Performance Evaluation of Various Filtering Techniques for Speckle Suppression in Ultrasound Images

A.Mohanapreethi[1], Dr. V. SrinivasaRaghavan[2]
M.E, Communication Systems[1],
Loyola Institute of Technology[1, 2]
Chennai, India[1, 2]

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Abstract–In diagnosis of diseases, ultrasound imaging is the most commonly used imaging system in medical field. The main issue related to this imaging technique is the presence of speckle noise which degrades the quality of the image. Image denoising is an important pre-processing task, before further processing of image like segmentation, feature extraction etc. This work investigates some of the filtering techniques used in smoothing or suppression of speckle noise and edge preservation in ultrasound images. This work proposes different hybrid filtering techniques for removal of speckle noise from ultrasound images. The key point in effective speckle removal is balance between speckle suppression and feature preservation, which is achieved by using hybrid filtering techniques. Performance evaluations are performed by using statistical parameters like Mean Square Error(MSE), Signal to Noise Ratio(SNR), Peak Signal to Noise Ratio(PSNR), Speckle Index (SI) and Edge Preservation Index (EPI).

Keywords: *Ultrasound imaging, Speckle noise, PSNR, SI, EPI.*

1. INTRODUCTION

Ultrasonography is a powerful technique for imaging the internal anatomy of human body. A high frequency sound wave is transmitted and the reflected echoes are used to create the image. The advantage of ultrasound imaging over X-ray, Computed Tomography(CT), Magnetic Resonance Imaging (MRI) are reported as being painless, non-invasive, does not use ionizing radiation, is less expensive, can be performed real time, needs no special environment. An image is often corrupted by noise during its acquisition or transmission. In medical images noise suppression is delicate and difficult task. A tradeoff between noise reduction and preservation of actual image features has to be maintained.

The main disadvantage of using ultrasound imaging is the poor quality of image which is affected by speckle noise. Speckle is a kind of multiplicative noise. It is random interference pattern in an image formed with coherent radiation of a medium containing many sub resolution scatters. In case of medical literature, speckle noise is also known as texture. General model of speckle is represented as

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

Where f(x,y) is the real noise image,g(x,y) is unobservable original image, η(x,y) is multiplicative component.

The main need for despeckling is to improve human interpretation over ultrasound images and also speckle reduction makes the image cleaner with clearer boundaries.

MuhdZain et al. [2] have reported the use of average, median, Wiener filtering techniques for speckle reduction from ultrasound images and concluded that Wiener filtering is better technique in reducing the speckle without fully eliminating edges. S.Sudha et al. [6] have reported the use of wavelet based thresholding scheme for noise suppression. The thresholding technique removes speckle effectively but the thresholding technique has difficulty in determining an appropriate threshold. K.Karthikeyan et al. [4] have reported the combination of anisotropic diffusion combined with speckle reduction anisotropic diffusion (SRAD) and Bayesshrink threshold gives better result in suppression of speckle noise. Irraivan Elamvazhuthi et al. [1] have reported the use of Dabechies and Wiener gave best result when combined with anisotropic diffusion filter. Bobby et al. [3] have reported about salt and pepper, Gaussian ,speckle noise and various denoising filter and concluded that wavelet filter removes speckle noise effectively.

2. FILTERING ALGORITHMS

In this section several despeckling algorithms such as Median, Average, Wiener, Ideal, Butterworth, Wavelet and Homomorphic filter are discussed.

A. Median Filter

It is a spatial domain filter. A median filter generally smoothens the image to reduce noise and at the same time it preserves edges.

Algorithm

Step1: Get a two dimensional image.
Step2: For handling pixels near the boundary zero padding is done.
Step3: Neighborhood processing involves defining a center point (x, y) then forms a 3 x 3 (user defined size) window.
Step4: Sort the elements within the window in ascending order.
Step5: Find the median element.
Step6: Place the median element into the output matrix.
Step7: Repeat the procedure again from step 4 for the complete input matrix.
This filter doesnot create new pixel value.Instead it chooses the median value which is selected from the neighborhood. This will not affect other pixels significantly. Hence this filter preserves the edges.

B. Average Filter
This filter is a spatial domain filter. This filter acts on the image by smoothing it. It reduces the variation in terms of intensity between adjacent pixels.

Algorithm
Step1: Get a two dimensional image.
Step2: For handling pixels near the boundary zero padding is done.
Step3: Neighborhood processing involves defining a center point (x,y) then form a 3x3 (user defined size) window.
Step4:Multiply each pixel in the neighborhood by corresponding coefficient of 3x3 kernel.
Step5: Sum all the pixels within the mask to obtain the response at point (x,y).

This filter removes the noise by smoothing but the edges are not preserved. This is because new pixel values are created which affects the other pixels significantly.

C. Wiener Filter
It is an adaptive filter which changes the characteristic according to the local statistics in the neighborhood of the current pixel. It generally uses small window size within each window the local mean and variance are calculated. This filter is based on the fact that if the variance over an area is high then smoothing is not done.If the variance over an area is low or constant then smoothing is done.

Algorithm
Step1: Input a two dimensional image.
Step2: For handling pixels near the boundary zero padding is done.
Step3**:**Choose the mask size.
Step4**:**Local mean and variance for the mask is calculated.

(2)

$$\mu = \frac{1}{PQ}\sum_{n=0}^{Q-1}\sum_{m=0}^{P-1} f_b(m,n)$$

$$\sigma^2 = \frac{1}{PQ}\sum_{n=0}^{Q-1}\sum_{m=0}^{P-1}(f_b^2(m,n) - \mu^2) \qquad (3)$$

Step5: Filtered image is obtained by using

$$R(m, n) = \mu + \frac{\sigma^2 - V^2}{\sigma^2}(f_b(m,n) - \mu) \qquad (4)$$

Where V^2 is the user defined noise variance.
Step7:Similar computation finally results the wiener filtered R(m, n) matrix.

D***. Low-Pass Filtering***
Edges and sharp transitions in the gray levels of an image contribute significantly to the high-frequency content of its Fourier transform. Blurring (smoothing) is achieved in the frequency domain by attenuating a specified range of high-frequency components. This task is performed through low-pass filtering.The two low-pass filters that we consider are:

i. Ideal low-pass filter
ii. Butterworth low-pass filter

i. ***Ideal Low-pass Filter***
The ideal low-pass filter is one which satisfies the relation:

$$H(u,v) = \begin{cases} 1 \text{ , if } D(u,v) \le Do \\ 0 \text{ , if } D(u,v) > Do \end{cases} \qquad (5)$$

Where D_0 is a specified non-negative quantity,D(u, v) is the distance from point (u,v) to the origin of the frequency plane

$$D(u,v) = (u^2 + v^2)^{1/2} \qquad (6)$$

The filter is called ideal because all the frequencies inside the circle of radius D_0 are passed with no attenuation, whereas all frequencies outside this circle are completely attenuated.
The drawback of this filter function is a ringing effect that occurs along the edges of the filtered spatial domain image.

ii. ***Butterworth Low Pass Filter***
The Butterworth low-pass filter is an approximation to the ideal filter without the step discontinuity. The transfer function of the Butterworth low-pass filter of order n and with cut-off frequency locus at a distance D_0 from the origin is defined by the relation:

$$H(u,v) = \frac{1}{1 + [D(u,v)/Do]^{2n}} \qquad (7)$$

Where D(u,v) is given by,

$$D(u,v) = (u^2 + v^2)^{1/2} \qquad (8)$$

n is the order of the filter.

Unlike the ideal low-pass filter, the Butterworth filter does not have a sharp discontinuity that establishes a clear cut-off between passed and filtered frequencies.

Algorithm

Step 1: Read the input image
Step 2:Determine the size of the input image
Step 3:Obtain padding.When we consider Fourier transform, the images and transforms are periodic. Periodic function can cause interference between adjacent periods; this will lead to wraparound error.To avoid wraparound error we go for padding.

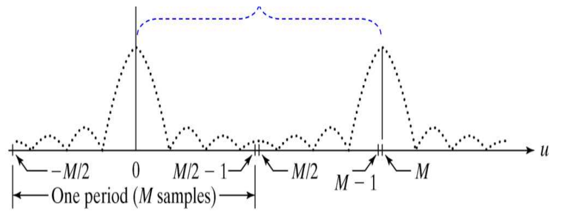


Fig.1 Fourier Spectrum showing back to back half periods in the interval [0, M-1].

Step 4**:** Apply FFT to the preprocessed image.
Step 5:Get the cutoff frequency Do.
Step6: Multiply the transfer function of Ideal or Butterworth filter with Fourier transformed image.
Step 7:Take inverse Fourier transform.

E***. Wavelet Filtering***

Wavelet filtering exploits the decomposition of the image into the wavelet basis and zeros out the wavelet coefficients to despeckle the image. Wavelets are simply mathematical functions and these functions analyze data according to scale or resolution. We use a processing which is carried out without implementing very complex transform. It consists of eliminating certain frequencies in order to eliminate any existing noise. Since we know that in an image HH, LH and HL components contain most of the noise. We can eliminate noise by eliminating those components.This does not mean that all noise present in the image is eliminated. Some details in the image may also be lost.

Algorithm

Step 1: Read the input image.
Step 2: Preprocess the input image.
Step 3**:**Apply Discrete Wavelet Transform (see Fig. 2)by getting the wavelet name, level of decomposition requiredand band to be eliminated.

The Fig.2 describes schematically the two dimensional forward discrete wavelet transform.When DWT is applied to an image,the image is decomposed into 4 components namely approximated component (LL),horizontal component(HL), vertical component(LH),diagonal component(HH).

This technique involves eliminating certain frequencies in order to eliminate any existing noise. Generally in an image high frequency components contain noise.

Step 4**:** To eliminate a particular band get the size of that band.
Step 5**:** Eliminate the band by making them zero.
Step 6**:** Take Inverse Discrete Wavelet Transform.(Fig.3)

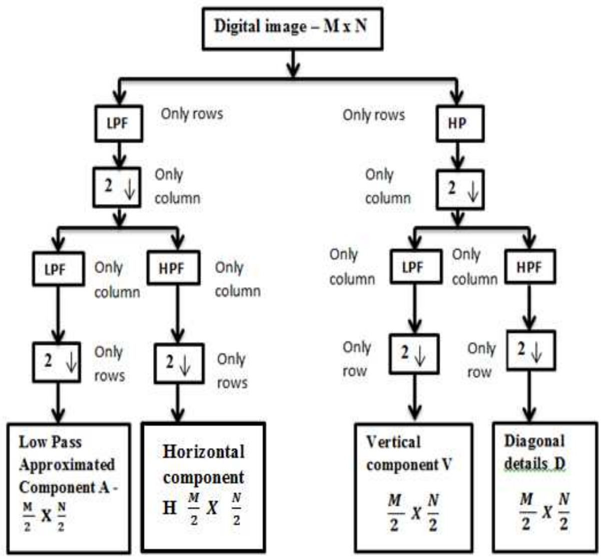


Fig.2 Two Dimensional Forward Discrete Wavelet Transform.

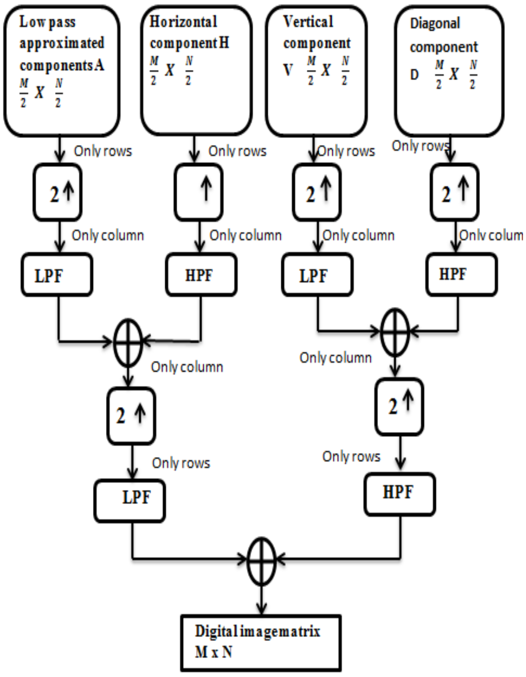


Fig.3 Two Dimensional Inverse Discrete Wavelet Transform

F. ***Homomorphic Filter***

These filters are used for image enhancement. It simultaneously normalizes the brightness across an image and increase contrast. Homomorphic filter is used to remove multiplicative noise. Natural log is taken to the input image which converts multiplicative noise into additive noise. Then a user defined filter is used and finally exponential operation is done.

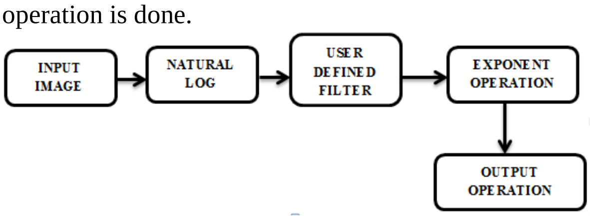


Fig. 4 Homomorphic Filtering

G. ***Hybrid Combination of Filtering Algorithm***

Here hybrid combinations are done using sequential combination. Sequence combination will have series of methods where the output of one will be the input of the next one. Several sequential combinations of above mentioned filters are experimented. Some of the hybrid combinations that gave best results are represented below.

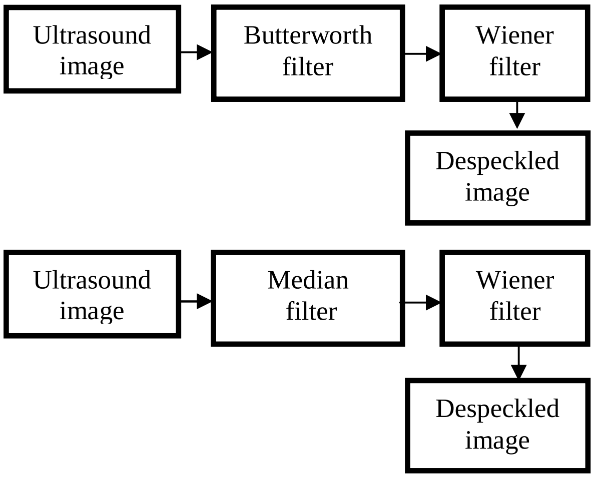


Fig.5 Hybrid Combination of Filters

3. EVALUATION METRICS

Some common measurements that are needed to evaluate the performance of speckle reduction filters for ultrasound images are listed below

A. Mean Square Error

It indicates how different the images being compared are. It is given by

$$\mathrm{MSE} = \frac{1}{M.N}\sum_{m=0}^{M-1}.\sum_{n=0}^{N-1}.[\,I(m,n) - \hat{I}(m,n)]^2 \qquad (9)$$

WhereI(m, n) is original image,$\hat{I}$(m,n) is filtered image,M is number of rows,N is number of columns. Therefore lower its value is the closer the estimated image to the original image and the better performance the algorithm which was used to obtain the estimation, has.

B. Signal to Noise Ratio

It shows the relationship between the real image and estimated image. This ratio indicates how strong the noise corrupted the original image. It is given by

$$\mathrm{SNR} = 10\,\log_{10}\frac{\frac{1}{M.N}\sum_{m=0}^{M-1}.\sum_{n=0}^{N-1} I^2(m,n)}{\mathrm{MSE}} \qquad (10)$$

Where Iis the original image, M is number of rows, N is number of columns.Here higher the value indicates an improvement.

C. ***Peak Signal to Noise Ratio***

In PSNR we are interested in signal peak.This is more content specific than pure SNR.Here we say how high intensity regions of the image come through the noise and paying much less attention to low intensity regions. It is given by

(11)

$$PSNR=10\log_{10}(2^{B}-1)^2 / MSE$$

WhereB is number of bits used for each pixel,MSE is mean squared error.Here higher the value indicates an improvement.

D.***Speckle Index (SI)***

SI is a measure of speckle reduction in terms of average contrast of the image.Lower value of SI corresponds to improved image quality. The SI is defined as follow

$$SI = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\sigma(i,j)}{\mu(i,j)} \qquad (12)$$

σ(i,j) and μ(i,j) are the standard deviation and mean corresponding to neighbor domain.

E. ***Edge Preservation Index***

EPIis used to evaluate the preservation of edges.In this case an increase of this parameter also indicates better performance quality.

$$EPI = \frac{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}[\Delta I(m,n) - \widehat{\Delta I}].[\Delta \hat{I}(m,n) - \widehat{\Delta \hat{I}}(\ldots,\ldots)]}{\sqrt{\sum_{n=0}^{N-1}[\Delta I(m,n) - \widehat{\Delta I}]^2 . [\Delta \hat{I}(m,n) - \widehat{\Delta \hat{I}}(m,n)]^2}} \qquad (13)$$

WhereΔ operator means applying a high pass filter to the image. To perform the filtering, the Laplacian operator is used in its 3 x 3 version. Delta is the mean value of the image after operator is applied.

4. EXPERIMENTAL RESULTS AND DICUSSION

To compare the algorithms, we experiment those algorithms with the pancreas image in Fig.6a. Since we only have a noise corrupted image and the real noise-free image does not exist, conventional metrics cannot be used to indicate the quality obtained with filtering.So, from this image we have generated a noisy image (see Fig.6b).

In case of average filter different window sizes have been used such as 3x3, 5x5, and 7x7. According to the metrics(Table 1), average filter with 3 x 3 window size eliminates noise in such a way that we obtain a better quality image than the noisy image.

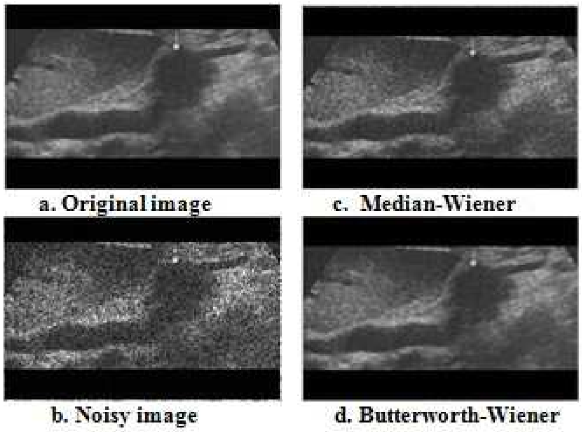


Fig.6Results of Hybrid Filters

Table 1: Computed Performance Metrics of Various Filters
(Note: The SI value of original image is 2.956 e^-6)

Filters	MSE	SNR	PSNR	SI x e^-6	EPI
NOISY	8.718	65.71	68.72	3.284	1708
Average 3x3	2.000	72.10	75.12	2.882	1765
Median 3x3	3.063	70.25	73.27	2.980	**2091**
Wiener 3x3	2.965	70.48	73.41	2.976	1791
Homomorphic Wiener	2.033	72.12	75.05	2.976	1468
Ideal fc=60	1.821	72.51	75.51	2.896	1187
Homomorphic Ideal fc=60	2.806	70.72	73.64	2.983	996
Butterworth fc=60	**1.567**	**73.16**	**76.17**	**2.850**	1239
Homomorphic Butterworth	2.537	71.16	74.08	2.842	1137
Wavelet LH-HL-HH	3.132	70.16	73.17	2.995	1614
Wavelet LH-HH	4.985	68.14	71.15	3.097	1934
Wavelet Level 2	3.151	70.13	73.14	2.994	1598
Homomorphic Wavelet LH-HH	5.389	67.89	70.81	3.076	2049

In case of median filter different window sizes have been used such as 3x3, 5x5, and 7x7. According to the metrics (Table 1), a median filter with 3 x 3 window size eliminates noise in such a way that we obtain a better quality image than the noisy image. We have also noticed that as the window size increases noise is reduced effectively but smoothing also increase which means that edges are not preserved, as the window size increase.

To sum up we use small window size (3x3) with these methods. We can make some of the noise disappear, the borders are still well defined.

When we compare average and median filter, average filters removes noise effectively (this is observed by seeing the PSNR value in Table1) but edges are not preserved (this is observed by seeing the EPI value in Table1) .Whereas median filter preserves edges effectively.In case of Ideal and Butterworth filter evaluation is done by varying Cutoff frequency such as 30, 40, and 60.

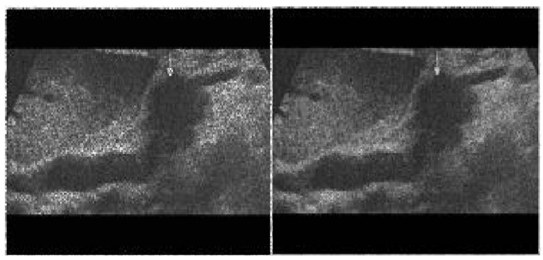
We have observed that in case of Ideal filter (IDL) some part of the background of the image is smoother but the object contours have become blurred and there is a wave like effect around the background. This wave effect decreases as the cutoff frequency increases. Hence an Ideal filter with cutoff frequency 60 gives best result.

HYBRID	MSE	SNR	PSNR	SI x e^-6	EPI
Median-Wiener	2.240	71.615	74.628	2.918	**2100**
Wiener-Median	1.919	72.286	75.299	2.902	2051
BTW-Wiener	**1.586**	**73.112**	**76.125**	**2.836**	1228
Wiener-BTW	1.626	73.004	76.017	2.837	1243
BTW-Hwiener	1.674	72.880	75.893	2.859	1203
Wlet-BTW	1.692	72.832	75.845	2.831	1201
Avg-Wiener	1.701	72.808	75.821	2.849	1763
IDL-BTW	2.011	72.083	75.096	2.811	1180
Avg-Hwiener	1.715	72.774	75.786	2.918	1269
BTW-Hwiener	1.674	72.880	75.893	2.859	1203

In case of Butterworth filter (BTW), it tries to eliminate the wave effect which is introduced in Ideal filter.If the cutoff value is lowered even more, we would get greater smoothness but we would also lose sharpness in the image and the Gibbs effect may become more significant. That is why we do not lower the cutoff value more significantly. On the contrary, it is raised to 60 to avoid these damaging effects. Hence the Butterworth filter with cutoff frequency 60 gives best result.

In wavelet filtering (WLET) bands such as LH, HL, HH, LH-HH-HL, LH-HL, HL-HH, and LH-HH are eliminated separately and their evaluation metrics are calculated. Some those metrics are listed in Table1.By eliminating bands white spots is created in the image which is not present in the original image,this white spots is not that much prevalent when we remove LH-HH-HL together.

Wiener filtering preserved the edges reasonably well, but in this case the noise elements are visible (clearly visible on the background of image(see Fig.7a).) and can be seen with the naked eye as well.This is overcomed by using homomorphic Wiener filter.In relation to the images, noise in bright regions have higher variations and could be interpreted wrongly as features in the original image by Wiener filter. Thus, it is harder and more complicated to smooth the noise without degrading true image feature. Hence by using homomorphic Wiener filtering technique, noise in the brighter regions are also removed (see Fig.7b).



(a) (b)

Fig.7Effect of Homomorphic Weiner filter

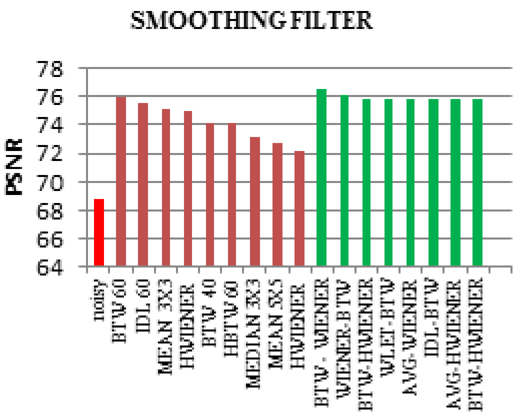
Homomorphic combination is tried with filters like Ideal (H-IDL), Butterworth (H-BTW), Wiener (H-Wiener), and Wavelet (H-WLET). Some of their results are listed in Table 1.Several hybrid combination of above mentioned filters are experimented. Some of the hybrid combination that gave best results are listed in Table 2.

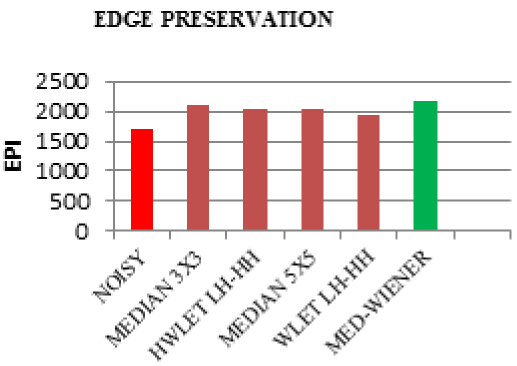
Table 2: Computed Performance Metrics of Hybrid Filters

(Note: The SI value of original image is 2.956 e^-6

We can notice from the chart (Fig.8) that hybrid combinations removes noise effective and also preserve edges.The SI of the original image is 2.956

e^-6 whereas the SI of the hybrid filtered image is 2.836 e^-6. From this we can observe that the designed hybrid filter not only removes the noise we added but also removes the speckle noise that already exist in the original image.





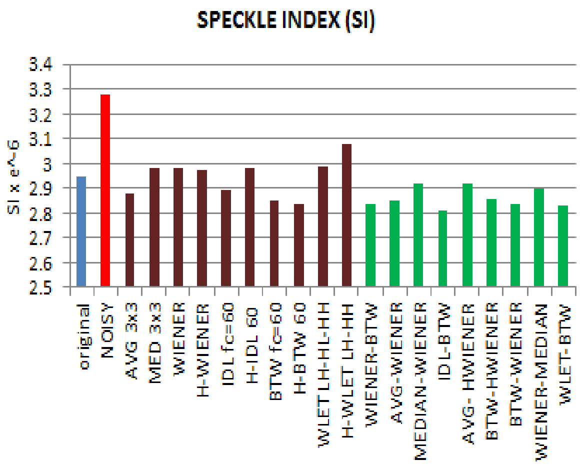


Fig.8PSNR and EPI and SI of individual and hybrid filters

5. CONCLUSION

The current need of the healthcare industries is to preserve useful diagnostic information with minimum noise. Ultrasound images often suffer with a special type of noise called speckle. Introduction of speckle degrades the image contrast and block out the under lying anatomy. In order for the medical practitioners to achieve correct diagnosis, the ultrasound images have to be despeckled. This study focus on comparison of different filters based on the performance metrics like MSE, SNR and PSNR, SI, EPI. From these results hybrid combination of filters are designed to improve the performance. A hybrid combination of Butterworth with Wiener, Butterworth with Homomorphic Wiener removes noise effectively than individual filters and also hybrid combination of median with Wiener preserve edges effectively than individual filters. It is anticipated that future work would involve more experimental work with a variety of ultrasound images.

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