PAPER • **OPEN ACCESS**

A Review on Speckle Noise Reduction Techniques in Ultrasound Medical images based on Spatial Domain, Transform Domain and CNN Methods

To cite this article: S Pradeep and P Nirmaladevi 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1055** 012116

A Review on Speckle Noise Reduction Techniques in Ultrasound Medical images based on Spatial Domain, Transform Domain and CNN Methods

S Pradeep[1*], P Nirmaladevi[2]

[1]Assistant Professor, Department of ECE, M.Kumarasamy College of Engineering, Thalavapalayam, Karur 639113, India
[2]Professor, Department of ECE, Kongu Engineering College, Perundurai 638060, India

Email: *researchpradeeps@gmail.com

Abstract: Ultrasonography is non-invasive and painless. In Ultrasonography the images are often affected with Speckle noise. It is a multiplicative noise. To help the doctors to identify the abnormalities properly there are several methods to diagnose as speckle is a major problem. This paper gives details about popular spatial domain, transform domain, CNN techniques for despeckling in ultrasound images. Transform domain methods like Wavelet methods, Curvelet methods, Bayes Shrink methods are prominent among many researches. Deep learning based methods are evolving like DnCNN, ECNDNet etc. for efficient despeckling. An overview of the methods is given here with certain measurement parameters like PSNR, MSE.

Keywords: Ultrasound, Speckle Noise, Wavelet, Curvelet, CNN, Spatial Domain, Transform Domain.

1. Introduction:

Ultrasonography technique is often affected with multiplicative noise[1]. Speckle noise is given by the equation 1.

$$I(p,q) = F(p,q) \quad N(p,q) \qquad (1)$$

Where I(p,q) = Image with Speckle Noise, F(p,q)= original image, N(p,q)= speckle noise. Ultrasound is preferred as it is non invasive and it uses about 1MHz to 15MHz. It uses hazard free high frequency sound waves for imaging the human organs. Human organs include uterus, spleen, kidney, bladder, thyroid, blood vessels, thyroid etc. Speckle noise in ultrasound is due to interference of sound waves and reflected echo. It is like a granular pattern of salt and pepper. Speckle reduction is often required for exact detection of lesions, edge detection etc[2]. To reduce speckle there are two ways it can be either post processing task or spatial and frequency compounding. The later one has significant higher PSNR.

2. Speckle Noise

Ultrasound is low cost imaging technique and radiation free. The multiplicative nature of the speckle noise which makes the ultrasound image unsuitable for

IOP Conf. Series: Materials Science and Engineering 1055 (2021) 012116 doi:10.1088/1757-899X/1055/1/012116

diagnosis by Medical Practitioner. Speckle Noise presence may lead to wrong conclusion in edges, textures and lines. Speckle noise free Medical Ultrasound is must for a better diagnosis. Speckle Noise in Ultrasound images can degrade the quality of image[3]. The Presence of Speckle noise leads to false findings of edges. It may affect the perfect segmentation, classification, restoration process in Medical Image Processing.

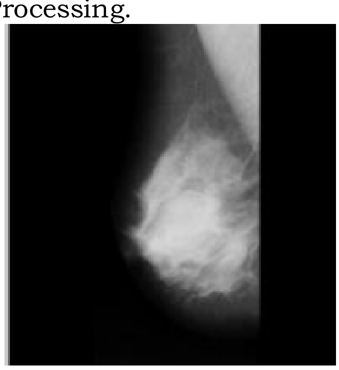


Figure 1: Normal Image

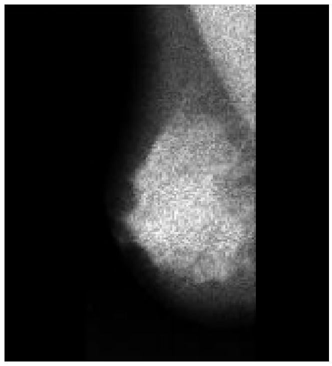


Figure 2: Speckle Noise image

3. Speckle Reduction Techniques

The Speckle noise filtering techniques are classified as follows

1. Spatial domain techniques
2. Transform domain techniques
3. Deep learning based techniques

3.1 Spatial Domain Techniques

Spatial domain filters includes Median filters, Non local Means Filter, LMMSE, BM4D etc. Usage of this filters are much effective as these filters offers a less complexity in terms of computation but spatial domain filters may sometimes blurs the image and there may be resolution losses[4].

3.1.1 Mean Filter:

The mean filter is the best to denoise the Gaussian, speckle and Poisson noise but with high blurriness value. This problem is overcome using the wiener filter in case of the Gaussian noise and using the median filter in case of the speckle and the Poisson noise. Mean filter has blurring effect. Ja I. Koo et al [5] has proposed a An adaptive image filtering technique known as homogeneous region growing mean filter has assumed a region which is more than average speckle in order to identify the proper speckle region,. If the center point is determined homogeneous region can be found according to similarity and homogeneity. Here the edges are preserved with any degradation.

3.1.2 Adaptive Mean Filters:

Standard Adaptive mean filters are Lee (1980) [6], Frost (1982) [7], Kuan filter (1985) [8]. Huge Despeckling has evolved still it is a challenge for the researcher and doctors as there is no suitable denoising model present till date. Lee and Kuan filters are similar and it is better for the normal regions. Speckle noise may be there in lines, edges, textures etc. ENL is considered in Kuan filter for weighting function. Both filters differ with the weighting function. Frost filter [1982] proposed for the reduction of noise which is multiplicative in nature. Here the noisy pixel of an image is replaced with the value which is sum of all the pixels of the kernel considered.

IOP Conf. Series: Materials Science and Engineering 1055 (2021) 012116 doi:10.1088/1757-899X/1055/1/012116

3.1.3 Anisotropic Diffusion Algorithm

Perona and Malik in 1990 [9], proposed Anisotropic diffusion algorithm and has been improved by many research works later [11]. PMD filter aims at reduction of speckle by preserving the edges, lines, regions of images. PMD filter is similar to Gaussian blurring. If the diffusion coefficient is persistant, the PMD equation is reduced to Heat equation. For detection of image boundaries sometimes PMD filters can be used. Perona Malik Diffusion (PMD) or Anisotropic diffusion filter is given as

$$\begin{cases} \frac{\partial I_{gt}}{\partial x} = div(c(x,y,t).\ \nabla I_{gt} \\ I_{gt}(t=0) = I_O \end{cases} \tag{2}$$

C(x,y,t) is known as coefficient of diffusion and ∇ is a Del Operator

3.1.4 Non Local Means Filter

A mean filter takes average of all pixels of a kernel whereas Non Local means filter is based on the concept of taking mean values of all pixels weighted by same type of pixel value to the target pixel value. Non local Means (NLM) filter protects the edges pixel of an image being changed [10]. The average pixels that have similar neighbourhood is given as

$$g(P) = \frac{1}{z} \sum G_{\sigma}(\mathrm{N_p} - \mathrm{N_q})\ \mathrm{f(q)} \tag{3}$$

where $G_{\sigma}(x) = e^{-\left(\frac{\sum_i x_i^2}{2\sigma^2}\right)}$ is Gaussian weighting based on Difference in Image intensities, Z is the Normalization.

3.2 Transform Domain Filters

Wavelet transforms is a tool used now a days for removal of speckle in an image. Wavelet transform is a popular transformation used for conversion from time domain to frequency domain and inverse wavelet transform is to transform from frequency domain to time domain. There are many wavelet transforms which has several purpose like removal of noise, enhancing image etc. Based on the peculiar property of wavelet it can be used for various purpose of image processing. Numerous despeckling channels are proposed dependent on multiscale changes for intelligent pictures like ultrasound and SAR pictures.

X. Zong et al 1998 [11], proposed multiscale nonlinear technique in which wavelet shrinkage techniques are employed for the reduction of speckle noise. Usage of wavelet shrinkage technique preserves the edges of the image. Coefficients of logarithmically transformed echocardiograms are soft thresholded for wavelet coefficient shrinkage. The features are restored and the features are enhanced with the non linear stretching of coefficients of wavelet. Various ultrasound images are used for result.

Chang and Vetterli 1997 [12], has proposed a wavelet thresholding technique which has increased the threshold uniformly in regions like textures edges as images are segmented into different sub regions. All the sub regions has threshold which is helpful for soft thresholding. Limitation of the work is that it has increased complexity due to complete segmentation of regions of the image.

Chang et al 2000 [13], has proposed a technique based on wavelet threshold which is improved spatially adaptive wavelet thresholding model especially for compression of images. Variables assumed for each coefficient of subband is taken as random one. This method is for preserving the edge and texture.

Michailovich, Tannenbaum 2006 [14], has analysed the coorelation properties. Between the image samples there may be correlation it can be reduced

IOP Conf. Series: Materials Science and Engineering 1055 (2021) 012116 doi:10.1088/1757-899X/1055/1/012116

by means of whitening procedure. In the proposed Modified Homomorphic Despeckling Algorithm, by Wavelet transform the signal is converted to orthogonal domain resulting with wavelet coefficients. These coefficients are soft-thresholded. Inverse wavelet transform is then applied.

S.Sudha et al 2009 [15], has proposed adaptive threshold selection model in wavelet thresholding technique. Taking Logarithm for the multiplicative noise results in additive noise. Discrete Wavelet Transform (DWT) is performed for level 2 and the subband are obtained for which noise variance is obtained. Weighted variance is calculated and threshold has been computed. By soft thresholding all the sub band coefficients are thresholded. Inverse DWT is performed to get noise free image.

Nirmala devi, Asokan 2014 [16], proposed Shift invariant improved adaptive wavelet thresholding function (SIIATF), it is a versatile method in case of wavelet shrinkage algorithm and it is also an adaptive algorithm, with subband adaptive threshold for the removal of speckle noise in ultrasound images is proposed. Tuncation Threshold for identifying the wavelet coefficient. This method eliminates the fixed bias problem. Performance metrics are PSNR, MSE, NSD, ENL, NMV, SSIM, EPI [.

Elyasi et al 2016 [17], proposed Homogeneity modified bayes shrink algorithm. Ultrasound image is filtered by Homogenity filter then discrete wavelet filtering is applied to filtered image. The coefficient of approximation and the coefficient of detail are obtained. Modified Bayes Shrink thresholding (MBS) technique is applied for detailed coefficients. A soft thresholding technique is applied after MBS technique. Approximation coefficients are then combined with MBS thresholded coefficients then Inverse discrete wavelet transform (IDWT) is applied to get a despeckled image.

Mafi et al 2018 [18], proposed a method for removal of speckle and Gaussian Noise in ultrasound images where 2 level DT-CWT is applied to the noisy image. First stage is applied with the dual tree wavelet transform and next stage 10-tap Kingsburry Q-shift filters are applied. Soft thresholding with SURE estimation is applied. Then inverse DT-CWT is used to get reconstructed image [23].

Shan Gai et al 2018 [19], proposed Monogenic Wavelet Transform (MWT) and Bayesian framework, a unique speckle noise reduction methodology for medical ultrasound images. Noiseless and noisy component are generally termed as Monogenic coefficients in this paper. Theese noisy and noise free components are modelled as Rayleigh distribution and Laplacian mixture distribution. Bayseian based estimator is designed for removal of noise. Expectation maximization algorithm plays a vital role in evaluation of parameters of MWT.

Chen Bing-quan et al 2019 [20], has proposed Image denoising technique known as Improved Discrete wavelet transform with Modified Median filter as well as image enhancement using canny edge operator. Quantitative analysis and Visual quality of the results illustrates that the method proposed is better than previous algorithms proposed. X-ray, Ultrasound, CT, MRI – tumor images of 256x256 are considered by adding two noises namely impulse Noise and Gaussian noise.

S. Shajun Nisha et al 2020 [21], has proposed multiscale transforms like contourlet, Ridgelet, wavelet. After decomposition, coefficients are thresholded with Sureshrink, bayeshrink, Neighsureshrink. Various Images of MRI, CT, are used. Neighsureshrink with Contourlet based denoising showed better results for Medical Images as per the metrics PSNR, SSIM, WSNR.

Randhawa et al 2018 [22], has proposed a Novel adaptive wavelet thresholding function in which orthogonal wavlet, biorthogonal wavelet filters, symlet 8 are applied to the synthetic images to take the result. Images are added with multiplicative speckle noise with variance of initial value taken as 0.01 and final value as 0.2. Symlet 8 has better performance results. The technique is applied to Liver ultrasound images.

Sirapat Chiewchanwattana et al 2020 [23], proposed a despeckling filter with an aim to keep all the required features in the same without degrading. The algorithm proposed is based on adaptive thresholding function and a cuckoo search algorithm (CS-WT thresholding adaptive filter) . It preserves the lines, edges and textures with lower complexity and reduced MSE and MAE. PSNR and SSIM are comparatively improved compared with other optimization algorithms.

The wavelet proposed by leal et al [24] has better results than wavelets from Daubechies etc along with Nelder Mead simplex method and numerical optimization algorithm characterized by different filter taps. The actuual image is affected with speckle noise with variance V. Two dimensional decomposition of the corrupted image results in wavelet coefficients. Lower values of coefficients compared with the threshold are removed.

3.3 CNN based Denoising methods

Y.Chang et al 2019 [25], has proposed Two stage CNN based image denoising model where both image and noise are modelled at a time with Image decomposition concept for better performance of the model. A noise sub network of this Deep CNN model gives the estimation of noise. Noise distribution is easy to grasp as Image sub network is guided by the Noise sub network. Measurement metrics like PSNR and SSIM are estimated for Speckle noise and Gaussian Noise.

Shahdoosti et al 2019 [26], proposed a deep convolutional neural network which has unsampled shearlet transform to decompose the image to various sub bands of low, high frequency. A 3Dimensional patch is given as input for the deep CNN to know whether it has edge features. Higher frequency subband's 2Dimensional block are arranged to form a 3Dimensional block. Edge Coefficients are unaltered and Noisy pixels are denoised using wavelet shrinkage and adaptive threshold (Soft Thresholding Technique). Canny algorithm is used for training to determine the edge.

W Jifara et al 2019 [27], has proposed a CNN in which residual learning approach is used to learn the noise from the image corrupted with noise. This approach will not use clean image for learning. The noise free image is obtained by determining the difference between the noisy image and residual. The stability of the network line accuracy is improved by Batch normalization process with an improvement in time taken for training the model. This method out performs others in terms of PSNR and Structural similarity.

C Tian et al 2018 [28], proposed a deep CNN known as ECNDNet where Batch Normalization (BN), Residual Learning, Dilated Convolution are used. Batch Normalization handles the Internal Covariate shift problem also it enhances the performance of Network whereas Dilated convolution can extract more features of a medical image and 17 layers with Residual learning solve the disappearing texture problem. This method shows that it performs better than IRCNN.

4. Image Quality Metrics

4.1 Mean Square Error MSE

MSE is an evaluation metric very often used in digital image processing which is the average squared difference between the actual value and measured value [29]. MSE value should be less than other methods

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}.\sum_{j=1}^{N}\left(x(i,j) - \ddot{x}(i,j)\right)$$

4.2 Peak Signal to Noise Ratio PSNR

It is an evaluation metric which identifies the Signals to Noise ratio among the Original image and image with speckle noise of same dimension MxN in Decibels(dB) [30].

$$PSNR = 10\,log_{10}\left(\frac{255^2}{MSE}\right)$$

4.3 Speckle Suppression Index SSI

SSI is the measure of quality of real ultrasound images

SSI= $\frac{\sqrt{var(x)}}{mean(x)}$ x $\frac{mean\ (y)}{\sqrt{var(y)}}$

The value of SSI should be less than 1 if the filter used is efficient in reducing speckle [31].

5. Comparison of Results

Ultrasound image has been taken and applied with noise variance of 0.01 and 0.1 and corresponding PSNR values are compared for various filters. For variance of 0.01 PSNR values are as follows for Frost filter 38.64 dB, Kaun filter 39.84 dB, Lee filter 39.79 dB, Bayes Shrink 36.25 dB, SIIAF 42.22 dB.

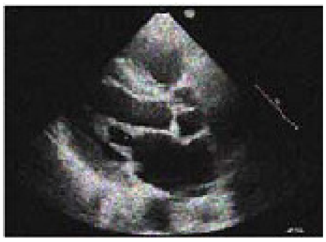


Fig 3: Noisy Image

Fig 4: Lee Filtered

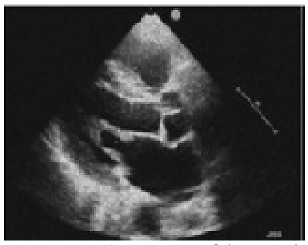


Fig 5: Frost filtered

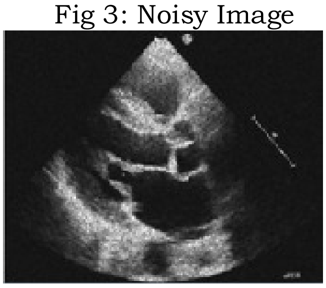


Fig 6 : Kuan Filtered

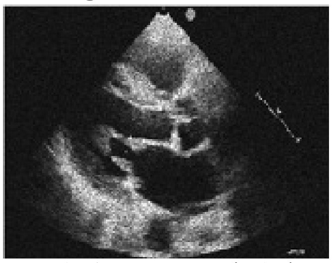


Fig 7: Bayes Shrink

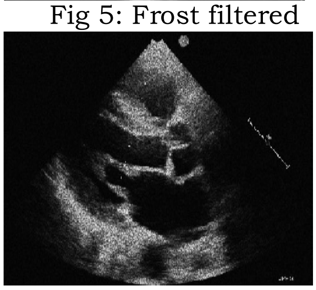


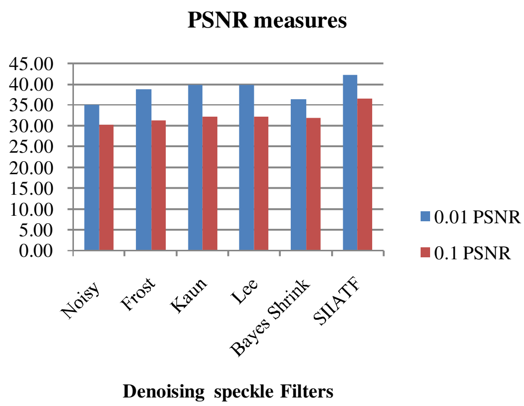
Fig 8: SIIATF

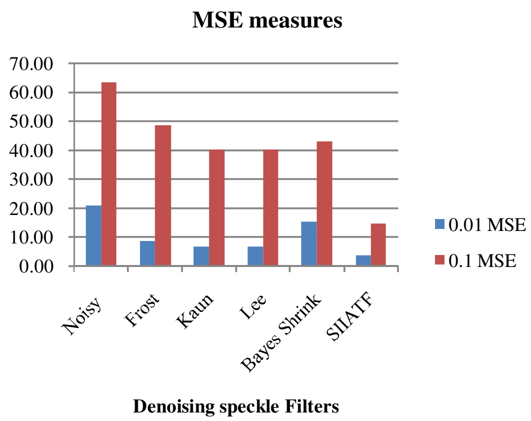
Nirmala Devi et al, 2014 [11]	Variance of noise	Measures	Noisy Image	Frost Filter	Kaun Filter	Lee Filter	Bayes Shrink	SIIATF
	0.01	PSNR	34.94	38.64	39.84	39.79	36.25	42.22
	0.1	PSNR	30.11	31.27	32.09	32.08	31.79	36.44

Table 1: PSNR values of various filters for σ = 0.01 and σ=0.1 [11]

Nirmala Devi et al, 2014 [11]	Noise variance	Measures	Noisy Image	Frost Filter	Kaun Filter	Lee Filter	Bayes Shrink	SIIATF
	0.01	MSE	20.83	8.89	6.75	6.82	15.42	3.90
	0.1	MSE	63.35	48.56	40.20	40.32	43.03	14.77

Table 2: MSE values of various filters for σ = 0.01 and σ=0.1





6. Conclusion

Thus various methods for denoising of speckle in ultrasound images are summarized. From this the observation is Anisotropic diffusion based filters depends on diffusion coefficient. Algorithm is much complex in case of multi scale techniques. Spatial domain filters have the problem of size limitation and shape of window problem. Fuzzy based techniques better results if combined with single and multi scale techniques to preserve the image information. Transform domain techniques has better results compared to spatial domain filters. CNN models can give a better visual quality by extracting various features of an image for both quantitative and qualitative analysis. It can provide better results compared to conventional methods. CNN based models are evolving and there is a huge scope in future.

References

[1] Michailovich O V and Tannenbaum A 2006 Despeckling of medical ultrasound images. *IEEE transactions on ultrasonics, ferroelectrics, and frequency control* ***53***(1) 64-78.

[2] Fatima M Osman, Moi Hoon Yap 2018 The effect of filtering algorithms for breast ultrasound lesions segmentation, *Informatics in Medicine Unlocked* **12**, 14-20, ISSN 2352-9148, https://doi.org/10.1016/j.imu.2018.04.008.

[3] Fabio Baselice 2017 Ultrasound Image Despeckling Based on Statistical Similarity *Ultrasound in Medicine & Biology* **43**(9) 2017, 2065-2078, ISSN 0301-5629, https://doi.org/10.1016/j.ultrasmedbio.2017.05.006.

[4] Linwei Fan, Fan Zhang, Hui Fan and Caiming Zhang 2019 Brief review of image denoising techniques. *Visual Computing for Industry, Biomedicine, and Art*, **2**(1), 7.

[5] Ja I Koo and Song B Park 1991 Speckle reduction with edge preservation in medical ultrasonic images using a homogeneous region growing mean filter (HRGMF) *Ultrasonic Imaging* **13**(3) 211-237 https://doi.org/10.1016/0161-7346(91)90073-Q

[6] Jong-Sen Lee 1980 Digital Image Enhancement and Noise Filtering by Use of Local Statistics," in *IEEE Transactions on Pattern Analysis and Machine Intelligence* **PAMI-2**, no. 2 pp. 165-168. https://doi.org/10.1109/TPAMI.1980.4766994

[7] Victor S Frost and Josephine Abbott Stiles 1982 K S Shanmugan and Julian C Holtzman A Model for Radar Images and Its Application to Adaptive Digital Filtering of Multiplicative Noise *IEEE Trans. Pattern Anal., Machine Intell.* vol. **4** no. 2 pp. 157-166.

[8] Darwin T Kuan, Alexander A Sawchuk, Timothy C Strand and Pierre Chavel 1985 Adaptive Noise Smoothing Filter for Images with Signal-Dependent Noise *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. **PAMI-7**, no. 2, pp. 165-177.

[9] P Perona and J Malik 1990 Scale-space and edge detection using anisotropic diffusion *IEEE Trans Pattern Anal Mach Intell*, **12** (7), pp. 629-639

[10] Froment J 2014 Parameter-free fast pixelwise non-local means denoising. *Image Processing On Line*, ***4*,** 300-326.

[11] Xuli Zong, A F Laine and E A Geiser 1998 Speckle reduction and contrast enhancement of echocardiograms via multiscale nonlinear processing *IEEE transactions on medical imaging* **17**, no. 4 pp -532-540.

[12] S G Chang and M Vetterli 1997 Spatial adaptive wavelet thresholding for image denoising *Proceedings of International Conference on Image Processing*. Vol. **2**. IEEE.

[13] S G Chang, Bin Yu and M Vetterli 2000 Adaptive wavelet thresholding for image denoising and compression *IEEE transactions on image processing* **9.9** pp: 1532-1546.

[14] O V Michailovich and A Tannenbaum 2006 Despeckling of medical ultrasound images *IEEE Trans Ultrason Ferroelectr Freq Control.* **53**(1):64-78.

[15] Sudha, Ganesh and Sukanesh 2009 Speckle Noise Reduction in Ultrasound Images by Wavelet Thresholding based on Weighted Variance *International Journal of Computer Theory and Engineering* **1**(1) pp (7-12)

[16] Nirmala Devi P, Asokan R 2014 An improved adaptive wavelet shrinkage for ultrasound despeckling *Sadhana* **39**, no. 4 pp: 971-988.

[17] Iman Elyasi, Mohammad Ali Pourmina and Mohammad-Shahram Moin 2016 Speckle reduction in breast cancer ultrasound images by using homogeneity modified bayes shrink *Measurement,* Volume **91**, 2016, Pages 55-65.
[18] Mehdi Mafi, Solale Tabarestani, Mercedes Cabrerizo, Armando Barreto and Malek Adjouadi 2018 Denoising of ultrasound images affected by combined speckle and Gaussian noise *IET Image Processing*, **12**(12), p. 2346-2351
[19] Shan Gai, Boyu Zhang, Cihui Yang, Lei Yu 2018 Speckle noise reduction in medical ultrasound image using monogenic wavelet and Laplace mixture distribution *Digital Signal Processing* **72** pp192-207.
[20] Bing –quan Chen, Jin-ge Cui , Qing Xu , Ting Shu and Hong-li Liu 2019 Coupling denoising algorithm based on discrete wavelet transform and modified median filter for medical image *Journal of Central South University* **26**, 120–131
[21] S Shajun Nisha and S P Raja 2020 Multiscale Transform and Shrinkage Thresholding Techniques for Medical Image Denoising – Performance Evaluation *Cybernetics and Information Technologies* **20**(3).
[22] Simarjot Kaur Randhawa, Ramesh Kumar Sunkaria and Emjee Puthooran 2019 Despeckling of ultrasound images using novel adaptive wavelet thresholding function *Multidimensional Systems and Signal Processing* **30**, no. 3 pp - 1545-1561.
[23] Nitit WangNo, Sirapat Chiewchanwattana and Khamron Sunat 2020 An efficient adaptive thresholding function optimized by a cuckoo search algorithm for a despeckling filter of medical ultrasound images *Journal of Ambient Intelligence and Humanized Computing*
[24] Andréia SeixasLeal, Henrique Mohallem Paiva 2019 A new wavelet family for speckle noise reduction in medical ultrasound images *Measurement* **140** pp-572-581.
[25] Yi Chang, Luxin Yan, Meiya Chen, Houzhang Fang and Sheng Zhong 2019 Two-stage convolutional neural network for medical noise removal via image decomposition *IEEE Transactions on Instrumentation and Measurement* **69**, no. 6 pp- 2707-2721.
[26] Hamid Reza Shahdoosti and Zahra Rahemi 2019 Edge-preserving image denoising using a deep convolutional neural network *Signal Processing* **159** pp-20-32.
[27] Worku Jifara, Feng Jiang, Seungmin Rho, Maowei Cheng and Shaohui Liu 2019 Medical image denoising using convolutional neural network: a residual learning approach *The Journal of Supercomputing* **75**, no. 2 pp - 704-718.
[28] Chunwei Tian, Yong Xu, Lunke Fei, Junqian Wang, Jie Wen, Nan Luo 2019 Enhanced CNN for image denoising." *CAAI Transactions on Intelligence Technology* **4**, no. 1 pp- 17-23.
[29] Feng, Xiangfei, Xiaoyu Guo, and Qinghua Huang 2017 Systematic evaluation on speckle suppression methods in examination of ultrasound breast images *Applied Sciences* **7** no. 1: 37.
[30] Q. Huynh-Thu and M. Ghanbari 2008 Scope of validity of PSNR in image/video quality assessment," in Electronics Letters, vol. **44**, no. 13, pp. 800-801, doi: 10.1049/el:20080522.
[31] Feng, Xiangfei, Xiaoyu Guo, and Qinghua Huang Systematic evaluation on speckle suppression methods in examination of ultrasound breast images *Applied Sciences* **7**, no. 1 (2017): 37.