

Enhancing Vehicle License Plate Image Quality Using Median Filtering: Implications for ANPR Performance

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Abstract: Automatic vehicle license plate detection is a crucial component in traffic monitoring and law enforcement. One of the primary challenges in Automatic Number Plate Recognition (ANPR) systems is the presence of impulsive noise, such as salt-and-pepper noise, which can disrupt the accuracy of character detection. This study serves as a baseline for ANPR research. The objective of this study is to optimize license plate detection by applying the Median Filtering method, while simultaneously comparing its performance on white and black license plates. Evaluation was conducted using 100 samples of Indonesian vehicle license plates, consisting of 50 white plates and 50 black plates, under consistent lighting conditions and angles. The testing results indicate that for white plates, the Mean Squared Error (MSE) ranged from 0.000018 to 0.000564, with an average Peak Signal-to-Noise Ratio (PSNR) of 38.38 dB and an average processing time of 1.105 seconds. For black plates, the MSE ranged from 0.000028 to 0.000592, with an average PSNR of 37.82 dB and an average processing time of 1.150 seconds. Comparative analysis shows that white plates produced slightly higher image quality than black plates, although both types of plates were processed efficiently. Overall, the Median Filtering method proved effective in reducing impulsive noise, preserving the sharpness of license plate characters, and maintaining processing speed. These findings demonstrate that Median Filtering is a reliable method for enhancing the accuracy and efficiency of ANPR systems under various license plate colors and lighting conditions.

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INTRODUCTION

Automatic detection is essential to many object identification systems in the age of contemporary technology. The process of identifying or recognizing the existence of anything based on indicators or data is known as detection, and it may be carried out manually or automatically utilizing computer systems (Sunardi, Yudhana, & Wijaya, 2022). The automobile license plate recognition system is one significant use of automated detection technology (Alvarino et al., 2026; Nardes et al., 2026; Pham et al., 2026).

An official identification provided by the government to lawfully identify a vehicle is a motor vehicle license plate (Masril et al., 2024; Srikanth & Kumar, 2022; Sugiyono et al., 2023). Indonesian license plates have distinctive features that differ depending on the area, kind of vehicle, and ownership company. Jakarta license plates, for example, start with the letter "B," whereas government cars have red plates with white writing (Damayanti et al., 2019; Meirza & Puteri, 2024). These variants include changes in shape, registration format, and color (yellow for public, black and white for private) (Sholehurrohman et al., 2025). Recent developments show innovations such as yellow plates for online transportation (2023) and plans for green plates for electric vehicles, further enriching the diversity of license plates in Indonesia.

Automatic Number Plate Recognition (ANPR) systems play a crucial role in law enforcement and traffic monitoring. The initial step before recognizing an object is to detect its precise location. However, in practice, the detection process faces various technical challenges. Character recognition methods are frequently hampered by noise like Gaussian and salt-and-pepper (Srikanth & Kumar, 2022; Sunardi et al., 2023; Sunardi, Yudhana, & Ardi, 2022). The use of improper preprocessing techniques, such as the mean filter, can blur important character edges (Sunardi et al., 2023). Suboptimal processing settings and fluctuating ambient circumstances (shadows, reflections) are additional difficulties (Ma et al., 2023; Sunardi et al., 2023; Sunardi, Yudhana, & Ardi, 2022).

This study serves as a baseline for ANPR research. It aims to apply the median filtering method for vehicle license plate detection and, additionally, to compare the processing speed between white and black license plates. Due to its shown benefits in current scientific literature, the median filtering strategy was selected. First, by substituting each noise-contaminated pixel with the median value of its surrounding pixels, the median filter effectively reduces impulsive noise, particularly salt-and-pepper noise. This eliminates severe disruptions without ruining the general structure of the image. In contrast to linear filters like Gaussian filters in the event of impulsive noise, experimental investigations demonstrate that the median filter maintains picture detail better while producing cleaner images and improving quality metrics like PSNR and MSE (Alamsyah et al., 2025). Using adaptive median filtering with dynamic kernels (3×3 to 5×5), this study offers a complete solution. This technique was chosen because of its exceptional capacity to maintain edge sharpness while lowering noise. 100 Indonesian license plate samples 50 blacks and 50 whites will be evaluated using MSE and PSNR measures (Nalawade & Dua, 2025; Sahu & Sahu, 2026), where ideal outcomes are indicated by MSE values around zero and good PSNR.

Varma (2020) demonstrated CNN's efficacy for license plate detection based on earlier studies, however it required a lot of data and lacked preprocessing optimization [15]. However, Sunardi (2023) showed that median filtering is better for face detection than mean filtering (Sunardi et al., 2023), however it hasn't been used for detecting license plates. This work is based on this research gap.

The Automatic Number Plate Recognition (ANPR) system's difficulties overcoming noise disturbances and changing ambient circumstances are discussed in this paper. It is envisaged that by using the median filtering approach, an efficient way to increase the accuracy of vehicle license plate identification would be found, especially in terms of lessening the influence of impulsive noise and maintaining character edge sharpness. This study attempts to compare the processing rates of white and black license plates and greatly improve the ANPR system's accuracy and efficiency using an adaptive method with dynamic kernels. It is anticipated that this study would close the gaps in the current literature and boost the use of automatic detection technologies in Indonesia, thereby improving the nation's law enforcement and traffic surveillance systems.

METHOD

Research Object

The object used in this research is the motor vehicle license plate in digital photos. The photos used in this research are in landscape format, consisting of 50 photos of black license plates and 50 photos of white license plates. A sample of the photos used is presented in Table 1.

Table 1. Sample Photos Used in Research

No	Sample	Description
1		Date: 28 August 2025, 09:47 AM File type: JPG 3,09 MB Size: 5712x4284 px
2		Date: 28 August 2025, 09:47 AM File type: JPG 3,09 MB Size: 5712x4284 px

In Table 1, there are sample images with two criteria as previously explained. A total of 100 motor vehicle license plate photos were used in this research.

Research Tools

The hardware tools used in this research are shown in Table 2.

Table 2. Research Tools

Tools	Operation System	Specifications
Realme 3	Android 9.0 (Pie)	16 MP, f/1.7, 1/2.6", 1.22µm, dual pixel PDAF Auxiliary lens
Laptop Axio Pongo 725	Windows 11 Pro 64-bit operating system, x64-based processor	12th Gen Intel(R) Core(TM) i7-12650H (2.30 GHz) 24,0 GB RAM 500 GB SSD

As shown in Table 2, there are two main devices used for processing: the first is the Realme 3 smartphone, which is used to capture photos of the vehicle license plates, and the second is the Axio Pongo 725 laptop, which is used for processing, analyzing, and testing the images.

Median Filtering

In mathematics, the median is the middle value after the data has been sorted. The method works by sorting the pixel values from smallest to largest based on the eight neighboring pixels, and then the middle value is taken (Hou et al., 2021; Kiggins & Edu, 2026; Sunardi et al., 2023) as shown in Table 3.

Table 3. Example of eight neighboring pixels

P1	P2	P3
P8	F(y,x)	P4
P7	P6	P5

Mathematically, the filter can be formulated as follows:

$$\text{Median}(x, y) = P1, P2, P3, P4, P5, P6, P7, P8, F(y,x) \quad (1)$$

After sorting as shown in equation (1), the middle value is taken, and the value at (x, y) is replaced with this value.

Mean Square Error (MSE)

Mean Square Error (MSE) is one of the commonly used evaluation metrics in image processing and statistical analysis to measure the level of error or difference between predicted values and actual values. A high degree of accuracy is indicated by an MSE value that is close to zero. Mathematically, MSE is computed by averaging the squared discrepancies between the anticipated and actual values. By comparing the original and treated images, MSE is frequently employed in image processing to assess the quality of reconstruction or denoising outcomes. MSE is frequently used in conjunction with other measures, such as Peak Signal-to-Noise Ratio (PSNR), despite its simplicity and ease of implementation. This is because MSE does not necessarily correlate with human visual perception (Chachlakis et al., 2021; Sunardi, Yudhana, & Ardi, 2022).

$$MSE = \frac{\sum_{a=0}^{x-1} \sum_{b=0}^{y-1} (M(a,b) - N(a,b))^2}{x \cdot y} \quad (2)$$

Because it shows a lower discrepancy between the expected and actual numbers, the model or approach utilized is more accurate if the MSE value is smaller (closer to 0). By comparing the original picture (YY) with the treated image (Y^Y^), MSE is frequently used in image processing to assess the quality of image restoration or compression outcomes. However, MSE is frequently combined with measurements like PSNR because of its limitations, as it solely analyzes pixel-by-pixel mistakes without taking into account human visual perception. Examples of its use include assessing the effectiveness of super-resolution, object recognition in photos, and denoising methods.

Peak Signal-to-Noise Ratio (PSNR)

Peak Signal-to-Noise Ratio (PSNR) is a commonly used quantitative metric to measure the quality of image or video reconstruction by comparing the original image (ground truth) and the processed image. PSNR is calculated in decibels (dB) using the following formula:

$$PSNR = 10 \log_{10} \frac{Max_i^2}{MSE} \quad (3)$$

The higher the PSNR value (in dB), the smaller the difference between the original image and the processed image, indicating better reconstruction quality. PSNR is often used together with MSE to evaluate compression, denoising, or super-resolution algorithms, although it has limitations because it does not fully reflect human visual quality perception (Fute et al., 2023; Li et al., 2024; Sunardi, Yudhana, & Ardi, 2022; Yan et al., 2026; Yugander et al., 2020).

Proposed Method

Overall, the vehicle license plate detection process consists of nine stages, namely image input, resizing, grayscaling, filtering, Haar features, integral image, boosting algorithm, cascaded classifier, and labeling. The flowchart for this research can be seen in Figure 1.

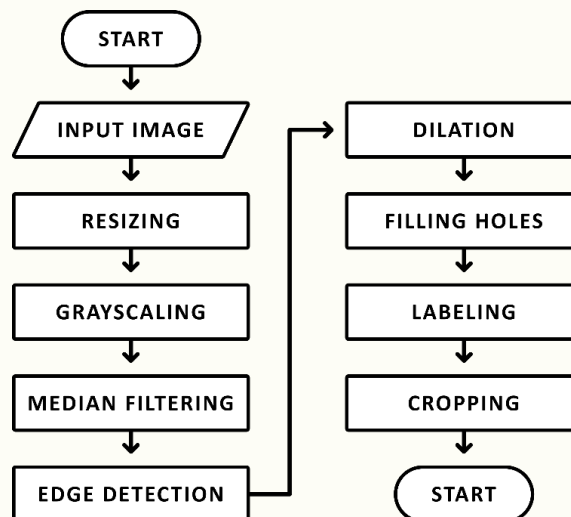


Figure 1. Research Flow

The steps used in this research method:

1. Input image into the MATLAB application. The input image is in .JPEG format and RGB mode with a size of 3264x1836 px.
2. Resizing: The purpose is to reduce the sample size and make the process faster and lighter. This is done by multiplying the dimensions by a scale of 0-1. In this study, a scale of 0.5 is used, so both horizontal and vertical pixel counts are multiplied by 0.5.
3. Convert RGB image to grayscale using the grayscaling process. The RGB image is converted to grayscale using the following equation (4):

$$I_y = (FR + FG + FB) / 3 \quad (4)$$

Where FR is the intensity for Red, FG is the intensity for Green, FB is the intensity for Blue, and I_y is the corresponding grayscale intensity.

4. Median Filtering: The image enhancement process is done to reduce the noise in the image. To find the median, the pixel values are sorted from smallest to largest based on eight neighboring pixels, and the middle value is taken.
5. Edge Detection: This process is used to extract edge lines from the grayscale image. The edge detection method used in this study is the Prewitt method.
6. Dilation: In this process, a disk-shaped structuring element (strel) is used. Disk-shaped strel is commonly used in detection applications and is the most used shape in morphological processes. The effect produced is uniform in all directions, making it easier to perform the next steps.
7. Filling Holes: This process fills the holes in the image that appear due to differences in pixel values.
8. Labeling: In this stage, labeling is applied. The image, which has been converted into a matrix of values, will go through a process to determine the area location. If a region with the most frequent value of 1 (or the area with the largest or most dominant white pixels) is found, it is marked using the regional descriptor bounding box and area in the regionprops function. The bounding box is used to mark the area with the largest number of white pixels. The area is used to describe the number of pixels marked by the bounding box, which will give the final image with the location of the vehicle's license plate.
9. Cropping: The image that has passed through the labeling process is cropped, so the cropped image corresponds to the area identified by the labeling process.

RESULTS AND DISCUSSIONS

The findings and analysis pertaining to the use of the median filtering technique in car license plate detecting systems will be provided in this chapter. This study aims to evaluate how well median filtering reduces impulsive noise, including salt-and-pepper noise, which frequently interferes with license plate character identification. The comparison of detection processing times between white and black car license plates is also included in this study. The findings, which are based on the analysis of fifty Indonesian license plate samples, should give a better understanding of how the median filtering technique enhances the precision and effectiveness of the Automatic Number Plate Recognition (ANPR) system. The impact of kernel size on detection performance will be discussed, along with a comparison of picture quality measures like PSNR and MSE.

Result of the Median Filtering Method

In this investigation, the median filtering technique was effectively used. MSE, PSNR, processing speed, and identified license plates are among the outcomes. Table 4 displays the outcomes of the Median Filtering Method test on White License Plates.

Table 4. Results of the Median Filtering Method Test on White License Plates

Dataset	Median Filtering			Dataset	Median Filtering		
	MSE	PNSR	Speed (s)		MSE	PNSR	Speed (s)
1	0.000111	39.543	1.211	26	0.000267	35.727	1.055
2	0.000110	39.588	1.364	27	0.000231	36.365	1.509
3	0.000092	40.370	1.125	28	0.000276	35.590	1.093
4	0.000062	42.058	1.187	29	0.000257	35.894	1.011
5	0.000059	42.256	1.019	30	0.000416	33.811	1.271
6	0.000060	42.203	1.052	31	0.000222	36.539	0.994
7	0.000067	41.708	1.021	32	0.000308	35.120	1.019
8	0.000065	41.882	1.074	33	0.000279	35.548	1.162
9	0.000079	41.043	1.123	34	0.000433	33.633	1.000
10	0.000057	42.419	1.044	35	0.000257	35.900	0.944
11	0.000070	41.565	1.151	36	0.000272	35.650	0.982
12	0.000054	42.665	1.276	37	0.000311	35.070	0.960
13	0.000059	42.273	1.043	38	0.000172	37.643	0.957
14	0.000058	42.345	1.110	39	0.000235	36.286	0.984
15	0.000108	39.653	1.208	40	0.000297	35.266	0.958
16	0.000106	39.754	1.149	41	0.000302	35.194	0.925
17	0.000096	40.163	1.128	42	0.000564	32.488	1.078
18	0.000078	41.085	1.153	43	0.000318	34.979	1.090
19	0.000060	42.203	1.297	44	0.000310	35.092	0.920
20	0.000053	42.729	1.121	45	0.000408	33.894	1.316
21	0.000069	41.603	1.089	46	0.000208	36.824	1.364
22	0.000018	47.426	1.015	47	0.000418	33.785	0.932
23	0.000126	38.984	1.089	48	0.000218	36.614	0.949
24	0.000100	40.011	1.260	49	0.000367	34.348	0.964
25	0.000089	40.488	1.439	50	0.000275	35.614	1.054

Based on Table 4, which presents the results of Median Filtering tests on white license plates across all 50 datasets, the method demonstrates fairly consistent performance in terms of both image quality and processing speed. The Mean Squared Error (MSE) ranged from 0.000018 to 0.000564, with the majority of datasets exhibiting low MSE values below 0.0001, indicating minimal average error and accurate image reproduction. Meanwhile, the Peak Signal-to-Noise Ratio (PSNR) ranged from 32.49 dB to 47.43 dB. Datasets with the lowest MSE tended to yield the highest PSNR; for instance, dataset 22 had an MSE of 0.000018 and a PSNR of 47.43 dB, demonstrating excellent image quality. Datasets with higher MSE, such as dataset 42 with an MSE of 0.000564, showed lower PSNR values (32.49 dB), reflecting reduced image quality. These results confirm that Median Filtering is effective for processing white license plates under varying image conditions. In general, higher PSNR values indicate better image quality after filtering. Figure 2 illustrates an example of a detected white vehicle license plate.



Figure 2. Detected White License Plate

In terms of processing speed, the execution time across all datasets remained relatively stable, ranging from 0.920 seconds to 1.439 seconds. This indicates that Median Filtering can process images rapidly without significant loss of accuracy. Overall, the method provides a good balance between

image restoration quality indicated by low MSE and high PSNR and processing efficiency, although a few datasets were outliers with slightly lower quality or longer processing times. In summary, these results demonstrate that the application of Median Filtering not only enhances image quality by reducing noise but also remains relatively efficient in terms of processing time. The results of Median Filtering tests on black license plates are presented in Table 5.

Table 4. Results of the Median Filtering Method Test on Black License Plates

Dataset	Median Filtering			Dataset	Median Filtering		
	MSE	PNSR	Speed (s)		MSE	PNSR	Speed (s)
1	0.000056	42.514	1.538	26	0.000243	36.145	0.986
2	0.000103	39.865	1.469	27	0.000345	34.617	1.027
3	0.000028	45.541	1.321	28	0.000372	34.289	0.988
4	0.000075	41.262	1.095	29	0.000331	34.808	1.001
5	0.000100	40.006	1.130	30	0.000352	34.532	0.952
6	0.000075	41.246	1.188	31	0.000366	34.362	0.975
7	0.000103	39.862	1.185	32	0.000328	34.837	0.998
8	0.000082	40.861	1.188	33	0.000273	35.644	0.959
9	0.000092	40.353	1.259	34	0.000297	35.270	1.385
10	0.000107	39.688	1.267	35	0.000341	34.677	1.161
11	0.000093	40.330	1.242	36	0.000306	35.141	0.983
12	0.000089	40.492	1.199	37	0.000354	34.514	0.956
13	0.000092	40.341	1.335	38	0.000320	34.947	0.977
14	0.000144	38.429	1.324	39	0.000425	33.719	1.036
15	0.000107	39.699	1.197	40	0.000274	35.617	0.956
16	0.000066	41.824	1.180	41	0.000592	32.277	1.059
17	0.000111	39.552	1.245	42	0.000300	35.234	0.967
18	0.000074	41.329	1.165	43	0.000306	35.147	1.109
19	0.000066	41.785	1.266	44	0.000270	35.687	1.113
20	0.000059	42.269	1.297	45	0.000516	32.874	1.276
21	0.000091	40.406	1.244	46	0.000254	35.949	1.083
22	0.000137	38.623	1.215	47	0.000250	36.021	1.021
23	0.000088	40.566	1.268	48	0.000347	34.600	1.099
24	0.000075	41.225	1.115	49	0.000540	32.673	1.127
25	0.000056	42.543	1.240	50	0.000214	36.703	1.115

Based on Table 5, the results of Median Filtering tests on black license plates across all 50 datasets demonstrate consistent and stable performance. The Mean Squared Error (MSE) ranged from 0.000028 to 0.000592, with the majority of datasets exhibiting MSE values below 0.00015, indicating low average error and good image processing accuracy. Datasets with the lowest MSE, such as dataset 3 (0.000028) and dataset 25 (0.000056), produced high Peak Signal-to-Noise Ratio (PSNR) values of 45.54 dB and 42.54 dB, respectively, reflecting excellent image quality. Conversely, datasets with higher MSE, such as dataset 16 (0.000592) and dataset 45 (0.000516), showed lower PSNR values of 32.28 dB and 32.87 dB, respectively, indicating reduced image quality. Figure 3 illustrates an example of a detected black vehicle license plate.



Figure 3. Detected Black License Plate

In terms of processing speed, the execution time of Median Filtering ranged from 0.952 seconds to 1.538 seconds, with the majority of datasets falling within 1–1.3 seconds, indicating that the method is efficient across all datasets. Overall, Median Filtering for black license plates maintains a balance between image quality and processing time, producing high PSNR values for most datasets while sustaining adequate speed. Although some outliers exhibited higher MSE and lower PSNR, the method still demonstrates reliable performance for processing dark-colored license plate images.

Comparison of Result for White and Black License Plates

The following stage is to compare the processing results of White and Black License Plates after getting the results, which include the detected license plates, MSE, PSNR, and processing speed. Figure 4 below shows the comparing findings.

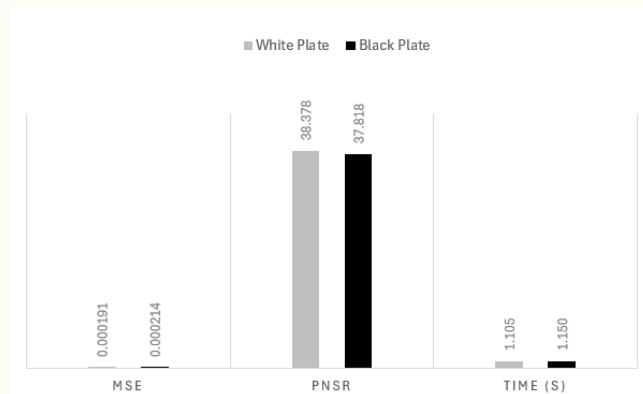


Figure 4. Comparison of License Plate Detection Results

Based on Figure 4, the comparative graph of license plate detection results illustrates the overall performance of Median Filtering on white and black plates. For Mean Squared Error (MSE), white plates exhibited slightly lower values at 0.000191 compared to black plates at 0.000214, indicating a smaller average error for white plate images. In terms of Peak Signal-to-Noise Ratio (PSNR), white plates also showed slightly higher values, 38.378 dB versus 37.818 dB for black plates, suggesting that the images of white plates achieved overall better quality. Regarding processing time, both types of plates were processed relatively quickly, with white plates requiring an average of 1.105 seconds and black plates 1.150 seconds, indicating minimal speed differences and stable method efficiency. Overall, the graph demonstrates that Median Filtering performs well for both plate types, with white plates producing slightly more accurate and higher-quality images, while processing time remains efficient for both.

CONCLUSIONS

Based on the results of this study, it can be concluded that the application of the Median Filtering method in vehicle license plate detection is effective in enhancing image quality by reducing impulsive noise, particularly salt-and-pepper noise, without compromising the sharpness of license plate characters. Testing on 50 white plate datasets yielded MSE values ranging from 0.000018 to 0.000564, with an average PSNR of 38.38 dB and an average processing time of 1.105 seconds. For 50 black plate datasets, MSE ranged from 0.000028 to 0.000592, with an average PSNR of 37.82 dB and an average processing time of 1.150 seconds. Comparative analysis indicates that white plates performed slightly better than black plates in terms of both image accuracy and visual quality. Overall, the Median Filtering method proved stable and efficient, providing an optimal balance between license plate detection accuracy and processing speed, making it reliably implementable in ANPR systems under various lighting conditions and plate colors.

This study is limited to samples of white and black plates under uniform lighting and image capture angles, so the results may not be fully representative of more varied environmental conditions.

Additionally, the use of a static median filter kernel limits adaptability to different license plate character patterns. Future research is recommended to evaluate Median Filtering across plates of other colors, diverse lighting conditions, and varying capture angles. Exploring combinations of median filtering with machine learning algorithms, such as convolutional neural networks (CNNs), or adaptive filters, could further improve character detection accuracy and enhance the robustness of ANPR systems in real-world scenarios.

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