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Improved Ultrasonic Image De-noising Algorithm

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***Abstract*—De-noising characteristics of soft threshold, semi-soft threshold, hard threshold and noise statistical nature in wavelet transform are analyzed; Based on this a new De-noising algorithm of medical ultrasonic image based on wavelet transform is proposed. Towards borderline blur of soft threshold algorithm, linear operation is carried out to wavelet coefficients according to maximum of wavelet coefficients in each sub-band, meanwhile, high frequency wavelet coefficients bulge of semi-soft threshold algorithm is improved. Experimental results show that the detail information is reserved well while speckle noises are efficiently removed. Also the whole visual effect is improved.**

Keywords- wavelet transform; medical ultrasonic image; threshold de-noising; noise statistical nature

I. INTRODUCTION

Medical ultrasonic image is an important assistant diagnosis method as advantages of harmless to human beings, real-time visualization, low cost and convenience. However, if the size of human body tissue is smaller than the wavelength of incident ultrasonic waves or similar to the wavelength of incident ultrasonic waves, the ultrasonic beam produce scattering and mutual interference between different phase scattering echo produce speckle noise [1, 2]. The details of medical ultrasonic image, which play an important role in clinical diagnosis, are not easily distinguished because of speckle noises. So how to de-noise medical ultrasonic image while preserve details becomes a popular research spot.

Wavelet transform is a powerful tool for signal analysis and processing, has been widely used in the field of image de-noising [3]. De-noising method based on wavelet transform was proposed by Guo and others [4]. Subsequently, Donoho proposed a de noising algorithm by soft threshold [5] and Bruce & Gao proposed a improved estimation model of wavelet coefficients, that is semi-soft threshold. Although these algorithms have been used widely, soft threshold can bring on fuzzy boundary of medical ultrasonic image and it can produce new artifacts that hard threshold and semi-soft threshold can cause relatively strengthened during parts of high frequency signals when speckle noises were being removed.

A new de noising algorithm of medical ultrasonic image based on wavelet transform was proposed in this paper. The experimental results show that the detail information is reserved well while speckle noises are efficiently removed also the whole visual effect is improved.

II. NOISE STATISTICAL NATURE

If a zero mean white noise sequence is expressed by $n(k)$, the wavelet transform of $n(k)$ is still mean zero sequence, and coefficient sequence of wavelet base formula is still mean zero sequence with the same variance. If $n(k)$ is zero mean, stationary white noise sequence and its variance of is σ^2, then

$$\mathrm{E}[n(k)] = 0 \tag{1}$$

$$\mathrm{E}[n(u)n(v)] = \sigma^2 \delta(u - v) \tag{2}$$

The wavelet transform is given by

$$W_\sigma(s,k) = n(k) * \psi_s(k) = \sum_u n(u)\psi_s(k-u) \tag{3}$$

$$|W_\sigma(s,k)|^2 = \sum_u \sum_v n(u)n(v)$$

$$\psi_s(k-u)\psi_s(k-v) \tag{4}$$

$$\mathrm{E}[|W_\sigma(s,k)|^2] = \frac{a^2 \|\psi\|}{s} \tag{5}$$

Eq.(5) shows that wavelet transform amplitude $W_\sigma(s,k)$ reduces with the scale s increasing. If $n(k)$ is a Gaussian noise, then the wavelet transform $W_\sigma(s,k)$ is also Gaussian distribution. According to statistical nature of signal and noise, multi-scale edge detection is carried out to extract points whose modular maximum reducing with the scale decreasing. These points are retained unchanged, and the rest points are treated with threshold function, in this way signal can be better de-noised and the details of edge are retained well.

III. WAVELET THRESHOLD DE NOSING

Hard threshold algorithm can well reserve local characteristics of medical ultrasonic image, but the continuity of estimated wavelet coefficients is bad, it can lead to oscillation of reconstruction signals, ringing artifact and Gibbs phenomena (lead to artifacts).

Hard threshold function can be written as

$$W_\delta = \begin{cases} W, & |W| \geq \delta \\ 0, & |W| < \delta \end{cases} \tag{6}$$

where δ is threshold, W denotes wavelet coefficients, W_δ denotes the wavelet coefficients which are processed by threshold. δ is related to σ which is a robust estimate of the noise standard deviation, δ can be written as

$$\delta = \sigma\sqrt{2\ln N} \tag{7a}$$

where N is the length of noise, σ is the measured wavelet coefficients as[7]

$$\sigma = \frac{median(|d_j|)}{0.6745} \tag{7b}$$

where d_j is the high frequencies of wavelet transform.

Soft threshold function can be written as

$$W_\delta = \begin{cases} \mathrm{sgn}(W)(|W| - \delta), & |W| \geq \delta \\ 0, & |W| < \delta \end{cases} \tag{8}$$

where δ is threshold, W denotes wavelet coefficients, W_δ denotes the wavelet coefficients which are processed by threshold[8].

The continuity of estimated wavelet coefficients which are processed by threshold is better for fuzzy boundary.

Bruce & Gao proposed an improved estimation model of wavelet coefficient, that is semi-soft threshold. Semi-soft threshold algorithm not only suppressed Gibbs phenomenon, but also improved fuzzy boundary. According to the characteristics of medical ultrasonic image, it is required that processed image is close to original image as much as possible and it is not allowed that partial images excessive enhanced. If partial medical ultrasonic images were excessive enhanced, it maybe bring on illusion that the organ has been occurred lesions, which aren't close to actual experiences, this phenomenon is also called artifact. The medical ultrasonic images bring on new artifacts because of partial wavelet coefficients were decreased to zero, partial wavelet coefficients were decreased and the others weren't changed, which will bring on error diagnosis for lesions.

IV. Adaptive Threshold Algorithm

The processed wavelet coefficients must be enlarged in order to improve the borderline blurred images that are produced by soft threshold de noising. Linear operation of wavelet coefficients was carried out in order to improve the excessive enhanced high frequency signals caused by semi-soft threshold and hard threshold. Based on these analyses, a new de noising algorithm of medical image based on wavelet transform was proposed in this paper. In the algorithm, the maximum of wavelet coefficients' absolute value is extracted. Linear operation of wavelet coefficients were carried out using the maximum. The algorithm can not only suppresses Gibbs phenomenon, but also improve the borderline blurred images, meanwhile, the wavelet coefficients are close to the original wavelet coefficients as much as possible. According to the links between threshold and wavelet coefficients, the function formula of improved adaptive threshold algorithm can be written as

$$W_\delta = \begin{cases} \mathrm{sgn}(W)(|W| - \delta)[W_{\max}/(W_{\max} - \delta)], |W| \geq \delta \\ 0, |W| \geq \delta \end{cases} \tag{9}$$

where δ is threshold, W denotes wavelet coefficients, W_δ denotes the wavelet coefficients which are processed by threshold, $W_{\max}$ denotes the maximum number of wavelet coefficients' absolute value.

At first, we apply the logarithmic function transform the multiplicative noise into an additive one. The secondly, the logarithmic ultrasonic image is analyzed by means of the wavelet transform, then the maximum of wavelet coefficients' absolute value. Subsequently, the empirical wavelet coefficients are shrunk, and they are carried out linear operation. At last, the de noised logarithmic ultrasonic image is synthesized from the processed wavelet coefficients through the inverse wavelet transform, we deal with the de noised logarithmic ultrasonic image by exponential transform, then we obtain the de noised ultrasonic image.

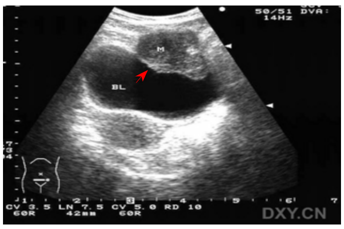
V. Experimental Results and Analysis

Speckle noises are added in original image. Then we processed the degraded image according to the means of adaptive threshold algorithm. We compared the results of our approach with wavelet shrinkage de nosing using soft threshold.

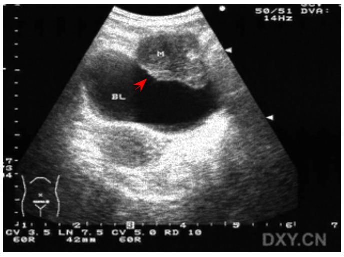
In order to quantify the achieved performance improvement, three different measures were computed based on the original and the de noised data. For quantitative evaluation, an extensively used measure is the root mean square error (RMSE) defined as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1}(f_i - \hat{f}_i)^2} \tag{10}$$

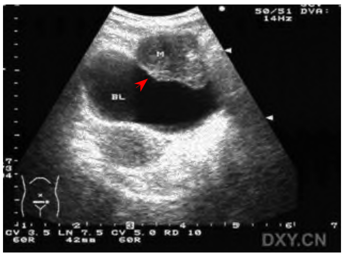
where f_i is the original image, $\hat{f}_i$ is the de noised image, and N is the image size. The standard signal to noise ratio (SNR) is not adequate to evaluate the noise suppression in the case of multiplicative noise. Instead, a common way to achieve this in coherent imaging is to calculate the peak signal to noise ratio (PSNE),



(a) Original image



(b) Speckle noise image $\sigma = 0.1$



(c) Hard threshold algorithm

(d) Soft threshold algorithm

(e) Adaptive threshold algorithm

Defined as:

$$PSNR = 10\lg \frac{1^2}{\frac{1}{N}\sum_{i=0}^{N-1}(f_i - \hat{f}_i)^2} \qquad (11)$$

Remember that in ultrasound imaging, we are interested in suppressing speckle noise while at the same time preserving the edges of the original image that often constitute features of interest for diagnosis. Thus, in addition to the above quantitative performance measures, we also consider a qualitative measure for edge preservation. More specifically, we used a parameter ρ originally defined in :

$$\rho = \frac{\Gamma(\Delta f - \overline{\Delta f}, \Delta\hat{f} - \overline{\Delta\hat{f}})}{\sqrt{\Gamma(\Delta f - \overline{\Delta f}, \Delta f - \overline{\Delta f}) \cdot \Gamma(\Delta\hat{f} - \overline{\Delta\hat{f}}, \Delta\hat{f} - \overline{\Delta\hat{f}})}} \qquad (12)$$

where Δf and $\Delta\hat{f}$ are the high-pass filtered versions of f and $\hat{f}$ respectively, obtained with a 3×3 pixel standard approximation of the Laplacian operator, and

$$\Gamma(f_1, f_2) = \sum_{(i,j)\in ROI} f_1(i,j)\cdot f_2(i,j) \qquad (13)$$

The correlation measure ρ should be close to unity for an optimal effect of edge preservation.

In order to prove that adaptive threshold algorithm is effective, we show that one picture of bladder tumor that was processed using soft threshold, hard threshold semi-soft threshold and adaptive threshold algorithm in fig.3.

Fig.3 shows that hard threshold bring on Gibbs phenomena, semi-soft threshold improve Gibbs phenomena in a certain extent, but the image still Gibbs phenomena. Figure 3(e) and (f) don't produce Gibbs phenomena, but fig. 3(f) compare with fig. 3(e), the former improve the fuzzy boundary in a certain extent, meanwhile, results show that on the whole, the former is much brighter than the latter. The former got better effect than the latter.

VI. Conclusions

A new de noising algorithm of medical ultrasonic image based on wavelet transform introduced is introduced. The main different during between soft threshold, hard threshold, semi-threshold and adaptive threshold algorithm is that adaptive threshold algorithm enhance the processed wavelet coefficients using the maximum of each level wavelet coefficients' absolute value. Though the algorithm can reserve details information when the speckle noises were effectively being removed, partial high frequency signals which wavelet coefficients were smaller than threshold were discarded. So how to abstract the high frequency signals which were discarded will be an important research topic.

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