Reduction of Speckle Noise in Medical Images using Stationary Wavelet Transform and Fuzzy logic

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***Abstract*—To scan different organs of human beings, medical imaging devices such as Magnetic Resonance Image, Computer Tomography, X-Ray and Ultrasound are used. These devices are used to get medical images to investigate most of diseases. Medical images are oftentimes effected by speckle noise. To utilize medical images accurately for given applications, it is very important to remove speckle noise from these images. Stationary wavelet transform is vastly used technique in image processing to remove noise, but decomposition at higher level can also cause to lose some information such as edges and contrast. Therefore to preserve and enhance edges, the proposed method uses denoising, edge preserving and enhancing techniques separately on noisy image. Finally, image fusion is used to combine three enhanced images. Wavelet transform has been used to denoise, sharpening and fusion while fuzzy logic is used to enhance the contrast.**

***Index Terms*—Fuzzy Logic; Image Fusion; Medical Imaging; Speckle noise; Stationary Wavelet Transform.**

I. INTRODUCTION

High quality medical images are obtained in the era of modern digital world. These images are used increasingly by medical society, for accurate diagnosis of different diseases. However, the introduction of speckle noise degrades the quality of these images, due to which some of the diagnostic information is lost. Therefore, to preserve edges and to remove speckle noise, despeckling is required. Research community has vast interest to develop robust despeckling technique, which can remove speckle noise from images, as well as preserve edges.

The introduction of artifacts and noise are responsible for poor visualization of medical images[1]. To improve the performance of denoising, several techniques have been used in the past decade. These techniques can be classified broadly as spatial and transform domain denoising. Spatial filters works directly on the pixels of images such as mean filter, median filter, Wiener filter, Lee filter [2], Frost filter [3]. Median filter removes small isolated points but it depends on window size. Increasing the size of window can blur the image, while decreasing the size has poor performance reducing the noise. To remove speckle noise from ultrasound images, an adaptive weighted median filter was proposed by Loupas [4], which improved performance of median filter, but the technique tends to lose some details due to inaccurate model. Local wiener provides trade off between blur and noise reduction, but is unable to protect details resolution, as it fails to remove noise in edges where variance is high [5]. Non linear filter was proposed by Tomasi and Manduchi [6] known as bilateral filter. It is based on the idea that neighborhood has geometric similarities. Non local means (NLM) considers to average the repeating structures to de-noise image. This method preserve edges but has a problem of high computation [7]. Filtering in transform domain are Fourier transform, contourlet transform [8], wavelet transform [9], cosine transform etc. In [10] and [11], a two step denoising method was proposed. From the squared magnitude image, bias was removed in the first step, while the denosing was performed in the second step on square root of the image in wavelet domain.

This paper presents a technique to enhance medical images for better visual quality. The quality of de-noised images are measured by quantitative performance metrics like Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), and Entropy (E). BaysSrink threshold has been used in this paper and the proposed method is compared with different wavelets such as Haar, Bi-orthogonal and Coiflets. The remainder of this paper is organized as follow. In Section 2, a brief description of proposed technique is given. We take a look at the experimental results acquired in section 3. Finally, a conclusion is given in Section 4.

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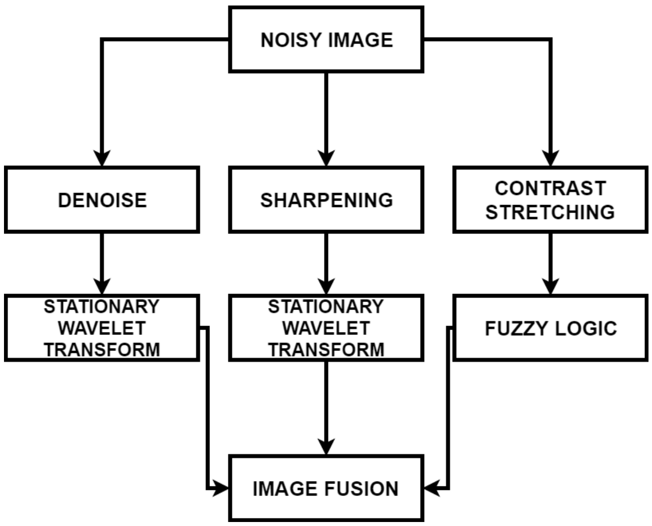

Fig. 1. schematic overview of proposed method

II. Proposed Method

This paper proposes a method to reduce speckle noise from medical images based on stationary wavelet transform and fuzzy logic. Stationary wavelet transform decompose an image into high frequency details and low frequency approximations. High frequency noise, as well as edge information is contained in details. So some threshold is applied on high frequency details to suppress noise, but preserving high frequency details, such as edges. At higher level decomposition such as level 3, speckle noise is reduced, but the image also lose some edge, and contrast information. So, in proposed algorithm, a technique is proposed which not only reduce speckle noise, but also sharpens edges, and increase the contrast of image. Three different methods are applied on noisy images separately, such as threshold for noise reduction, wavelet transform for sharpening, and fuzzy logic for contrast stretching. Finally three enhanced images are combined by image fusion. Figure 1 presents schematic overview of proposed method.

A. Noise Reduction

Stationary Wavelet Transform (SWT) is applied to noisy image to remove noise. It divides the image into low frequency approximation and high frequency detail sub bands. Threshold is applied on details sub-band, while approximation sub bands may be further decomposed into approximations and details.

As the detail contains noise as well as edges, so some threshold criteria is needed to remove the noise while keep the edges.

An image is divided into four sub-bands namely HH, HL, LH, LL. LL shows lower frequency approximation while HH, HL, LH represents diagonal, horizontal and vertical details respectively. Soft and hard threshold are two widely used thresholds. A threshold is defined, and then soft or hard threshold is applied on these values which are below threshold. Soft threshold kill or shrink the noisy pixels, while hard threshold keeps or kill the noisy pixels.

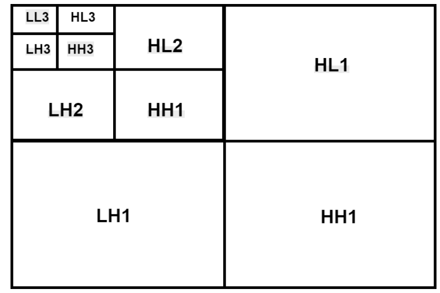

Fig. 2. sub-bands of image after decomposition

Hard threshold for a given value of wavelet coefficient d, and given threshold T is defined as:

$$D^H(d|T) = \begin{cases} 0, & \text{for } |d| \leq T \\ d, & \text{for } |d| > T \end{cases} \tag{1}$$

whereas following equation governs soft threshold:

$$D^H(d|T) = \begin{cases} 0, & \text{for } |d| \leq T \\ d-T, & \text{for } |d| > T \\ d+T, & \text{for } |d| > -T \end{cases} \tag{2}$$

We have chosen Bays[12] shrink with soft threshold and haar wavelet to denoise image. It is sub-band dependent threshold which means that at each sub-band, and at each decomposition level, threshold is calculated. The Bayes threshold tb is defined as

$$t_b = \sigma^2/\sigma_{sig} \tag{3}$$

Where σ^2 is variance of noise which is calculated from HH sub-band using:

$$\sigma = \frac{Median(\{|g_{j=1,k}| \cdot .k = 0, 1_2 \ldots\ldots 2^{j-1} - 1\})}{0.6745} \tag{4}$$

σ_{sig} is the variance of signal. As the noise and the signal are independent, which is given by:

$$\sigma_{\mathrm{n}}^2 = \sigma_{\mathrm{sig}}^2 + \sigma^2 \tag{5}$$

where σ_{n}^2 is defined as:

$$\sigma_n^2 = \frac{1}{N^2} \sum_{i,j=1}^{N} x^2(x,y) \tag{6}$$

where N shows the number of pixels in image x. Finally, the signal variance σ_{sig} is calculated as:

$$\sigma_{sig} = \sqrt{\max(\sigma_n^2 - \sigma^2, 0)} \tag{7}$$

The threshold is calculated at each sub-band of each decomposition level. In this paper the decomposition is performed upto level 3. At each level and each sub-band the gray scale intensity values are compared with threshold. The values are made zero, if they are less then threshold.

B. Edge Enhancement

Enhancement of edges is one of the most important operation in image processing. Edge enhancement needs detection of edges. Many edge detection techniques [13] exists but the mostly used methods are Gradient and Laplacian based methods. Gradients based are first derivative edge detection technique which finds the maximum and minimum gradient intensity. Laplacian method is based on second derivative and it finds edges by searching zero crossing in the second derivative in the image. These technique will work fine when the image is not contaminated by noise. For noisy image, these techniques generally fails. Therefore, we are using stationary wavelet transform to obtain and enhance edges. The advantage of using wavelet transform is that the image is divided into lower and higher frequencies. As the low frequency contents does not represent details so we can ignore the low frequencies, while only operate on high frequency contents to get the edges. The proposed algorithm to detect edges in noisy image is given below:

1· Take input noisy image.

2· Decompose image into approximation A and details H, V, D.

3· As the approximation does not represents edges and details. Therefore, make the approximation A=0;

4· For details V, H and create 9x9 window.

5· Replace the central pixel in the window by calculating the mean value of the window. The mean can be computed by

$$\mu_{i,j} = \frac{1}{M*N} \sum_{i-M/4}^{i+M/4} \sum_{j-N/4}^{J+N/4} x(i,j) \tag{8}$$

Where M and N represents number of rows and columns respectively in a window.

6· Slide the window, and perform the above operation for all pixels.

7· Take average of all three detail sub-band, which will represent edge detected image.

8· Finally, subtract the edge detected image from noisy image to get edge enhanced image.

C. Contrast Enhancement

Contrast enhancement can be performed both in spatial and frequency domain. A large number of contrast enhancement techniques exists for low contrast images. Contrast enhancement can be categorized into two broad categories [14] :indirect methods and direct methods. Histogram equalization and histogram specification are indirect methods, where histogram is modified by assigning new values to original grey level values. On the other hand, in direct method, values of pixel intensities are directly mapped to new values to stretch the contrast[14].

In this paper we use fuzzy logic [15] to stretch the contrast of images. The methods used in this paper for contrast enhancement are fuzzification, rule base, inference mechanism, and defuzzification. These methods form Fuzzy Interface System (FIS). Two main types of FIS are Mamdani and Sugeno.

1) Fuzzification: The purpose using fuzzy logic is to operate on fuzzy sets, or linguistic variables, rather then crisp inputs. Therefore the first step in FIS is to convert crisp input into fuzzy sets. Member Function(MF) is assigned to each input. Therefore, MF represents the conversion of fuzzy values. Bell shape MF is used in this paper which is given by

$$f(x;a,b,c) = \frac{1}{1+ \mid \frac{x-c}{a} \mid^{2b}} \tag{9}$$

The center of the curve is located by parameter c. Figure 3 shows input and output member functions.

2) Rule Base: The rule base map input MF called premise to output MF consequence. The rule-based uses linguistic variables as its premise and consequence. If-then fuzzy rule-based system is given by, IF premise, THEN consequent. The type of FIS used is this paper is Mamdani, in which output member functions are used to defined rules. On the other hand, Sugeno type FIS has no output member function.

In Sugeno type FIS, mathematical equations are used to determine the output. A single fuzzy if-then rule can be defined as follow

If a is X, then b is Y.

where X is a set of premise that has to be satisfied and Z is a set of consequences that can be inferred. To combine more then one input, min, max and additive complement is used for AND, OR and NOT operation respectively.

In this paper, first input member functions are specified as mf1, mf2, mf3 mf4 and mf5. Similarly, output member functions are specified. For 8 bit gray scale image, if 0 is the smallest pixel value, while 1 is the highest pixel value, then the rules are defined in table 1, where the pixel values in input member functions are mapped to output member functions.

3) Inference Mechanisms: Inference Mechanism uses MF, logical operations and if-then rules to map given input to an output using fuzzy logic. There are two types of inference systems: Mamdani type FIS and Sugeno type FIS. Sugeno type FIS rule base system does not use the output member function but uses mathematical equations to find out put. In this paper we have used Mamdani type FIS which have member

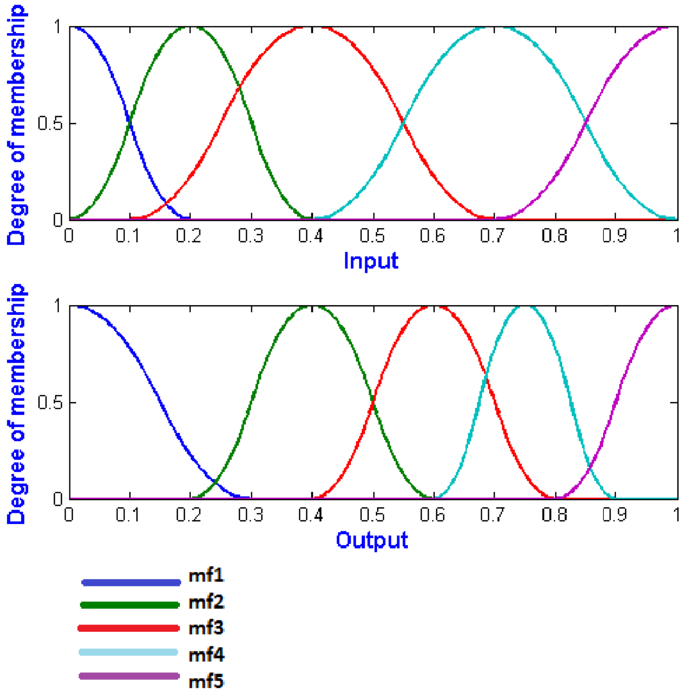

Fig. 3. (a) Input member function (b) Output member function

TABLE I
RULE BASE

Input				Output			
MF	min	c	max	MF	min	c	max
mf1	0	0	0.2	mf1	0	0	0.3
mf2	0	0.2	0.4	mf2	0.2	0.4	0.6
mf3	0.1	0.4	0.7	mf3	0.4	0.6	0.8
mf4	0.4	0.7	1	mf4	0.6	0.75	0.9
mf5	0.7	0.85	1	mf5	0.8	0.9	1

fmunctions for input and output. The final MF produced by FIS is then defuzzified using defuzzification mechanism to obtain crisp output. Figure 4 depicts FIS.

4) Defuzzification: Defuzzification is the mechanism to convert fuzzy sets back into crisp data. The existing mathematical techniques for defuzzification are: mean, average, bisector, centroid, weighted, maximum and minimum. Centroid defuzzification is used in this paper which is the most accurate and mostly used defuzzification. It can be expressed as:

$$z = \frac{\int \mu_i(x) x dx}{\int \mu_i(x) dx} \tag{10}$$

where x is the output variable, μ_i is MF and z is defuzzified output.

D. Image Fusion

Image fusion is a technique which combine the features from two or images of same class and size. Image fusion can be done in spatial domain or in transform domain [16].

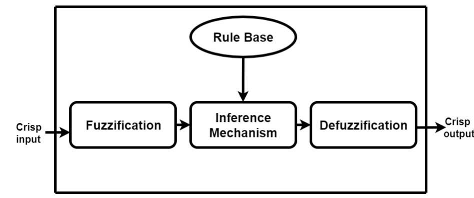

Fig. 4. Fuzzy Interface System

Taking average, maximum or minimum in spatial domain is the simplest technique but it can introduce artifacts into output fused image. Therefore, we have used stationary wavelet transform to fuse the three enhanced images to get final result. Following is the algorithm used in this paper:

1. Decompose three enhanced images upto level 2, such as HH2, HL2, LH2, LL2 and HH1, HL1, LH1 sub-bands.

2. Take horizontal sub-bands HH2 of three images and find avg (HH2 (image 1), HH2 (image 2), HH2 (image 3)).

3. Take mean value of HH1 of three images as avg (HH1 (image 1), HH1 (image 2), HH1 (image 3)).

4. Take mean value of HH1 and HH2 and save the new sub-band as named H

5. Repeat same steps for vertical, diagonal and approximation sub-bands and name them V, D and A respectively.

6. Reconstruct by taking inverse stationary wavelet transform of H, V, D and A.

III. RESULTS

To evaluate the performance of the proposed technique, performance evaluation metrics like information entropy, mean square error and peak signal to noise ratio are calculated.

A. Mean Square Error

MSE measures the difference between reference and processed images. It is given by following equation:

$$\mathrm{MSE} = \frac{1}{\mathrm{N}^2} \sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}=1}^{\mathrm{N}} [\mathrm{s(i,j)} - \mathrm{y(i,j)}]^2 \tag{11}$$

B. Peak Signal to Noise Ratio

It measures the reconstruction quality and is given by:

$$\mathrm{PSNR} = 10 \log_{10} \left[\frac{\mathrm{I}^2}{\sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}=1}^{\mathrm{N}} [\mathrm{s(i,j)} - \mathrm{y(i,j)}]^2} \right] \tag{12}$$

C. Entropy

Entropy is an index to evaluate the information quantity in an image. Entropy is calculated using the equation

$$\mathrm{E} = -\mathrm{plogp} \tag{13}$$

Figure 5-8 shows the results of applying different methods on noisy images. From these images, it can be clearly seen that the composite method performs better when compared with SWT. Table 2 shows superiority of proposed technique over different wavelet families such as haar, bior1.3 (Bi-orthogonal) and coif2 (Coiflets). The proposed method has also been verified against different noise densities, which is summarized in Fig 9.

IV. Conclusion

We have introduced a new combined technique to improve the quality of degraded medical images. The method comprised of three techniques. Bays threshold is used to reduce speckle noise. Wavelet transform is used to enhance edges, while contrast is enhanced by fuzzy logic. Finally, three enhanced images are combined, using image fusion, in transform domain. The obtained results demonstrates improvement in quality by the proposed method.

Fig. 5. (a) Noisy image (b) SWT (c) Proposed

Fig. 6. (a) Noisy image (b) SWT (c) Proposed

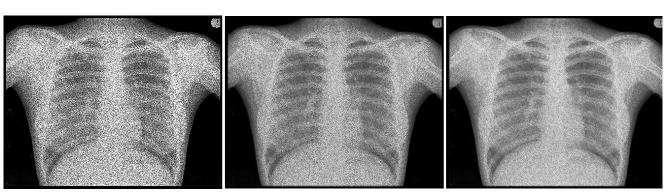

Fig. 7. (a) Noisy image (b) SWT (c) Proposed

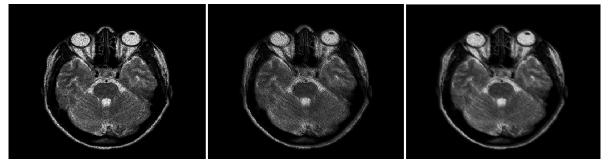

Fig. 8. (a) Noisy image (b) SWT (c) Proposed

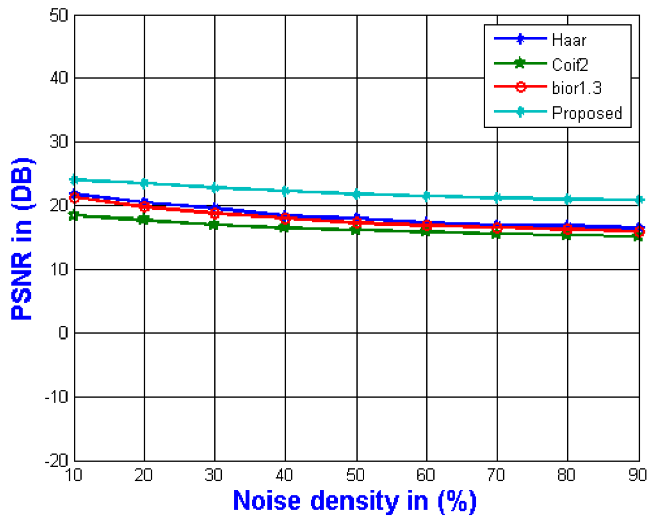

Fig. 9. Comparison of different techniques

TABLE II
Speckle noise reduction using different methods

img	Technique	PSNR	MSE	E
1	coif2	18.4432	930.5983	1.6258
	Bior1.3	21.3372	477.9207	1.4859
	Haar	21.7526	434.3288	1.1929
	Proposed	24.0584	255.4136	1.5062
2	coif2	21.1974	493.5582	3.9166
	Bior1.3	22.5125	364.6154	3.9443
	Haar	22.5478	361.6632	3.759
	Proposed	27.635	112.093	4.0428
3	coif2	19.9065	664.4003	1.1362
	Bior1.3	20.7026	553.1234	1.0903
	Haar	20.9331	524.528	1.1947
	Proposed	23.0819	319.8116	1.2256
4	coif2	19.5494	721.3421	0.9244
	Bior1.3	20.489	581.0018	0.9628
	Haar	20.7963	541.313	0.6104
	Proposed	24.0545	255.6383	0.3312

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