Ventricle Image Restoration and Enhancement with Multi-thresholding and Multi-Filtering

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***Abstract*—**Speckle noise reduction for power Doppler ventricle coherent image for restoration and enhancement using Fast Wavelet Transform with multi-thresholding and multi-filtering on the each subbands is presented. Fast Wavelet Transform divides into low frequency component image to high frequency component image to be multi-resolved. Speckle noise is located on high frequency component in multi-resolution image mainly. A Doppler ventricle image is transformed and inversed with separated threshold function and filtering from low to high resolved images for restoration to utilize visualization for ventricle diagnosis. The experimental result shows that the proposed method has better performance in comparison with the conventional method.

***Index Terms*—**Speckle reduction, Multi-thresholding, Multi-filtering, Doppler ventricle image, Fast Wavelet Transform, Image restoration and enhancement.

I. INTRODUCTION

Medical ultrasound imaging equipments have been studying remarkably because that are evaluated by being convenient for making diagnosis human body in real time, low-cost and practicable compared with MRI and PET, and harmless for human beings relatively.[1-3] The 2D and 3D ultrasound imaging of equipment displays an anatomical structures of human body by using ultrasound differences of a boundary reflections between different medium The reflections are displayed with 2D image converted reflected value to brightness value. Scanning is used B-mode. 3D visualization comes from 2D image composition with Doppler. The image has dropout and degradation with speckle noise.[4-5] Speckle noise is a random, stochastic, deterministic, interference pattern in an image formed with coherent radiation of a medium containing lots of sub-resolution scatterers with 3 significant features of speckle patterns. The granular pattern speckle noise reduction has proposed the removal and edge detection using gradient and symmetry, suppression filter, variable windowing mean filter, and adaptive weighted median filter, Lee-Sigma and Lee filter, local region filter, Mamma-map filter and Frost filter.[9-10] However a clear Doppler image for ventricle which are low frequency components of desirable image is enhanced and RF speckle random noise is reduced, is required to study increasingly.

Thus Speckle noise reduction for 3D dimensional power Doppler ventricle image using Fast Wavelet Transform will be presented in this paper. Fast Wavelet Transform makes an image reduce noise due to multi-resolution and has high resolution in compare to normal Wavelet Transform. Fast Wavelet Transform resolves into low frequency component image to high frequency component image in detail like pyramid structure to be multi-resolved. An inherent characteristic of coherent imaging, speckle noise is located on high frequency component image mainly. A Doppler ventricle image is transformed and inversed with separated threshold function from low to high resolved images for restoration to utilize visualization for ventricle diagnosis.

II. RESTORATION AND ENHANCEMENT

A. Ventricle Doppler Image

A cardiac ultrasound is a sonogram of the human heart. This uses standard ultrasound to image 2D slices of the heart and a ultrasound systems employs 3D real time imaging. A system can also produce accurate assessment of the velocity of blood and cardiac tissue at any arbitrary point using pulsed or continuous wave Doppler ultrasound. This allows assessment of cardiac valve areas and function, a abnormal communications between left and right ventricles of the heart, a leaking of blood through the valvular regurgitation, and calculation of the cardiac

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output.

One of the ultrasonography modes is Doppler mode that makes use of the Doppler's effect in measuring and visualizing blood flow. The Doppler's effect is the change in frequency of a wave for a transducer moving relative to the ventricle of the wave. Velocity measurement of blood flow in arteries and veins is an effective tool for diagnosis of vascular problems. The Doppler image is displayed graphically using color Doppler or power Doppler. The depth penetration of ultrasound may be limited depending on the frequency of imaging. The image has some degradation with speckle noise like complex impulse noise.

There are 3 significant features of speckle pattern on the human organ images, depends on the number of scatterers a resolution cell or SND (Scatterer Number Density) and these spatial distribution and the characteristics of the imaging system. The fully formed speckle pattern such as blood cells is caused by many fine random distributed scatterer within SND>10. The number of the backscattered signal be modeled by a Rayleigh distributed random variable. This pattern is replaced by a local mean value to image regions. The lobes in the liver parenchyma have tissue scatterers that are nonrandom distribution within finite SND<10, this pattern contributes a coherent or spatial variant specular backscattered intensity, modeled by K distribution. An organ surfaces and blood vessels are caused by a spatial invariant coherent structure within the random scatterer region. This pattern is associated with SNR>1.92, and the probability density function of the backscattered signals has Rician distribution. These coherence phenomena results in studying further more partial or complete resolution.

B. Speckle Noise Pattern

Speckle noise pattern is a random, stochastic, deterministic, mutual interference and different phases in an image formed with coherent radiation of a medium containing lots of sub-resolution scatterers due to penetration and reflection between different mediums. This makes a dropout in the required image and is difficult to eliminate completely. A coherent component adds a constant strong phaser to the diffuse scatters echo signal and shits the mean of the complex echo signal away from the origin in the complex plane. Generally the amplitude (I) of speckle noise is defined as the probability density function P(I) with random walk, and described by the following equation (1). I is known as speckle noise brightness of ultrasonography and is based on multiplicative Rayleigh PDF (Probability Density Function).

$$P(I) = \begin{cases} \frac{1}{2\sigma^2} exp\left(-I/_{2\sigma^2}\right) & I \geq 0, \\ 0 & otherwise. \end{cases} \quad (1)$$

Speckle noise model of ultrasound image is given by the equation (2) with multiplicative noise and signal.

$$s_{i,j} = x_{i,j}\, n_{i,j} \quad i = 0, \ldots, N_1,\ j = 0, \ldots, N_2 \quad (2)$$

,where $s_{i,j}$ is image pixel included noise, $x_{i,j}$ is pixel of the original image, $n_{i,j}$ is speckle noise, and N_1, N_2 is image size. If image and noise is uncorrelated, then speckle noise mean is given by equation (3).

$$\bar{s} = \bar{x}\,\bar{n} \quad (3)$$

$\bar{s}$ and $\bar{n}$ are mean of the origin and noise. The variance is calculated by equation (2) and becomes Eq. (4).

$$\sigma_s^2 = \overline{x^2}\, [E(n^2 - \overline{n}^2)] = \overline{x}^2 \sigma_n^2 \quad (4)$$

Substituting Eq. (3) into Eq. (4), there results standard deviation, Eq. (5).

$$\frac{\sigma_n}{\bar{n}} = \frac{\sigma_s}{\bar{s}} \quad (5)$$

The proportion of standard deviation to mean on the speckle noise is able to describe as the ratio of standard deviation to mean on the speckle image. This results in the ratio of standard deviation to noise on the practical ventricle images with $\sigma_s/\bar{s}$. Noise $\sigma_n/\bar{n}$ is the ratio of standard deviation to mean. Speckle noise is independent to image signal. The SI (speckle noise index) is given as summing the ratio of the standard deviation to mean in whole image Eq. (6). Where $m(i+k_1, j+k_2)$ is mean of image, N is image size. $\sigma(i+k_1, j+k_2)$ is variance. The Threshold range is based on SI to be reduced noise in reconstruction.

$$SI = \frac{1}{(N-2)^2} \sum_{i,j=1}^{i,j=n-1} \sum_{k_1 k_2=-1}^{1} \frac{\sigma(i+k_1, j+k_2)}{m(i+k_1, j+k_2)} \quad (6)$$

C. FWT, Multi-thresholding and Multi-filtering

1) FWT

FWT (Fast Wavelet Transform) makes an image reduce noise due to multiresolution except increasing cost, has high resolution in compare to normal

Wavelet Transform. The biorthogonal wavelet function has characteristic of linear phase symmetrically not to make additional noise. 2D biorthogonal wavelet function is described as Eq. (7)

$$\begin{aligned} \varphi_{j,m,n}(x,y) &= 2^{j/2}\varphi(2^j x - m, 2^j y - n) \\ \psi^i_{j,m,n}(x,y) &= 2^{j/2}\psi^i(2^j x - m, 2^j y - n) \end{aligned} \quad (7)$$

2D FWT is described as tensor product of 1D wavelet transform, and scaling function is $\varphi(x,y) = \varphi(x)\varphi(y)$ and 3 wavelet functions are $\psi^H(x,y) = \psi(x)\varphi(y)$, $\psi^V(x,y) = \varphi(x)\psi(y)$, $\psi^D(x,y) = \psi(x)\psi(y)$, and FWT is given in Eq. (8), where i indicates horizontal, vertical and diagonal subbands.

$$\begin{aligned} W_\varphi(j_0,m,n) &= \frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\varphi_{j_0,m,n}(x,y) \\ W^i_\psi(j,m,n) &= \frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\psi^i_{j,m,n}(x,y) \end{aligned} \quad (8)$$

2) Mult-thresholding

Multi-thresholding is given in Eq. (9) with thresholding from speckle noise index. Eq.(5) and Eq. (6) yields threshold value Eq. (9) and Eq. (10), where $T_{a,b}$ is 4x4 subband images, $\overline{x_{a,b}}$ is the thresholded image from soft threshold function Eq. (10), $\sigma_{S_{i,j}}/\overline{S_{i,j}}$ is the ratio of standard deviation to mean, and x is subband images from FWT. This results in image reduced speckle noise.

$$T_{a,b} = \sigma_{S_{i,j}}/\overline{S_{i,j}} - (\sigma_n/\overline{n} * SI) \quad (9)$$

$$\overline{x_{a,b_j}} = \begin{cases} 0 & |x_{i,j}| < T_{a,b} \\ \mathrm{sgn}(x_{i,j})(|x_{i,j} - T_{(a,b)}|) & |x_{i,j}| \geq T_{a,b} \end{cases} \quad (10)$$

3) Multi-filtering

The convolution of multi-resolution 4x4 is described as Eq. (11) with multi-filtering masks 3x3 from Fig. 1. Each subbands are filtered by each 2D convolution. The Laplacian sharpening is applied to the low frequency bands, e.g. Eq. (13), and the blurring is the high frequency bands, e.g. Eq. (14). The thresholding and filtering inverse FWT is given by Eq. (12). This results in enhanced and restored image.

$$f(x,y) * h(x,y) = \frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} f(m,n)h(x-m,y-n) \quad (11)$$

$$\begin{aligned} f(x,y) &= \frac{1}{\sqrt{MN}}\sum_m\sum_n W_\varphi(j_0,m,n)\varphi_{j_0,m,n}(x,y) \\ &+ \frac{1}{\sqrt{MN}}\sum_i\sum_{j_0}\sum_m\sum_n W^i_\psi(j,m,n)\psi^i_{j,m,n}(x,y) \end{aligned} \quad (12)$$

where

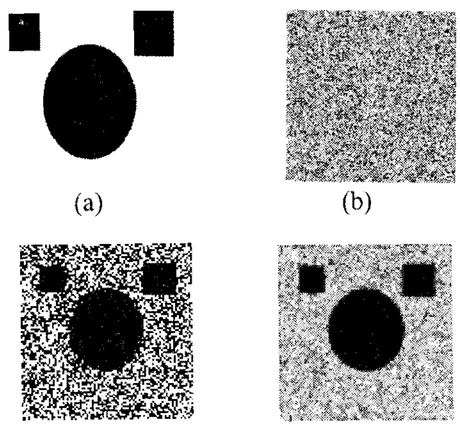
$$N = M = 2^J,\ j = 0,1,2,\cdots J-1,$$
$$m,n = 0,1,2,\cdots 2^j - 1$$

$$\text{Sharpening mask} = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \quad (13)$$

$$\text{Blurring mask} = \begin{bmatrix} 0.0625 & 0.125 & 0.0625 \\ 0.125 & 0.25 & 0.125 \\ 0.0625 & 0.125 & 0.0625 \end{bmatrix} \quad (14)$$

III. EXPERIMENT AND RESULT

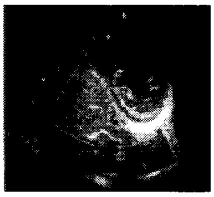
The experimental sample image size is 256x256 as shown in Fig.1 (a) the original, var. 36.95, SD/mean 0.43(b) speckle image, var. 13.008, SD/mean 0.43 (c) speckled image, var. 33.59, SD/mean 13.51 and (d) restored and enhanced image, var. 17.5, SD/mean 8.3. PSNR (d) is 7dB on (c).



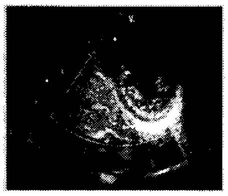
(a) (b) (c) (d)

Fig. 1 Sample image and result

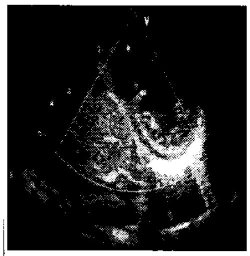
The practical ventricle image size is 512x512 shown as Fig. 2 (a) input, (b) restoration and (c) enhancement. The ratio of standard deviation to mean is average 0.1817, and speckle noise index is average 0.2441. Each image of FWT subbands is filtered from low to high frequency on the Fig. 2 (a). The 4x4 subband threshold values [%] are shown as table 1. The image reduced speckle noise and restored is shown as Fig. 2 (b) on the origin (a), and (c) is enhanced. PSNR yields about 3.5 dB. The PSNR is better about 5% than normal wavelet transform.



(a) Original image



(b) Restoration



(c) Enhancement

Fig. 2 Practical ventricle image results

Table 1 FWT subband threshold values

0.0672	0.1059	0.1079	0.1111
0.1142	0.1169	0.2261	0.1515
0.2497	0.2816	0.3122	0.3189
0.3405	0.3632	0.3625	0.3629

Ⅳ. CONCLUSION

Speckle noise reduction for power Doppler ventricle coherent image for restoration and enhancement using fast wavelet transform with separated threshold function from speckle noise index is experimented. Fast Wavelet Transform divides into low frequency component image to high frequency component image to be multi-resolved. Speckle noise is located on high frequency component in multiresolution image mainly. A ventricle image is transformed and inversed with separated thresholding on low and high resolved images for restoration and enhancement to be utilize visualization for ventricle diagnosis. The ratio of standard deviation to mean is average 0.27, and speckle noise index is average 0.19 approximately. PSNR yields about 3.5 dB. This is enhanced to about 5% than normal wavelet transform and threshold.

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