

Preprocessing Image for License Plate Detection: A Systematic Literature Review

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Abstrak

Pertumbuhan populasi yang pesat berkontribusi pada peningkatan volume kendaraan, sehingga menciptakan tantangan besar dalam pengelolaannya. Salah satu solusi potensial adalah penerapan teknologi kecerdasan buatan berbasis deep learning untuk deteksi otomatis plat nomor kendaraan. Researcheran ini menggunakan pendekatan Systematic Literature Review (SLR) untuk mengevaluasi kinerja berbagai arsitektur deep learning dalam proses deteksi. Dari 125 artikel yang diidentifikasi, 20 artikel dipilih berdasarkan kriteria seleksi tertentu. Hasil analisis mengungkapkan bahwa teknik preprocessing, seperti HE, AHE, ECHE, CLAHE, dan ECLACHE, memiliki kontribusi signifikan dalam pengolahan dataset plat nomor kendaraan. Teknik-teknik ini mampu meningkatkan kualitas visual gambar, sehingga mendukung proses deteksi dengan tingkat akurasi lebih dari 90%. Researcheran ini juga mengidentifikasi tantangan, seperti kebutuhan komputasi yang tinggi dan pengolahan data berskala besar. Researcheran lanjutan disarankan untuk menerapkan preprocessing pada dataset standar guna mengembangkan sistem deteksi yang andal, efisien, dan berkelanjutan.

Kata kunci— Deep Learning, Deteksi Plat Nomor, Systematic Literature Review, Preprocessing

Abstract

Rapid population growth contributes to an increase in the volume of vehicles, creating major challenges in their management. One potential solution is the application of deep learning-based artificial intelligence technology for automatic detection of vehicle license plates. This research uses a Systematic Literature Review (SLR) approach to evaluate the performance of various deep learning architectures in the detection process. Out of 125 articles identified, 20 articles were selected based on specific selection criteria. The analysis revealed that preprocessing techniques, such as HE, AHE, ECHE, CLAHE, and ECLACHE, have significant contributions in the processing of vehicle license plate datasets. These techniques were able to improve the visual quality of the images, thus supporting the detection process with an accuracy rate of more than 95%. This research also identified challenges, such as high computational requirements and large-scale data processing. Further research is recommended

to apply preprocessing on standardized datasets to develop a reliable, efficient and sustainable detection system.

Keywords— *Deep Learning, License Plate Detection, Systematic Literature Review, Preprocessing*

1. INTRODUCTION

In this modern world, the population is increasing rapidly. As the population increases, so does the number of motorized vehicles. This gradual increase in the number of vehicles inevitably leads to various parking-related problems, including parking lot security. A parking area is a facility provided to assist motorists in parking or stopping their vehicles in a more organized manner. As the number of vehicles increases, a larger parking area is required. The slow process of vehicle data collection is caused by technology that still relies on manual validation of vehicle plates. In addition, limitations in the placement of parking areas are also a problem, where the limited number of parking attendants requires the use of extra energy and time to manage and check vehicles that have entered the parking area [1].

One important aspect of maintaining vehicle security in parking areas is the identification of motor vehicle license plates, where motor vehicle license plates act as a unique mark given by the police for each vehicle. Each vehicle number is unique and has a code that varies from region to region, helping in the efficient identification and management of vehicles [2]. Automatic license plate recognition involves acquiring a license plate image of the desired situation using a camera, either a still image or a photographic video is captured and further processed by a series of image processing-based recognition algorithms to achieve alpha-numeric conversion of the captured image into a text entry [3].

Over the past decade, various vehicle license plate recognition methods have been proposed for various transportation applications, one of the vehicle license plate recognition methods is OCR. Optical Character Recognition (OCR) is the electronic or mechanical conversion of typed images, handwritten or printed text into machine-encoded text, either from scanned documents, photographs of documents, photographs of scenes or from subtitled text superimposed on images [4]. While vehicle license plate recognition technology continues to evolve, challenges remain. Vehicle license plate identification problems are significantly affected by lighting and weather conditions, which have an impact on the license plate detection results of ALPR systems in outdoor environments. For example, under challenging weather conditions such as rain, fog, and snow, random patterns generated by particles can interfere with feature extraction, reducing accuracy by up to 19% compared to a model trained with an optimized dataset. In contrast, low illumination has a different effect, as variations in texture patterns generated by changes in light can be recognized by the model. Training with low-contrast images increased accuracy by 29%, indicating that low lighting has a more positive impact when included in the training dataset [5].

In order to overcome challenges such as the need for fast processing time, sensitivity to environmental conditions, and the resolution required to accurately recognize each character, the preprocessing stage is crucial in improving the success of license plate recognition [6]. Preprocessing is a series of changes made to the initial image to improve its quality and facilitate statistical analysis to make it more consistent and comparable [7]. This stage is important in image processing to prepare the data for easier processing and improve system efficiency. In addition, preprocessing includes grayscaling, binaryization, and segmentation, which aim to simplify the image so that it is lighter and easier to compare with the template image. By applying preprocessing, the image becomes better prepared for the recognition stage, improving the overall accuracy and speed of the system [8].

For example, research using the Enhanced Contrast Limited Adaptive Cumulative

Histogram Equalization (ECLACHE) image preprocessing technique to overcome all the difficulties associated with high/low illumination and twilight, hazy, and foggy conditions. This research uses a dataset of 3,000 vehicle images with 640×480 pixel resolution, with complex environmental conditions such as low/high illumination, blurring, distortion, and complex background, and various license plate sizes (25×100, 50×200, 75×300). Tests show that ECLACHE preprocessing improves the detection accuracy to 99.71%, reduces the detection error (FPR 2.24%), and speeds up the average detection time to 0.323 ms [9].

Other research applied Dark Channel Prior (DCP) preprocessing techniques for defogging, Hough Transform (HT) for skew correction, and Adaptive Histogram Equalization (AHE) and Image Edge Padding (IEP) to enhance contrast and homogenize image size. The dataset consists of 4759 text images, including 2259 original ship plate images from direct observation and 2500 blended text images from ICDAR2019, resulting in improved CRNN model text recognition accuracy of up to 92.93%, outperforming other methods such as DenseNet and PaddleOCR [10]. In addition, there are also studies that apply Gaussian filter preprocessing techniques, enhancement cumulative histogram equalization (ECHE), and contrast-limited adaptive histogram equalization (CLAHE) to improve the quality of complex vehicle license plate images [11]. The dataset consists of 2050 vehicle images, including 510 images under simple conditions and 1540 images under complex conditions such as blurring, darkness, distortion, and high/low illumination. As a result, the system achieved a detection rate of 99.62% with a false positive rate of only 1.675% and an average detection time per image of 0.2408 ms, demonstrating excellence in accuracy and time efficiency.

Research on the use of image preprocessing techniques in vehicle license plate detection often leads to different conclusions. Therefore, an in-depth study is needed to assess and determine the most effective preprocessing method in this context. This study was conducted using a systematic literature review approach to reduce potential bias from previous research. The results of this study are expected to provide more focused guidance for researchers and developers in choosing the most appropriate image preprocessing technique as needed, so as to increase the level of accuracy and efficiency in vehicle license plate detection systems.

2. METHODS

This research uses the Systematic Literature Review (SLR) method, which is a research approach that aims to collect, analyze, synthesize, and evaluate literature relevant to a particular topic. This method provides a theoretical basis for the preparation of research reports and helps prevent duplication of previous research. This process involves reading, understanding, reviewing, and critiquing literature from various sources, followed by analysis and synthesis of previous research results [12].

Building research that links it to existing knowledge is the foundation of all academic research activity, regardless of discipline. Doing so accurately should therefore be a priority for all academics. However, this task is becoming increasingly complicated. Knowledge production within the field of business research is growing rapidly, while at the same time remaining fragmented and interdisciplinary. This makes it difficult to keep up with the latest research developments and stay ahead of the curve, as well as to assess the collective evidence in a given field of research. This is why literature review as a research method is more relevant than ever [13].

This research concept was developed based on a literature review to answer two main questions: (1) How image preprocessing methods affect the accuracy of vehicle license plate detection in deep learning algorithms; (2) What image preprocessing techniques are effective in improving the performance of object detection algorithms in vehicle license plate recognition. Based on the analyzed literature, there are several image preprocessing techniques that are relevant and applicable in vehicle license plate detection.

In the initial stage of the review, about 125 articles indexed in Scopus and DOAJ were collected. These articles were obtained using keywords such as “license plate detection accuracy with image preprocessing” and “image preprocessing techniques for license plate detection.” The distribution of sources used in this study is shown in Figure 1.

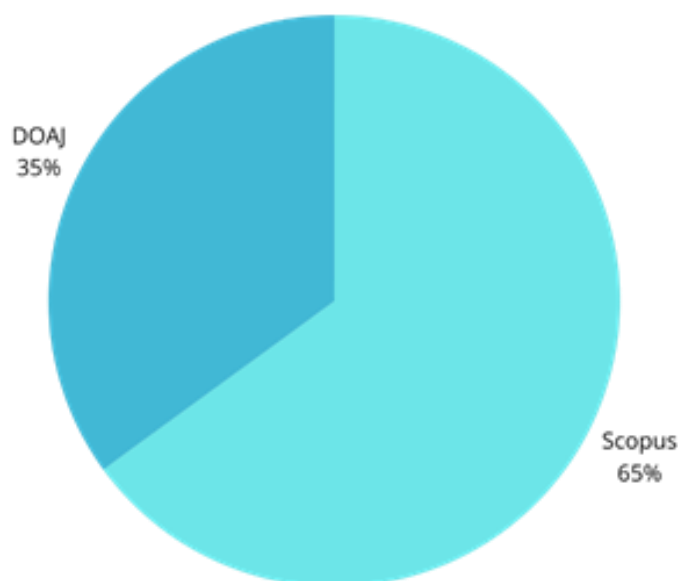


Figure 1 Article distribution

The next step was to determine the inclusion and exclusion criteria, which are presented in Table 1.

Table 1 Inclusion and Exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
Articles published on or after 2019	Articles published before 2019
Articles with journal publication type (not books or conference proceedings)	Articles with publication types other than journals (e.g., books or conference proceedings)
Articles relevant to the research topic based on title, abstract, and full-text evaluation	Articles that do not match the research objectives based on the title and abstract.
Articles available in full-text access for further evaluation	Articles that are not available in full access (cannot be downloaded or accessed)
Articles that are not duplicated between sources (Scopus and DOAJ).	Articles whose topics are outside the scope of the research field.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram in Figure 2 illustrates the steps taken in the literature selection process. The PRISMA analysis served as a guide for this SLR study. This approach uses high-quality LR guidelines due to its extensive data collection process and rigorous and detailed steps. PRISMA has the advantage of integrating specific procedures that ensure consistency, transparency and adherence to high standards in producing qualitative research reports. This method is called systematic because it follows a clear protocol and includes a variety of relevant materials that allow replication of previous research on similar topics. Researchers can utilize the PRISMA approach to access works from reputable and well-known databases, especially in the social sciences. This approach utilizes keywords to clearly define the scope and boundaries of the study, thus preventing authors from wasting time or guessing whether the essential elements of

the research are sufficiently covered. Through four stages-identification, screening, eligibility, and inclusion-PRISMA helps authors find literature that meets their research objectives [14].

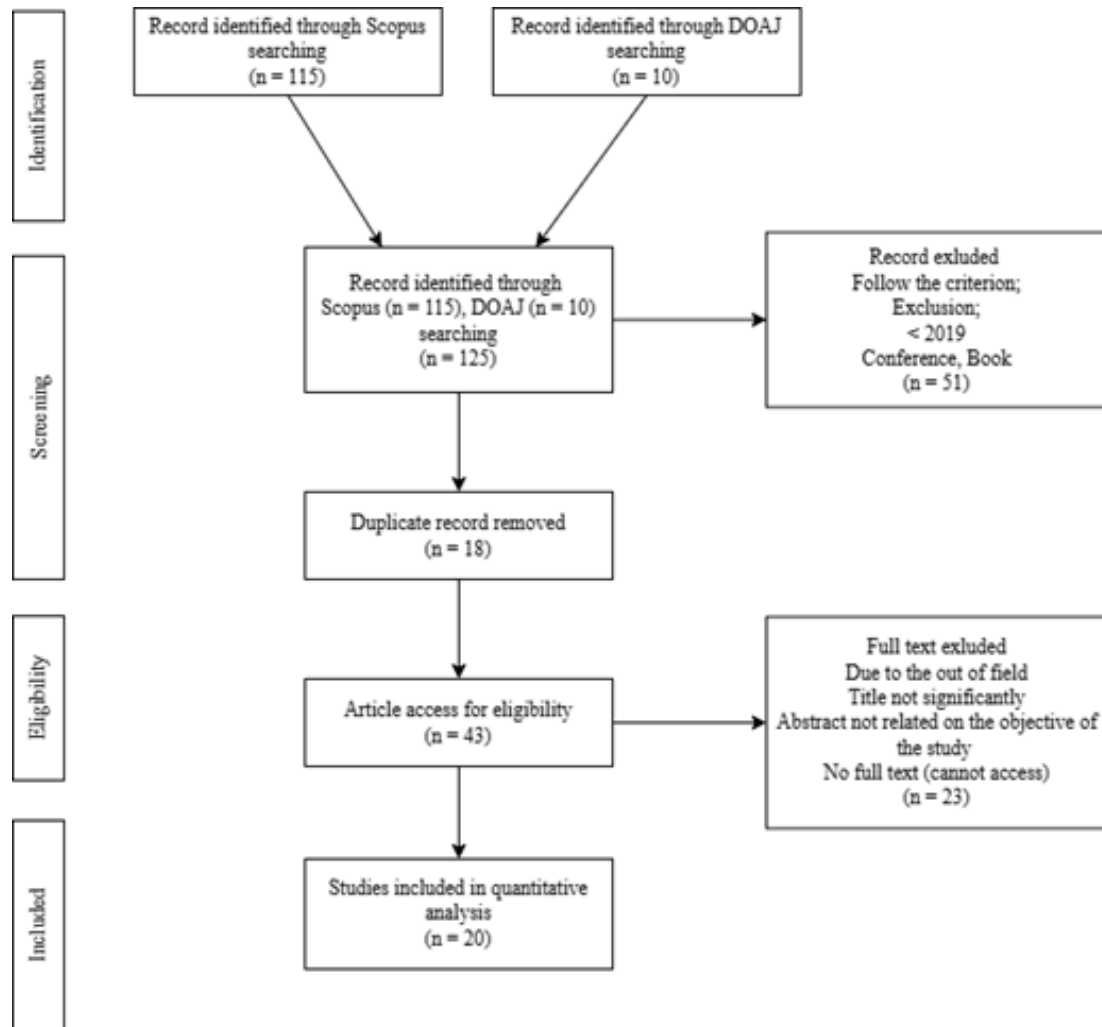


Figure 2 PRISMA Flowchart

3. RESULTS AND DISCUSSION

3.1 Result

In this literature study, data was classified based on research information, journal type, research subject, and findings obtained. The results of the literature analysis are presented in Table 2.

Table 2 Research Results of Image Preprocessing Techniques on Vehicle Number Plate Detection

Research	Journal	Subject	Research Result
Title: License Plate Recognition Using Three-Dimensional Rotated Character Recognition and Instance Segmentation	Journal of Advanced Computational Intelligence and Intelligent Informatics, 28(5), 1178-1185.	Images of vehicles with license plates from two countries, Taiwan and Japan, taken	Image preprocessing techniques play an important role in improving the accuracy of vehicle license plate detection in deep learning algorithms by preparing

Research	Journal	Subject	Research Result
by Deep Learning Researcher: Sasaki, T., Morita, K., & Wakabayashi, T. [15]		from different angles.	the image for easy recognition. This process includes license plate area detection using YOLOv5, trapezoidal correction to flatten the image, and the use of filters such as DoG and MSER segmentation techniques to improve character identification accuracy. This approach reduces noise, improves character recognition, and overall improves detection accuracy.
Title: A Bio-Inspired Retinal Model as a Prefiltering Step Applied to Letter and Number Recognition on Chilean Vehicle License Plates Researcher: Kern, J., Urrea, C., Cubillos, F., & Navarrete, R. [6]	Applied Sciences, 14(12), 5011.	An image of a real vehicle license plate from Chile, which includes alphanumeric characters that comply with the country's license plate regulations.	The application of retinal models as an image preprocessing method serves to improve the accuracy of vehicle license plate detection by enhancing contrast and accentuating object contours, which can reduce character recognition errors. Although effective, this model may worsen detection in low-quality images, such as those that are heavily dirty or obscured by shadows.
Title: An efficient automated vehicle license plate recognition system under image processing Researcher: Islam, D., Mahmud, T., & Chowdhury, T. [16]	Indonesian Journal of Electrical Engineering and Computer Science, 29(2), 1055-1062.	Images of vehicle license plates taken under various lighting conditions and image quality, including alphanumeric characters that comply with license plate regulations.	Image preprocessing steps can improve the accuracy of vehicle license plate detection by improving image quality through conversion to grayscale, noise reduction with bilateral filtering, and morphological operations. These techniques highlight important features, facilitate character extraction, and increase recognition accuracy to 94.17%.
Title: Automatic number plate	Engineering, Technology &	An image of a vehicle license	Image preprocessing affects the improvement

Research	Journal	Subject	Research Result
<p>recognition of Saudi license car plates</p> <p>Researcher: Antar, R., Alghamdi, S., Alotaibi, J., & Alghamdi, M. [17]</p>	<p>Applied Science Research, 12(2), 8266-8272.</p>	<p>plate that includes characters in Arabic and English, with two different plate sizes (30cm x 16cm and 53cm x 14cm).</p>	<p>of license plate detection accuracy with steps such as conversion to grayscale, noise removal using bilateral filters, and Canny edge detection. These techniques reduce visual distractions, highlight important features, and increase the effectiveness of deep learning models in recognizing characters. Accuracy reached 92.4% for Arabic text and 96% for English text, emphasizing the importance of image quality.</p>
<p>Title: Edge-AI-based real-time automated license plate recognition system</p> <p>Researcher: Lin, C. J., Chuang, C. C., & Lin, H. Y. [18]</p>	<p>Applied Sciences, 12(3), 1445.</p>	<p>An image of a vehicle license plate that includes various styles and characters, including Latin characters and numbers, that complies with license plate regulations in Taiwan.</p>	<p>Through image preprocessing techniques, the accuracy of vehicle license plate detection can be improved by optimizing image quality through RGB to grayscale conversion, which separates characters from the background, reduces complexity, and increases contrast. This technique enables character recognition of up to 97% during the day and 95% at night, demonstrating its significant impact.</p>
<p>Title: Metode Otsu dan Mathematical Morphology Dalam Segmentasi Region Karakter Plat Nomor Kendaraan</p> <p>Researcher: Apridiansyah, Y., Toyib, R., & Wijaya, A. [19]</p>	<p>Journal of Applied Computer Science and Technology, 3(1), 134-143.</p>	<p>Indonesian standard motor vehicle license plates taken from indoor and outdoor parking lots.</p>	<p>With image preprocessing steps, the accuracy of vehicle license plate detection can be improved through conversion to grayscale, noise removal, and morphological techniques. These processes bring out the characters, facilitate recognition, and improve model accuracy, making</p>

Research	Journal	Subject	Research Result
			them a crucial step in an automatic license plate recognition system.
Title: Iraqi license plate recognition based on machine learning. Researcher: Abd Alhamza, D. A., & Alaythawy, A. D. [20]	Iraqi Journal of Information and Communication Technology, 3(4), 1-10.	Different vehicle license plates in Iraq, including different types and sizes of license plates that have characters in Arabic and English.	Image preprocessing to improve the accuracy of vehicle license plate detection involves conversion to grayscale, noise reduction with a Gaussian filter, and morphological transformation. These techniques accentuate characters, reduce noise, and improve model effectiveness, making them an important step in an automated license plate recognition system.
Title: Deep homography for license plate detection Researcher: Yoo, H., & Jun, K. [21]	Information, 11(4), 221.	An image of a vehicle license plate taken under various lighting conditions, with an image size of 416×416 pixels.	Image rectification, such as using angle prediction and homography, helps improve license plate detection accuracy in ALPR. This technique turns a skewed image into a regular one, easing character recognition and improving accuracy by up to 3.1% over previous warping methods.
Title: Automatic Number Plate Detection Using Optimal Black Window Evolutionary Transfer Moth Fly with Alex Net Classification Approach Researcher: Shelkikar, R. P., & Jagade, S. M. [22]	Wireless Personal Communications, 133(3), 1619-1642.	Images of vehicle license plates that include variations in design and character, including license plates from India that have different formats and characteristics.	With image preprocessing techniques, such as conversion to grayscale and binarization, contrast can be improved and noise reduced, which helps deep learning models focus on relevant features. These techniques increase license plate detection accuracy to 98.54%, demonstrating the importance of this step in image processing.
Title: MRIM: Lightweight	Pervasive and Mobile	Images taken from the	Through saliency estimation and non-

Research	Journal	Subject	Research Result
<p>saliency-based mixed-resolution imaging for low-power pervasive vision.</p> <p>Researcher: Wu, J. Y., Subasharan, V., Tran, T., Gamlath, K., & Misra, A. [23]</p>	<p>Computing, 96, 101858.</p>	<p>WildTrack and CityScapes datasets, which include various objects such as people and vehicles.</p>	<p>uniform downscaling, image preprocessing can improve license plate detection accuracy by highlighting important areas, reducing noise, and maintaining resolution in relevant sub-regions. This technique supports environmental adaptability and efficiency, maintaining high accuracy despite data reduction.</p>
<p>Title: Identifying License Plates in Distorted Vehicle Images: Detecting Distorted Vehicle Licence Plates Using a Novel Preprocessing Methods With Hybrid Feature Descriptors</p> <p>Researcher: Al-Shemarry, M. S., Li, Y., & Abdulla, S. [9]</p>	<p>IEEE Intelligent Transportation Systems Magazine, 15(2), 6-25.</p>	<p>The images used in this Researcheran include a variety of difficult environmental conditions, such as low/high lighting, fog, and distortion, as well as complex backgrounds.</p>	<p>The use of the ECLACHE (Enhanced, Contrast-Limited Adaptive Cumulative Histogram Equalization) method improves image quality by filtering out noise, enhancing contrast, and reducing unwanted LP features under complex lighting conditions, achieving a detection rate (DR) of 99.71%, an accuracy rate (AR) of 97.92%, and a false positive rate (FPR) of 2.24%</p>
<p>Title: License plate number detection and recognition using simplified linear-model.</p> <p>Researcher: Choong, Y. J., Keong, L. K., & Cheah, T. C. [24]</p>	<p>Journal of critical reviews, 7(3), 55-60.</p>	<p>Images of vehicle license plates taken in an indoor parking environment that includes various lighting conditions and license plate positions.</p>	<p>The preprocessing stages include grayscale conversion, binarization, contrast enhancement, noise filtering, and optional histogram equalization (HE), which improves the image quality. The success rates at each stage are: Grayscale 100%, Binarization 100%, License Plate Detection 89%, Character Segmentation 97%, Character Recognition 98%, with detection success affected by the size and location of the</p>

Research	Journal	Subject	Research Result
<p>Title: Real-time computer vision-based bangla vehicle license plate recognition using contour analysis and prediction algorithm Researcher: Pervej, M., Das, S., Hossain, M. P., Atikuzzaman, M., Mahin, M., & Rahaman, M. A. [25]</p>	<p>International Journal of Image and Graphics, 21(04), 2150042..</p>	<p>Bangla vehicle license plates that have characters and numbers in Bangla with different conditions, including dirty, opaque, and partially covered plates.</p>	<p>characters on the license plate.</p> <p>The preprocessing process includes conversion to grayscale, contrast enhancement with histogram equalization, edge detection using Sobel, noise removal through morphology and Gaussian filtering, binaryization with adaptive thresholding, and contour analysis to localize the license plate, resulting in an individual class recognition accuracy of 96.62% at a computational cost of 8.363 ms/f, and a license plate recognition accuracy of 95.41% at a cost of 35.803 ms/f, and better performance than other systems.</p>
<p>Title: A CRNN-based method for Chinese ship license plate recognition Researcher: Xu, F., Chen, C., Shang, Z., Peng, Y., & Li, X. [10]</p>	<p>IET Image Processing, 18(2), 298-311.</p>	<p>Images of ship license plates taken under diverse maritime environmental conditions, including fog conditions and abnormal viewing angles.</p>	<p>Preprocessing methods such as DCP, Hough Transform, AHE, IEP, and data augmentation increase the accuracy of ship license plate (SLP) recognition to 93%, with significant improvements thanks to DCP, HT, and edit-distance algorithms for result correction.</p>
<p>Title: Developing learning-based preprocessing methods for detecting complicated vehicle licence plates Researcher: Al-Shemarry, M. S., & Li, Y. [11]</p>	<p>IEEE Access, 8, 170951-170966.</p>	<p>License plate images in multiple languages, including English, Chinese, and Arabic taken under various conditions, including low/high</p>	<p>The preprocessing approaches used, namely a combination of Gaussian filter, Enhancement Cumulative Histogram Equalization (ECHE), and Contrast-Limited Adaptive Histogram Equalization (CLAHE), successfully improved the accuracy of vehicle license plate</p>

Research	Journal	Subject	Research Result
		lighting, fog, dirt, and distorted images.	detection with a detection rate of 99.62%, false positive rate of 1.675%, and average detection time of 0.2408 ms, outperforming current approaches in terms of detection and processing time.
Title: Deep learning adversarial attacks and defenses on license plate recognition system Researcher: Vizcarra, C., Alhamed, S., Algosaibi, A., Alnaeem, M., Aldalbahi, A., Aljaafari, N., ... & Anan, M. [26]	Cluster Computing, 1-18.	An image of a license plate that includes the various characters and positions of the numbers on the license plate.	The application of image denoising and inpainting techniques were applied to reduce noise and repair the part of the image affected by the adversarial attack, which previously reduced the license plate recognition accuracy to 46% (watermarking), 72% (FGSM), and 78% (C&W), but after the defense was applied, the accuracy significantly improved to 97.8%, 98%, and 99.3% respectively.
Title: Smart Insights on the Move Deep Convolution Neural Network and Segmentation for License Plate Recognition Researcher: Shajan Jacob, M.K Jeyakumar [27]	SSRG International Journal of Electronics and Communication Engineering, vol. 11, no. 8, pp. 172-184, 2024.	License plate images of various vehicles taken under various conditions, including multi-font and multi-line.	The preprocessing process, which includes grayscale conversion, Otsu thresholding, morphological operations, and alphanumeric character segmentation, achieved a license plate recognition accuracy of 99.54%, demonstrating the effectiveness of this approach in detecting and recognizing license plate numbers.
Title: A comprehensive review on helmet detection and number plate recognition approaches Researcher: Reddy, G. V., Gandla, A., Veldurthi, J., Dugyala, R.,	In E3S Web of Conferences (Vol. 507, p. 01075).	Motorcyclists wearing or not wearing helmets, as well as vehicles involved in traffic violations.	The use of preprocessing techniques with Canny Edge Detection to enhance object edges, while the proposed system with YOLOv8 and EasyOCR shows high accuracy in detecting helmet use violations and

Research	Journal	Subject	Research Result
Mohammed, K. A., Swathi, B., ... & Kumar, A. [28]			recognizing vehicle license plate numbers, potentially improving safety policies and traffic regulation enforcement..
Title: Key technologies of intelligent transportation based on image recognition. Researcher: Chen, Z., Su, Y., Liu, Y., Huang, J., & Cao, W. [29]	International Journal of Advanced Robotic Systems, 17(3), 1729881420917277.	Images of vehicles taken with a digital camera, which include different types of license plates (blue, yellow, white, and black).	With pre-processing techniques that include grayscale image processing, deviation correction, and weighted median filtering, it yields a license plate recognition accuracy of 88%, higher than other methods, with effective vertical projection-based license plate location and character segmentation algorithms.
Title: Development of ANPR framework for Pakistani vehicle number plates using object detection and OCR. Researcher: Salma, Saeed, M., ur Rahim, R., Gufran Khan, M., Zulfiqar, A., & Bhatti, M. T. [30]	Complexity, 2021(1), 5597337.	Images of vehicle license plates taken from different angles and environmental conditions in Pakistan, including variations in lighting and orientation.	Through preprocessing techniques, which include grayscale, binarization, thresholding, histogram equalization, noise removal, and morphological operations, it supports the YOLOv3 model with a mAP score of 94.3% and YOLOv4 99.5% for license plate detection, with an OCR Tesseract character recognition accuracy of 73%, as well as good performance under varying lighting conditions and plate styles.

Table 2 provides an overview of various image preprocessing techniques applied in vehicle license plate number recognition (ANPR) systems. Techniques such as conversion to grayscale, binarization, thresholding, noise removal, and morphological operations play an important role in improving image quality. In addition, contrast enhancement techniques such as ECLACHE, HE, AHE, CLAHE, and ECHE are also mentioned as key factors in this process. These techniques help to improve image quality under various lighting conditions, diverse license plate designs, and varying image quality, thus supporting the overall performance of the ANPR system.

3.2 Discussion

This systematic literature review aims to identify the optimal deep learning architecture and assess its performance in license plate detection. Through the analysis of 20 relevant articles, two main themes were found, namely the effect of image preprocessing on vehicle license plate detection accuracy and effective image preprocessing techniques for vehicle license plate detection.

Based on the data in Table 2, image preprocessing techniques have been used to detect vehicle license plates, showing the effect of image preprocessing on vehicle license plate detection accuracy:

1. High Detection Accuracy

License plate detection utilizing YOLOv5 and trapezoidal correction achieves notable accuracy by reducing noise and improving character recognition, especially for multi-angle images from Japan and Taiwan [15]. In addition, other research shows that preprocessing with grayscale conversion and background separation increases the recognition rate to 97% during the day and 95% at night for Taiwanese plates [18]. Furthermore, the binaryzation and greyscale conversion approach was also shown to improve accuracy to 98.54% on Indian plates, confirming the importance of preprocessing techniques in noise reduction and feature enhancement for various datasets [22].

2. Adaptation to Multiple Formats and Languages

Saudi license plates with Arabic and English characters achieved an accuracy of 92.4% for Arabic text and 96% for English text, highlighting the model's efficiency in handling multiple language variations [17]. Similarly, another study showed that a customized model of Arabic and English characters on Iraqi plates, through Gaussian filtering and morphological transformation, ensured consistent detection across different plate designs [20].

3. Image Quality Improvement

Biology-inspired retinal model effectively enhances contrast and contour visibility on Chilean plates, improving recognition accuracy for standard alphanumeric formats [6]. Meanwhile, other approaches have shown that techniques such as bilateral filtering and morphological operations are able to improve recognition accuracy up to 94.17%, even under varying lighting conditions [16].

4. Advanced Image Improvement for Better Recognition

Improvements using depth homography transformed the skewed license plate image into a regular format, improving detection accuracy by up to 3.1% compared to traditional bending techniques [21].

5. Special Techniques for Complex Scenarios

Saliency-based mixed-resolution imaging emphasizes critical regions while maintaining high accuracy on challenging datasets such as WildTrack and CityScapes, optimizing efficiency and adaptability [23].

6. Evaluation of Character Segmentation with Mathematical Morphology

The Otsu method initially failed to distinguish the three character regions, but with Mathematical Morphology, segmentation improved to 96%. Evaluation using Mean Square Error (MSE) showed 96% accuracy, confirming the importance of preprocessing, such as grayscale, noise removal, and morphology, in improving image quality and deep learning model accuracy [19].

The synthesis results show that most of the applied image preprocessing techniques are effective in detecting vehicle license plates, with superior results on various evaluation metrics.

A summary of image preprocessing techniques for vehicle license plate detection is presented in Table 3.

Table 3 Effective Image Preprocessing Techniques for Vehicle License Plate Detection

Reference	Datasets	Methods	Evaluation
[9]	3,000 vehicle images, divided into two sets: 2,000 images for training and 1,000 images for testing.	ECLACHE (Enhanced CLAHE)	DR: 99.71%, AR: 97.92%, FPR: 2.24%
[24]	30 images are used to test the performance of the system from the beginning to the end of the character recognition process.	Grayscale, binarization, contrast enhancement, noise filtering, optional HE	Grayscale: 100%, Binarization: 100%, Plate Detection: 89%, Character Segmentation: 97%, OCR: 98%
[25]	6800 different images from the training data, and another set of 500 images of vehicle license plates in various conditions.	Grayscale, histogram equalization, Sobel edge detection, morphology, Gaussian filtering, adaptive thresholding, contour analysis	Class accuracy: 96.62% (8,363 ms/f), Plate accuracy: 95.41% (35,803 ms/f)
[10]	4759 text images, which include 2000 real SLP images obtained from Researcheran equipment and more than 4000 characters.	DCP, Hough Transform, AHE, IEP, data augmentation	Ship license plate (SLP) recognition accuracy: 93%
[11]	This research utilized four databases consisting of a total of 2050 vehicle images. Out of these, 1520 images were used for training and 530	Gaussian filter, ECHE, CLAHE	DR: 99.62%, FPR: 1.675%, Time: 0.2408 ms
[26]	1000 license plate images taken from Saudi Arabia license plate templates.	Image denoising, inpainting	Accuracy: 97.8% (watermarking), 98% (FGSM), 99.3% (C&W)
[27]	License plate images with different types of vehicles, multi-line and multi-font license plates, and different lighting conditions. The training image is 28x28 pixels in size and includes 36 character classes (A-Z, 0-9).	Grayscale conversion, Otsu thresholding, morphological operations, alphanumeric character segmentation	License plate recognition accuracy: 99.54%
[28]	Images of motorcycles and riders in various conditions, as well as variations in vehicle license plate numbers from surveillance videos and real situations to improve the accuracy of the helmet and license plate detection model.	Canny Edge Detection, YOLOv8, EasyOCR	High accuracy in helmet and license plate violation detection

Reference	Datasets	Methods	Evaluation
[29]	100 images of vehicle license plate numbers for simulation experiments.	Grayscale processing, deviation correction, weighted median filtering, vertical projection-based plate location, and character segmentation	License plate number recognition accuracy: 88%
[30]	1000 vehicle images with various license plate formats.	Grayscale, binarization, thresholding, histogram equalization, noise removal, morphological operations	YOLOv3 mAP: 94.3%, YOLOv4 mAP: 99.5%, OCR Tesseract: 73%

Table 3 shows the results of researches that implement image preprocessing techniques for vehicle license plate detection. The main focus of these techniques is image quality improvement, with approaches such as edge detection, noise reduction, character segmentation, and the use of advanced algorithms such as YOLOv8 and EasyOCR. These approaches aim to improve the accuracy of license plate and helmet violation recognition. Contrast enhancement techniques such as HE, AHE, CLAHE, and ECLACHE contribute significantly to improving image quality and detection accuracy. For example, ECLACHE recorded a detection rate of 99.71% with a false positive rate (FPR) of 2.24%, while HE showed inferior results with a detection rate of about 89% and a higher FPR, indicating that although HE is effective in some conditions, it is not efficient in dealing with distorted images or in difficult lighting conditions.

ECLACHE has high accuracy in vehicle license plate detection due to its ability to improve image quality by overcoming problems of poor lighting, fog, and distortion. This method uses an adaptive histogram equalization technique to clarify important features on the license plate. The combination of ECLACHE with robust feature descriptors such as MRELBP and SURF enables more effective feature extraction, as well as reducing the dimensionality of irrelevant features. Experimental results show that the detection system using ECLACHE achieves an accuracy of 99.95% and a positive detection rate (TPR) of 99.71% with a low false positive rate (FPR), making it highly reliable in various difficult environmental conditions.

Detection results using Histogram Equalization (HE) that only reach 89% are caused by several factors. Sub-optimal image quality, such as poor lighting, fog, or distortion, can reduce the effectiveness of HE in improving the contrast and visibility of license plates. In addition, HE is not always effective in overcoming noise, which can interfere with the detection process. Variations in the size and position of license plates, as well as adjacent characters, can also make it difficult for the system to detect accurately. Compared to other methods such as ECLACHE, which is designed to overcome challenges in image processing, HE shows inferior results. Therefore, the selection of a more effective contrast enhancement method is essential to achieve higher detection accuracy in vehicle license plate recognition systems.

4. CONCLUSIONS

Based on the literature review, image preprocessing techniques such as HE, AHE, CLAHE, ECHE, and ECLACHE have great potential in improving the performance of ANPR systems. These techniques can improve image quality by enhancing contrast, reducing noise, and highlighting important features, which significantly supports detection accuracy of over 99%. ECLACHE, for example, records a detection rate of 99.71% with a false positive of only 2.24%, while CLAHE and ECHE are effective for handling multilingual and multi-line license plates. Therefore, this contrast enhancement technique is a crucial element in ANPR system preprocessing.

Further research is recommended to integrate these techniques with algorithms such as YOLO to create more adaptive and precise ANPR systems. The combination of contrast enhancement-based preprocessing with detection using YOLO has the potential to improve the accuracy, efficiency and scalability of the system, and opens up opportunities for further development, including object recognition in dynamic environments and large-scale traffic monitoring.

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