Speckle Noise Reduction for 3D Power Doppler Ventricle Image Restoration Using Wavelet Packet Transform

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ABSTRACT

Speckle noise reduction for 3D power doppler ventricle coherent image for restoration and enhancement using wavelet packet transform with separated thresholding is presented. Wavelet Packet Transform divide 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 threshold function from low to high resolved images for restoration to be utilize visualization for ventricle diagnosis. The experimental result shows that the proposed method has better performance in comparison with the conventional method.

KEYWORDS

Speckle noise, Power doppler, Ventricle, Wavelet Packet Transform, Image restoration

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 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. 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.[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 wavelet packet transform will be presented in this paper. Wavelet Packet Transform makes an image reduce noise due to multiresolution and has high resolution in compare to normal Wavelet Transform. Wavelet Packet Transform divide 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 be utilize visualization for ventricle diagnosis.

II. SPECKLE DOPPLER IMAGE AND WAVELET PACKET TRANSFORM

1. 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 output.

One of the ultrasonography modes is doppler mode that makes use of the doppler effect in measuring and visualizing blood flow. The doppler effect is the change in frequency of a wave for an 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.

2. 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 phasor 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).

$$p(I) = \frac{1}{b} exp(-\frac{I}{2b}), \quad \text{for} \quad I \geq 0 \quad (1)$$

Where b is a parameter($2\sigma^2$). Speckle noise model of ultrasound image is given by the equation (2) with multiplicative noise and signal.

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

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

$$\overline{S} = \overline{x}\,\overline{n} \quad (3)$$

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

$$\begin{aligned} \sigma_s^2 &= E(x_{i,j} n_{i,j} - \overline{xn})^2 \\ &= \overline{x^2}[E(n^2 - \overline{n^2}] = \overline{x^2}\sigma_n^2 \end{aligned} \quad (4)$$

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

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

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 the ratio of standard deviation to noise on the practical ventricle images with noise, is $\sigma_s / \overline{s}$. $\sigma_n / \overline{n}$ is the ratio of standard deviation to mean of noise. 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 reduce noise in reconstruction.

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

2. Wavelet Packet Transform

WPT(Wavelet Packet 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)

$$\phi_{j,m,n}(x,y) = 2^{j/2}\phi(2^j x - m, 2^j y - n) \quad (7)$$
$$\psi_{j,m,n}(x,y) = 2^{j/2}\psi^i(2^j x - m, 2^j y - n)$$

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

$$W_\phi(j_0, m, n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)\phi_{j_0,m,n}(x,y) \quad (8)$$
$$W_\psi(j,m,n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)\psi^i_{j,m,n}(x,y)$$

2D WPT defined as Eq. (9) from Eq. (8), this decomposition results structure of subband binary tree as shown in Fig. 1 according to down-sampling with best basis and cost function.

$$V_j = V_{j-3} \oplus W_{j-3} \oplus W_{j-2,A} \oplus W_{j-2,D} \oplus W_{j-1,AA} \oplus W_{j-1,AD} \oplus W_{j-1,DA} \oplus W_{j-1,DD} \quad (9)$$

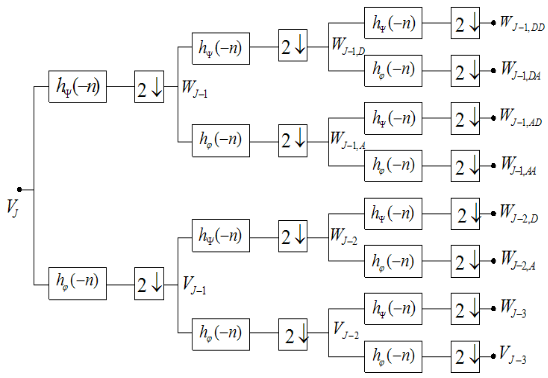


Fig 1. Wavelet packet decomposition tree

2D inverse WPT is given in Eq. (10) with thresholding from speckle noise index. Eq.(5) and Eq. (6) yields threshold value Eq. (10) and Eq. (11). Where T_i is subband images, and $\bar{x}$ is the thresholded image from soft threshold function Eq. (11), and σ_{si} / $\bar{s_i}$ is the ratio of standard deviation to mean, and x is subband images from WPT. This results in image reduced speckle noise.

$$T_i = \frac{\sigma_{si}}{\overline{si}} - (\sigma_n / \bar{n} * SI) \quad (10)$$

$$\bar{x} = \begin{cases} 0, & |x| < T_i \\ sgn(x)(|x| - T_i), & |x| \geq T_i \end{cases} \quad (11)$$

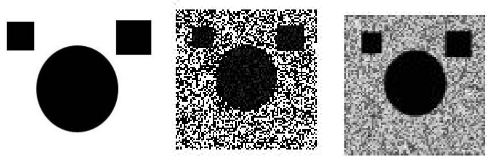
The thresholding inverse WPT is given by Eq. (12). This results in enhanced and restored image.

$$f(\acute{x},\acute{y}) = \frac{1}{\sqrt{MN}} \sum_m \sum_n W_\phi(j,m,n)\phi_{j_0,m,n}(\acute{x},\acute{y}) + \frac{1}{\sqrt{MN}} \sum_i \sum_{j_0} \sum_m \sum_n W^i_\psi(j,m,n)\psi^i_{j,m,n}(\acute{x},\acute{y}) \quad (12)$$

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

III. EXPERIMENTS AND RESULTS

The experimental sample image size is 256x256 as shown in Fig.2 (a), (b) speckled image and (c) reduced image. The practical ventricle image size is 512x512 shown as Fig. 3 (a) input, (b) restoration and (c)enhancement.

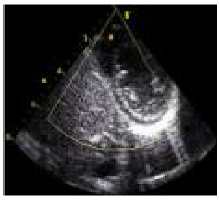


(a) (b) (c)

Fig. 2 Sample image and result

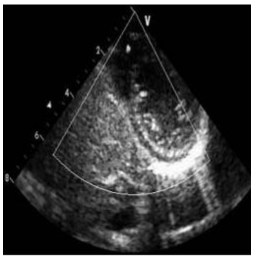
The ratio of standard deviation to mean is average 0.27, and speckle noise index is average 0.19. Fig. 3 is shown WPT subbands. Each image is filtered from low to high frequency on the Fig. 3 (a).

The 16 subband threshold values [%] are shown as table 1. The image reduced speckle noise and enhanced is shown as Fig. 3 (b). PSNR yields about 3.5 dB. The PSNR is better about 5% than normal wavelet transform.



(a) Input image

(b) Restoration



(c) Enhancement

Fig. 3 Practical ventricle image results

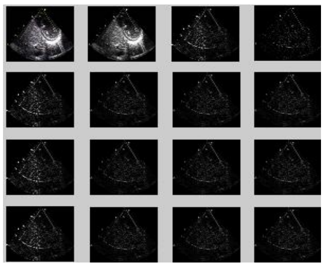


Fig. 4 WPT subbands

Table 1 WPT subband threshold value

0.0005	0.0009	0.0011	0.0227
0.0445	0.0512	0.0818	0.1137
0.2119	0.2261	0.2465	0.2492
0.2523	0.2555	0.2575	0.2962

Ⅳ. CONCLUSION

Speckle noise reduction for 3D power doppler ventricle coherent image for restoration and enhancement using wavelet packet transform with separated threshold function from speckle noise index is experimented. Wavelet Packet Transform divide 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. The PSNR is better about 5% than normal wavelet transform.

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