IJEASM
International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 5 Issue 6, June 2024

A Survey of Image Noise Types and the Effectiveness of Filtering Methods in Digital Image Processing

Mani Bhushan[1], Abhishek Agwekar[2]
[1]Research Scholar, Department of Electronics and Communication, T.I.E.I.T, Bhopal, India
[2]HoD, Department of Electronics and Communication, T.I.E.I.T, Bhopal, India
[1]mbhushan881@gmail.com, [2]abhishek.agwekar@trubainstitute.ac.in

Abstract: Image noise is a common phenomenon that affects the quality of digital images, arising from factors such as sensor imperfections, transmission errors, and environmental conditions. Effective noise removal is essential in numerous applications of digital image processing, including medical imaging, remote sensing, and computer vision, where accurate image representation is critical. This survey paper explores the various types of noise typically encountered in digital images—such as Gaussian, Salt & Pepper, Speckle, and Poisson noise—and evaluates the effectiveness of different filtering techniques used to mitigate their effects. Filters such as Mean, Median, Gaussian, and Wiener filters are examined for their performance in restoring image quality, with comparative analysis based on metrics like Peak Signal-to-Noise Ratio (PSNR), Mean Squared Error (MSE), and classification accuracy. Through this survey, we provide a comprehensive understanding of the strengths and weaknesses of these filters when applied to specific noise types, offering insights into the best practices for selecting filtering techniques in diverse noise environments.

Keywords: *Digital image processing, Image noise, Noise filtering techniques, Gaussian noise, Median filter*

1. Introduction

Computers are faster and more accurate than human beings in processing numerical data [1]. However, human beings score over computers in recognition capability. The human brain is so sophisticated that we recognize objects in a few seconds, without much difficulty. We may see a friend after ten years, yet recognize him/her inspite of the change in his/her appearance. as the method by which humans gather knowledge for recognition is very unique [2]. Human beings use all the five sensory parts of the body to gather knowledge about the outside world. Among these perceptions, visual information plays a major role in understanding the surroundings. Other kinds of sensory information are obtained from hearing, taste, smell, and touch. The old Chinese proverb “A picture speaks a thousand words” rightly points out the images are very powerful tools in communication. With the advent of cheaper digital cameras and computer systems, we are witnessing a powerful digital revolution where images are being increasingly used to communicate ideas effectively [3].

We encounter images everywhere in our daily lives. We see many visual information sources such as paintings and photographs in magazines, journals, image galleries, digital libraries, newspapers, advertisement boards, television, and the internet. Images are virtually everywhere! Many of us take digital snaps of important events in our lives and preserve them as digital albums [4]. Then through the digital album we print digital pictures and/or mail them to our friends to share our feelings of happiness and sorrow. However, images are not used merely for entertainment purposes. Doctors use medical images to diagnose problems for providing treatments. With modern technologies, it is possible to image virtually all anatomical structures, which is of immense help to doctors, in providing better treatment. Forensic imaging applications process fingerprints recognition, hand recognition, faces recognition, and irises to identify criminals. Industrial applications use imaging technology to count and analyze industrial components [5]. Remote sensing applications use images sent by satellites to locate the minerals present in the earth. Thus, images find major applications in our everyday life [6].

Images are imitations of real world objects. Often an image is a two dimensional (2D) signal f(x,y) represent the amplitude or intensity of the image. For processing using digital computers, this image has to be converted to the discrete form using the process of sampling and quantization, known collectively as digitization. In image processing, the term 'image' is used to denote the image data that is sampled, quantized and readily available in a form suitable for further processing by digital computers [7]. Figure 1 shows 8×8 set of pixels stored as a linear combination of 64 different images.

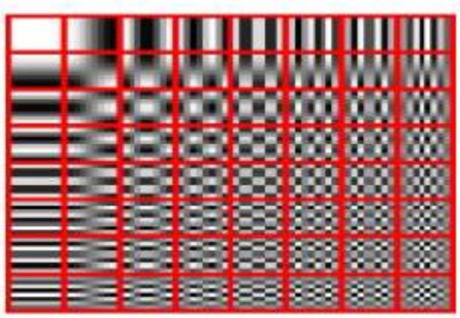


Fig. 1: 8×8 set of pixels stored as a linear combination of 64 different images.

This paper describes the various aspects of image processing, the causes and the effect of noise on image. There is no single accepted way of classifying images. They can be classified based on many criteria. Some ways in which images can be classified are shown in Figure 2.

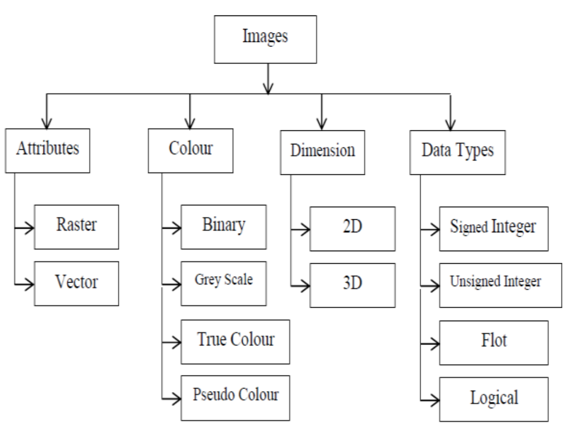


Fig. 2: Classification of Images

Images can be broadly classified based on attributes, as raster images and vector graphics. Vector graphics use basic geometric attributes such as lines and circles, to describe an image. Hence the notion of resolution is practically not present in graphics. However, raster images are pixel- based. The quality of the raster images is dependent on the number of pixels. So operations such as enlarging or blowing-up of a raster image often result in quality reduction [8].

2. Types of Images Based on Color

Based on colour, images can be classified as grey scale, binary, true colour, and pseudo colour images. Grey scale and binary images are called monochrome images as there is no colour component in these images. True colour (or full colour) images represent the full range of available colours. So the images are almost similar to the actual object and hence called true colour images. In addition, true colour images do not use any lookup table but store the pixel information with full precision. On the other hand, pseudo colour images are false colour images where the colour is added artificially based on the interpretation of data [9].

Grey scale images- Grey scale images are different from binary images as they have many shades of grey between black and white. These images are also called monochromatic as there is no colour component in the image, like in binary images. Grey scale is the term that refers to the range of shades between white and black or vice versa. Eight bits (28 = 256) are enough to represent grey scale as the human visual system can distinguish only 32 different grey levels. The additional bits are necessary to cover noise margins. Most medical images such as X-rays, CT images, MRIs, and ultrasound images are grey scale images. These images may use more than eight bits. For example, CT images may require a range of 10-12 bits to accurately represent the image contrast [10].

Binary images- In binary images, the pixels assume a value of 0 or 1. So one bit is sufficient to represent the pixel value. Binary images are also called bi-level images. In image processing, binary images are encountered in many ways. The binary image is created from a grey scale image using a threshold process. The pixel value is compared with the threshold value. If the pixel value of the grey scale image is greater than the threshold value, the pixel value in the binary image is considered as 1. Otherwise, the pixel value is 0. They are also used as masks. In addition, image processing operations produce binary images at intermediate stages [11]

True color images- In true colour images, the pixel has a colour that is obtained by mixing the primary colours red, green, and blue. Each colour component is represented like a grey scale image using eight bits. Mostly, true color images use 24 bits to represent all the colours. Hence true colour images can be considered as three band images. The number of colours that is possible is 256×3 (i.e., 256 × 256 × 256 = 1,67,77,216 colours). Figure 3 illustrates the general storage structure of the colour image. A display controller then uses a digital-to-analog converter (DAC) to convert the colour value to the pixel intensity of the monitor. A special category of colour images is the indexed image. In most images, the full range of colors is not used. So it is better to reduce the number of bits by maintaining a colour map, gamut, or palette with the image [12].

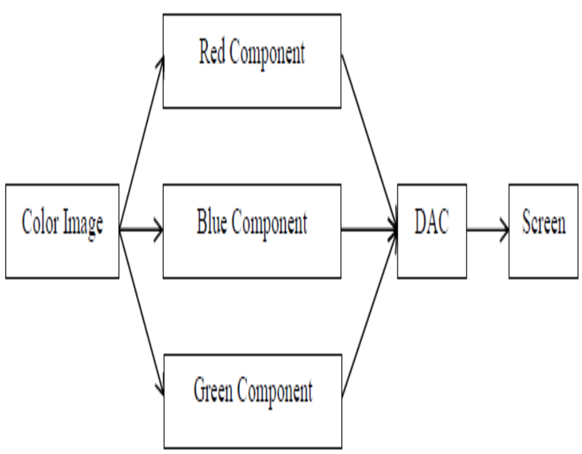


Fig. 3: Storage Structure of Color Images

Figure 4 illustrates the storage structure of an indexed image. The pixel value can be considered as a pointer to the index, which contains the address of the colour map. The colour map has RGB components. Using this indexed approach, the number of bits required to represent the colours can be drastically reduced. The display controller uses a DAC to convert the RGB value to the pixel intensity of the monitor [14].

Pseudocolour images- Like true colour images, pseudocolour images are also used widely in image processing. True colour images are called three-band images. However, in remote sensing applications, multi-band images or multi spectral images are generally used. These images, which are captured by satellites, contain many bands. A typical remote sensing image may have 3-11 bands in an image. This information is beyond the human perceptual range. Hence it is mostly not visible to the human observer. So colour is artificially added to these bands and to increase operational convenience. These are called artificial colour or pseudocolor images. Pseudocolour images are popular in the medical domain also. For example, the Doppler colour image is a pseudocolour image [13].

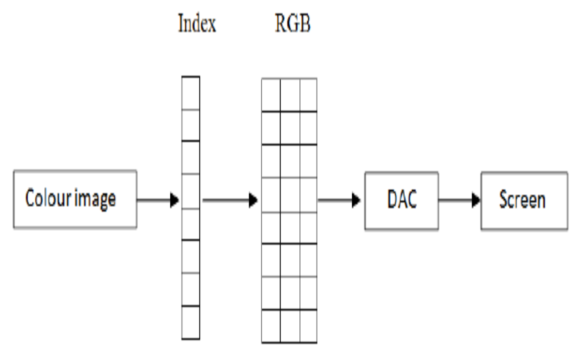


Fig. 4: Storage structure of an Indexed Image

3. Impulse Noise

During the transmission and acquisition, pixels gray values are affected by different type of noise present in medium. These noise can be Gaussian type or impulse noise [14]. The most common type of noise which affects the image in the form of black and white dots is impulse noise. Impulse noise is of two types:

1). Fixed value impulse noise and

2). Random valued impulse noise.

Fixed valued impulse noise is noise which can have values either 0 or 255 i.e for black and 255 for white. On the other hand random valued impulse noise can have 0, 255 or any value between 0 and 255. So the different types of detection and removal algorithms are requiring for different types of noise. Filters are better option for image de-noising. There are so many filters already available for image de-noising. The mean filter or average is very simple and easy filter for image noise removal but while removing the noise, mean filter affects fine details of image and causes blurring into the image. Also the nature of impulse noise is non-linear so the non-linear filter will work most efficiently then mean filter [15].

Median filter also knows as simple median filter known as SMF.It is very common used non-linear filter. The main concept of median filter is sorting. It sorts the all elements of the selected filtering window of size nxn, where n is odd number. Then it chooses the middle element of the sorted sequence and then replaces this median element with the central noisy pixel. After replacing noisy pixel, that window will slides to the next pixel and repeat the process. This filter produces better results and quality than average and other linear filters. But it has one disadvantage that it also effects noise-free pixels. That is why some improvement has been made in median filter to get better results like first identify the noisy pixels and then replace only noisy pixels and other left unaltered [16]. Weighted median filter, known as WMF, is an improvement in the median filter. Some other filters are centre weighted median filter known as CWM, Adaptive median filter known as AMF, Adaptive centre weighted median filter known as ACWM, Switching median filter known as SMF, progressive switching median filter known as PSMF. The combined median and other filter also use to improve the performance of median filter like median filter combine with average filtering and median filter with high pass filter [17].

4. Noise Modelling

Noise is a disturbance which causes fluctuations in the pixel values. Hence the pixel values show random variation and this cannot be avoided. Hence suitable strategies should be designed to model and manage noise. Noise can be viewed in multiple ways some of the frequent noises that are encountered in image processing are categorized based on the criteria of distributions, correlation, nature, and source [18].

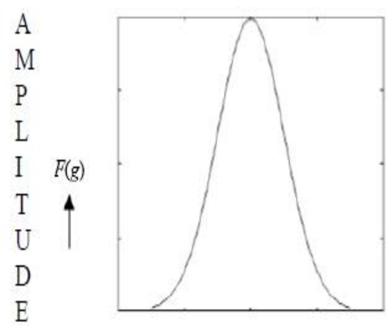
Noise Categories Based on Distribution

Since noise is a fluctuation of pixel values, it is categorized as a random variable. A random variable probability distribution is an equation that links the value of the statistical result with its probability of occurrence. Noise categorization based on probability distributions is very popular [19]. On the basis of its distribution, it can be classified as follow:

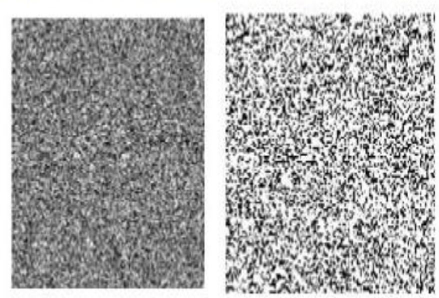
Gaussian Noise- Gaussian noise is evenly distributed over the signal. This means that each pixel in the noisy image is the sum of the true pixel value and a random Gaussian distributed noise value. As the name indicates, this type of noise has a Gaussian distribution, which has a bell shaped probability distribution function given by

$$F(g) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(g-m)^2/2\sigma^2}$$

Where g represents the gray level, m is the mean or average of the function and σ is the standard deviation of the noise. Graphically, it is represented as shown in Figure 5 (a). When introduced into an image, Gaussian noise with zero mean and variance as 0.05 would look as in Figure 5 (b). Figure 5(c) illustrates the Gaussian noise with mean (variance) as 1.5 over a base image with a constant pixel value of 100.



(a) Probability Density Function of Gaussian Distribution Function



(b) (c)

Fig. 5: (a) Gaussian distribution
(b) Gaussian Noise (mean=0; Variance= 0.05)
(c) Gaussian Noise (Mean = 0; Variance = 1.5)

Salt & pepper noise model- Salt and pepper noise is an impulse type of noise, which is also referred to as intensity spikes. This is caused generally due to errors in data transmission. It has only two possible values, a and b. The probability of each is typically less than 0.1The adulterated pixels are set on the other hand to the base or to the most extreme esteem, giving the picture a "salt and pepper" like appearance. Unaffected pixels stay unaltered. For a 8-bit picture, the commonplace incentive for pepper clamour is 0 and for salt commotion 255. The salt and pepper commotion is for the most part caused by breaking down of pixel components in the camera sensors, broken memory areas, or timing blunders in the digitization procedure. The probability density function for this type of noise is shown in Figure 6. Salt and pepper noise with a variance of 0.05 is shown in Figure 7.

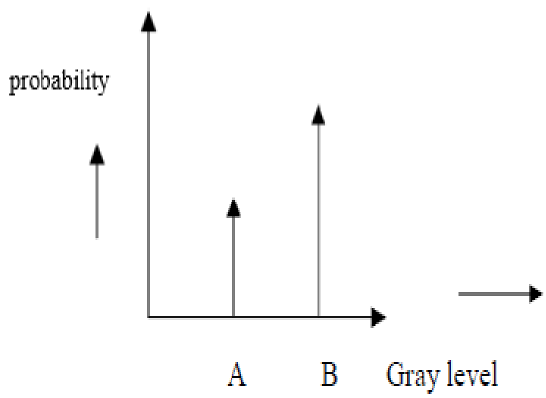


Fig. 6: PDF for salt and pepper noise

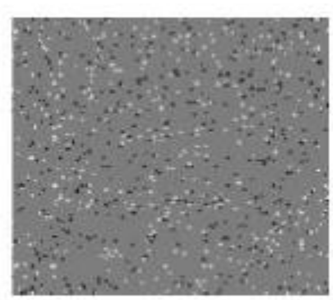


Fig. 7: Salt and pepper noise

Poisson distribution model- A Poisson distribution noise model is commonly used to describe random noise in systems where the occurrence of events is both rare and independent. In the context of imaging or communication systems, Poisson noise arises when the number of discrete events, such as photons hitting a sensor or data packet arrivals, follows a Poisson process. The probability of a certain number of events occurring in a fixed time interval or space is proportional to the average rate of occurrence, making it useful for modeling low-light conditions in cameras or packet loss in networks. This noise model is particularly suited to situations where the signal itself is proportional to the variance in noise, reflecting the inherent randomness in event-based processes.

Exponential Noise- Exponential noise refers to a type of noise where the probability distribution of noise values follows an exponential distribution. This distribution is characterized by a high probability of small noise values and a long tail for larger values, meaning that smaller disturbances are more frequent, but occasional large deviations can occur. Exponential noise is often encountered in systems involving waiting times between independent events, such as in queuing theory or signal processing, where the time between occurrences or errors follows an exponential decay. It is particularly useful for modeling random processes with memory less properties, where the likelihood of an event happening does not depend on past occurrences.

Gamma distribution- The Gamma distribution noise model is used to represent noise in systems where the underlying processes involve the summation of multiple exponential events. Unlike simpler distributions, the Gamma distribution can capture a wider range of skewed noise patterns, which makes it effective for modeling phenomena where events occur in clusters or bursts. The shape and scale parameters of the Gamma distribution control the spread and skewness of the noise, allowing for flexibility in modeling different types of random variations. This noise model is commonly applied in fields like telecommunications, biology, and image processing, where it can describe signal fluctuations or delays that result from aggregated random events.

5. Types of Filter

Spatial filters are useful for removing noise. Image restoration spatial filters are of two types- mean filter and order-statistic filter. The difference is that, mean filter is based on the concept of convolution, whereas order-statistics filter doesnot use convolution, but only orders the pixels of the neighborhood and selects a pixel value based on its order.

Mean Filters

A mean filter acts on an image by smoothing it; that is, it reduces the intensity variation between adjacent pixels. The mean filter is nothing but a simple sliding window spatial filter that replaces the center value in the window with the average of all the neighboring pixel values including itself. By doing this, it replaces pixels that are unrepresentative of their surroundings [16, 17]. It is implemented with a convolution mask, which provides a result that is a weighted sum of the values of a pixel and its neighbors. It is also called a linear filter. The mask or kernel is a square. Often a 3×3 square kernel is used. If the coefficients of the mask sum up to one, then the average brightness of the image is not changed. If the coefficients sum to zero, the average brightness is lost, and it returns a dark image. The mean or average filter works on the shift-multiply-sum principle. This principle in the two-dimensional image can be represented as shown below:

Fig. 8: Input to mean filter corrupted with salt and pepper noise

Fig. 9: Image after mean filtering

The mean filter is used in applications where the noise in certain regions of the image needs to be removed is shown in figure 8 and figure 9. In other words, the mean filter is useful when only a part of the image needs to be processed.

Order Statistics Filter

Order statistics (also known as rank, rank order, or order) filters are a general form of filters that are not based on the convolution. Here, instead of using convolution, the pixels that come under the mask are simply ordered. Then depending upon the filter requirement, based on a predetermined value of n, the nth value of the list is chosen as this value replaces the central pixel [18].

Median Filter- A median filter belongs to the class of nonlinear filters unlike the mean filter. The median filter also follows the moving window principle similar to the mean filter.

Fig. 10: Input to Median Filter

Fig. 11: Output from Median Filter

Median filtering is done by, first sorting all the pixel values from the surrounding neighborhood into numerical order and then replacing the pixel being considered with the middle pixel value is shown in figure 10 and figure 11. The median is more robust compared to the mean. Thus, a single very unrepresentative pixel in a neighborhood will not affect the median value significantly. Since the median value must actually be the value of one of the pixels in the neighborhood, the median filter does not create new unrealistic pixel values when the filter straddles an edge. For this reason the median filter is much better at preserving sharp edges than the mean filter. These advantages aid median filters in denoising uniform noise as well from an image [12].

Maximum Filter- This filter selects the largest value in the sorted list. The largest value is the last element of the list. This filter is used for removing pepper type noise [13].

Minimum Filter- This filter selects the smallest value, which is the first element of the sorted list. It is very effective in eliminating salt type noise [14].

Midpoint filter- This filter selects the midpoint. The mid-point is (f1+fN/2). This is nothing but the average of the minimum and the maximum values. This filter is effective in removing Gaussian Noise and Uniform Noise [15].

Alpha trimmed mean filter- Alpha trimmed mean filter is an order statistics filter. It is based on the concept of computation of the average of the pixels that fall within the window. This is same as the simple average filter, but the difference is that the user can clip some of the pixels by specifying an alpha value.

The main challenge in research is to removal of impulsive noise as well as preserving the image details. Our schemes utilize detection of impulsive noise followed by filtering. In the filtering without detection, a window mask is moved across the observed image. The mask is usually of size (2N +1) 2, where N is a positive integer. Generally the Centre element is the pixel of interest as shown in figure 12. When the mask is moved starting from the left-top corner of the image to the right-bottom corner, it performs some arithmetical operations without discriminating any pixel [17, 18].

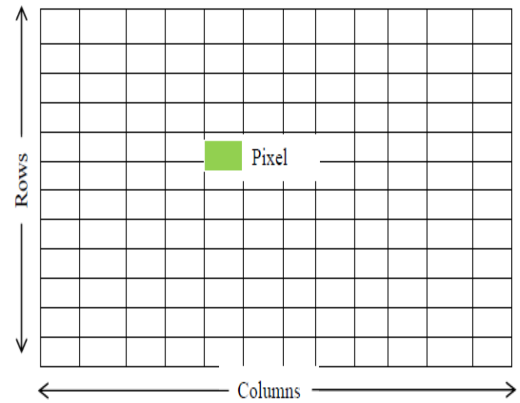


Fig. 12: Neighbourhoods of a Central Pixel (x, y)

Detection followed by filtering involves two steps. In first step it identifies noisy pixels and in second step it filters those pixels. Here also a mask is moved across the image and some arithmetical operations are carried out to detect the noisy pixels. Then filtering operation is performed only on those pixels which are found to be noisy in the previous step, keeping the non-noisy intact. The de-noising algorithm based on the threshold filter is widely used, because it’s comparatively efficient and easy to realize. We can select a threshold according to the characteristic of the image, modifying all of the discrete detail coefficients so as to reduce the noise. However, we are in the dilemma of determining the level of the threshold.

Threshold can be of two types:

1. Soft threshold.
2. Hard threshold.

Soft threshold is an extension of hard threshold, first setting to zero the elements whose absolute values are lower than the threshold, and then decrease the nonzero coefficients towards 0. Hard threshold can be described as the usual process of setting to zero the elements whose absolute values are lower than the threshold as shown in figure 13.

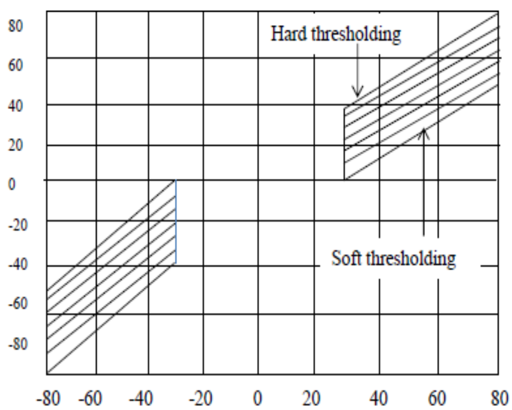


Fig. 13: Decision based on threshold

6. Conclusion

This survey highlights the diversity of image noise types and the varied performance of filtering techniques in addressing noise reduction challenges in digital image processing. Our analysis shows that each type of noise requires a specialized approach for effective filtering. The Median filter, for example, performs exceptionally well against Salt & Pepper noise, while Gaussian filters are better suited for images corrupted by Gaussian noise. Meanwhile, Speckle and Poisson noise are handled more effectively by Wiener filters in most scenarios. The results emphasize that no single filter can comprehensively manage all types of noise, which underscores the importance of selecting noise-specific filtering techniques. Additionally, the survey reveals that hybrid methods, which combine multiple filtering approaches, may offer enhanced noise reduction capabilities for complex noise environments. The study provides practitioners and researchers with valuable insights into how to choose the most appropriate filters for specific noise conditions, paving the way for more robust and reliable image processing solutions in real-world applications.

REFERENCES

[1] Anitha S, Laxminarayana Kola, Sushma P and Archana S, “Analysis of Filtering and Novel Technique for Noise Removal in MRI and CT Images”, International Conference on Electrical, Electronics, Communication, Computer and Optimization Techniques (ICEECCOT), IEEE 2017
[2] Zhao, Ting. "Filtering Methods for Biomedical Image Denoising." (2023).
[3] Ashraf, Raniya, et al. "Cutting through the Noise: A Three-Way Comparison of Median, Adaptive Median, and Non-Local Means Filter for MRI Images." Sir Syed University Research Journal of Engineering & Technology 14.1 (2024): 01-06.
[4] Abdulah, Cik Siti Khadijah, et al. "Review Study of Image De-Noising on Digital Image Processing and Applications." Journal of Advanced Research in Applied Sciences and Engineering Technology 30.1 (2023): 331-343.
[5] Ali, Kazim, et al. "De-Noising Brain MRI Images by Mixing Concatenation and Residual Learning (MCR)." Computer Systems Science & Engineering 45.2 (2023).
[6] Rajesh, M. N., and B. S. Chandrasekar. "Denoising and Enhancement of Prostate MRI Image Using a Hybrid Wiener-Median Filter."
[7] Gautam, Divya, Kavita Khare, and Bhavana P. Shrivastava. "A Novel Guided Box Filter Based on Hybrid Optimization for Medical Image Denoising." Applied Sciences 13.12 (2023): 7032.
[8] Annavarapu, Ambika, et al. "A hybrid medical image denoising based on block matching 3D collaborative filtering." SN Computer Science 5.1 (2023): 35.
[9] Aetesam, Hazique, Suman Kumar Maji, and Jerome Boulanger. "Image enhancement under Gaussian impulse noise for satellite and medical applications." Handbook of Research on Computer Vision and Image Processing in the Deep Learning Era. IGI Global, 2023. 309-342.
[10] Neela Chithirala, Natasha. B, Rubini. N and Anisha Radhakrishnan, “Weighted Mean Filter for Removal of High Density Salt and Pepper Noise”, 3rd International Conference on Advanced Computing and Communication Systems (ICACCS -2016), Jan. 22 – 23, 2016.
[11] Kumar, B. B. S. "Triple Image Compression and Denoising using Wavelet.", GIS Science Journal, Volume 10, Issue 4, 2023
[12] Duraivelu, Hemanand, et al. "Performance Comparison of Different Digital and Analog Filters Used for Biomedical Signal and Image Processing." Journal of Information Technology Management 16.1 (2024): 135-148.
[13] Sikhakhane, Kwazikwenkosi, et al. "Evaluation of Speckle Noise Reduction Filters and Machine Learning Algorithms for Ultrasound Images." IEEE Access 12 (2024): 81293-81312.
[14] Sherlin, Mrs C. Clement, and NA Sheela Selvakumari. "Liver CT Image Noise Reduction Using Enhanced Filtering and Edge Detection Technique for Liver Segmentation."
[15] Ranjitha, K. V., and T. P. Pushphavathi. "Analysis on Improved Gaussian-Wiener filtering technique and GLCM based Feature Extraction for Breast Cancer Diagnosis." Procedia Computer Science 235 (2024): 2857-2866.
[16] SATHISHA, N. "Image De-Noising Algorithm Using Adaptive Modfied Decision Base Filters." Obstetrics and Gynaecology Forum. Vol. 34. No. 3s. 2024.

[17] Habib, Muhammad, et al. "Convolved feature vector based adaptive fuzzy filter for image de-noising." Applied Sciences 13.8 (2023): 4861.
[18] Ashraf, Raniya, et al. "Cutting through the Noise: A Three-Way Comparison of Median, Adaptive Median, and Non-Local Means Filter for MRI Images." Sir Syed University Research Journal of Engineering & Technology 14.1 (2024): 01-06.
[19] Afandi Ahmad, Janifal Alipal, Noor Huda Jaaf, "Efficient Analysis of DWT Thresholding Algorithm for Medical Image De-noising", 2012 IEEE EMBS International Conference on Biomedical Engineering and Sciences.