Effect of Wiener-Helstrom Filtering Cascaded with Bacterial Foraging Optimization to Despeckle the Ultrasound Images

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Abstract
The diagnosing of disease using speckled ultrasound image is a very difficult task for doctors. The speckle noise not only hinders the visual information but also affect the segmentation process used in ultrasound image processing. Thus speckle noise suppression is necessary pre-processing task in order to maintain the diagnostic potential of ultrasound imaging. This paper proposes an efficient technique for speckle noise removal. The proposed technique is implemented using Bacterial Foraging Optimization (BFO) cascaded with Wiener-Helstrom filter. Wiener-Helstrom filter processes the ultrasound image by making the filtering less sensitive to slight changes in input conditions. BFO algorithm used as an optimization technique to minimize the error between the noisy image and the Wiener-Helstrom filter output image. The error percentage of 0.0001 is maintained here. It has been observed by the experimental results that the proposed method outperform and gives superior result to conventional methods. The efficiency is measured in the form of Peak Signal to Noise Ratio(PSNR), Mean Square Error(MSE) and Mean Absolute Error(MAE) and Signal to Mean Square error(S/MSE).

Keywords: *Speckle noise, Wiener-Helstrom filter, BFO, PSNR, MSE, MAE, S/MSE.*

1. Introduction
Ultrasound Imaging is popular in medical sciences due to it's features: non-invasive nature, portable, cost effective, safe and non-radiant. Ultrasonography uses sound waves in Mega Hertz(MHz) range to produce images by reflection from the heterogeneities of the patient under examination[1]. The reflected waves come with different phases and amplitude, causes rise to an interference pattern known as speckle noise. It hampers the perception and extraction of fine details in the image. The presence of speckle noise reduces the ability to detect lesions by a factor of eight[2]. In literature the maximum methods despeckle at the expense of blurring the image details. To analyse a degraded image is very difficult task. Thus for diagnosing purpose it becomes important to protect the relevant information from the noise. Noise may be additive or multiplicative in nature. In ultrasound imaging the multiplicative (speckle) noise is found to be prominent as compared to additive noise. Different methods are available for despeckling. These method works either in spatial domain or in frequency domain. Lee, kuan and frost are standard filters and are based on local statistics[4-5]. Others are mean[6], median[7], adaptive weighted median [8-9], bilateral[10] and wiener[11] filter, available in literature. The transformation based methods cover Fourier transform [12], wavelet transform[13-16] and diffusion based filtering [17]. Other techniques used for despeckling are neural network [18-19] and fuzzy logic based[20].

In this paper we propose a bacterial foraging optimization technique[21] cascaded with wiener-helstrom filter[22] to remove speckle noise from ultrasound image. Wiener filtering is selected because over time or frequency range of interest, it gives least mean square error(MSE) between desired function and the output of filtering[23]. The BFO algorithm cascaded with wiener filter, to optimize the output of the wiener filter and to enhance the PSNR, and S/MSE. To test the performance of proposed method , the original test images are corrupted with varied noise density. It is observed by the experimental results that the proposed method is better and outperforms as compared to other conventional methods in form of PSNR, MAE, MSE and S/MSE.

The remainder of the paper is organized as follow; Section2 gives idea about Imaging Model, Section3 describes wiener filter , Section4 describes BFO, Section5 describe the proposed method. Quantative results are presented in Section6. Finally conclusion is considered in Section7.

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2. Imaging Model

All digital images originate from somewhere. The mathematical equation for image formation is given as[22]:

Image = PSF*Object function + noise (1)

Where

PSF stands for point spread function. It describes the way by which the information on the object function is spread for recording the data. It depends on the imaging instruments(i.e. camera).

Object function describes the scene that is being imaged.

Noise is a non-deterministic function which may be additive or multiplicative in nature.

* is the symbol of convolution, used to convolve one function with another.

The linear imaging system (equation 1) can be represented as

$$s(x, y) = f(x, y) ** h(x, y) + n(x, y) \quad (2)$$

where

$s(x, y)$= output distribution

$f(x, y)$= input distribution

$h(x, y)$= point spread function

$n(x, y)$=noise

** = two dimensional convolution operator

Eq. 2 may be written as

$$s(x, y) = \iint f(x', y')h(x - x', y - y')\, dx'dy' + n(x, y) \quad (3)$$

In frequency domain equation 2 becomes

$$F_T\{s(x, y)\} = F_T\{f(x, y)\} ** h(x, y) + n(x, y)\}$$

$$S(k_x, k_y) = F(k_x, k_y)H(k_x, k_y) + N(k_x, k_y) \quad (4)$$

Now assume additive noise is zero then in equation 4, divide both side by $H(k_x, k_y)$

$$F(k_x, k_y) = \frac{S(k_x,k_y)}{H(k_x,k_y)} = Y(k_x, k_y)S(k_x, k_y) \ldots\ldots\ldots\ldots\ldots(5)$$

Taking inverse transform

$$f(x, y) = F^{-1}\{Y(k_x, k_y)\, S(k_x, k_y)\}$$

Where $Y(k_x, k_y) = \frac{1}{H(k_x,k_y)}$

$H(k_x, k_y)$ is system optical transfer function (OTF) but when noise is available then

$$\hat{F}(k_x, k_y) = Y(k_x, k_y)S(k_x, k_y)$$

$$= \frac{S(k_x,k_y)}{H(k_x,k_y)} + \frac{N(k_x,k_y)}{H(k_x,k_y)} = F(k_x, k_y) + \frac{N(k_x,k_y)}{H(k_x,k_y)} \quad (6)$$

where $\frac{N(k_x,k_y)}{H(k_x,k_y)}$ is an additional term

Eq. 6 contains additional term as compare to equation 5 so this additional term should be as small as possible so that estimated spectrum $\left(\hat{F}(k_x, k_y)\right)$ approach to true input spectrum

$$\hat{F}(k_x, k_y) = Y(k_x, k_y)S(k_x, k_y) =$$

$$Y(k_x, k_y)[H(k_x, k_y)F(k_x, k_y)+N(k_x, k_y)] \quad (7)$$

The true input spectrum directly depends on the $Y(k_x, k_y)$ as shown in equation 7. It is achieved by Wiener-Helsrom filter.

3. Wiener-Helstrom Filtering

The frequency domain filter $Y(k_x, k_y)$ should have the following qualitative properties to recover the true input spectrum.

i) At those spatial frequency pairs for which the $|N(k_x, k_y)| \ll |S(k_x, k_y)|$
   Where $|N(k_x, k_y)|$ is noise component and $|S(k_x, k_y)|$ is image component

The filter should approach to $Y(k_x, k_y) \approx \frac{1}{H(k_x,k_y)}$

ii) When $|N(k_x, k_y)| \gg |S(k_x, k_y)|$ then the filter should approach to $Y(k_x, k_y) \approx 0$

This ensures that the spatial frequency pairs which are dominated by the noise components are not restored.

iii) When $|N(k_x, k_y)| \approx |S(k_x, k_y)|$ then filter should damp these frequencies .

These 3 properties are achieved by Wiener-Helstrom [22] filter, defined as

$$Y(k_x, k_y) = \frac{H^*(k_x,k_y)W_F(k_x,k_y)}{|N(k_x,k_y)|^2 W_F(k_x,k_y)+W_N(k_x,k_y)} \quad (8)$$

Where H* denotes the complex conjugate of the OTF and quantities $W_F(k_x, k_y)$and $W_N(k_x, k_y)$ are respectively input and noise power spectra.

To restore the image in presence of blur as well as noise, wiener filtering is used. For wiener filtering to work, local image variance is computed and then the smoothing of image is performed . If local variance of image is large, smoothing will be less and for small value of local variance, smoothing will be more.

4. Bacterial Foraging Optimization(BFO)

In engineering design problems the main emphasis relies on either maximizing or minimizing a certain goal. For this purpose optimization algorithms are used. BFO is an optimization technique proposed by K.M Passino [21]. Passino used the foraging strategies of the Escheria Coli(E.Coli) bacterium cells[25] which are living in our intestines. The E.Coli bacterium has a cell wall,

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capsule(contains cytoplasm and nucleoid) and a plasma membrane.
The E.Coli bacterium search the food and avoids from noxious substances by using its control mechanism. The control mechanism used for foraging follows chemotaxis (swimming and tumbling), swarming, reproduction, elimination & dispersal processes. The foraging decisions are made on the basis of energy intake E per unit time(E/T). Maximization of E/T function provides nutrient sources to survive and extra time for other important activities[25]. Swimming is done for fixed distance and tumbling is done for changing the direction. Different combinations of swimming and tumbling defines the type of search strategy like cruise, salutatory and ambush. One time swim and tumble constitutes one chemotaxix step. If concentration of food is greater at next location then bacterium takes next step in same direction otherwise they tumble for finding the more concentration of food in another direction. The chemotaxix steps continue till the life time of the bacterium. During swarming, the bacteria move out from their respective places in a ring of cells by moving up the mean square error to the minimum value. During reproduction, the least healthy bacteria die and others split in to two, are placed in same location. Thus population of bacteria remain constant. Such type of control mechanism of E.Coli bacterium for maximizing E/T function has led researchers to conjecture it for optimization in the field of engineering.
The BFO algorithm is presented below
Bacterial Foraging Optimization Algorithm[25]
Initialize parameters p, S, Nc , Ns , Nre , Ned , ped , and the C(i), i = 1,2,……… S.
where
p = dimension of search space
S = Number of bacteria in the population
Nc = Number of chemotaxis steps
Ns = Number of swimming steps
Nre = Number of reproduction steps
Ned = Number of elimination and dispersal steps
Ped = Probability of elimination and dispersal
$\theta^i(j,k,l)$=Position vector of the ith bacterium, in jth chemotaxis step, kth reproduction step, in lth elimination and dispersal step.
1) Elimination-dispersal loop: $l = l + 1$
2) Reproduction loop: $k = k + 1$
3) Chemotaxis loop: $j = j + 1$
a) For i = 1,2,3,4,…….. S, take a chemotaxis step for bacterium i as follows.
b) Compute fitness function $J(i, j,k,l)$.
c) Let J last = $J(i, j, k, l)$ to save this value since we may find a better cost via a run.
d)Tumble: Generate a random vector Δ(i) Î $\in R^p$ with each element $\Delta_m(i)$, m = 1,2,……..,p, a random number on [−1,1]
e) Move: Let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

This results in a step of size $C(i)$ in the direction of the tumble for bacterium i.
f) Compute $J(i, j + 1,k,l)$.
g) Swim
i) Let $m = 0$ (counter for swim length).
ii) While $m < Ns$ (if have not climbed down too long)
• Let $m = m+ 1$.
• If $J(i, j + 1,k,l) < J$last (if doing better),
Let J last = $J(i, j+1, k, l)$ and let

$$\theta^i(j+1,k,l) = \theta^i(j+1,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

and use this $\theta^i(j + 1, k, l)$ to compute the *new* $J(i, j + 1,k,l)$ as we did in (f)
• Else, let $m = Ns$. This is the end of the while statement.
h) Go to next bacterium $(i + 1)$ if $i \neq S$ (i.e., go to b) to process the next bacterium).
4) If $j < Nc$, go to step 3. In this case, continue chemotaxis, since the life of the bacteria is not over.
5) Reproductions:
a) For the given k and l, and for each i = 1,2,3,4,…, S, let

$$J^i_{health} = \sum_{j=1}^{Nc+1} J(i,j,k,l)$$

be the health of bacterium i
a) measure of how many nutrients it got over its lifetime and how successful it was at avoiding noxious substances). Sort bacteria and chemotactic parameters $C(i)$ in order of ascending cost J_{health} (higher cost means lower health).
b) The $S_r = S/2$ bacteria with the highest J_{health} values die and the other $S_r = S/2$ bacteria with the best values split.
6) If $k < Nre$, go to step 2. In this case, we have not reached the number of specified reproduction steps, so we start the next generation in the chemotactic loop.
7) Elimination-dispersal: For i = 1,2,3,4…………, S, with probability Ped , eliminate and disperse each bacterium (this keeps the number of bacteria in the population constant). To do this, if you eliminate a bacterium, simply disperse one to a random location on the optimization domain.
8) If $l < Ned$, then go to step 1; otherwise end.

5. Proposed Method

In proposed technique a standard ultrasound image is taken as shown in figure 1 and it was corrupted by speckle noise of varied noise densities from 10% to 90%. The noisy image is first passed through the Wiener-Helstrom filter. The wiener filtering is chosen because it gives least MSE between a desired function and the output of the filtering over time/frequency range of interest. The filter take variation in the operation $Y(k_x,k_y)$ in such a way that optimization criterion is

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achieved. The filter works by accepting low noise frequency components and rejecting high frequency component[22]. This method produces better results as compared to other type of filtering [26]. To optimize the value of minimum mean square error(MMSE), BFO algorithm is cascaded with wiener filter. The MSE as given in [27] is used as cost function for the BFO to optimize PSNR & S/MSE. The following parameters are selected for BFO:
The following parameters are selected for BFO:

1) Number of bacteria used for searching total region = Row*Colum of image.
2) Number of iteration taken in chemotaxis loop = 3
3) Swimming steps = 2
4) Number of reproduction = 2
5) Number of elimination and dispersal = 2
6) Probability of elimination and dispersal = 0.25

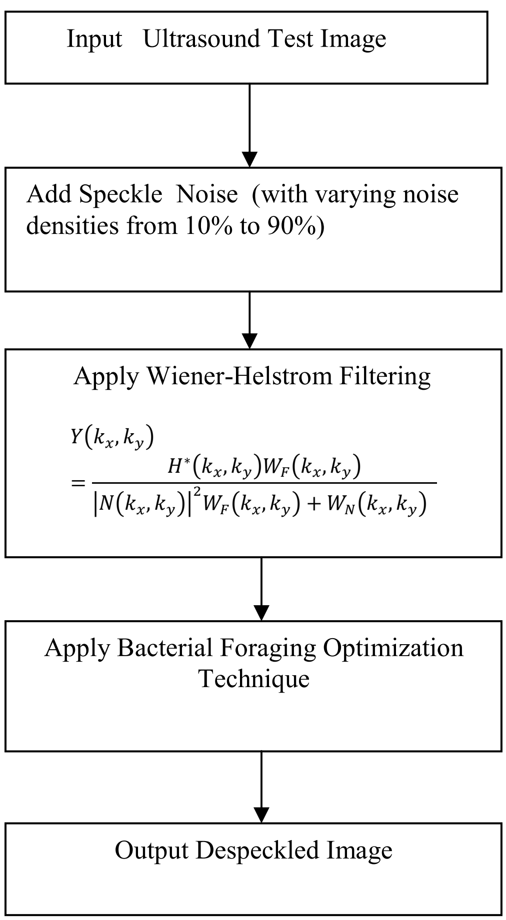

Figure 1: Block Diagram of proposed method

The performance of this method is quantified on the basis of PSNR, MSE, MAE S/MSE [24]:

i) Mean Absolute Error (MAE): MAE is average of absolute difference between the reference signal and test image. It is given as:
$$\mathrm{MAE} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} |x(i,j) - y(i,j)| \quad (9)$$
Where $x(i,j)$ and $y(i,j)$ denote the pixel values of the restored image and original image respectively and M x N is the size of the image.
ii) PSNR: PSNR is a classical index defined as the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. It is given by:
$$PSNR = 10\log_{10} 255^2 / MSE \quad (10)$$
Where 255 is the maximal possible value the image pixels when pixels are represented using 8 bits per sample, and MSE is mean square error.
iii) MSE (mean square error) is the Euclidian distance between the original and the degraded images.
$$MSE = (1/M \times N)\sum_{i=1}^{M}\sum_{j=1}^{N}(a_{ij} - b_{ij})^2 \quad (11)$$
In above Eq. 11, a_{ij} means the pixel value at position (i, j) in the original image and b_{ij} means the pixel value at the same position in the corresponding distorted image.
The major advantages of these metrics are its simplicity and mathematical tractability. Greater value of PSNR indicates greater image similarity, while greater value of MSE indicate lower image similarity.
iv) S/MSE(signal to mean square error) is the quality parameter which indicates the signal strength. Higher value of S/MSE indicates greater image quality.

6. Experimental Results & Discussions

The performance analysis of proposed method has been done by testing it on standard ultrasound test images. The original images distorted with various speckle noise densities. The proposed method remove speckle noise, calculates PSNR, MAE, MSE and S/MSE for each case. The results of the proposed technique have been compared with some existing techniques used for noise removal like median filter[7], adaptive median filter[28] and wiener[22] filter with varied noise densities from 10% to 90% as shown in figures 3-6. Figures 3-6 shows the graphical representation of the comparative results in form PSNR, MSE, MAE & S/MSE.
The original ultrasound images, corrupted images and despeckled images using different techniques are shown in figure 2 a-f . Table 1 & Table 2 shows the result of proposed method and some available techniques in terms of PSNR, MSE, MAE and S/MSE. Table 3 shows the comparative results of proposed method in terms of enhanced PSNR with Wiener-Helstrom filter. As seen, the proposed technique is better in terms of PSNR and clarity and finer detail preservation.

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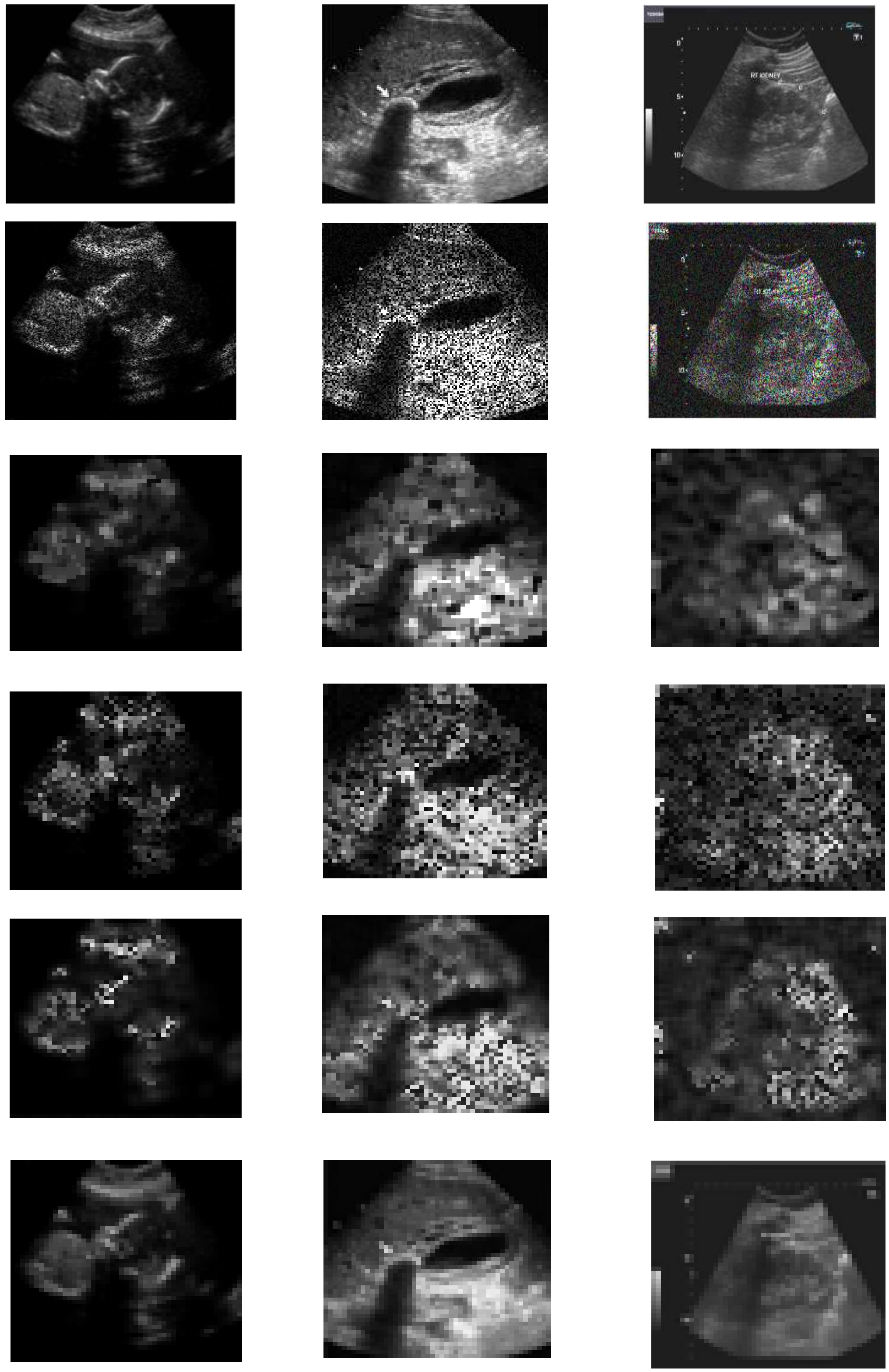

Figure2: (a) Ultrasound images(image1 is of foetus , image2 is of liver & image3 is of kidney); (b) Images with 50% noise density; (c) median filter output; (d) Adaptive median filter output; (e) Wiener filter output ; (f) Restored images using proposed method .

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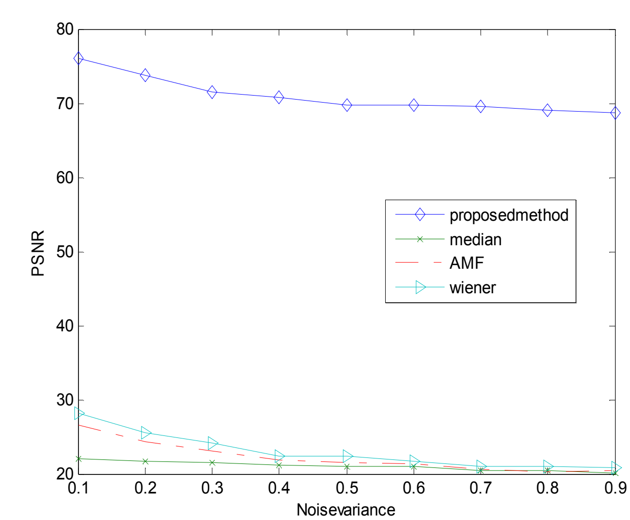

Figure 3

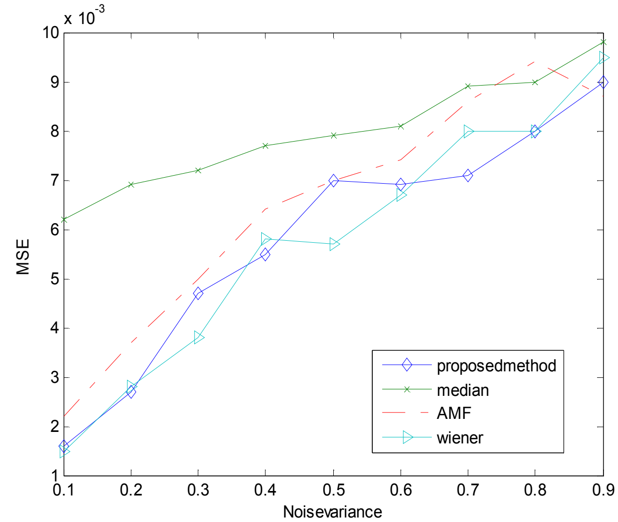

Figure 4

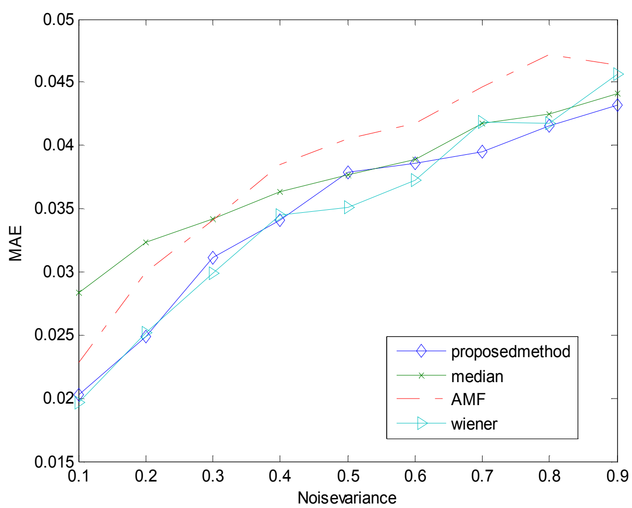

Figure 5

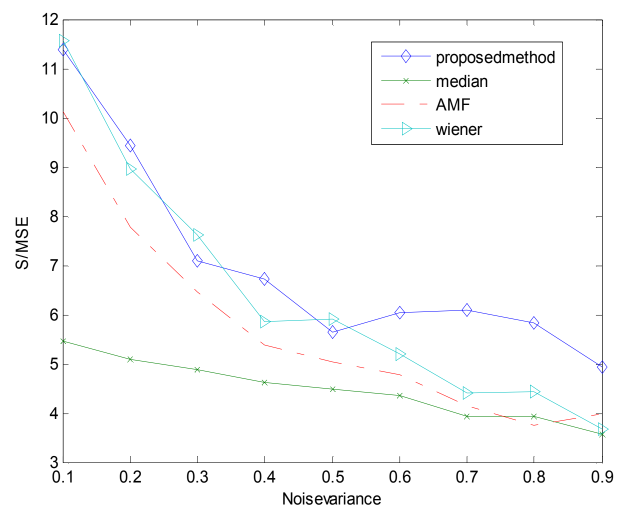

Figure 6

Table 1. Comparison of PSNR & MSE Values of The Proposed Method with other existing methods for an Ultrasound Image of foetus

Noise Density In %age	PSNR(dB)				MSE			
	Median filter	Adaptive median filter	Wiener filter	Proposed method	Median filter	Adaptive median filter	Wiener filter	Proposed method
10	22.012	26.650	28.108	76.044	0.0062	0.0022	0.0015	0.0016
20	21.637	24.320	25.501	73.859	0.0069	0.0037	0.0028	0.0027
30	21.422	23.013	24.151	71.420	0.0072	0.0050	0.0038	0.0047
40	21.155	21.914	22.387	70.714	0.0077	0.0064	0.0058	0.0055
50	21.036	21.571	22.438	69.706	0.0079	0.0070	0.0057	0.0070
60	20.893	21.321	21.752	69.749	0.0081	0.0074	0.0067	0.0069
70	20.484	20.677	20.947	69.627	0.0089	0.0086	0.0080	0.0071
80	20.474	20.288	20.988	69.078	0.0090	0.0094	0.0080	0.0080
90	20.104	20.517	20.818	68.605	0.0098	0.0087	0.0095	0.0090

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Table 2: Comparison of MAE & S/MSE Values of The Proposed Method with other existing methods for an Ultrasound Image of foetus

Noise Density In %age	MAE				S/MSE(dB)			
	Median filter	Adaptive median filter	Wiener filter	Proposed method	Median filter	Adaptive median filter	Wiener filter	Proposed method
10	0.0284	0.0228	0.0197	0.0203	5.469	10.108	11.567	11.39
20	0.0323	0.0300	0.0252	0.0249	5.095	7.778	8.958	9.429
30	0.0342	0.0341	0.0299	0.0311	4.880	6.471	7.609	7.097
40	0.0363	0.0385	0.0345	0.0341	4.613	5.371	5.845	6.711
50	0.0377	0.0405	0.0351	0.0379	4.494	5.028	5.895	5.646
60	0.0389	0.0418	0.0373	0.0386	4.350	4.779	5.209	6.037
70	0.0418	0.0446	0.0419	0.0395	3.942	4.134	4.405	6.087
80	0.0425	0.0472	0.0418	0.0416	3.932	3.745	4.445	5.827
90	0.0441	0.0464	0.0456	0.0432	3.558	3.974	3.670	4.925

Table 3: Comparative Result (PSNR) of Proposed Method with Wiener-Helstrom filter for an Ultrasound Image of foetus

Noise Density In %age	Wiener filter (PSNR)	Proposed method (PSNR)	Enhancement in PSNR (in dB)
10	28.108	76.044	47.936
20	25.501	73.859	48.358
30	24.151	71.420	47.269
40	22.387	70.714	48.327
50	22.438	69.706	47.268
60	21.752	69.749	48.029
70	20.947	69.627	48.680
80	20.988	69.078	48.090
90	20.818	68.605	47.878

7. Conclusion

A new approach is presented in this paper to remove the speckle noise from ultrasound images. The proposed method used BFO technique with Wiener-Helstrom filter to improve PSNR of highly corrupted images in absence of original image. The efficiency of the proposed method is quantified on the basis of subjective and objective image quality assessment techniques. The result obtained in terms of PSNR, MSE, MAE, S/MSE and perceptual image quality proves that the proposed method is a robust technique which yields better signal to noise ratio. Thus proposed method has very large potentiality for pre-processing of ultrasound images.

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