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Comparison of Median Filter and Gaussian Filter Performance in Removing Salt and Pepper Noise

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Abstract

Image processing plays a critical role in various applications, from medical diagnostics to surveillance systems. However, one of the major challenges in digital image processing is the presence of noise, particularly salt and pepper noise, which significantly degrades image quality. This study aims to compare the effectiveness of two popular filtering techniques—Median Filter and Gaussian Filter—in removing salt and pepper noise from digital images. The evaluation is conducted both quantitatively, using Peak Signal-to-Noise Ratio (PSNR) and Mean Squared Error (MSE) metrics, and qualitatively, through visual analysis.
The experimental results show that the Median Filter consistently outperforms the Gaussian Filter in terms of noise reduction performance. Median filtering yields higher PSNR and lower MSE values across various levels of noise intensity (5%, 10%, and 15%). Moreover, the visual assessment indicates that Median Filter preserves image edges and fine details more effectively, whereas Gaussian Filter tends to introduce blurring artifacts due to its smoothing nature.
These findings suggest that for impulsive noise such as salt and pepper, Median Filter is a more appropriate and robust method, offering better restoration quality without compromising important image features.

Keywords: *image processing, salt and pepper noise, median filter, gaussian filter, PSNR, MSE*

1. Introduction

Digital image processing is a rapidly developing branch of computer science that plays a vital role in various fields such as medicine, security, industry, and information technology. The advancement of technology in the field of image processing today has attracted significant attention for further exploration. [1]. With these advancements, image processing has become a field of knowledge that can be understood and applied in everyday life. One of the main challenges in image processing is the presence of disturbances or noise, which can degrade visual quality and hinder further analysis.

A digital image is a two-dimensional picture that can be displayed on a computer screen as a discrete set of digital values known as pixels or picture elements. Digital images are highly susceptible to noise due to various influencing factors, such as insufficient lighting during image capture, the use of low-quality digital cameras, long distances between the object and the camera, and others. Noise is problematic because it reduces image quality and makes it difficult to extract meaningful information from the image due to the excessive presence of distortions [2]. An image consists of a collection of colored pixels or points that form a picture. Therefore, images play an important role in understanding and representing various phenomena, which in turn can support analysis and decision-making in various fields, including science and technology [1]

Technological advancements, particularly with the introduction of scanners, have made it possible to convert physical documents into digital images through the scanning process. Besides scanners, this process can also be performed using high-quality cameras. The digital data produced from scanning can be easily stored and accessed, making it a practical solution for document management. However, the scanning process is not without challenges. One of the main obstacles is the varying quality of paper used, which can affect the final quality of the digital image. Poor or damaged paper often results in blurry images or images filled with noise, thereby reducing the clarity and readability of the scanned documents. [3].

One of the most common types of noise is salt-and-pepper noise, which appears as randomly scattered black and white pixels across an image. This noise typically occurs due to data transmission errors or damage to the digital camera sensor. Salt-and-pepper noise is characterized by the random appearance of black (pepper) and white (salt) pixels throughout the image, meaning that some randomly selected pixels are set to either black or white [4]. Noise reduction is a crucial step in image processing to enhance visual quality and prepare the image for subsequent analysis stages. [5]

In efforts to remove noise from digital images, various filtering methods have been developed. Noise reduction is the process of decreasing or minimizing noise in digital images. [6]. Two commonly used methods are the Median Filter and the Gaussian Filter. The Median Filter is a nonlinear digital filtering technique used to reduce noise from images or signals. It is particularly effective in reducing salt-and-pepper noise. [7]. This filter is known to be effective in handling impulsive noise such as salt-and-pepper noise because of its ability to preserve image edge details. It helps eliminate the salt-and-pepper noise commonly found in digital images, thereby improving the accuracy of object detection [8]. The working principle of the Median Filter is to replace the intensity value of a pixel in an image with the median value of the surrounding pixels, effectively removing impulsive noise or visual disturbances [9]. Meanwhile, the Gaussian Filter is a linear convolution-based filter that uses the Gaussian distribution function to smooth pixel intensity variations. This filter is widely used due to its simplicity and effectiveness in smoothing images; however, its effectiveness against impulsive noise remains a subject of study. The Gaussian Filter is well-suited for reducing disturbances and minimizing estimation errors during system modeling processes [10]. Both Median filters are quite popular because they effectively reduce various types of random noise, such as salt noise and pepper noise. This technique is able to reduce noise better compared to linear smoothing models of the same size [11].

This study compares the performance of the Median Filter and the Gaussian Filter in removing salt-and-pepper noise from digital images. The evaluation is conducted by measuring the quality of the filtered results using quantitative metrics such as Peak Signal-to-Noise Ratio (PSNR) and Mean Square Error (MSE). The results of this research are expected to contribute to selecting the most appropriate filtering method to improve image quality before further analysis.

2. Literature Review

2.1. Salt and Pepper Noise

Noise is a disturbance that appears in images and can degrade their visual quality. This disturbance may arise from physical issues in the acquisition device, errors during the image processing stage, or dirt present on the image itself. Generally, there are three types of noise in digital images, each with distinct characteristics. First, salt-and-pepper noise, characterized by the appearance of white (salt) and black (pepper) spots on the image. Second, Gaussian noise, which resembles the colors around it, making it difficult to detect and still a subject of ongoing research for reduction. The third type is also Gaussian noise, which similarly affects image clarity.

Noise typically occurs due to imperfections during image capture, such as sensor errors or photographic signal amplification. These disturbances usually appear as variations in intensity between pixels, especially when one pixel differs markedly from its neighbors. Noisy pixels often contain high-frequency components, while low-frequency components tend to remain stable or change gradually. To address this disturbance, a denoising process is applied to suppress high frequencies and preserve low frequencies.
Noise reduction is the process of decreasing or eliminating disturbances from a signal. Although the basic concept is similar across various signal types, its implementation heavily depends on the characteristics of the signal being processed. In digital image processing, noise reduction methods are commonly carried out through filtering operations, which apply a neighborhood window to parts of the image to filter out unwanted noise. [12].

Salt-and-pepper noise is a type of impulsive noise that appears as random white (salt) and black (pepper) dots in digital images. This noise is usually caused by data transmission errors, sensor damage, or disturbances during the image acquisition process. Its presence can significantly interfere with image analysis by obscuring important details and producing extreme pixel values that do not represent the true information of the image.

2.2. *Median* Filter

The median filter is a type of nonlinear filter that works by sorting the intensity values of a group of pixels and then replacing the value of the central pixel with the median value of that group. This filter is widely used to smooth images and restore areas of the image affected by noise in the form of white spots. The median filter reduces noise in an image by taking the median value of the surrounding pixels. [13].

In its process, the median filter uses a window containing an odd number of pixels. This window is gradually moved across the entire image. At each position, the pixel value at the center of the window is replaced by the median value of the pixels within that window. The original pixel value is also included in the calculation of the median.
The median filter is popular due to its ability to reduce various types of random noise, especially salt-and-pepper noise. Compared to conventional linear smoothing methods of the same size, this filter is more effective in handling noise. It works by equalizing the grayscale levels of differing pixels to approximate the values of the surrounding pixels. Isolated pixels that are too bright, too dark, or very small are also replaced with the median value of the surrounding area, significantly reducing noise. Median filtering processes the image using a sliding neighborhood approach, where the output pixel value is selected based on the median of the pixels in the window [14].

In the context of image filtering, the median filter is often used as an alternative to low-pass filters for the image smoothing process. This process involves sorting the pixel values within the filter area and then selecting the middle value from the sorted list. An odd-sized filter is chosen to ensure a clear central point, making the pixel replacement process more focused. The main advantage of the median filter is its effectiveness in reducing impulsive noise. Compared to other nonlinear spatial filters, the median filter is considered one of the most effective methods for handling images affected by this type of noise. [11].

2.3. *Gaussian* Filter

Gaussian filter is an image filtering method that is known to be effective in improving image quality, especially Before the compression process to a smaller size is performed, this filter is very useful for reducing visual disturbances (noise) and helps minimize errors during estimation in system modeling. The Gaussian filter is a type of linear filter where the weighting values for each element are selected based on the shape of the Gaussian function. The Gaussian filter is chosen as a smoothing filter because it has a centrally

focused kernel [15]
In various studies, the Gaussian filter is used to blur images in order to remove disturbances that can interfere with analysis results. Additionally, this filter is regarded as highly accurate in estimation processes, making it suitable for application in a wide range of uses, both in general image processing and in more complex systems.

The Gaussian filter has also been shown to produce more stable and accurate results compared to several other filtering methods. In comparative studies involving filters such as Wiener, Median, Histogram Equalization, Weighted Median, Hybrid Filters, Multiscale Retinex with Color Restoration, and Homomorphic Filtering, the Gaussian filter demonstrated distinct advantages in improving image quality [10].

3. Research Methodology

The steps of this research are explained as follows:

1. Test Image Data; The data used in this study are standard grayscale images commonly used for digital image processing testing, such as Lena, Cameraman, and Peppers images. Each image has a resolution of 512×512 pixels and is used as a noise-free reference image.
2. Noise Addition; To simulate disturbances, the test images are added with salt-and-pepper noise at density levels of 5%, 10%, and 15%. The noise addition process is carried out using an algorithmic function that generates random noise according to the specified percentage.
3. Filter Application; The images contaminated with noise are then processed using the following two types of filters:
   a. Median Filter: A nonlinear filter with kernel sizes of 3×3 and 5×5 that replaces the central pixel value with the median of the neighboring pixels.
   b. Gaussian Filter: A linear filter with kernel sizes of 3×3 and 5×5, using a Gaussian function with a standard deviation (σ) of 1.0 to smooth the pixel intensity around the center.
4. Performance Evaluation; The performance of both filters is quantitatively evaluated using two main metrics:
   a. Peak Signal-to-Noise Ratio (PSNR): Measures the quality of the filtered image compared to the original image. A higher PSNR value indicates better filtering results.
   b. Mean Square Error (MSE): Measures the average squared error between the filtered image and the original image. A lower MSE value indicates less difference between the two.

The analysis is conducted by comparing the PSNR and MSE values of each filtered image, using both the Median Filter and Gaussian Filter, across each noise level. Visual comparisons between the original images, noisy images, and filtered results are also performed.

4. Result and Discussion

4.1. Experimental Results

The experiments in this study were conducted on three commonly used test images in digital image processing: Lena, Cameraman, and Peppers. Each image was gradually corrupted by salt-and-pepper noise with density variations of 5%, 10%, and 15% to simulate different levels of damage caused by impulsive noise. Subsequently, each noisy image was processed using two filtering methods compared in this study—Median Filter and Gaussian Filter—with two different kernel sizes, 3×3 and 5×5, to evaluate the effect of window size on noise filtering performance.

To provide a quantitative overview of the performance of both filters, measurements were conducted using two widely used metrics for image quality evaluation: Peak Signal-to-Noise Ratio (PSNR) and Mean Squared Error (MSE). Specifically for the Lena image, the results showed that for all noise density variations, the Median Filter consistently produced higher PSNR values and lower MSE values compared to the Gaussian Filter, for both kernel sizes of 3×3 and 5×5.
The following are the PSNR and MSE calculation results for each filter applied to the Lena image.

Tingkat Noise	Filter	Ukuran Kernel	PSNR (dB)	MSE
5%	Median Filter	3×3	34.82	38.12
5%	Gaussian Filter	3×3	30.14	75.65
10%	Median Filter	3×3	31.67	62.94
10%	Gaussian Filter	3×3	27.92	115.27
15%	Median Filter	3×3	28.34	93.85
15%	Gaussian Filter	3×3	24.56	158.32

Figure 1: Table of PSNR and MSE Comparison Values at Various Noise Levels

These results clearly demonstrate that the Median Filter has a significant advantage in reducing impulsive noise such as salt and pepper noise. This is due to the median mechanism's ability to remove extreme pixel values without blurring important image details. In contrast, the Gaussian Filter, which uses a smoothing approach based on the Gaussian distribution, tends to blur the entire image area including crucial details, making it less effective in handling impulsive noise. Therefore, it can be concluded that the Median Filter is a more suitable choice for salt and pepper noise removal applications, especially when preserving the structure and sharpness of the image is critical.

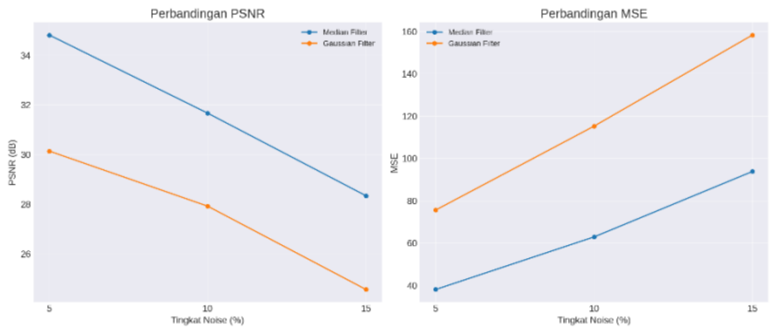

Figure 2: Comparison Graph of PSNR and MSE Values between Median Filter and Gaussian Filter for Salt and Pepper Noise

4.2. Analisis Kinerja Median Filter

The Median Filter demonstrates excellent and consistent performance in reducing salt and pepper noise across various noise density levels (5%, 10%, and 15%). The main advantage of this method lies in its working principle, which replaces the center pixel value in the filter window with the median value of all surrounding pixels. This approach is highly effective because extreme values (i.e., 0 and 255), characteristic of salt and pepper noise, can be easily ignored during the median calculation without affecting other unaffected pixels.

Based on the test results shown in Table 1, the Median Filter consistently delivers higher PSNR values and lower MSE values compared to the Gaussian Filter, regardless of the kernel size used. This indicates that the image quality after Median Filter processing is statistically closer to the original image in terms of clarity and visual details.
Furthermore, the Median Filter's ability to preserve edge sharpness and fine details makes it a highly effective method for applications requiring feature preservation, such as medical image processing, satellite image monitoring, and pattern recognition systems. Even when applied to images with a high noise level (15%), the Median Filter can maintain the image structure intact with minimal distortion. This fact reinforces the conclusion that the Median Filter is the most suitable method for handling impulsive noise such as salt and pepper noise.

4.3. Analisis Kinerja Gaussian Filter

In contrast to the Median Filter, the Gaussian Filter shows weaker performance in handling salt and pepper noise, despite its popularity for image smoothing or blurring purposes. The Gaussian Filter works by applying weights based on the Gaussian distribution function to the pixels within the kernel, meaning that all pixels in the window—including those contaminated by noise—contribute to the averaged output value. In the case of salt and pepper noise, this becomes a major drawback because the extreme pixel values (0 and 255) are still taken into account, resulting in an output that cannot effectively eliminate the noise.
The limitation of this filter is clearly evidenced by the lower PSNR values and higher MSE values of the Gaussian Filter compared to the Median Filter across all tested noise levels. Moreover, the visual effect of using the Gaussian Filter tends to blur the image, especially in areas with sharp contours or edges. This blurring effect arises from the smoothing process that weakens the transitions between pixels, thereby negatively impacting the overall visual quality of the image.
Therefore, it can be concluded that although the Gaussian Filter is useful for reducing other types of noise (such as Gaussian noise), it is not suitable for handling impulsive noise like salt and pepper noise. In this context, its use may actually degrade the image quality and obscure important structural details.

4.4. Perbandingan Visual

The visual comparison between the original image, the image contaminated with salt and pepper noise, and the images processed using the Median Filter and Gaussian Filter shows a significant difference in the effectiveness of each method in restoring image quality. In this experiment, the test images were contaminated with noise at a 10% density level to represent a moderate condition commonly encountered in digital image processing practice. The following visualization demonstrates the difference in image quality before and after the filtering process using both methods.

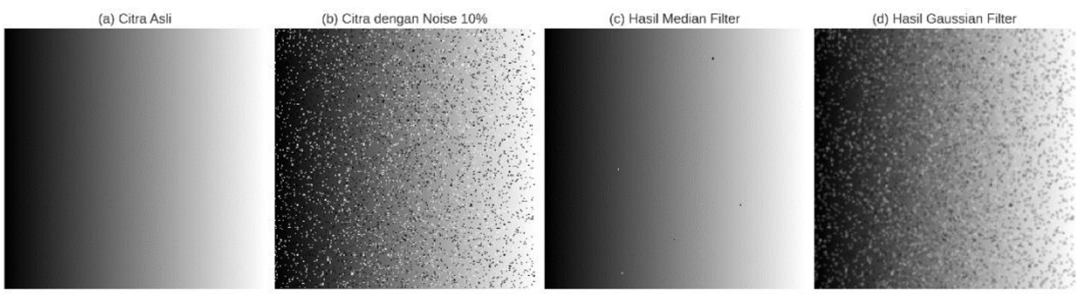

Figure 3. Visual Comparison between Median Filter and Gaussian Filter for Salt and Pepper Noise

(a) Original Image
(b) Image with 10% Noise
(c) Result of Median Filter
(d) Result of Gaussian Filter

In the original image, details of the object's structure such as contours, texture, and gradation are clearly visible and free from distortion. After adding salt and pepper noise, the image appears rough and is filled with random black and white spots that disrupt the overall visual appearance. This indicates that the noise is impulsive and unevenly distributed throughout the image area.

The processing results using the Median Filter show that this method can significantly reduce the amount of noise in the image while preserving structural details such as edges and object shapes. The image processed by the Median Filter appears cleaner, with contrast maintained and object shapes clearly visible without significant blurring. This indicates that the median algorithm effectively ignores extreme values and replaces them with median values that represent the surrounding environment.

In contrast, the result from the Gaussian Filter shows a lower improvement in visual quality. Although some noise spots are reduced, the image tends to experience a noticeable blur effect. Contours and boundaries between objects become less sharp, and textural information degrades. This supports the finding that the Gaussian Filter is not sufficiently effective in reducing impulsive noise due to its averaging approach, which lacks the ability to selectively recognize and remove outlier values.

Thus, from this visual comparison, it can be concluded that the Median Filter is superior in maintaining the visual quality of images after the denoising process, especially for noise types like salt and pepper noise.

4.5. Discussion

The findings of this study generally support previous research indicating that the Median Filter is more suitable for handling salt and pepper noise compared to the Gaussian Filter. The effectiveness of the Median Filter lies in its ability to eliminate extreme values without compromising the integrity of the image structure, making it the preferred choice in various digital imaging applications sensitive to impulsive noise.

Quantitative data obtained through metrics such as PSNR (Peak Signal-to-Noise Ratio) and MSE (Mean Squared Error) show a consistent trend where the Median Filter produces higher PSNR and lower MSE values across all noise density levels. This indicates that statistically, images processed by the Median Filter are closer to the original images in terms of accuracy and clarity. However, the results also indicate that the Gaussian Filter can still provide acceptable visual performance at very low noise levels, such as 5%. Under these conditions, the blurring effect caused by the Gaussian Filter is not yet significant, so the images still appear reasonably good. This suggests that the effectiveness of each filter depends heavily on the noise characteristics as well as the context of image usage.

Furthermore, it is important to understand that no single universal approach fits all types of image disturbances. Therefore, selecting the appropriate filter should consider not only the type of noise but also the processing objectives and the tolerance level for loss of visual detail. In the context of removing salt and pepper noise, the experimental results clearly show that the Median Filter is the most efficient and effective solution.

5. Conclusion

Digital image processing has become a vital component in modern technology, used across various fields such as surveillance systems, pattern recognition, and medical imaging. One of the main issues frequently encountered in image processing is the presence of salt and pepper noise—an impulsive noise that causes pixels to randomly turn black or white, thereby damaging the visual integrity of the image and reducing the accuracy of subsequent analysis processes.

In this study, a performance comparison was conducted between two filtering methods, namely the Median Filter and the Gaussian Filter, to remove salt and pepper noise from digital images. The Median Filter works by replacing the pixel value with the median of the surrounding pixel neighborhood, whereas the Gaussian Filter smooths pixel values based on the Gaussian distribution to blur the image.

Test results showed that the Median Filter consistently produces better image quality compared to the Gaussian Filter. This is evidenced by higher Peak Signal-to-Noise Ratio (PSNR) values and lower Mean Squared Error (MSE) values across all noise levels (5%, 10%, and 15%). Visualizations of the filtered results also demonstrated that the Median Filter better preserves image details and edge structures, while the Gaussian Filter tends to produce overly smooth images with loss of sharpness, especially on objects with clear contours or boundaries.

Thus, it can be concluded that the Median Filter outperforms both quantitatively and qualitatively in handling salt and pepper noise, particularly in images requiring preservation of visual details. The Gaussian Filter may still be relevant for other noise types such as Gaussian noise or images needing global smoothing; however, for the specific case of impulsive noise, the Median Filter is the more optimal choice. This conclusion underscores the importance of selecting a filtering method suited to the type of noise being addressed, to ensure that the image processing results remain accurate and informative.

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