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Image Denoising in Ultra Sound image using DWT with various Filters

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***Abstract*—** Image denoising is the predominant task in the field of image processing and computer vision. The occurrence of noise is due to the influence of various internal and external sources that creates de trop signals, resulting in image noise. In medical images the presence of noise may leads to false clinical diagnosis. To prevent the contingence of noise, various image denoising algorithms are employed expeditiously to uproot the noise. Discrete Wavelet Transform (DWT) is employed to extinguish the occurrence of noise in medical images. It decomposes the input image into detailed and approximate coefficients at three levels. The sampled data is transformed into array of wavelet coefficients. Filters are introduced to eliminate the noises which are coupled with the input image. Wiener Filter, Adaptive Bilateral Filters (ABF) and Boundary Discriminative Noise Detection (BDND) are used to denoise the speckle noise and salt and pepper noise present in the Ultra Sound image. From these results it is observed that ABF filter works well against the speckle noise with the following metrics Peak Signal to Noise Ratio (PSNR), SSIM (Structural Similarity Index Measure), CoC (Coefficient of Correlation), EPI (Edge Preserving Index) for Medical images corrupted with noise.

***Keywords*—** Wavelet transform, Wiener filter, BDND filter, ABF

I. INTRODUCTION

One of the primary tasks in the area of image processing and computer vision is denoising images. Image denoising algorithm deals with the elimination of the noisy components while preserving the important signal as much as possible. Degradation in digital images betides due to the electronic and photometric sources. Image restoration is the process of diminution of the degraded images which are incurred while the image is being acquired.

Medical Imaging employs the noninvasive strategy that produces the visual representations of the interior of a body for clinical analysis and medical intervention. Medical imaging seeks to reveal internal structures hidden by the skin and bones, as well as to diagnose and treat disease. In the field of Medical image processing, the quality of the image cannot be compromised at any cost. Medical image processing adopts the processes of digital image processing techniques for the identification and localization of the diseases. Noninvasive imaging includes X-rays, CT and MRI, fMRI, PET, and SPECT. Scans like CT and MRI has the potentiality to image the anatomical structures in three-dimension. The recent breakthroughs in medical imaging such as fMRI, PET, and SPECT, captures the functionality of organs with ultra-high resolutions rather than acquiring only structural anatomy.

Ultrasound imaging (US), or sonography, uses high-frequency sound waves to view soft tissues of the human body such as internal organs and muscles. Because ultrasound images are captured in real-time, they can show movement of the body's internal organs as well as blood flowing through blood vessels.

Noise present in the digital mammograms and sonography images directly influences the competence of a classification task. Study reveals that overall accuracy of classification systems decreases due to the increase in noise. Noises are coupled with the images during data acquisition and at preprocessing stage. The sparse occurrence of white and black pixels due to the fluctuation in signals gives rise to Salt and Pepper noise. Speckles arise from the patterns of constructive and destructive interference from the transducers resulting in bright and dark dots in the image. Adaptive filtering exploits the use of variable filters with adjustable parameters until the error is minimized. Non adaptive filtering works well against the speckles with less computation power and better at preserving edges whilst eliminating the noise spikes. This paper analyzes both the Adaptive filtering and Non adaptive filtering techniques for reducing noise in medical images.

A. Related Works

Image denoising is a process in image processing which eliminate noise from the image, enhance the image quality and recover fine details that may be hidden in the image. The traditional way of image denoising is filtering. Image filtering is done by linear and nonlinear methods [28]. Image Denoising is a central pre-processing step in image processing to eliminate the noise in order to strengthen and recover small details that may be hidden in the data [2].

The principal sources of noise in digital images arise during image acquisition and/or transmission [21]. Noise represents unwanted information which destroys the image quality [9]. Image noise is the random variation of brightness or color information in images produced by the sensor and circuitry of a scanner or digital camera. Image noise can also originate in film grain and in the unavoidable shot noise of an ideal photon detector [12].

A noise can be categorized depending on its source, frequency spectrum and time characteristics. Depending on a source, the noises are categorized into six types: acoustic noise; thermal and shot noise; electromagnetic noise; electrostatic noise; channel distortions, echo and fading; processing noise [29]. Pepper and Salt noise are a form of the noise classically seen on the images. Salt and pepper noise represents itself as randomly happening black and white pixels. Salt and pepper noise is random in nature, it distributed randomly in the image pixel values [27]. Poisson noise is induced by the nonlinear response of the image detectors and recorders. This type of noise is image data dependent. This term arises because detection and recording processes involve random electron emission having a Poisson distribution with a mean response value [10].

Wavelet transform is a mathematical technique that decomposes the signal into series of small basis function called wavelets. It allow the multi resolution analysis of image and is well localized in both time and frequency domain. As a result of wavelet transform the image is decomposed into low frequency and high frequency components. The information content of these sub images that corresponds to Horizontal, Vertical and Diagonal directions implies unique feature of an image [1]. The conventional wavelet decomposes only the low frequency components to obtain the next level's approximation and detail components; the current level of the detail components remains intact [8]. Wavelet denoising attempts to remove noise which is present in the signal while retaining all the signal characteristics regardless of its frequency contents [11]. Using a set of analyzing functions the wavelet transform provides multi resolution representations which are dilations and translations of a few functions (wavelets). It overcomes some of the limitations of the Fourier transform with its ability to represent a function simultaneously in the frequency and time domains using a single prototype function (or wavelet) and its scales and shifts [14].

Filtering is a vital part of any signal processing system, which entails estimation of signal degradation and restoring the signal satisfactorily with its features preserved intact. The filters having good edge and image detail preservation properties are highly desirable for visual perception [33], [29]. Generally, filters are divided into two groups as linear and non-linear. Linear filters have simple design and encoding and they are intended for general aim [32]. In Non-Linear filters, noise can be removed without identifying it exclusively. It employs a low-pass filtering on the assumption that noise always occupies a higher region of spectrum frequency. It removes the noise to a very large extent, but at the cost of blurring of images. Rank conditioned selection [15], weighted median, relaxed median have been developed over recent years to cover up some of the drawbacks [23].

Objective quality measures are based on a mathematical comparison of the original and processed or enhanced image and can give an immediate estimate of the perceptual quality of an image enhancement algorithm [19], [22].

B. Motivation and Justification

In image processing, denoising is the essential and initial work on which the further processing like edge detection, classification, segmentation, etc., rely on it. An efficient denoising algorithm aims at reducing the noise levels without damaging the original image features. At present, image denoising algorithms works well against denoising a noisy image, but it compromises the quality of the image which hits the image features. The impact of poor quality increases the intricacy of clinical analysis and medical intervention.

The wavelet based transform for denoising filters out the noise effectively without compromising the image data. In DWT, noisy image consist of small number of coefficients having high SNR and large number of coefficients having low SNR. Applying inverse DWT, image reconstruction is done after removing the coefficients with low SNR. Time and frequency localization is concurrently provided by Wavelet transform. Due to the effective shrinkage of noise by dividing sub bands to the extreme and it curbs the intensity of heavily noise loaded pixels. Further it is observed that the shift in performance depends on the various factors of noise levels. Motivated by these facts, discrete wavelet transform is exerted for denoising medical images.

C. Organization of the Paper

The remaining paper is organized as follows. Methodology which include the proposed work of Discrete Wavelet Transform and filtering are represented in section II. Experimental results are shown in section III. Performance evaluation is discussed in section IV. Conclusion in Section V.

II. METHODOLOGY

A. Outline of the Proposed Work

Diverse artifacts are coupled with the input image and is allowed to undergo wavelet transform. Further the discrete levels of wavelet families at 3 levels are employed to decompose the noisy image. After the successful decomposition, wavelet coefficients are incurred. Filtering followed by inverse transform is applied to reconstruct the image artifacts free.

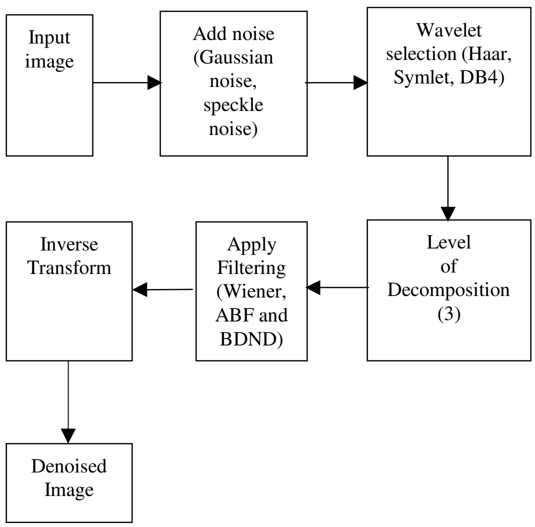

Figure 1: Image Denoising Block diagram using wavelet transforms

B .DWT (Discrete Wavelet Transform)

Wavelet denoising attempts to remove noise which is present in the signal while retaining all the signal characteristics regardless of its frequency contents. Discrete wavelet transform decompose the original cover image into four frequency sub-bands namely LL, HH, LH and HL. LL frequency sub-band establishes the estimate details. The frequency sub-band LH is used to constitute the vertical details of the image, HL contains the horizontal details of the image and the HH sub-band contains the diagonal details of the image. The LL sub-band that is the approximation of the digital image could be further decomposed with the use of discrete wavelet transform to get any level of decomposition of the digital content and it will generate the further four sub-bands. Thus the information of image is stored in decomposed form in these sub bands [3].

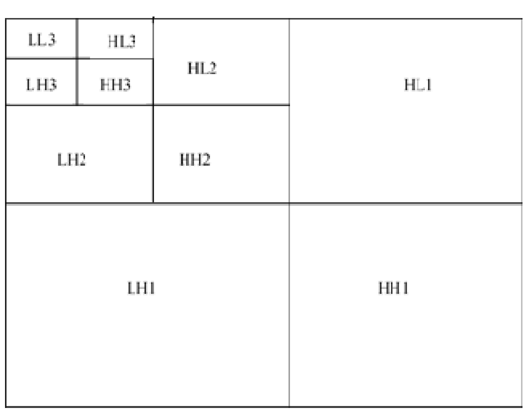

Figure 2: Wavelet decomposition at level 3.

The role of decomposition in the analysis of N*N image can be explained as:

1) Initial low pass filtering of the rows blurs the image values along each row followed by low pass filtering along the columns which result in a low pass approximation of the whole image.
2) Low pass filtering of the rows followed by high pass filtering of the columns highlights the changes that occur between the rows - horizontal details.
3) Initial high pass filtering of the original rows of the image highlights the changes between elements in any given low. Subsequent low pass filtering of the columns blurs the changes that may occur between the rows thus providing the vertical details.
4) High pass filtering of the rows followed by high pass filtering of the columns only changes that are neither horizontal are emphasized. This sequence gives the diagonal details of the original image [33].

C. Wavelet Families

1. Haar Wavelet

The Haar wavelet transform may be considered to pair up input values, store the difference and passing the sum. This process is repeated again and again, pairing up the sums to provide the next scale, finally results in differences and one final sum. The Haar wavelet is a simple form of compression which involves average and difference terms, storing detail coefficients, eliminating data, and reconstruct the matrix so that the resulting matrix is similar to the initial matrix [24].

2. Symlets

The family of Symlet wavelet is short of “symmetrical wavelets”. They are designed so that they have the least asymmetry and maximum number of vanishing moments for a given compact support [6].

3. Daubechies Wavelets

Ingrid Daubechies invented what are called compactly supported orthonormal wavelets, one of the brightest stars in the world of wavelet research, thus making discrete wavelet analysis practicable. The Daubechies family wavelets are written as dbN, where N is the order, db is the family name of the wavelet [13].

D. Noise Models

1. Gaussian Noise

Gaussian noise is the statistical noise which has its probability density function equal to that of a normal distribution, which is called as the Gaussian distribution. In the different words, the noise values can take on being Gaussian distributed. A different case is white Gaussian noise, values at any pair of the times are identically distributed and also statistically independent. In applications, Gaussian noise is normally used as additive white noise to the yield additive white Gaussian noise[10].

$$g(x, y) = f(x, y) + n(x, y) \quad (1)$$

Where g(x,y) is the output of the original image function f(x,y)corrupted by the additive Gaussian noise n(x,y).

Probability density function for Gaussian noise given below

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

Where g represents the grey level, μ the mean value and σ the standard deviation.

2. Speckle Noise

Speckle is a complex phenomenon, which degrades image quality with a backscattered wave appearance which originates from many microscopic diffused reflections that passing through internal organs and makes it more difficult for the observer to discriminate fine detail of the images in diagnostic examinations. The speckle noise follows a gamma distribution [31]. Thus, denoising or reducing the noise from a noisy image has become the predominant step in medical image processing. For the quality and edge preservation of images, we have taken different denoising techniques into consideration. Speckle noise comes into multiplicative noise model [25].

$$g(x, y) = f(x, y) * n(x, y) \quad (3)$$

Where g(x,y) is the result of the original image function f(x,y) corrupted by the multiplicative noise n(x,y).

E. Filtering Techniques

1. Wiener Filter

Wiener filters are a class of optimum linear filters which involve linear estimation of a desired signal sequence from another related sequence. It is not an adaptive filter. The wiener filter's main purpose is to reduce the amount of noise present in an image by comparison with an estimation of the desired noiseless image. The Wiener filter may also be used for smoothing. This filter is the mean squares error-optimal stationary linear filter for images degraded by additive noise and blurring [3]. The goal of the Wiener filter is to filter out noise that has corrupted a signal. Wiener filters are characterized by the following:

1. Assumption: signal and (additive) noise are stationary linear random processes with known spectral characteristics.
2. Requirement: the filter must be physically realizable,
3. Performance criteria: minimum mean-square error. Wiener Filter in the Fourier Domain as in equation[18]

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

where H(u,v) is the degradation function $H(u,v)^*$ is its conjugate complex and G(u,v) is the degraded image. Functions $s_f(u,v)$ and $s_n(u,v)$are power spectra of the original image and the noise [5].

2. Boundary Discriminative Noise Detection (BDND)

The boundary discriminative process consist of two iterations, in which the first iteration is essentially a noise detection step which is based on clustering the pixels in the image in a localized window into three groups, namely; lower intensity impulse noise, uncorrupted pixels, and higher intensity impulse noise. The clustering is based on defining two boundaries using the intensity differences in the ordered set of the pixels in the window. The pixel is classified as uncorrupted if it belongs to the middle cluster. Otherwise it is a noisy pixel [4].

3. Adaptive Bilateral Filter (ABF)

In order to increase the sharpness of the image some modifications to the bilateral filter is to be done, a new method for both sharpening and smoothing the image is been proposed here. The ABF retains the general form of a bilateral filter, but contains two important modifications. First, an offset is introduced to the range filter in the ABF. Second, both and the width of the range filter σr in the ABF are locally adaptive. The combination of a locally adaptive and σr transforms the bilateral filter into a much more powerful filter that is capable of both smoothing and sharpening [7].

III. EXPERIMENTAL RESULTS

To denoise an ultra sound image is shown in Fig 3.The noise speckle noise and Gaussian noise is chosen. Fig 4 shows the denoised image of a various wavelet base. It found that Symlet and Db4 performed very well. Then the decomposition of let to the various level to find out the best level of Symlet and Db4 and found the best filter is shown in Fig 5. Then applying different noise variance to best filter is shown in Fig 6. It is observed that ABF filter performs better for removal of speckle noise.

Figure. 3 Original Image

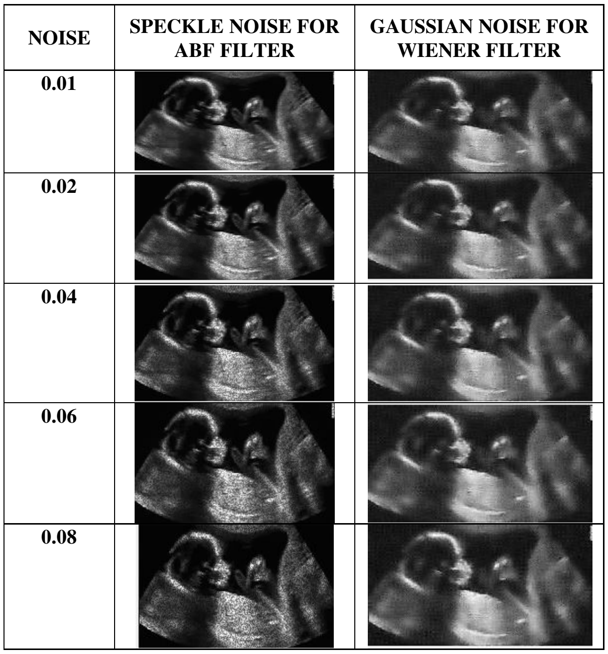

Figure. 4 Denoised image of a various wavelet base

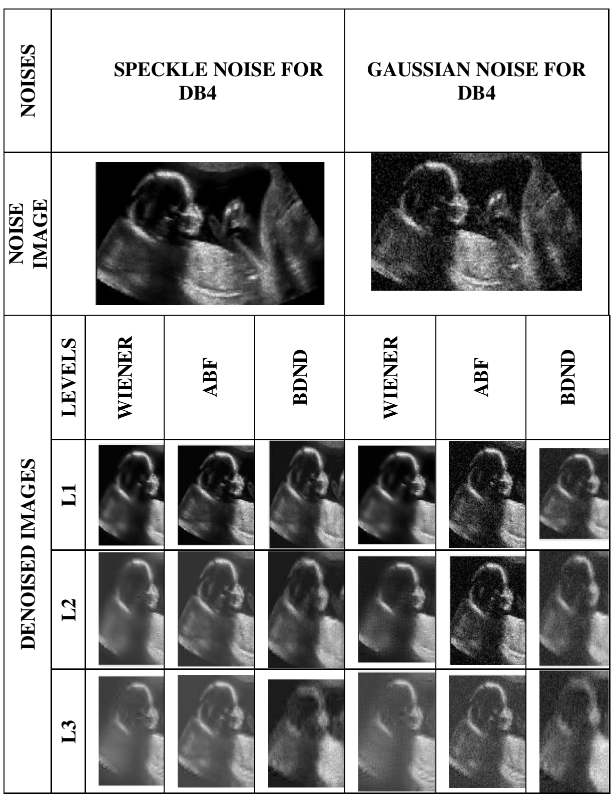

Figure. 5 Denoised Image at various level of decomposition

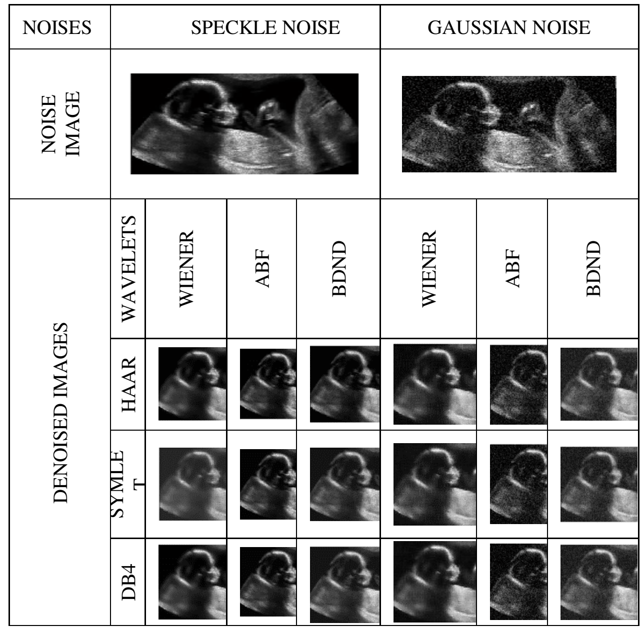

Figure. 6 Noise Variance to the filter

A. Performance Metrics

1. Peak Signal to Noise Ratio (PSNR)

It is the ratio between maximum possible power of a signal and the power of corrupting noise that affects the quality and reliability of its representation.

$$PSNR = 10Log_{10}\left(\frac{MAX^2}{MSE}\right) \quad (5)$$

Where MSE is mean square error and MAX is the maximum pixel value of image [15].

2. Structural Similarity Index (SSIM)

It is a method for measuring the similarity between two images. The SSIM measure the image quality based on an initial distortion-free image as reference.

$$SSIM=\frac{(2\mu_x \mu_y + C_1)(2\sigma_{xy} C_2)}{(\mu_x^2+\mu_y^2+C1)(\sigma_x^2+\sigma_y^2+C2)} \quad (6)$$

μ_x the average of x; μ_y the average of y;

σx^2 The variance of x;

σy^2 The variance of y;

σ_{xy} The covariance of x and y;

$C_1 = (k1L)^2$ and $C2 = (k2L)^2$

are two variables to stabilize the division with weak denominator. L the dynamic range of the pixel-values k1

= 0.01 and k2 = 0.03 by default. The resultant SSIM index is a decimal value between -1 and 1, and value 1 is only reachable in the case of two identical sets of data [20].

3. Edge Preservation Index (EPI)

$$EPI=\frac{\sum(\Delta X-\overline{\Delta X})(\Delta Y-\overline{\Delta Y})}{\sum(\Delta X-\overline{\Delta X})^2(\Delta Y-\overline{\Delta Y})^2} \quad (7)$$

where, $\overline{\Delta X}$ and $\overline{\Delta Y}$are the high pass filtered versions of images x and y, obtained with a 3×3 pixel standard approximation of the Laplacian operator. The $\overline{\Delta X}$ and $\overline{\Delta Y}$ are the mean values of the high pass filtered versions of Δx and Δy respectively [30].

4. Correlation Coefficient (COC)

$$CoC = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2(Y-\bar{Y})^2}} \quad (8)$$

where, x and y are the mean of the original and denoised image respectively. The CoC is used to measure the similarity between the original image and despeckled image [30].

5. Universal Quality Index (UQI)

Universal quality index [26] is the new parameter for comparison of quality of the image. Let x={xi|i=1,2,…,N} and y={yi|i=1,2,…,N} be the original and the test image signal respectively. The quality index Q is defined as:

$$Q = \frac{4\sigma_{xy}\bar{x}\bar{y}}{(\sigma_x{}^2+\sigma_y{}^2)[(\bar{x})^2+(\bar{y})^2]} \quad (9)$$

Where

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \ , \quad \bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$$

$$\sigma_x{}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})^2 \ ,$$

$$\sigma_y{}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i-\bar{y})^2$$

$$\sigma_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})$$

The range of Q is [-1, 1]. The ideal value Q=1 will achieve iffy yi=xi for all i=1, 2… N, i.e. both images are same.

B. Performance Evaluation

The performance of wavelet bases and filtering were studied using PSNR, UQI. The first experiment to find out the performance of different wavelet base such as Haar, Symlet, DB4 .Results are shown in table 1. The metrics PSNR, UQI taken in account, the DB4 perform well. Then second test conduct on various levels of decomposition is done for

NOISE		SPECKLE NOISE FOR DB4			GAUSSIAN NOISE FOR DB4		
METRICS	LEVELS	WIENER	ABF	BDND	WIENER	ABF	BDND
PSNR	L1	29.123	**32.119**	28.310	**25.684**	20.981	23.63
	L2	23.50	24.779	23.798	22.402	21.054	21.793
	L3	20.171	21.187	19.901	19.584	18.56	19.211
UQI	L1	0.5968	0.7931	0.7974	0.4330	0.3190	0.3729
	L2	0.3697	0.6001	0.5112	0.2785	0.3214	0.2614
	L3	0.2141	0.4241	0.2615	0.1658	0.1840	0.1321

DB4.Result shown in table 2 with best level and best filter are shown. Table 3 shown that various noise variance to the find out the best filter. Table 4 shown the various metrics to the Adaptive bilateral filter for removing speckle noise.

Table 1: Wavelet type Vs Metrics

NOISE		SPECKLE NOISE			GAUSSIAN NOISE		
METRICS	WAVELET	WIENER	ABF	BDND	WIENER	ABF	BDND
PSNR	HAAR	29.0636	32.0374	28.4555	25.6507	20.9989	23.6252
	SYMLET	25.0994	32.0209	28.5274	**25.6802**	21.0737	23.7029
	DB4	29.1238	**32.1199**	28.3886	25.7156	21.0147	23.5994
UQI	HAAR	0.63519	0.80662	0.8685	0.4346	0.31826	0.3681
	SYMLET	0.53887	0.80088	0.83527	0.43267	0.32046	0.3749
	DB4	0.59683	0.79319	0.79797	0.4364	0.32135	0.3721

Table 2: Three level of decomposition Vs metrics

Table 3: Noise Variance Vs Metrics

METRICS	SPECKLE NOISE WITH ABF FILTER
PSNR	32.1308
SSIM	0.92347
COC	0.99216
UQI	0.79341
EPI	1.3608

Table 4: Various Metrics

NOISE WITH FILTER	SPECKLE NOISE FOR ABF FILTER		GAUSSIAN NOISE FOR WIENER FILTER	
NOISE VARIENCE	PSNR	UQI	PSNR	UQI
0.01	32.0492	0.79262	**25.908**	0.4309
0.02	28.8095	0.73947	25.0336	0.42934
0.04	25.7325	0.6635	23.6484	0.42069
0.06	23.911	0.61023	21.9468	0.40914
0.08	22.5933	0.56705	20.4129	0.40159

From table 1, it found that wavelet techniques will be suitable for the removal of speckle noise. The wavelet bases perform well in removing both noises. It identifies that DB4 will perform better than other bases. For DB4 the various level of decomposition will be taken.

From the table 2 it is found the level 1 perform well for both speckle and Gaussian noise. Then best filter also found using various noise variances in table 3. It is found that adaptive bilateral filter will perform well for the speckle noise. Then various metrics SSIM, COC, EPI are calculated for the adaptive bilateral filter is shown in table 4.

IV.CONCLUSION

The wavelet based noise removal with filtering offers high quality and flexibility for noise problem in images. Filters are used to exert the information containing pixels & edges. The results are observed with various wavelet bases such as Haar, Symlet, and DB4. Various level of decomposition is performed to attain super fine image quality. Denoised image is obtained by employing the filters like wiener filter, Adaptive Bilateral Filter (ABF) and Boundary discriminative noise detection (BDND).

The Quantitative measures such as PSNR, UQI, EPI, COC, SSIM are used to analyze the denoised image. The Symlet performed well against Gaussian noise at level 1 for wiener filter. It is observed that the DB4 performed well against the speckle noise at level1 decomposition with Adaptive Bilateral Filter and produced better image denoising.

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