A Comparative Study of Different Image Filtering Techniques for Removing Various Noise in the Image Using MATLAB GUI

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***Abstract* -** Digital images are often subjected to various types of noise during acquisition, transmission, or processing, which deteriorates their quality and affects subsequent analysis or interpretation. In this research paper, we present a comprehensive comparative study of different image filtering techniques for the removal of noise from digital images using MATLAB Graphical User Interface (GUI). The study encompasses common types of noise such as Gaussian noise, salt and pepper noise, and speckle noise, and evaluates the performance of filtering techniques including mean filtering, median filtering, and Gaussian filtering. The effectiveness of each technique is analyzed based on parameters such as peak signal-to-noise ratio (PSNR) and mean squared error (MSE). Through this comparative analysis, insights into the strengths and weaknesses of each filtering technique are provided, aiding in the selection of the most suitable method for noise reduction in specific applications.

Keywords— image processing, Noise removal, filtering, mean, median, MATLAB GUI

I. INTRODUCTION

Digital images are ubiquitous in modern society, utilized in various fields including medical imaging, remote sensing, surveillance, and entertainment. However, images captured by digital devices are often corrupted by unwanted disturbances known as noise. Noise can arise due to several factors such as electronic interference, sensor limitations, environmental conditions, or errors introduced during image acquisition and processing. The presence of noise in images degrades their quality, making it challenging to extract meaningful information and perform accurate analysis or interpretation. In the early development of image processing, linear filters were the primary tools for image enhancement and restoration. Their mathematical simplicity and the existence of some desirable properties made them easy to design and implement. Moreover, linear filters offered satisfactory performance in many applications. However, they have poor performance in the presence of non-additive noise and in situations where system nonlinearities or Gaussian statistics are encountered [1]. In image processing applications, linear filters tend to blur the edges and do not remove Gaussian and mixed Gaussian impulse noise effectively. Linear noise removal methods are not so effective when transient non-stationary wideband components are involved since their spectrum is similar to the spectrum of noise, the basic idea that the energy of a signal will often be concentrated in a few coefficients in the transform domain while the energy of noise is spread among all coefficients in the transform domain. Therefore, the nonlinear methods will tend to keep a few larger coefficients representing the signal while the noise coefficients will tend to reduce to zero. Noise removal methods based on multiresolution transforms involve three steps: A linear forward transform, a nonlinear thresholding step, and a linear inverse transform. Wavelets are successful in representing point discontinuities in one dimension, but less successful in two dimensions. As a new multiscale representation suited for edges and other singularity curves, the curvelet transform has emerged as a powerful tool. The developing theory of curvelets predicts that, in recovering images which are smooth away from edges, curvelets obtain smaller asymptotic mean square error of reconstruction than wavelet methods [2]

Image filtering techniques play a crucial role in mitigating the effects of noise and enhancing the visual quality of images. These techniques aim to suppress noise while preserving important image features and details. Various filtering algorithms have been developed for this purpose, each with its unique approach and effectiveness in different noise scenarios. In this research paper, we focus on comparing the performance of several image filtering techniques for noise removal using MATLAB GUI.

1.1 Type of Noise in Image

Noise represents unwanted information that collapses image quality. In the image noise removal process, information about the type of noise present in the original image plays a significant role. Typical images are corrupted with noise modeled with either a Gaussian, uniform, or salt or pepper distribution. Another typical noise is a speckle noise, which is multiplicative. The behavior of each of these noises is described below

Impulse noise is a common occurrence in digital images, prompting active research into effective reduction methods in recent years. Researchers have proposed various models to address this issue, as impulse noise typically corrupts images by replacing certain pixels with new ones having luminance values close to the minimum or maximum allowable range [3]. This type of noise stems from malfunctioning camera sensors, hardware faults, or transmission errors in noisy channels. It can be categorized into fixed-valued impulse noise, also known as salt-and-pepper noise, where noisy pixel values are either at the minimum or maximum grayscale levels and random-valued impulse noise, where pixel values are uniformly distributed within the grayscale range of [0, 255]. Impulse noise manifests as black-and-white speckles on images, with affected pixels often displaying extremely high or low-intensity values, resulting in noticeable contrasts with the surrounding areas [4]. This degradation in image quality occurs even at low levels of impulse noise. Removal of random-valued impulse noise poses greater complexity due to the random distribution of noisy pixels.

(a)

(b)

Figure 1: (a) Orignal image (b) image denoise with impulse noise[3]

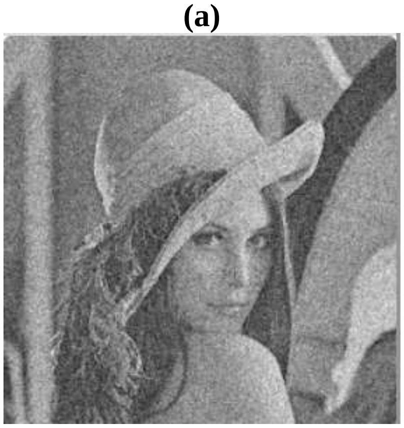
Gaussian noise is a form of statistical noise characterized by a probability density function following the normal distribution, commonly referred to as the Gaussian distribution. Essentially, the values assumed by the noise adhere to a Gaussian-distributed pattern. Specifically, Gaussian noise is accurately described as noise exhibiting a

Gaussian amplitude distribution. It is often modeled as additive white Gaussian noise (AWGN), wherein all pixel values in an image deviate from their original values by the Gaussian curve. Mathematically, for each pixel in an image with intensity value f_ij (where $1 \leq i \leq m$, $1 \leq j \leq n$ for an m x n image), the corresponding pixel in the noisy image g_ij is determined as follows [5]:

$$g\_ij = f\_ij + n$$

Here, each noise value 'n' is drawn from a zero-mean Gaussian distribution.

(a)



(b)

Figure 2: (a) Orignal image (b) image denoise with gaussian noise[5]

Salt and pepper noise is a common type of image corruption caused by sudden and sharp disruptions in the signal during image acquisition, processing, or transmission. When this noise occurs, it manifests as random occurrences of white, black, or both white and black pixels scattered throughout the image. These pixels disrupt the original image content by appearing as bright spots in dark regions and dark spots in bright regions, creating a visually disruptive effect akin to grains of salt and pepper sprinkled on the image. The appearance of salt and pepper noise can be attributed to various sources of error within the imaging system. Dead pixels, which are malfunctioning or non-responsive elements within the image sensor, may contribute to the appearance of isolated bright or dark spots in the captured image. Additionally, errors in the analog-to-digital conversion process, where continuous analog signals are converted into discrete digital values, can introduce abrupt changes in pixel intensity, leading to the formation of salt and pepper noise [6], [7]. Furthermore, during image transmission over communication channels, such as the Internet or wireless networks, bit errors may occur due to noise interference or transmission errors. These errors can cause random bits within the image data to flip, resulting in the appearance of sporadic bright or dark pixels, similar to salt and pepper noise. Overall, salt and pepper noise can significantly degrade the quality of digital images by introducing unwanted artifacts and disrupting visual coherence. Mitigating the effects of this noise is essential for maintaining image fidelity and ensuring accurate analysis and interpretation in various applications, including medical imaging, surveillance, and digital photography.

(a)

(b)

Figure 3: (a) Orignal image (b) image denoise with salt and pepper noise [7]

Speckle noise is a significant concern in coherent imaging, particularly in medical ultrasound imaging, where it can affect the interpretation of diagnostic information. This type of noise arises from the coherent processing of backscattered signals originating from multiple distributed targets within the imaged area. Speckle noise results from the inherent characteristics of the signals emitted by elementary scatters and is often described in medical literature as "texture," potentially containing valuable diagnostic insights [8]. However, while speckle noise may contain useful information, its presence can complicate visual interpretation. Physicians often prefer the original noisy images over smoothed versions because even sophisticated filtering techniques can inadvertently remove relevant image details. Therefore, there is a critical need to develop noise filtering methods that can effectively remove speckle noise while preserving diagnostically relevant features. Various methods have been proposed to address speckle noise, each based on different mathematical models of the phenomenon. In our research, we advocate for the use of hybrid filtering techniques tailored specifically for removing speckle noise in ultrasound images. These techniques combine multiple filtering approaches to achieve optimal noise reduction while retaining diagnostically relevant image features. The speckle noise model, which describes the relationship between noisy and clean image pixels, is represented mathematically as follows: for each pixel in an image with intensity value f_ij (where $1 \leq i \leq m$, $1 \leq j \leq n$ for an m x n image), the corresponding pixel in the noisy image g_ij is determined as follows[9]:

$$g\_ij = f\_ij * (1 + n)$$

Here, each noise value 'n' is drawn from a uniform distribution with a mean of 0 and a variance of σ^2. This model captures the multiplicative nature of speckle noise and forms the basis for developing effective filtering techniques tailored to ultrasound image denoising.

1.2 Type of image filters

Image filters are mathematical operations applied to digital images to modify their appearance or extract specific features. These filters are typically implemented as convolution operations, where a small matrix called a kernel is passed over the image, and at each position, the pixel values within the kernel's neighborhood are combined to produce a new pixel value [10].

Mean Filtering: Mean filtering stands as one of the simplest yet widely used techniques for noise suppression. The methodology involves replacing

(a)

(b)

Figure 4: (a) Orignal image (b) image denoise with Speekle noise[10]

each pixel value with the average of its neighboring pixel values within a predefined window or kernel. By computing the local average, mean filtering effectively mitigates high-frequency noise, particularly Gaussian noise. However, one significant drawback of mean filtering is its tendency to blur image details, particularly in regions with sharp transitions or edges.

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Median Filtering: Median filtering emerges as a nonlinear alternative to mean filtering, offering superior preservation of edges and fine details while effectively removing impulse noise, such as salt and pepper noise. Instead of computing the mean, median filtering replaces each pixel value with the median value of its neighboring pixels within the specified window or kernel. This approach is robust against outliers, making it particularly suitable for images contaminated with sporadic noise.

Wiener Filtering: Wiener filtering represents an adaptive filtering technique designed to minimize the mean square error between the original image and the filtered image. Unlike traditional filters, Wiener filtering estimates the power spectral density of both the noise and the original image. By utilizing this information, Wiener filtering adaptively adjusts the filter coefficients to achieve optimal noise reduction. While Wiener filtering excels in reducing Gaussian noise, its effectiveness hinges on accurate knowledge of the noise statistics, which may not always be available in practical scenarios[11].

Adaptive Filtering: Adaptive filtering techniques offer a flexible approach to noise removal by adjusting filter parameters based on local image characteristics. These techniques leverage spatial or frequency domain information to dynamically adapt the filtering process to varying noise levels and image structures. By considering the context of each pixel, adaptive filtering methods can effectively suppress noise while preserving essential image features. These techniques are particularly advantageous in nonstationary noise environments where noise characteristics vary across the image.

2. Literature review

This section covers different image pre-processing techniques used and discussed by various researchers and authors in their papers. An image enhancement algorithm under non-uniform lighting conditions for digital images is proposed by Saibabu et al. [12]. The proposed algorithm constitutes three problems, adaptive intensity enhancement, contrast improvement, and color restoration. Cheng et al. [6], [8] have worked on detection of over-enhancement. The over-enhanced areas are located accurately and effectively as shown in an experimental result. To optimize the parameter settings of the contrast improvement algorithms, the given method will be useful. Jaiswal et.al. [13] Worked with the denoising of salt–pepper and Gaussian noise. Results of PSNR (peak signal-to-noise ratio) and MSE (mean square error) are calculated for analysis. Chandrika Saxena et.al [13] have presented a survey on Noises and Image Denoising Techniques. Different types of noises and filters for denoising images are covered in the paper. For an image having salt and pepper noise, the filtering approach has been proven to be the best. For images that are corrupted with Gaussian noise, the wavelet-based approach found the optimum. Meenal et al. [14] surveyed and analyzed different traditional image-denoising methods and suggested a new approach that provides a heterogeneous way for the challenging issue. Parmar J.M et. al. [15] proposed an image-denoising method using a partial differential equation. They proposed three different approaches for blur, noise, and blur & noise. This paper discusses different types of noises and result of filters applied to denoise the images.

Yang [16] proposed MATLAB-based image processing for medical engineering applications. He highlighted the importance of image data in medical engineering as the main source of information exchange and posited that although the medical engineering application of digital image processing attracts a huge cost, it always produces effective results by minimizing noise effects and enhancing the image quality. In the medical engineering field, processed images carry much medical, and pathological information about a particular ailment. A software simulation analysis of image recognition using a MATLAB-based technique is presented in [17]. The paper highlights a methodological approach showing a MATLAB-based implementation of a software system for the analysis of image recognition. Buksh *et al.* [18] proposed a MATLAB-based image editing and color detection that exploits functions inherent in the MATLAB toolbox to implement various image processing applications. The use of MATLAB as a computing platform and backbone of emerging visual communication, suitable for developing, and testing several applications was emphasized in [19], where authors also suggested its use in the the teaching of digital signal processing. According to the authors, MATLAB provides a GUI that enhances easy understanding of the concepts

3. Methodology

The methodology flow diagram (Figure 5) outlines the step-by-step process of the study. Initially, the algorithm prompts the user to input an image, followed by selecting the type of noise to be added, resulting in a noisy version of the image. Subsequently, the user selects a filter type for noise reduction, which is then applied to the noisy image to minimize the noise present, ultimately producing a filtered image with reduced noise. Additionally, the study incorporates Wavelet thresholding, a signal estimation technique leveraging the Wavelet transform for noise removal. This involves reading the noisy image, performing Discrete Wavelet Transform (DWT), estimating noise variance, calculating the threshold value, applying soft or hard thresholding functions to the noisy coefficients, and reconstructing the denoised image using inverse DWT. The choice between soft and hard thresholding functions is crucial, with soft thresholding preferred for its visually pleasing results. Overall, the methodology integrates image acquisition, noise addition, noise reduction through filtering, and Wavelet thresholding to achieve effective noise removal and produce high-quality denoised images suitable for further analysis or interpretation.

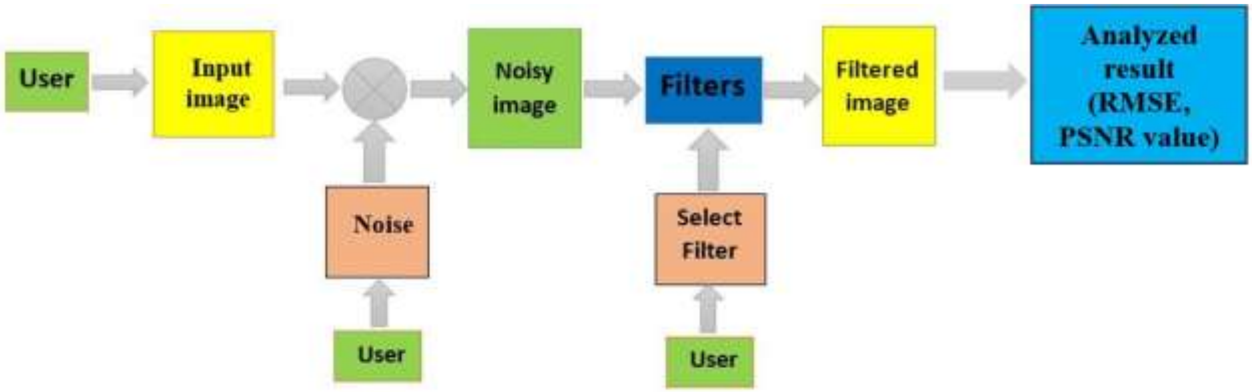

Figure 5: Proposed methodology

4. GUI Development

In this section, we embark on a detailed exploration of the Graphical User Interface (GUI) development process and the intricacies of various image filtering techniques for noise removal and enhancement. The GUI is meticulously crafted to ensure user-friendliness and ease of navigation. The development journey begins with the initialization of the interface and the design of its layout. Careful consideration is given to the arrangement of components such as buttons, image display areas, and input/output fields, aiming for optimal usability and visual appeal. Each element is strategically placed to streamline the user's workflow and enhance the overall user experience. A pivotal feature of the GUI is the "Load" button, which serves as the gateway for users to import their desired image into the interface. Upon activation, the button prompts the user to select an image file from their local directory. Once the image is chosen, it is seamlessly loaded into the interface and displayed for further processing. Following image loading, users are presented with the option to convert the RGB image into grayscale. This conversion step is essential for simplifying subsequent image processing tasks and reducing computational complexity, as grayscale images require fewer computational resources for analysis and manipulation. The GUI also facilitates the addition of noise to the image, simulating real-world scenarios where images are corrupted during acquisition or transmission. By selecting the "Noise" button, users can introduce various types of noise, such as Gaussian, salt and pepper, or speckle, to the image. This feature allows users to experiment with different noise levels and types, providing valuable insights into noise mitigation techniques. Once the image is noisy, users have the flexibility to apply different filtering techniques for noise reduction and enhancement. Several filtering options are available, including mean filtering, median filtering, Wiener filtering, and adaptive filtering. Each filtering technique is accompanied by a dedicated button for easy selection and application. Users can explore the strengths and limitations of each technique and choose the most suitable approach based on their specific requirements and preferences. To enhance usability and facilitate experimentation, the GUI includes a "Reset" button. This button allows users to revert the interface to its original state, undoing any changes made during the image processing or filtering process. This feature empowers users to iterate freely, exploring different filtering techniques and noise levels without fear of irreversible alterations.

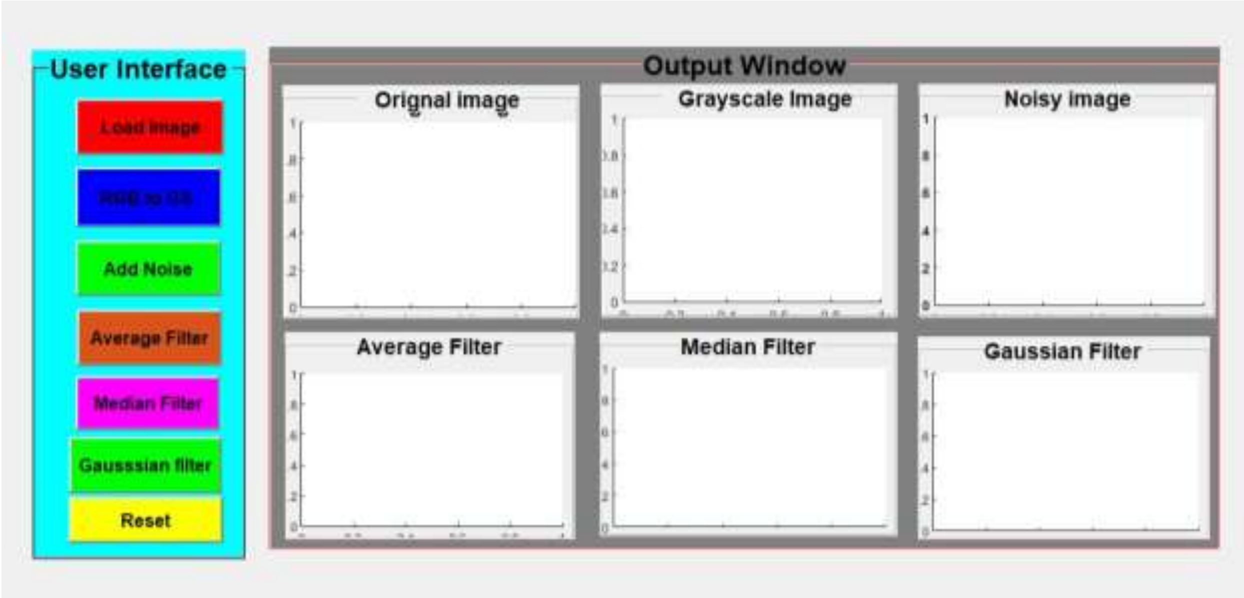

Figure 6: Developed GUI for noising and filtering of image

5. Result and Discusiion

The experimental evaluation is conducted on original images provided by the authors. These images are loaded into the system, and different types and levels of noise are added according to predetermined percentages. The objective quality of the reconstructed images is assessed using two key metrics: Root Mean Square Error (RMSE) and Peak Signal Noise Ratio (PSNR). RMSE quantifies the average error in the reconstructed image, weighted by the square of the error magnitude. PSNR, on the other hand, represents the ratio of signal power to noise power and measures the gray value difference between the resulting image and the original image. Mathematically, RMSE and PSNR are defined as follows:

$$\text{RMSE} = \sqrt{\frac{\sum(f(i,j)-g(i,j)^2}{mn}} \qquad (1)$$

$$\text{PSNR} = 20\log_{10}\frac{255}{RMSE} \qquad (2)$$

Here, f(i,j) represents the original image with noise, g(i,j) represents the enhanced image, and m and n denote the total number of pixels in the horizontal and vertical dimensions of the image, respectively. A lower RMSE value indicates a more accurate enhancement approach, while a higher PSNR value indicates better image quality. The original noisy image and the filtered images obtained through various filtering techniques are illustrated in Figure 7, providing visual insight into the effectiveness of the enhancement methods. Through rigorous evaluation using RMSE and PSNR metrics, the performance of each filtering technique can be objectively assessed and compared.

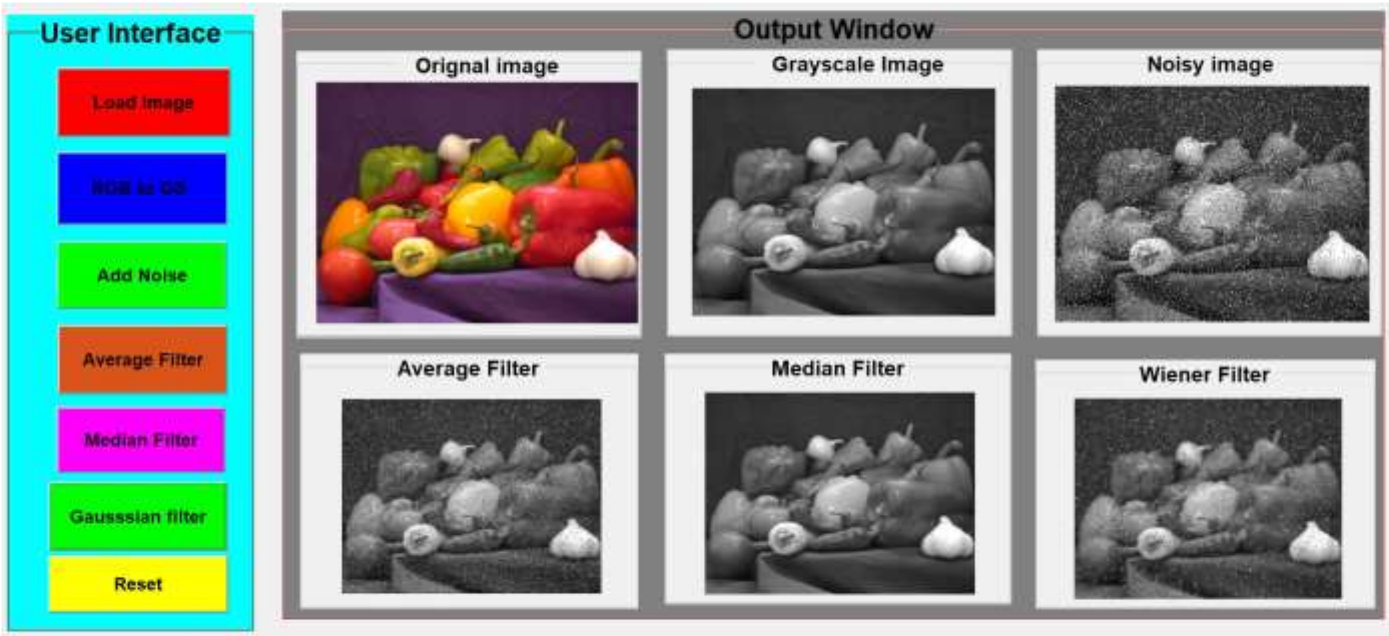

Figure 7: Noisy and filtered image

Visual comparisons of Peak Signal Noise Ratio (PSNR) and Root Mean Square Error (RMSE) for the removal of Gaussian noise, salt and pepper noise, and speckle noise are presented. These results illustrate the performance of various filtering techniques, including Average Filter, Median Filter, and Gaussian Filter, in enhancing image quality and reducing noise. Each figure provides graphical representations of PSNR and RMSE values, allowing for a comprehensive assessment of the effectiveness of different noise removal methods. Tables 1 to 6 present detailed RMSE and PSNR values for images filtered by three different types of filters.

For RMSE values, the Gaussian filter consistently shows the lowest values across all percentages of Gaussian noise. This suggests that it performs better in terms of accurate denoising the images compared to Mean and median. For PSNR values, the Gaussian filter also demonstrates the highest values across all levels of Gaussian noise. Higher PSNR values indicate better preservation of image quality after denoising. Based on both RMSE and PSNR values, the "Winner" filter appears to be the most effective in denoising aerial images with Gaussian noise. It consistently achieves lower RMSE values and higher PSNR values compared to other filters, indicating superior performance in terms of both accuracy and preservation of image quality.

Table 1. RMSE Values for Images with Different Percentage of Gaussian Noise Denoised by different filter

Types of filters / % of Noise	Average filter	Median filter	Gaussian filter
10%	28.12	28.52	26.11
20%	51.23	52.33	52.10
30%	74.23	78.22	75.23
40%	94.32	98.23	94.09
50%	109.21	112.23	108.12

Table 2. PSNR Values for Images with Different Percentage of Gaussian Noise Denoised by different filter

Types of filters / % of Noise	Average filter	Median filter	Gaussian filter
10%	19.23	18.98	18.32
20%	13.24	13.10	13.07
30%	10.33	10.22	10.08
40%	8.23	8.11	8.020
50%	7.43	7.32	7.102

From Table 3, it's apparent that for denoising images with salt and pepper noise, the Median filter consistently outperforms the Average and Gaussian filters, showing the lowest RMSE values across all percentages of noise. Thus, the Median filter is the most effective in accurately denoising images affected by salt and pepper noise. In Table 4, for denoising images with salt and pepper noise, the Median filter also exhibits the highest PSNR values across all levels of noise, indicating better preservation of image quality after denoising. Therefore, based on both RMSE and PSNR values, the Median filter emerges as the most effective choice for denoising images with salt and pepper noise.

Table 3. RMSE Values for Images with Different Percentage of salt and pepper Noise Denoised by different filter

Types of filters / % of Noise	Average filter	Median filter	Gaussian filter
10%	16.12	8.52	22.31
20%	22.23	11.33	29.10
30%	26.97	18.32	33.34
40%	31.34	28.23	36.39
50%	34.65	42.84	39.34

Table 4. PSNR Values for Images with Different Percentage of Salt and Pepper Noise Denoised by Different Filters

Types of filters / % of Noise	Average filter	Median filter	Gaussian filter
10%	23.53	29.88	20.32
20%	21.24	27.40	18.27
30%	19.56	23.18	17.71
40%	18.23	18.11	16.94
50%	17.42	15.32	16.26

From Table 5, it's evident that for denoising images with speckle noise, the Median filter consistently outperforms the Average and Gaussian filters, showing the lowest RMSE values across all percentages of noise. Thus, the Median filter is the most effective in accurately denoising images affected by speckle noise. In Table 6, for denoising images with speckle noise, the Median filter also exhibits the highest PSNR values across all levels of noise, indicating better preservation of image quality after denoising. Therefore, based on both RMSE and PSNR values, the Median filter emerges as the most effective choice for denoising images with speckle noise.

Table 5. RMSE Values for Images with Different Percentage of Speckle Noise Denoised by Different Filters

Types of filters / % of Noise	Average filter	Median filter	Gaussian filter
10%	17.12	24.52	19.31
20%	22.43	33.43	26.10
30%	26.77	40.32	30.34
40%	29.34	46.43	34.49
50%	32.21	51.06	36.31

Table 6. PSNR Values for Images with Different Percentage of Speckle Noise Denoised by Different Filters

Types of filters / % of Noise	Average filter	Median filter	Gaussian filter
10%	23.63	20.88	22.32
20%	21.28	17.40	19.27
30%	19.66	16.18	18.71
40%	18.33	14.81	17.94
50%	18.46	14.32	16.96

6. CONCLUSION

In this research, we focused on addressing the challenge of noise reduction in digital images, which is crucial for enhancing the accuracy of subsequent image processing tasks. We conducted a thorough investigation of different image filtering techniques using MATLAB Graphical User Interface (GUI), aiming to provide a comparative analysis of their effectiveness in removing various types of noise commonly encountered in digital images. Our study encompassed three prominent types of noise: Gaussian noise, which often appears as random variations in brightness; salt and pepper noise, characterized by sporadic occurrence of very bright or very dark pixels; and speckle noise, typically observed as granular interference in images. We evaluated the performance of three widely used filtering techniques: mean filtering, which smooths images by replacing each pixel's value with the average value of its neighbourhood; median filtering, which replaces each pixel's value with the median value of its neighbourhood, thus effectively removing outliers; and Gaussian filtering, which applies a weighted average of neighbouring pixel values to smooth images while preserving edges. To quantitatively assess the efficacy of these techniques, we employed two key metrics: Mean Square Error (MSE), which measures the average squared difference between the original and filtered images; and Peak Signal to Noise Ratio (PSNR), which quantifies the ratio of the maximum possible power of the signal to the power of the noise. Our findings revealed nuanced insights into the performance of each technique across different types and levels of noise. Specifically, we observed that Gaussian filtering yielded the best results for Gaussian noise, while the average filter performed most effectively for salt and pepper noise. Conversely, the median filter consistently outperformed other techniques for reducing speckle noise. These findings not only contribute to advancing our understanding of image processing techniques but also have practical implications for various applications requiring accurate and reliable image analysis.

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