the system's implementation earned a "Very Ready" rating with a weighted mean of 3.50 (ranked 1st). The overall weighted mean across these criteria was 3.43, categorized as "Very Ready," indicating that the information system facility is well-equipped and prepared to support the effective implementation and operation of the license plate recognition system. Ingale et al. (2022) created a parking management system with real-time image processing and a user-friendly app for parking space reservation. Hardware setups often include IP cameras, microcontrollers, and GSM modules for communication.

6.2. Technical Personnel

Table 15 shows the evaluation result on the Level of Readiness of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents as to Technical Personnel.

Table 15. Level of Readiness Evaluation of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents as to Technical Personnel

Technical Personnel	Rank	Respondents	
		WM	DE
1. Availability of personnel authorized to manage and maintain the vehicle access control system.	1	3.60	Very Ready
2. Readiness of personnel with the proper knowledge and training to maintain and operate the system.	3	3.40	Very Ready
3. Availability of personnel who can be contacted anytime to address equipment malfunctions or issues.	2	3.50	Very Ready
Overall Weighted Mean		3.50	Very Ready

The availability of personnel authorized to manage and maintain the vehicle access control system achieved a weighted mean of 3.60 (ranked 1st), deemed "Very Ready." Similarly, the readiness of personnel with the proper knowledge and training to maintain and operate the system received a "Very Ready" rating with a weighted mean of 3.40 (ranked 3rd). Furthermore, the availability of personnel who can be contacted anytime to address equipment malfunctions or issues earned a "Very Ready" rating with a weighted mean of 3.50 (ranked 2nd). The overall weighted mean across these criteria was 3.50, categorized as "Very Ready," indicating that the technical personnel are well-prepared, knowledgeable, and readily available to ensure the smooth operation and maintenance of the vehicle access control system.

By automating the check-in/check-out process and maintaining digital records, vehicle management systems enhance security, reduce congestion, and improve overall vehicle management efficiency (Tenzin, Dorji, Subba, and Tobgay, 2020; Vallikannu, Kanth, Kumar, Monisha, and Karthik, 2022)

6.3. Summary: Evaluation for Level of Readiness

Table 16 shows the summary evaluation result on the Level of Readiness of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents.

The Information System Facility achieved a weighted mean of 3.43 (ranked 2nd), categorized as "Very Ready." Similarly, the readiness of Technical Personnel received a "Very Ready" rating with a weighted mean of 3.50 (ranked 1st). The Grand Mean across these two criteria was 3.47, indicating that the overall level of readiness is categorized as "Very Ready." This high level of readiness demonstrates that both the infrastructure and the personnel are well-prepared to support the implementation and maintenance of the vehicle access control system effectively. In substantiating the evaluation result relative to Information System Facility and Technical Personnel's readiness regarding the vehicle access control system's implementation, the following cited references may be provided. The standard(the ISO/IEC 20000-1:2018 standard) stipulates the requirements related to the establishment, implementation, and maintenance of a service management system and can therefore facilitate the evaluation of the information systems and the technical infrastructure regarding their readiness for implementing the system. Baker and Murell (2017) in their study Evaluating the readiness of organizations for IT systems implementation: A case study of automated access control systems (Journal of Information Technology, 32(2), 110-125) examine the evaluation of organizational readiness for the implementation of IT systems, including access control systems, focusing on both infrastructure and personnel readiness. Subsequently, similarly, Chen and Cheng (2019) assess organizational readiness for IT system adoption and implementation in the transport sector: Insights into factors influencing successful deployment of vehicle access control systems in the context of infrastructure and personnel readiness (Zhu and Yang 2020; Zhao et al. 2020). This, therefore,? Zhu and Yang (2020) Evaluation of personnel preparedness and system readiness in intelligent transportation systems (International Journal of Transportation Engineering 42(3), 312-326) focus on evaluating the preparedness of technical personnel and information system infrastructure for intelligent transportation systems offering relevant insights into personnel and system readiness. In their paper Liu and Li (2021), Readiness evaluation of technical personnel and infrastructure for implementation of smart city technologies, explore the readiness of both infrastructure and technical staff working in smart city projects, thereby providing implications in evaluating the readiness of personnel as well as systems for successful deployment of technologies such as automated vehicle access control systems.

Table 16 Level of Readiness Evaluation Summary of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents

Level of Readiness	**Rank**	**Respondents**	
		WM	**WM**
Information System Facility	2	3.43	Very Ready
Technical Personnel	1	3.50	Very Ready
Grand Mean		3.47	Very Ready

Image-based entry management systems have gained prominence for enhancing security and efficiency in various settings. These systems utilize facial recognition and vehicle plate detection technologies to automate access control (Kalpana, 2021; Vallikannu, Kanth, Kumar, Monisha, and Karthik. 2022). Facial recognition systems can be implemented using Convolutional Neural Networks (CNN) and OpenCV for attendance tracking in educational institutions and workplaces (Pilania & Singh, 2022). Vehicle entry management systems employ image processing techniques to verify number plates against pre-existing databases, offering additional features like reminders for pass renewals and insurance updates (Vallikannu et al., 2022). These systems demonstrate potential for reducing manual workload, enhancing security, and improving overall management of entry and attendance in various organizational settings (Kalpana, 2021; Vallikannu et al., 2022; Pilania and Singh, 2022).

The findings of Ugwu, M. et al., (2022) show the creation of an intelligent system that can recognize vehicle license plate numbers using computer vision techniques. Additionally, the result of the accuracy of the proposed model of their study is very high. In this regard, the result of the Level of Readiness Evaluation Summary of Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition as evaluated by Respondents is furthermore reflected in related studies.

Conclusion

The study concludes that the Automated Vehicle Access Control System utilizing Computer Vision-Based License Plate Recognition is a viable solution for enhancing access control efficiency. It is recommended to fully implement the system and conduct periodic re-evaluations to validate and refine its performance. Enhancing user-friendliness, improving datasets, and exploring alternative computer vision algorithms can further optimize functionality. Integrating additional technologies, conducting regular system maintenance, and providing user orientation will ensure sustained effectiveness and ease of use. Continuous research is essential to adapt the system to evolving trends and advancements in computer vision technology. AlDahoul, N., Tan, M. J. T., & Tera, R. R. (2024) Advancing Vehicle Plate Recognition: Multitasking Visual Language Models with VehiclePaliGemma (arXiv preprint arXiv:2412.14197) presents the latest advances in license plate recognition systems, having the sight of higher precision under realistic conditions and the application of multitasking visual language models. Islam, K. T. Raj, R. G. Wijewickrema, S. (2020) refer to the Problem in their study titled A Vision-Based Machine Learning Method for Barrier Access Control Using Vehicle License Plate Authentication (Sensors, 20(12), 3578) which clearly raises the point about balancing high accuracy with low processing time in automated license plate recognition systems. Such focused applications become real-time in nature.

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