Speckle noise reduction using Linear and non-linear filters in ultrasound images: a study

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Abstract —Ultrasound images are widely used in medical applications to visualize muscles and many internal organs. Ultrasound images are potent tool in medical. The obtained image mostly corrupted by speckle noise after transmission that makes visual observation more difficult. It is necessary to remove noise from image before used in any application. Many denoising algorithms such as wavelet based method; diffusion filtering method and linear-nonlinear filtering method are used to restore the original characteristics of image. It is compulsory to have idea about which type of noise is present in image for the selection of denoising algorithm. Filtering approach gives better result in many applications. The prime focus of this paper is to attenuate speckle noise from the ultrasound image by keeping most of the information. In this paper linear-nonlinear and diffusion filtering techniques are discussed for ultrasound image.

Keywords: Ultrasound Image; Weiner Filter; Lee Filter; Median Filter and Anti-Diffusion Filter.

I. INTRODUCTION

Image Processing, a part of Signal Processing allude to managing digital images with advance features like sharpness in image, maximize the clarity, and details information for further analysis [1]. It is widely used in various fields like education and industry as well as digital image processing widely used in medical applications like as X-Ray, Ultrasound and Nuclear medicine extra. In past only x-ray technique was available that showed the shadow picture of organs, but now many techniques are used like Computed tomography (CT), MRI and Ultrasonography that shows cross-sectional picture of patient.Ultrasound imaging has served as a new dawn in the medical diagnostic industry due to its economic, real time and portable nature. Ultrasound uses a simple pulse echo and high frequency sound wave that is basically used of reflection of ultrasound wave throughout the body. It has ability to produce real time images, reduce computational complexity, reduce memory requirements and easy to understand. Ultrasound images are basically a sound wave having frequency up to 20 KHz [1]. It transmits energy and propagates through pulsating pressure wave. It defined no. of wave parameters, for example, particle displacement, propagation direction and pressure density. Wavelength is the main characteristics of ultrasound wave. Wavelength is the guideline properties of ultrasound wave. The technique of ultrasound wave is mainly based on measuring the echoes of sound particle. In this technique ultrasound (US) wave interacts with blood and tissue. Echo impulse and Doppler techniques are widely used in US waves. It transmits energy and propagates through pulsating pressure wave [3]. It defined no. of wave parameters such as particle displacement, propagation direction and pressure density. Wavelength is the main characteristics of ultrasound wave. The technique of ultrasound wave is mainly based on measuring the echoes of sound particle. In this technique ultrasound wave interacts with blood and tissue. Echo impulse and Doppler techniques are widely used in US waves. Scanning modes of US waves are A-mode, B-mode and M-mode. A-mode is strength of echo signal that is detected and measured which represents as a time varying signal in one direction. It is mainly a line with strong reflections that represents as increase amplitude in the signal. A-mode has limitation it records only 1D signals that why it is not preferable currently. Another scanning mode is B-mode used for brightness as and echoes are displayed in 2D or grayscale. The amplitude of the echoes is representing by the pixels of an image that having different gray values. One more mode is used in US which is M-mode mainly used in cardiology. It gives the detailed information about different-2 cardiac dimensions [3]. The main drawback of this ultrasound is low quality of image because it is affected by the speckle noise that is also known as multiplicative noise. For the image analysis it is necessary to remove this noise from original image [4]. Therefore the major hurdle is noise that will be introduced during image acquisition process and more one problem occurs after de-noising process that is destruction of image. To eliminate the noise factor several techniques are used for image de-noising as well as for image preservation [2]. When a given image goes under some losses of stored information in terms of pixels either due to conversion or digitization, this process is known as image degradation and it reduce the visual quality of the picture or we can say change the original properties of the picture. It comes in numerous structures as noise, movement obscure and camera misfocus. On the other hand image restoration is the process where we get the computed or estimated image, that is basically recover or undo the original image that is affected by noise. Basic diagram of noise degradation and restoration is shown in below figure [2].

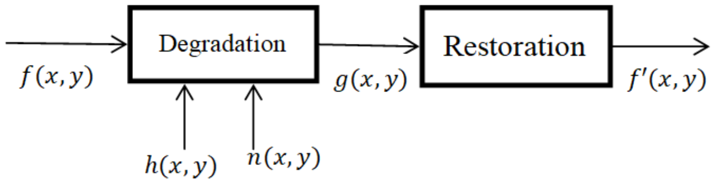

Fig.1. Model for image degradation and restoration

Whereas, f(x,y) = picture before degradation, g(x,y) = picture after degradation; observed picture, n(x,y) = additive noise, f'(x,y) = estimated or computed image, h(x,y) = degradation filter.

Noise Model-

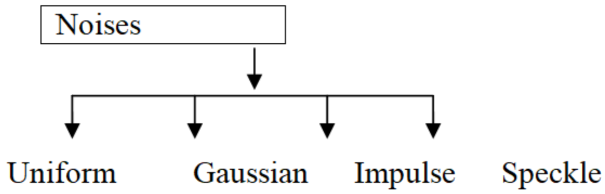

Fig.2. Noise Models

Uniform Noise also known as quantization noise and acquired by quantizing the pixels of picture to various particular levels are known as quantization commotion (noise). It shows the uniform distribution of noise in whole image [2]. Different patterns of noise can be generated using such type of noise distribution pattern.

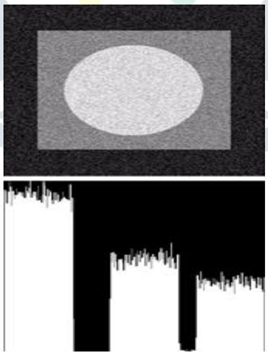

Fig.2. PDF of Uniform Noise

Gaussian Noise is most commonly occurring noise that emerges during the acquisition of image, for instance sensor noise brought about by poor brightening. It is basically occurred by random fluctuation in signals.

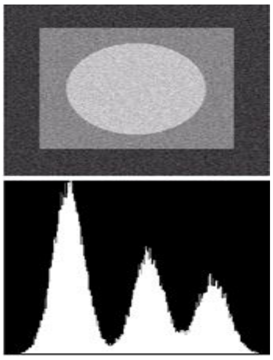

Fig.3. PDF of Gaussian Noise

Impulse noise, spike noise, shot noise and also sometime termed as salt and pepper noise that deals with dark and bright pixels of the image. It has dim pixels in splendid regions and brilliant pixels in dull regions. The main cause of introduced of these type of noise in digital images are A/D or D/A converters and timing mistake during digitization [4].

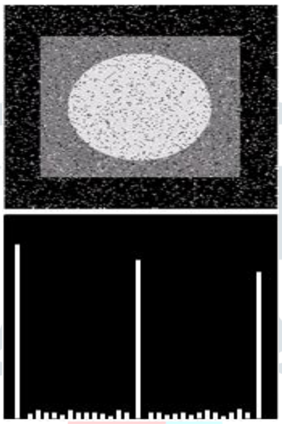

Fig.4. PDF of Salt and Pepper Noise

Speckle Noise otherwise called multiplicative noise, and granular noise that is inherently exists in and corrupts the nature of RADAR and medical ultrasound images [4]. It comes when any error arrived during data transmission and also known as data dropout noise. It presents in all type of sensible images like ultrasound images, synthetic aperture radar (SAR), laser illuminated and acoustic imagery. It is changeable in nature and diminishes the quality of the picture that made difficult to examine or observe the processing steps like edge detection and segmentation extra. It degrades the fine details and limits the contrast resolution and edges definition. It is basically signal dependent noise as well as correlated spatially similar to other noises. It occurs because of accidental interference of the wavelets which is scattered by fluctuations of the objects. This clamor displayed by irregular values that duplicate with pixel estimation of an image and communicated as-

$$J = I + n * I \quad (1)$$

while, J = Speckle noise distribution in an image, n = Uniform image noise, I = Input image.

*A. **Original Image:***

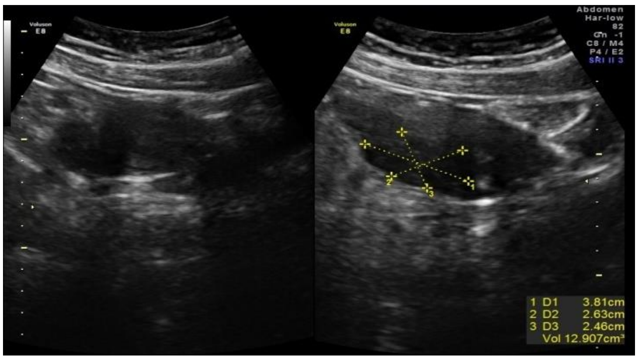

Fig.4. PCOD real Ultrasound image

B. ***Noisy Image:***

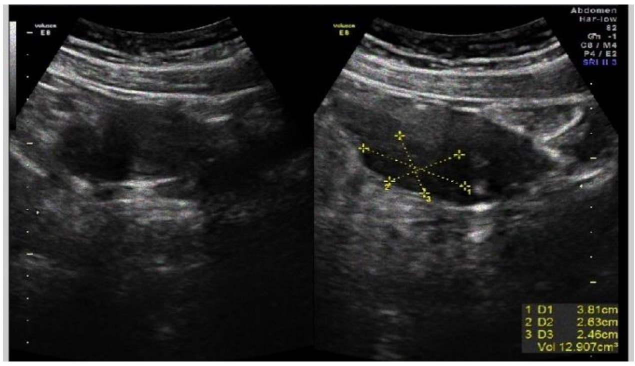

Fig.5. Image after add speckle noise

This noise image have variance and mean factor and random in nature. In this paper real fetus ultrasound image is taken and speckle noise introduced with the variance factor and remove by linear and non-linear filtering techniques that is explained in next section.

II. METHODS OF LINEAR , NON-LINEAR AND DIFFUSION FILTERING TECHNIQUES

Speckle filtering contain of moving kernel with each pixel of image, on that image mathematical calculations applied below the moving kernel and replacing the middle pixel with the new calculated value. The kernel slides one pixel at a time till the complete image has been covered. With filtering technique smoothing effect achieved as well as clear visualization of image [5]. There are plenty of filters utilized in digital imaging which are further categorized in four types including (i) Linear filters, (ii) Non-linear filters, (iii) Diffusion filters, and (iv) Wavelet filters. Linear filtering technique based on local statistics, therefore method used in this based on moving window by local statics. It also defined by linearity and shift invariance property as well as also imposed stable and causal condition. It is use where noise factor is more but area and magnitude is less. This technique useful for improve the sharpness the edges of objects, correcting for unequal illumination and reducing random noises. Some linear filters are Weiner, lee, frost and kuan. Non-linear filtering does not follow the principal of linear filter and take odd values as sample. It is based on homogenous neighborhood around the pixels It is useful where non-linear feature is more important than the information of the image. It is widely used for preserving the edges and take input signal within finite window. This filter is useful where area or magnitude large but noise factor less. Non-linear filters are median filter and geometric filters. In this gray-level value is linearly scaled. Diffusion method also used for filtering, in this exponential damp kernel using diffusion and one more type that is wavelet filters which is used for only wavelets [6].

II (A). LINEAR FILTERING TECHNIQUES

Lee filters- It computes direct blend of the middle pixel intensity in channel window with a normal force of window for reduction speckle noise. It gives best result for edge preservation and works on the basis of variance factor [2]. If variance of area or size is small that time it gives good result. Its performance is degraded when variance of area or size is large. It is patch based processing therefore computation cost is high as well as not effective near the edges of images. It is calculated as-

$$Y_{ij} = \overline{K} + W * (C - \overline{K}) \quad (2)$$

Where, Y_{ij} = Despeckled image, W = Weighing function, K = mean of kernel window, C = center element in the kernel, and

$$W = \frac{\sigma_k^2}{(\sigma_k^2 + \sigma^2)} \quad (3)$$

Where, σ_k^2 = variance of the pixels in kernel / window of speckle image, σ^2 = variance of the reference image.

Weiner filter is come under liner-type. Alternatively, this type is also known as LMS (least mean square) filter and helps in reducing the overall mean square error. It has capacity to regain the blurred and noisy image simultaneously and gives output image that is equivalent to noiseless input image [3]. It works on the computation basis of image variance and performs well if value of variance is small and not well performed when value of variance is large [5]. This approach gives better results as compare to another filters and suitable for both additive and speckle noises [6]. When image has smoothies edges

Weiner filter gives better response as compare to frost and lee filter, but it takes more computation time as compare to another linear filters.

$$f(u,v) = \left[\frac{H(u,v)^*}{H(u,v)^2 + \frac{Sn(u,v)}{Sf(u,v)}}\right] G(u,v) \quad (4)$$

Where, f (u,v) = Original image function, H(u,v) = Degradation function, $H(u,v)^2$ = Complex Conjugate, $S_f(u,v)$ = Original image, Sn(u,v) = Power spectrum of noise, *G(u,v)*= Degraded image.

It reduces the amount of noise by comparing the received signal with approximation of desired noiseless signal. The aim of the Weiner filters to reduce minimum mean square error. Weiner filters do very good job in case of deblurring. By this reduce noise variance at very high level as well as it helpful for calculate the power spectrum of each image. Furthermore implementation of this filters can be used for perform analysis on images [5].

Frost filter falls under in category linear/adaptive filter. It is very efficient way for preserves the edges of image. It gives low MSE for speckle noise removal and requires damping factor that fixes the degree of exponential damping. Lesser or minimum measure of this damping factor gives good result for edge sharpness.

II (B). NON-LINEAR FILTERING TECHNIQUES

Median filter is a non-linear filter and utilized in removing speckle and salt & pepper noises from the images. The principal of median filter based on moving pixel to pixel all through the picture and supplanted each an incentive with the middle benefit of neighboring pixels, example of neighbor's pixels known as window that slides pixels to pixels. It is calculating all pixel values by first sorting from the neighbors after that replacing the first sorting pixel with the middle pixel value. For example [f_{ij}] is the matrix of any image and m*n is the odd integers of that image where m shows pixels in horizontal direction and n shows pixels in vertical direction and [g_{ij}] is the equal gray level of [f_{ij}]. It is basically used for 2D images and no. of pixels moving through the window, depend on window sizes. If the window size is large, it gives good result but take long time for computation and if window size is small, it gives better result and take less time for computation [7, 8]. It is different from mean filter because it takes median value of the neighbor pixel instead of taking mean value. It reduce the variance intensities in the image by the idea of taking value of median that resultant produces less blurring in the image. The sole advantage of median filter that it preserves the edges of the image and disadvantage of this filter is that it takes long computation time for sorting N pixels and costly [9, 10].

1	36	2	0	7
7	58	11	89	78
108	28	36	104	84
45	786	52	14	108
0	49	65	85	52

In above 5*5 matrixes shown that follows these steps. Firstly take matrix then in ascending manner sort the intensity value of pixel, after that select the middle value as new value of pixel. In homogenous areas larger window size is good and in heterogeneous smaller window size be good. Mostly 7*7 matrix gives fair response in between both of them and median filter gives good balance in between both of them [11, 12].

Hybrid Median filter modified term of median filter that capable for speckle noise reduction more efficiently as compare to median filter. It used 3-step ranking principle on 3*3 matrix of image. First step is hybrid median filter firstly collect, ordered and then restore the median (MR) of mediate vertical and horizontal pixels. Second step it is again collect, ordered and restore the median (MD) of mediate diagonal pixels. Finally centered or mediate is collected with MD and MR. Median rearrange by central pixel and process is repeated till 3*3 window.

Diffusion filters

In image processing anisotropic diffusion filters are beneficial for reduction the speckle noise because it provide noiseless image without loss of edges, lines & content of the image. The original formulation presented by Malik and Perona. It is also known as SRAD that means speckle reduction anisotropic diffusion. It removes speckle by solving a PDE (partial differential equation) [12].

$$\begin{cases} \frac{\partial I}{\partial t} = \partial iv[\, C(|\nabla I|)\nabla I] \\ I(t=0) = I_0 \end{cases} \quad (5)$$

Where, ∂iv= Divergence Operator, $C(|\nabla I|)$= Diffusion Coefficient, ∇= Gradient Operator, I= Original Image.

So with the strength of gradient increases, it decreases diffusion and perform good for speckle & Gaussian noise reduction. It used for edge enhancing and avoids logarithmic operations [13, 14].

Non-Linear Anisotropic Diffusion filters is better way to eliminate the multiplicative noise with preserve the exactness of edges of the image. In this method filtering process depends on the threshold level that means contrast of edges of the picture. The value of threshold varies from picture to picture and region to region of the picture. It is widely used in image processing, material science, nuclear science and quantum physics.

Table 2. Review of various proposed algorithms [1-4]

Year	Author	Title	Methodology	Advantages	Limitations
2015	Tarik Ahmad Lone, Showkat Hassan Malik	A Literature Survey of Image Denoising Techniques in the Spatial Domain	Focusing on spatial domain denoising techniques.	1. Edge preservation and robustness against large noise deviations. 2. Smoothes neighborhood varieties at the expense of obscuring.	1. Requires data about the spectrum of the noise and the original signal. 2. Removal of significant image subtleties, jitter and streaking is troublesome.
2015	Divya V, Dr. Sasi kumar M	Noise Removal in Images in the Non Sub sampled Contourlet Transform Domain using Orthogonal Matching Pursuit	Image is first transformed to the Non Sub sampled Contourlet Transform (NSCT) domain and then Support Vector Machine (SVM) is used for classifying noisy pixels from the edge related ones.	1. Achieves a decent visual quality with exceptionally less amount of upsetting antiques, while systematically guaranteeing the equivalent as far as subjective measurements, with no data on the commotion.	1. There is a challenge to take the initial estimate to the orthogonal matching Pursuit (OMP) algorithm. 2. For empowering the strategies in web base handling, calculation and time optimization strategies can be looked for.
2015	S. Shyam Prasad, R. Priya	Image Enhancement with Noise Reduction in Spatial Domain	Focusing on modified bilateral filtering method, when compared to average filter and vector median filter.	1. The reciprocal separating activity can at the same time expel incautious and added substance noise while saving edge structures.	

2015	Vinod Sharma, Deepika Bansal, Renu Bagoria	A Review on Digital Image Enhancement by Noise Removal	Focusing on image noise removal by the use of different filters	1. Various filters are better in removing the noise.	1. Unable to remove all types of noise from an image.

REFERENCES

[1] M. A. Gungor, and I. Kargoz, "The effects of median filter with different window sizes for ultrasound image," IEEE, PP. 549-552, 2016.

[2] H. P. Kumar, and S. Srinivasan, "Performance analysis of filters for speckle reduction in medical polyestic ovary ultrasound images," ICCCNT'12, IEEE, July 2012.

[3] Ma. G. Sanchez, V. Vidal, G. Verdu, P. Mayo, and F. Rodenas, "Medical image restoration with different types of noise," IEEE-EMBS, PP. 4382-4385, September 2012.

[4] Ch. K. Rekha, V. Vijaya, and B. Sreedevi, "Comparsion of higher order diffusion filters for speckle noise reduction," ICCAIE,IEEE, PP.697-701, December 2010.

[5] A. Boyot, B. K. Joshi, "Image denoising using wavelet transform and median filtering," NUiCONE, IEEE, PP. 1-6, 2013.

[6] J. Jaybhay, and R. Shastri, "A study of speckle noise reduction filters," SIPIJ, Vol.6, No. 3, PP. 71-80, June 2015.

[7] O. Magud, E. Tuba, and N. Bacanin, "Medical ultrasound image speckle noise reduction by adaptive median filter," E-ISSN, Vol. 14, PP. 38-41, 2017.

[8] S. Kushwaha, "An efficient filtering approach for speckle reduction in ultrasound images," Biomedical & pharmacology journal, Vol. 10(3), PP. 1355-1367, 2017.

[9] R.C. Gonzalez, and R. E. Woods, "Digital image processing," Nueva Jersey, 2008.

[10] C. P. Loizou, and C. S. Pattichis, "Despeckle filtering algorithms and software for ultrasound imaging," January 2008.

[11] A. Maity, A. Pattanaik, S. Sagnika, and S. Pani, "A comparative study on approaches to speckle noise reduction in images," ICINE, IEEE, PP. 148-155, 2015.

[12] R. Ayoubi, and Rafic Ayoubi, "Real time parallelized hybrid median filter for speckle removal in ultrasound images," GlobISIP, PP. 65-68, 2014.

[13] O. V. Michailovich, and A. Tannenbaum, "Despeckling of medical ultrasound images," IEEE Transactions, Vol. 53, No. 1, January 2006.

[14] H. A. Nugroho, and L. Choridah, "Performance analysis of filtering techniques for speckle reduction on breast ultrasound images," IES, IEEE, PP. 450-454, 2016.

[15] P. Kumari, P. Chaurasia, and P. Kumar, "A survey on noise reduction in images," NSFTICE'2015.

[16.] P. Nanglia, S. Kumar, D. Rathi, P. Singh, "Comparative Investigation of Different Feature Extraction Techniques for Lung Cancer Detection System" International conference on Advanced Informatics for Computing Research (ICAICR 2018), Communications in Computer and Information Science, vol.955, pp. 296-307, (2019). DOI:10.1007/978-981-13-3140-4_27.

[17.] S. Gupta and S. Kumar, "Variational level set formulation and filtering techniques on ct images" International Journal of Engineering Science and Technology, Vol. 4, pp. 3509-3513, 2012.

[18.] S. Sharma, P. Nanglia, S. Kumar, A. K. Luhach, "Detection and Analysis of Lung Cancer Using Radiomic Approach" Smart Computational Strategies: Theoretical and Practical Aspects, Springer, pp.13-24, 2019. DOI: 10.1007/978-981-13-6295-8_2.