RESEARCH ARTICLE

Improved Soft Thresholding Technique for Denoising Ultrasound Images”

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ABSTRACT

An improved algorithm for denoising ultrasound image is proposed in this paper. Generally ultrasound image is affected by multiplicative noise called speckle noise. Removal or reduction of speckle noise is highly essential in the disease diagnosis process. This paper added the features of statistical modeling in soft thresholding to develop an improved denoising method. Thresholding the wavelet coefficients require threshold value and in this paper the threshold value is calculated by modeling the wavelet coefficients. The heavy-tailed wavelet coefficients are modeled using a suitable Cauchy probability density function (PDF) to estimate the signal and noise variance information of the wavelet coefficients. Performance parameters such as Peak Signal-to-Noise Ratio (PSNR), Structural Similarity (SSIM) and Edge Preservation Index (EPI) are used in this paper to evaluate the efficacy of the proposed method. From the simulation results it is found that the proposed denoising method has achieved improved results than the state-of-the-art methods.

Keywords: Soft thresholding, Cauchy PDF, denoising, Speckle noise

INTRODUCTION

Ultrasound images are contaminated by speckle noise which results the degradation of image quality and it affects the disease diagnosis processes. So in medical image processing, an image denoising process is highly required. In literature several filtering approaches have been implemented by authors for reducing speckle noise from ultrasound images. These filtering approaches can be broadly categorized in to three sections. They are algorithmic, transform, and statistical modeling approaches. Algorithmic approaches include Adaptive median [1], Bilateral filtering [2], Rotating kernel transformation [3], Non-local mean filter [4] and Anisotropic diffusion filter [5]. Transform approach involves filtering using wavelet transform [6], Contourlet transform [7], and Curvelet transform [8]. Statistical modeling approached filters are designed by utilizing the statistical behavior of the noise and signal. Filters based on algorithmic approach suffer from limitations like loss of structural details and high computational complexity. Filters based on transform approach suffer from determination of accurate threshold value. Statistical modeled filters are generally depending on the choice of prior and estimator [9, 17].

Wavelet thresholding filter is a common type of wavelet-based filter. The basic steps of this type of filters involve generation of wavelet coefficients, modification of wavelet coefficients and recovering of image from the modified wavelet coefficients. For modifying the wavelet coefficients a threshold value is required and the denoising efficiency depends on the threshold value. Soft and Hard thresholding methods are widely used by the researchers and have been proved more promising in removing the multiplicative noise. This paper applies soft thresholding to the logarithmic transformed wavelet coefficients and the thresholding value is found out by modeling the wavelet coefficients statistically. The organization of the paper is as follows. Section 2 discusses about homomorphic approach, Cauchy PDF, statistical modeling of wavelet coefficients and Soft thresholding. Section 3 gives the denoising methodology. Simulation results are elaborated in section 4 and conclusion is given in section 5.

BACKGROUND

This section discusses the preliminaries of the proposed denoising method. Homomorphic approach which is used as a process for converting the speckle noise into white Gaussian noise is discussed in this section. Cauchy PDF which is used for modeling the wavelet coefficients is discussed. Soft threshold methodology is also discussed in this section.

Homomorphic Approach

The basic steps of homomorphic approach are logarithmic (LOG) transformation and exponential (EXP) transformation. This approach decomposes the multiplication response as given below [10]:

$$P\big(m(t)n(t)\big) = P\big(m(t)\big) + P\big(n(t)\big) \qquad (1)$$

P defines homomorphic system and is logarithmic in nature. A homomorphic system is shown in Fig. 1:

Cauchy PDF

A highly suitable probability density function is required for estimating the noise-free wavelet coefficients. This paper utilizes Cauchy PDF for modeling the wavelet coefficients due to its long-tail structure. Assuming X as a Cauchy random variable, Cauchy PDF and cumulative distribution function (CDF) are defined by the following expressions [11]:

$$f(x) = \frac{1}{\pi}\frac{b}{(x-m)^2+b^2} \qquad (2)$$

$$F(x) = \frac{1}{2} + \frac{1}{\pi}\tan^{-1}\left(\frac{x-m}{b}\right) \qquad (3)$$

Where $\boldsymbol{m}$ is the location and $\boldsymbol{b}$ is the scaling parameters. The PDF and CDF graphs are shown in figures 2 and 3 respectively.

Statistical Modeling of Wavelet Coefficients of Ultrasound Image

Wavelet coefficients are generated from the logarithmic transformed ultrasound image are modeled using Cauchy PDF to find out the signal and noise information. The distribution of wavelet coefficients in the approximation sub-band at level-1 is shown in figure 4. The noise-free signal density is calculated from the detailed sub-bands. The noise density is calculated from the diagonal detail sub-band of at level-1 [12].

Soft Thresholding

Soft thresholding procedure narrows the wavelet coefficients C whose values lies above the threshold level. The soft thresholding function given by Zaki et al. [13] is:

$$Soft_{th} = \begin{cases} 0; & |C| \le t_h \\ sgn(C) \quad [|C| - t_h]; & |C| > t_h \end{cases} \qquad (4)$$

t_h is the threshold value which is defines as:

$$t_h = \frac{\sigma_N^2}{\sigma_S} \qquad (5)$$

σ_N^2 is the variance of the noise and calculated from the diagonal sub-band coefficients at level-1 ($D1$). It is given by [14]:

$$\sigma_N^2 = \left(\frac{median(D1)}{0.6745}\right)^2 \qquad (6)$$

σ_S is the standard deviation of the noise-free signal defined by the fundamental theorem of probability as:

$$\sigma_S = \sqrt{\overline{C^2}} \qquad (7)$$

$\overline{(\ )}$ is the expectation operation.

METHODOLOGY

The complete denoising procedure is explained through the following procedural steps and also the explained through the block diagram given in the figure 5.

Step 1. Input ultrasound image.
Step 2. Application of homomorphic approach to the input ultrasound image.
Step 3. Application of discrete wavelet transform (DWT) to the image obtained from step2.
Step 4. Calculation of threshold value.
Step 5. Application of soft thresholding to recover the wavelet coefficients.
Step 6. Application of Inverse discrete wavelet waveform (IDWT) to recover the image.
Step 7. Application of exponential operation (EXP) to the image obtained from step 6 to get the noise free ultrasound image.

Comparisons are given in tables 1, 2, and 3. From tables 1, 2 and 3 it can be viewed that the PSNR(dB), SSIM and EPI values are better for the proposed method than the state-of-the-art methods irrespective of the noise variance value. The PSNR improvement of the proposed method is 10.42% and 8.22% than the Donoho's Soft threshold [16] and Zaki et al. [13] methods respectively for noise variance of 0.1. The SSIM improvement of the proposed method is 2.27% and 0.72% than the Donoho's Soft threshold [16] and Zaki et al. [13] methods respectively for noise variance of 0.1. The EPI improvement of the proposed method is 3.21% and 1.99% than the Donoho's Soft threshold [16] and Zaki et al. [13] methods respectively for noise variance of 0.1.

CONCLUSION

A speckle denoising technique using the improved soft thresholding was presented in this paper. At first the speckle noise which is a multiplicative noise was converted in to additive noise by using the logarithmic procedure. Further, multiresolution was applied to the image and resulted wavelet coefficients were modeled using Cauchy PDF and Gaussian PDF to get the signal and noise parameters. The threshold value was calculated from these information and further, the wavelet coefficients were soft thresholded to obtain the updated wavelet coefficients. From the comparison results it is seen that the proposed improved soft thresholding technique obtained better result than the state-of-the-art methods. In future the proposed method may be applied for other imaging modalities to enhance the diagnosis results.

REFERENCES

1. Loupas, T., McDicken, W. N., & Allan, P.L. (1989). An adaptive weighted median filter for speckle suppression in medical ultrasound images. *IEEE Transactions on Circuits and Systems*, 36(1), 129-135.
2. Anantrasirichai, N. Nicholson, , L. , Morgan, J. E. , Erchova, I., Mortlock, K., North, R. V. , Albon, J., & Achim, A.(2014). Adaptive-weighted bilateral filtering and other pre-processing techniques for optical coherence tomography. *Computerized Medical Imaging and Graphics*, 38(6), 526-539.
3. Rogowska, J., & Brezinski, M. E. (2000). Evaluation of the adaptive speckle suppression filter for coronary optical coherence tomography imaging. *IEEE Transaction on Medical Imaging*, 19(12), 1261-1266.
4. Yang, J., Fan, J., Ai, D., Wang, X., Zheng, Y., Tang, S., & Wang, Y. (2016). Local statistics and non-local mean filter for speckle noise reduction in medical ultrasound image. *Neurocomputing*, 195, 88-95.
5. Ramos-Llorden, G., Vegas-Sanchez-Ferrero, G., Martin-Fernandez, M., Alberola-Lopez, C., & Aja-Fernandez, S. (2015).Anisotropic diffusion filter with memory based on speckle statistics for ultrasound images. *IEEE Transaction on Image Processing*, 24(1), 345-358.
6. Reddy, M.S. and Reddy, T.H., 2017. Speckle Noise Reduction In Ultrasound Images Using Adaptive Wavelet Thresholding. *Journal of Current Engineering Research (JCER)*, *7*(2).
7. Jubairahmed, L., Satheeskumaran, S. and Venkatesan, C., 2017. Contourlet transform based adaptive nonlinear diffusion filtering for speckle noise removal in ultrasound images. *Cluster Computing*, pp.1-10.
8. Subbiah, L., Samiappan, D. and Muthu, P., 2017, March. Automated denoised ultrasound carotid artery image segmentation using curvelet threshold decomposition. In *Wireless Communications, Signal Processing and Networking (WiSPNET), 2017 International Conference on* (pp. 2261-2266). IEEE.
9. Sahu, S., Singh, H. V., Kumar, B., & Singh, A. K. (2017). De-noising of ultrasound image using Bayesian approached heavy-tailed Cauchy distribution. *Multimedia Tools and Applications*, 1-18.
10. Hill, P.R., Bhaskar, H., Al-Mualla, M.E. and Bull, D.R., 2016, March. Improved illumination invariant homomorphic filtering using the dual tree complex wavelet transform. In *ICASSP*(pp. 1214-1218).
11. Sahu, S., Singh, H.V., Kumar, B. and Singh, A.K., Statistical Modeling and Gaussianization Procedure based de-speckling algorithm for Retinal OCT images, *Journal of Ambient Intelligence and Humanized Computing (AIHC), an International Journal of Springer*. DOI: https://doi.org/10.1007/s12652-018-0823-2
12. Sahu, S., Singh, H. V., Kumar, B., & Singh, A. K. A Bayesian Multiresolution Approach for Noise Removal in Medical Magnetic Resonance Images. *Journal of Intelligent Systems*.
13. Zaki, F., Wang, Y., Yuan, X. and Liu, X., 2017, June. Adaptive Wavelet Thresholding for Optical Coherence Tomography Image Denoising. In *Computational Optical Sensing and Imaging* (pp. CTh4B-4). Optical Society of America.
14. H. Rabbani, Mansur Vafadust, Saeed Gazor, and Ivan Selesnick, Image Denoising Employing a Bivariate Cauchy Distribution with local variance in complex wavelet domain, IEEE 12th Digital Signal processing workshop & 4th IEEE Signal Processing Education Workshop, 203-208, 2006.
15. [online] Available: http://splab.cz/en/download/database/ultrasound.

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16. Donoho, D. L. (1995). De-noising by soft-thresholding. *IEEE transactions on information theory*, *41*(3), 613-627.
17. Khor, H. G., Ning, G., Zhang, X., & Liao, H. (2022). Ultrasound Speckle Reduction using Wavelet-based Generative Adversarial Network. *IEEE Journal of Biomedical and Health Informatics*.

Table 1.PSNR (dB) Parameter comparison for different methods

Noise Standard deviation	Donoho's Soft threshold [16]	Zaki et al. [13]	Proposed Method
0.1	27.66	28.34	30.88
0.2	26.39	27.05	29.32
0.3	25.82	26.98	28.66
0.4	24.55	25.77	27.52

Table 2. SSIM Parameter comparison for different methods

Noise Standard deviation	Donoho's Soft threshold [16]	Zaki et al. [13]	Proposed Method
0.1	0.943	0.958	0.965
0.2	0.863	0.903	0.954
0.3	0.825	0.862	0.930
0.4	0.739	0.840	0.906

Table 3. EPI Parameter comparison for different methods

Noise Standard deviation	Donoho's Soft threshold [16]	Zaki et al. [13]	Proposed Method
0.1	0.872	0.883	0.901
0.2	0.856	0.871	0.892
0.3	0.821	0.834	0.886
0.4	0.808	0.825	0.875

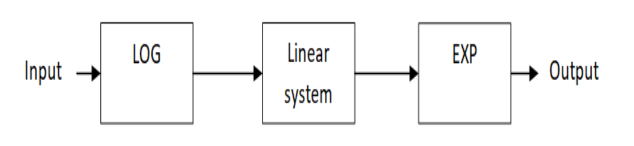

Fig. 1: Homomorphic system

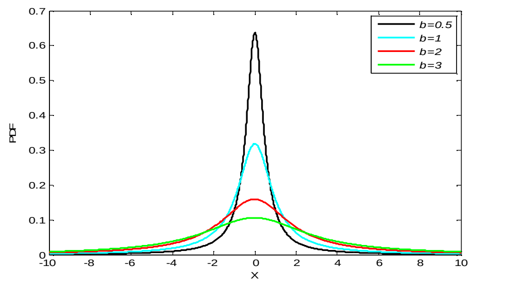

Fig. 2: Cauchy PDF for different values of scaling parameters

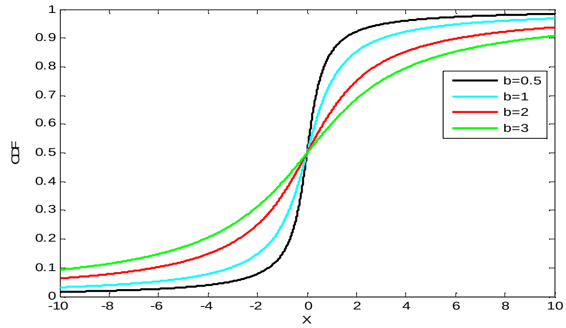

Fig. 3: Cauchy CDF for different values of scaling parameters

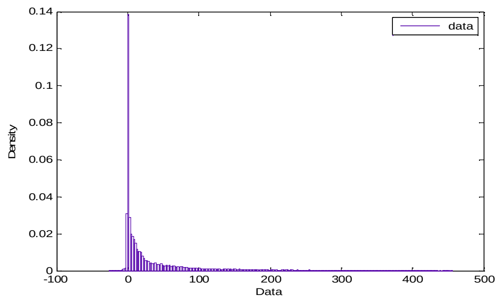

Fig. 4: Wavelet coefficient distribution in approximation sub-band at level-1

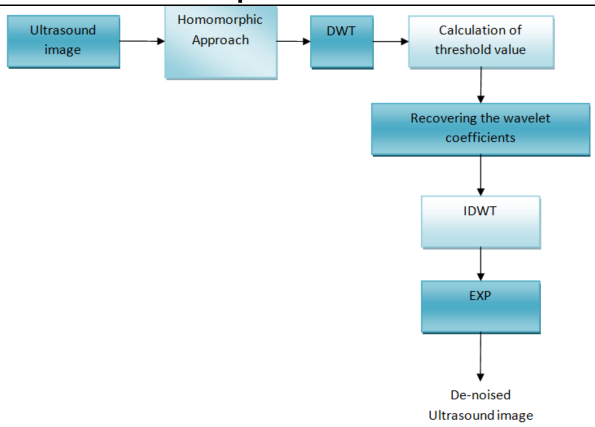

Fig. 5: Block diagram of the proposed method

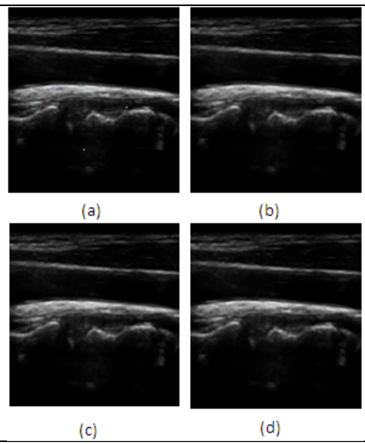

Fig. 6: De-noising performance (a) Original image (b) Donoho's Soft threshold method [19] (c) denoising result with Zaki et al. [10] (d) proposed method.