Proceedings of the Fifth International Conference on Intelligent Computing and Control Systems (ICICCS 2021)
IEEE Xplore Part Number: CFP21K74-ART; ISBN: 978-0-7381-1327-2

COVID-19 and MRI Image Denoising Using Wavelet Transform and Basic Filtering

Kavitha S and Dr. Hannah Inbarani
Computer Science Department
Periyar University
Salem, India

2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS) | 978-1-6654-1272-8/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICICCS51141.2021.9432307

Abstract: *Eliminating noise from digital image is considered as an essential problem in image processing, for example in medical images as the noise present in the image will degrade the image quality which cannot be further classified with high accuracy. Hence, it is required to provide the images without any noises for better classification. Since the selection of denoising method to generate the quality image depends on the type of noise present in the image, it is suggested to find the best method to eliminate the noise as far as possible by preserving the edges. This paper presents the various denoising techniques such as BayesShrink and VisuShrink wavelet transform, non-local mean filter and median filter to remove the noises added through Gaussian, Speckle and salt and pepper noise in the COVID 19 chest x-ray images and the MRI images. The experiment shows that wavelet transform method performance is good for removing Gaussian noise and median filter performance is good to remove speckle and salt and pepper noise. The results are measured through visually and through the quality measure using Peak Signal to Noise Ratio (PSNR).*

Keywords: *Non-Local Mean filter, Median filter, Discrete Wavelet Transform (DWT)***,** VisuShrink, BayesShrink, *COVID 19 chest x-ray images, MR FLAIR images, Peak Signal Noise Ratio (PSNR).*

I. Introduction

Since over the last few years, medical imaging and diagnostic techniques have been developing rapidly and have played an essential role in clinical analysis and decease diagnosis. Medical images are playing an important role to capture the internal human body parts such as brain, lung, heart etc.. Usually, the digital images are contaminated by noise during transmission and acquisition which reduces the quality of an image [1] and it is to be removed before using the images for further analysis. In the case of medical images such as x-rays, MRI (Magnetic Resonance Imaging), CT (Computed Tomography), etc.., the noise present in the images can reduce the accuracy of image processing operations such as object recognition and classification to detect the decease [2]. Hence, it is essential to restore the original image by removing the noise present in the images as far as possible. Hence image denoising is an important task to be done to obtain the good quality images by preserving the important features such as edges, corners which in turn will be used for better classification [3].

So far, several denoising algorithms such as filtering methods and wavelet transform methods are proposed by researchers to eliminate the noise in the different types of image data sets[4][5][6][7]. In [2], Spatial domain filters and wavelet transform filters are compared and the results have shown that wavelet transform outperforms spatial domain filters such as mean and median to denoise the images. In [8], different denoising methods such as mean, median and wavelet transform are compared and concluded that the wavelet transform method provides the best results than the other methods. Recently, Wavelet transform based denoising methods have been applied widely as it can find frequency and location information in the images in comparison with Fourier Transform methods [24] and it is more effective since the energy of a signal can be captured with a small number of values by using the wavelet coefficients [25]. The objective of this paper is to find the appropriate denoising technique to remove the noise from the COVID 19 chest X-ray and MRI image data sets since the performance of denoising techniques differs based on the types of noises and hence the images can be used for further classification in a better way. This paper is structured as follows: The literature study is specified in the next section followed by section 3 which discuss the motivation of research. Section 4 explains the medical images used for this study. Section 5 presents the proposed methodology followed by section 6 which analyses the result and in section 7 the conclusion is presented.

II Related Work

There are several studies have been carried out to denoise the images as reported in Table I aiming on pre-processing the images for further analysis. Table I analyses the various denoising techniques for the different types of noises added in the different kind of images. Although there are various denoising methods [8][12][13] available for removing the noise from the images, the successful processing of denoising methods basically depends on the type of images used and the types of noises added in the images.

Table I Related work of this study

Authors	Techniques	Result
Alisha P B, Gnana Sheela K. [2]	Spatial domain filters, wavelet transform methods are used.	Wavelet transform outperforms spatial domain filters such as mean and median to denoise the images.
Linwei Fan, Fan Zhang, Hui Fan & Caiming Zhang. [3]	Spatial domain filtering, Transform domain filtering, CNN based denoising methods.	It is concluded that different types of noises require different denoising methods.
Vikas Gupta, Rajesh Mahle, Raviprakash S Shriwas. [12]	BayesInvariant wavelet, VisuShrink and Sureshrink methods to denoise the images.	BayesInvariant wavelet based method performance is best compared with the VisuShrink and Sureshrink methods.
Anandbabu Gopatoti , Kiran Kumar Gopathoti, Sai Prasanna Shanganthi , Chappali Nirmala.[13]	Gaussian, Wiener, Mean and median filters are used to denoise the images added with Gaussian, impulsive, speckle, and Poisson noise.	The results have shown that Median filter works well for Impulsive noise than Mean, Gaussian, whereas Wiener filter works well for removing Poisson and speckle noise.
Gurmeet Kaur, Rupinder Kaur [14]	Wavelet transform, Gaussian filter, Average filter and wiener filters.	It is concluded that Wavelet transform is better than Gaussian filter, Average filter and wiener filters to denoise the image.
Dr. Ahmad Odat, Dr. Mohammed Otair, and Fadi Shehadeh.[15]	Comprehensive Median Filter is proposed to denoise the salt and pepper noise image.	The proposed median filter has shown the better image quality than traditional median filter after removing salt and pepper noise.
Qingkun Song,Li Ma,JianKun Cao,Xiao Han.[16]	Wavelet transform and mean filter is combined to denoise the images.	The proposed method has shown the better result compared with the hard and soft threshold function and median filter.
Jyotsna Patil, , Sunita Jadhav.[17]	Wavelet Transform and spatial filtering	It is concluded that the wavelet transform is best suitable than spatial filters as these filters causes over smoothing and causes blurring of image.
Kusum Tharani, Chandra Mani and Ishaan Arora.[21]	Wavelet based thresholding methods namely VisuShrink, SureShrink, BayesShrink and minimax are compared for denoising the detailed and smooth images.	The results have shown that Bayes shrink's performance is better for both detailed and smooth images among the other shrinking methods.
Payal Gupta and Amit Garg.[22]	2D discrete wavelet transform with the BayesShrink thresholding method is proposed to denoise the kidney Ultrasound image and the boat image.	The proposed method PSNR value is high compared with the wavelet based denoising method.
Anutam and Rajni.[24]	Wavelet methods with different decomposition levels are used to denoise the cameraman image.	The results reveal that wavelet based Bayes thresholding outperforms the filtering methods.

Agarwal S, Singh O.P, Nagaria D.[25]	Different wavelet transform methods such as Morlet transform, Haar transform, Daubechies Transform, Symlet Transform are proposed to denoise the brain MRI image.	The results show that Symlet Transform method outperformed other wavelet transforms.
C. Ning, S. Liu and M. Qu.[26]	Median filter and Adaptive median filter are proposed to denoise CT and MRI medical images which are added with impulse noise.	It is concluded that adaptive median filter works well to eliminate impulse noise with larger density.

III. Research Motivation

Since the medical images are prone to noises, it is required to denoise the images as a pre-processing step to give the better quality images by removing the irrelevant data for further analysis such as feature extraction and classification. Hence, it is necessary to find the suitable technique to eliminate the noise without losing any detail information as the denoised image quality is based on the types of noises and types of denoising techniques used. In this study COVID-19 chest x-ray images and MRI brain images are used to find the appropriate denoising technique to eliminate the noise present in the images for better classification.

IV. Medical Image Data Sets

Two types of image data sets are used for analysis such as chest x-ray images and Brain tumor MR images. The chest x-ray image data set has nearly 350 images which are categorized in two classes such as normal and covid-19 images. The images are grayscale and dimensions of images are 256 x 256. From the brain tumor MR image data set, 300 FLAIR modality MR images have taken for analysis. These images are grayscale and the dimensions of the images are 240 x 240.

V. Proposed Method

In this paper, we proposed various denoising techniques such as spatial domain filtering(NL-means and median) and transform domain filtering(wavelet transform) to remove the noise added in the chest x-ray images and MR FLAIR modality images through Gaussian, speckle noise and salt and pepper noise.

Fig. 1 shows the proposed model which consists of following steps:

i) A sample image from chest x-ray image data set is added with Gaussian, Speckle and Salt and Pepper noise with the sigma value as 0.15, 0.15 and 0.10 respectively.

ii) A sample image from brain MRI image data set is added with Gaussian, Speckle and Salt and Pepper noise with the sigma value as 0.1, 0.15 and 0.10 respectively.

iii) Then the noisy images are denoised using NL-means, median filters and wavelet transform methods with two thresholding functions such as BayesShrink and VisuShrink.

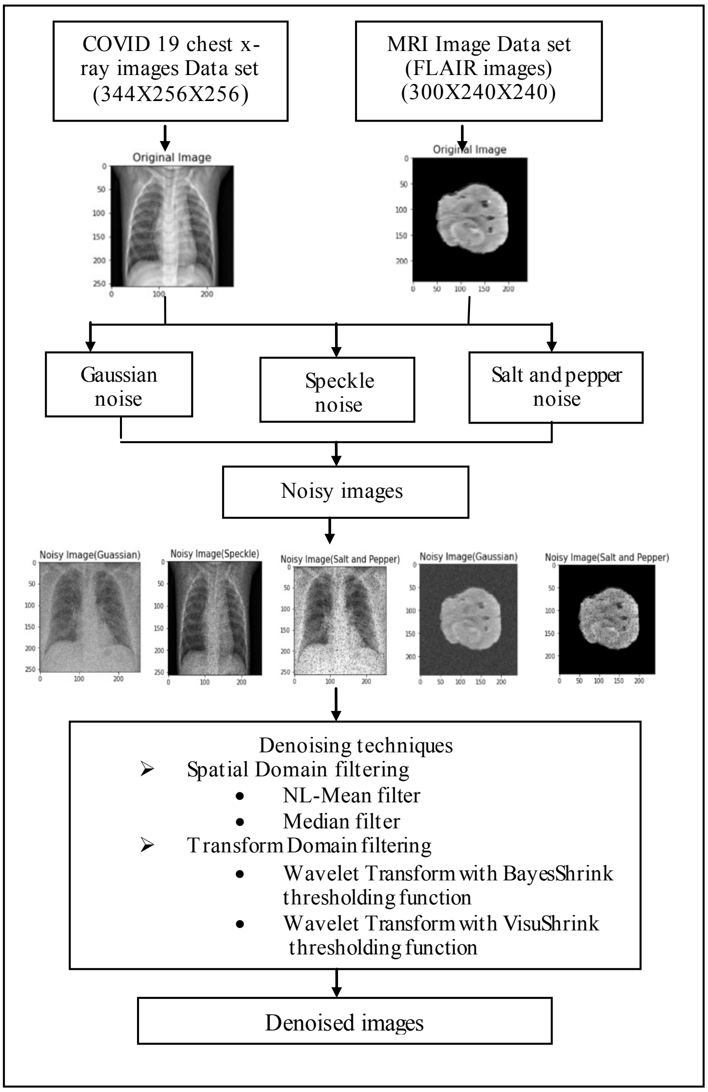


Fig.1 Block diagram of proposed method

A) Adding Gaussian noise

The sample image is added with Gaussian noise with the sigma value as 0.15 to produce a noisy image. It is an additive noise [8] in which each pixel is the sum of Gaussian distributed random noise value and true pixel values [9]. It is represented using the probability density function p as:

$$p(z) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(z-\mu)^2}{2\sigma^2}} \quad (1)$$

Where z is the gray level, μ is a mean value, σ is a standard deviation and σ^2 is the variance of g. The noise is generated by multiplying the sigma with the standard Gaussian distribution of mean 0 and variance 1 and then the noise is added with original image to produce a noisy image.

B) Adding Speckle noise

Speckle noise is a multiplicative noise [10][11] which has the following pattern:

$$A(x,y) = f(x,y) * N(x,y) + N1(x,y) \quad (2)$$

Where A(p,q) denotes observed image, N(p,q) and N1(p,q)indicate multiplicative, additive components[9]. It has gamma distribution as probability density function, and it is given as:

$$F(g) = \frac{g^{\alpha-1} e^{\frac{-g}{a}}}{\alpha-1!a^{\alpha}} \quad (3)$$

C) Adding Salt and Pepper noise

Salt and Pepper noise is appeared due to the error in data transmission and the error in analog to digital converter. It produces white and black spot in the image by taking either maximum value (i.e.255) or the minimum value (i.e.0) which can reduce the quality of an image [23]. The PDF of this noise is given by:

$$p(g) = \begin{cases} p_a & for\ g = a \\ p_b & for\ g = b \\ 0 & otherwise \end{cases} \quad (4)$$

Where, the 'region a' has the minimum value and 'region b' has the maximum value.

D) Denoising the images using mean, median and wavelet transform

In this study, three denoising techniques such as NL-means and median filter available under spatial domain filtering and wavelet transform methods available under transform domain filtering are applied to eliminate the noise from the images.

1) Non-Local Mean filter

Non-Local Mean filter estimates the value of a pixel based on the weighted average of all pixels in the image but the family of weights depend on the similarity between the pixels [27] which means the weighted average is calculated only for the pixels that are similar to the current pixel. It has the following representation:

$$NLM[v](i) = \sum_{j\in I} w(i,j)v(j) \quad (5)$$

Where NLM[v] (i) is a estimated value on the noisy image v at position i and w (i, j) is the set of weights which is calculated based on the correspondence of the pixels i and j.

2) Median filter

Median filter is a non-linear spatial filter in which the center pixel value is changed by the median of the intensity values in the adjacent pixels to achieve the smoothness in an image. It provides less blurring for an image for some types of random noise [18]. The two-dimensional median filter is given by the equation:

$$f(x,y) = median\{g(p,t\} \quad and \quad (p,t) \in p_{xy} \quad (6)$$

Where p_{xy} denotes the m x n sub image of a noisy input image 'g' at the coordinate (x, y) and f(x, y) is a result of median filter at the coordinate (x, y) [26].

3) Wavelet Transform

In Wavelet based denoising scheme, the signal f (k) is first decomposed using the DWT into the various wavelet coefficients. By using the thresholding function these coefficients are thresholded and then apply the inverse transform to these coefficients to achieve a denoised image. In this paper, VisuShrink and BayesShrink thresholding methods are implemented using three levels of decomposition.

a) VisuShrink

VisuShrink method is proposed by Dohono and Johnstone [19, 20]. It is a universal thresholding, non-adaptive method in which the threshold is calculated by the following equation:

$$T_v = \sigma\sqrt{2logK} \quad (7)$$

Where σ is noise variance and K is number of pixels of the image. For denoising the images, it is found to produce a smooth estimate as it has high threshold due to the dependency on the number of pixels in the image [21].

b) BayesShrink

BayesShrink uses the soft thresholding method to denoise the images and sets different threshold for each sub-band [21]. This method estimates a threshold value to minimize the Bayesian risk by assuming the Gaussian distribution for the wavelet coefficients in each detail sub-band [1]. The threshold value is given by the following equation.

$$T_b = \begin{Bmatrix} \frac{\sigma_v^2}{\sigma_x^2} & if \sigma_v^2 < \sigma_x^2 \\ otherwise & max\{|w_j|\} \end{Bmatrix} \quad (8)$$

Where W_j are the wavelet coefficients in each scale j, σ_v^2 is the noise variance which is estimated from the sub band by the median estimator and σ_x^2 is original image variance. The variance of degraded image for each sub band can be calculated as:

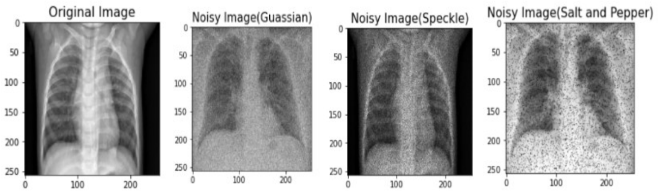
$$\sigma_y^2 = \frac{1}{J}\sum_{j=1}^{J} w_j^2 \quad (9)$$

Where J is the total number of coefficients in the sub band, and σ_x is calculated by the following equation:

$$\sigma_x = \sqrt{\max(\sigma_y^2 - \sigma_v^2)},0 \quad (10)$$

VI. Result Analysis

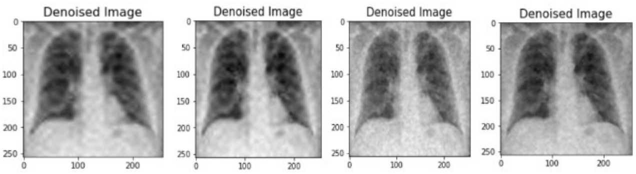
Fig. 2 shows the sample image of COVID 19 chest X-ray image data set after adding the noises.



(i) (ii) (iii) (iv)

Fig.2 i) Original Image ii) Gaussian noise (15%) iii) Speckle noise (15%) iv) Salt and Pepper noise (10%)

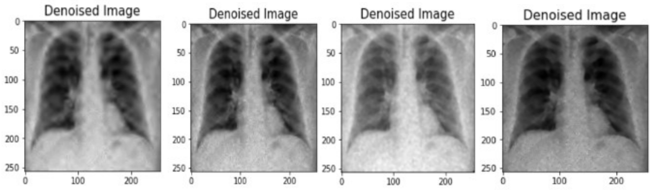
Fig. 3 displays the sample denoised images of Gaussian noisy image removed through wavelet transform, mean filter and median filter. These images are analyzed with the original images using the evaluation metric such as PSNR to assess the image quality. The results shown that the wavelet transform methods produce the good quality image compared with the mean and median filters for removing Gaussian noise which is also evaluated using PSNR and the results are given in Table II.



(i) (ii) (iii) (iv)

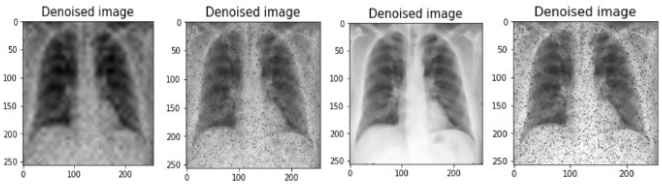
Fig.3 Denoised images of Gaussian noise i) Wavelet Visushrink ii) Wavelet Bayesshrink iii) Median fliter iv) NL-Mean Filter

Fig. 4 and Fig. 5 shows the sample denoised images of Speckle and Salt and Pepper noise produced through wavelet transform, mean filter and median filter and the outcomes describes that the median flilter produces the good quality image than the mean and wavelet transform methods for removing salt and pepper noise and for Speckle noise, wavelet transform method filters the noise well than the mean and median filters. It is evaluated using PSNR and the outcomes are given in Table II.



(i) (ii) (iii) (iv)

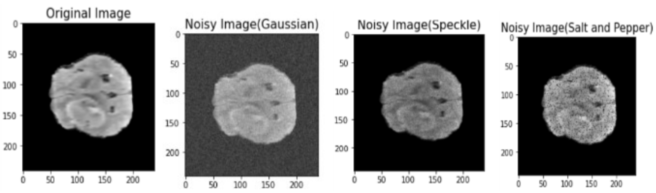
Fig.4 Denoised images of Speckle noise i) Wavelet Visushrink ii) Wavelet Bayesshrink iii) Median fliter iv) NL-Mean Filter



(i) (ii) (iii) (iv)

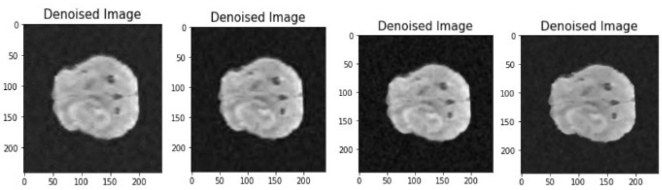
Fig.5 Denoised images of Salt and Pepper noise i) Wavelet Visushrink ii) Wavelet Bayesshrink iii) Median fliter iv) NL-Mean Filter

Fig. 6 shows the sample image of MRI FLAIR modality images after adding the noises. Fig. 7 shows the sample denoised images of Gaussian noisy image created through wavelet transform, mean filter and median filter. The quality of reconstructed image is analyzed using PSNR with the original image. The results describes that the Bayes Wavelet transform method produces the good quality image than the mean and median filters for removing Gaussian noise which is also evaluated using PSNR and the results are given in Table III.



(i) (ii) (iii) (iv)

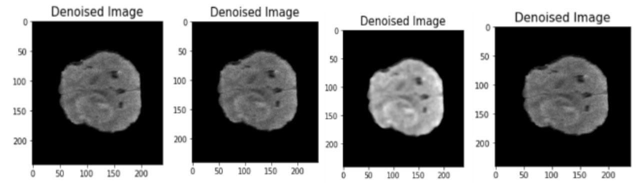
Fig.6 i) Original Image ii) Gaussian noise (1%) iii) Speckle noise (15%) iv) Salt and Pepper noise (10%)



(i) (ii) (iii) (iv)

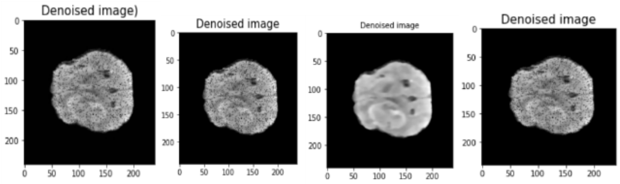
Fig.7 Denoised images of Gaussian noise i) Wavelet Visushrink ii) Wavelet Bayesshrink iii) Median fliter iv) NL-Mean Filter

Fig. 8 and Fig. 9 shows the sample denoised images of Speckle and Salt and Pepper noise generated through wavelet transform, mean filter and median filter and it is shown that the median flilter produces the good quality image compared with the mean and wavelet transform methods for removing both Speckle and Salt and Pepper noise. The results are evaluated using PSNR and it is given in Table III.



(i) (ii) (iii) (iv)

Fig.8 Denoised images of Speckle noie i) Wavelet Visushrink ii) Wavelet Bayesshrink iii) Median fliter iv) NL-Mean Filter



(i) (ii) (iii) (iv)

Fig.9 Denoised images of Salt and Pepper noie i) Wavelet Visushrink ii) Wavelet Bayesshrink iii) Median fliter iv) NL-Mean Filter

A) **Evaluation parameter**

Peak Signal to Noise Ratio(PSNR)

The PSNR is a metric used to calculate the peak signal-to-noise ratio between two images to assess the quality of the image by comparing denoised images with the original images. It shows the ratio between the power of a distorting noise and the maximum power of an image. It is represented in decibels. The higher PSNR value represents the better denoised image. The evaluation of all the denoising methods applied to the image datasets are analyzed using the PSNR to find the appropriate method. Table II shows the PSNR values of various denoising methods applied to COVID 19 chest X-ray images which are added with various noises.

Table II PSNR values of noises added in Chest x-ray images

Denoising methods	PSNR/dB (Gaussian)	PSNR/dB (Speckle)	PSNR/dB (Salt and Pepper)
Before denoising (Between Original and Noisy images)	16.47	20.26	14.04
Wavelet Transform-VisuShrink method (Between original and denoised images)	29.53	30.55	22.45
Wavelet transform-BayesShrink method (Between original and denoised images)	30.17	29.84	17.20
NL-Mean filter(Between original and denoised images)	27.81	27.63	15.11
Median filter (Between original and denoised images)	27.33	29.99	33.37

Table II explains that for Gaussian and Speckle noise, Wavelet transform method gives the higher PSNR values compared to mean and median filters. Median filter gives the higher PSNR value for Salt and pepper noise than mean and wavelet transform methods. If the value of PSNR is high, then the quality of the reconstructed image is also high which is good for better classification.

Table III PSNR values of noises added in MRI FLAIR images

Denoising methods	PSNR/dB (Gaussian)	PSNR/dB (Speckle)	PSNR/dB (Salt and Pepper)
Before denoising (Between Original and Noisy images)	**60.05**	65.95	**59.68**
Wavelet Transform-VisuShrink method (Between original and denoised images)	**69.88**	65.99	59.76
Wavelet transform-BayesShrink method (Between original and denoised images)	**71.11**	65.95	59.68
Mean filter(Between original and denoised images)	**70.80**	65.95	59.68
Median filter (Between original and denoised images)	**70.44**	72.96	73.55

Table III shows that for Gaussian noise, Bayes Wavelet transform method gives the higher PSNR values compared to mean and median filters. For Speckle and Salt and pepper noise, the higher PSNR value is achieved through median filter compared to mean and wavelet transform methods.

B) Performance analysis of denoising methods using PSNR for Chest x-ray images and MR FLAIR images

Fig. 10 and Fig. 11 show the graph which analyses the performance of the denoising methods used for eliminating the noise from the images. From the graph, it is shown that the wavelet transform gives the higher PSNR value among the other denoising techniques for Gaussian noise and for speckle and Salt and Pepper noise, median filter gives higher PSNR value compared to wavelet transform methods.

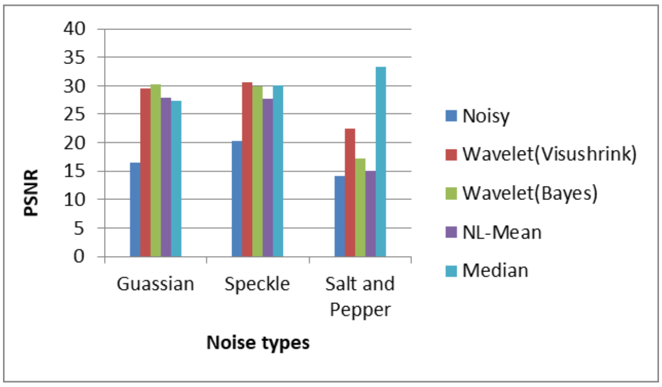


Fig.10 PSNR performance of denoising methods for chest x-ray images

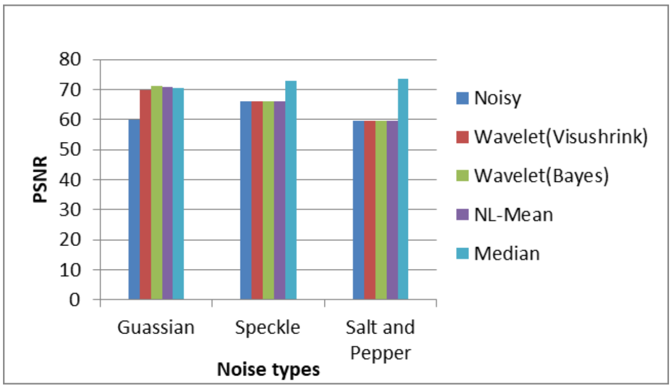


Fig.11 PSNR performance of denoising methods for MR FLAIR images

VII. Conclusion

In this study, different denoising methods are analyzed to denoise the images from the COVID-19 chest X-ray images and MRI FLAIR images for better classification. The denoised images are evaluated using PSNR. In the case where the chest x-ray images are corrupted with Gaussian noise, BayesShrink wavelet transform denoising method gives the better-quality image with high PSNR value. For speckle noise, VisuShrink wavelet transform gives the high PSNR value and for salt and pepper noise median filter gives the better-quality image with high PSNR value. In the case of brain MRI images, for Gaussian noise, BayesShrink wavelet transform removes the noise in a better way. For Speckle and salt and pepper noise, Median filter gives the better-quality image with high PSNR value. From the results, it is observed that Wavelet transform methods are good to remove Gaussian noise and median filter performs good to remove Speckle and salt and pepper noise. In the Future work, the denoised images will be used for segmentation and better classification.

References

1. Sanches, Joo M., Jacinto C. Nascimento, and Jorge S. Marques. ”Medical image noise reduction using the SylvesterLyapunov equation.” IEEE transactions on image processing 17.9 (2008): 1522-1539.
2. Alisha P B, Gnana Sheela K, “Image Denoising Techniques-An Overview”, IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 11, Issue 1, Ver. I (Jan. - Feb .2016).
3. Linwei Fan, Fan Zhang, Hui Fan & Caiming Zhang,” Brief review of image denoising techniques”, Visual Computing for Industry, Biomedicine, and Art volume 2, Article number: 7 (2019),Springer.
4. S. G. Chang, B. Yu, and M. Vetterli, “Spatially adaptive wavelet thresholding with context modeling for image denoising,” IEEE Transactions on Image Processing, vol. 9, no. 9, pp. 1522–1531, 2000.
5. A. Pižurica, W. Philips, I. Lemahieu, and M. Acheroy, “A joint inter- and intrascale statistical model for Bayesian wavelet based image denoising,” IEEE Transactions on Image Processing, vol. 11, no. 5, pp. 545–557, 2002.
6. Lovedeep Gondara,” Medical image denoising using convolutional denoising autoencoders”, 2016 IEEE 16th International Conference on Data Mining Workshops.
7. L. Zhang, P. Bao, and X. Wu, “Multiscale LMMSE-based image denoising with optimal wavelet selection,” IEEE Transactions on Circuits and Systems for Video Technology, vol. 15, no. 4, pp. 469–481, 2005.
8. Rajni, Anutam, “Image Denoising Techniques –An Overview,” International Journal of Computer, Vol. 86, No.16, January 2014.
9. Rafael C. Gonzalez and Richard E. Woods “Digital Image Processing “ , Pearson Education, Second Edition 2005.
10. Gagnon, L. “Wavelet Filtering of Speckle Noise- some Numerical Results, Proceedings of the Conference Vision Interface”, Trois-Reveres.1999.
11. Goodman, J. W. “Some fundamental properties of Speckle”, J. Opt. Soc. Am., 66, pp. 1145–1150. 1976.
12. Vikas Gupta, Rajesh Mahle, Raviprakash S Shriwas,” Image Denoising using Wavelet Transform Method”, Wireless and Optical Communications Networks (WOCN), 2013 IEEE ,Tenth International Conference.
13. Anandbabu Gopatoti , Kiran Kumar Gopathoti, Sai Prasanna Shanganthi , Chappali Nirmala,” Image Denoising using spatial filters and Image Transforms: A Review”, International Journal for Research in Applied Science & Engineering Technology (IJRASET) ISSN: 2321-9653, April 2018.
14. Gurmeet Kaur, Rupinder Kaur, ” image de-noising using wavelet transform and various filters”, International Journal of Research in Computer Science, February 2012.
15. Dr. Ahmad Odat, Dr. Mohammed Otair, and Fadi Shehadeh,” mage Denoising by Comprehensive Median Filter”, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 15 (2015).
16. Qingkun Song,Li Ma,JianKun Cao,Xiao Han,” Image Denoising Based on Mean Filter and Wavelet Transform”, 2015 4th International Conference on Advanced Information Technology and Sensor Application.
17. Jyotsna Patil, , Sunita Jadhav,” A Comparative Study of Image Denoising Techniques”, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 3, March 2013.
18. Rafael C. Gonzalez and Richard E. Woods “Digital Image Processing “ , Pearson Education, Fourth Edition 2018.
19. D.L. Donoho, and I.M. Johnstone, “Ideal spatial adaptation via wavelet shrinkage”, Biometrika, 81, 1994, pp.425-455.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
20. Donoho, D. L. “De-noising by softthresholding” IEEE Transactions on Information Theory, 41(3), 613-627., 1995.
21. Kusum Tharani, Chandra Mani and Ishaan Arora,” A Comparative Study of Image Denoising Methods Using Wavelet Thresholding Techniques”, Int. Journal of Engineering Research and Application, ISSN : 2248-9622, Vol. 6, Issue 12, (Part -1) December 2016.
22. Payal Gupta and Amit Garg,” Image Denoising Using Bayes Shrink Method Based On Wavelet Transform”, International Journal of Electronic and Electrical Engineering. ISSN 0974-2174 Volume 8, Number 1 (2015).
23. Fangfang Dong, Yunmei Chen, De-Xing Kong, Bailin Yang,”Salt and pepper noise removal based on an approximation of l0 norm”, Computers & Mathematics with Applications, Volume 70, Issue 5, 2015,Pages 789-804,ISSN 0898-1221.

24. Anutam and Rajni "Performance Analysis Of Image Denoising With Wavelet Thresholding Methods For Different Levels Of Decomposition" The International Journal of Multimedia & Its Applications (IJMA) Vol.6, No.3, June 2014.
25. Agarwal S, Singh O.P, Nagaria D. "Analysis and Comparison of Wavelet Transforms for Denoising MRI Image". Biomed Pharmacol J 2017;10(2).
26. C. Ning, S. Liu and M. Qu, "Research on removing noise in medical image based on median filter method," *2009 IEEE International Symposium on IT in Medicine & Education*, Jinan, China, 2009, pp. 384-388.
27. A. Buades, B. Coll and J. -. Morel, "A non-local algorithm for image denoising," 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05), San Diego, CA, USA, 2005, pp. 60-65 vol. 2, doi: 10.1109/CVPR.2005.38.