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Speckle noise reduction in medical ultrasound image using monogenic wavelet and Laplace mixture distribution

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ABSTRACT

Medical ultrasound images are corrupted with speckle noise inherently, which can cause negative effects on image-based interpretation and diagnostic procedure. Speckle reduction is an important step prior to the processing and analysis of the medical ultrasound images. In this study, a new speckle noise reduction algorithm in medical ultrasound images is proposed by employing monogenic wavelet transform (MWT) and Bayesian framework. The monogenic coefficients are modeled as the sum of noise-free component plus speckle noise component. First, the MWT coefficients of noise free signal and speckle noise signal are modeled as Laplace mixture distribution and Rayleigh distribution, respectively. Then, the new Bayesian minimum mean square error estimator is derived for the speckle noise reduction. Finally, we estimate the parameters of the proposed de-speckling algorithm by using the expectation maximization algorithm. To evaluate the effectiveness of the proposed de-speckling algorithm, we use both real medical ultrasound images and synthetic images for speckle reduction. The experimental results demonstrate that the proposed algorithm outperforms other state-of-the-art medical ultrasound image de-speckling algorithms by using quantitative indices.

1. Introduction

Ultrasonography is considered to be one of the most powerful techniques for imaging organs and soft tissues in the clinical diagnosis and therapeutic procedures. It is performed better than the other medical imaging methods as it is portable, economical and easy to use. However, ultrasound images are usually corrupted with speckle noise which can complicate the detection of small and low contrast lesions. Therefore, it is essential and valuable to remove speckle noise from ultrasound images for better analysis and diagnosis in many applications.

A lot of algorithms have been proposed for speckle reduction. They are classified into two classes which are algorithms based on spatial domain and transform domain. First of all, there are some methods in spatial domain are described as follows. Guan et al. [1] applied anisotropic diffusion filter to ultrasound speckle reduction. Lee [2] proposed noise reduction filter on two dimensional image arrays based on mean and variance. An effective speckle reduction algorithm based on bilateral filter is proposed in [3]. Then some nonlocal means filters are proposed, such as probabilistic patch based filter (PPB) [4] and optimized Bayesian non-local means (OBNLM) [5]. Frost et al. [6] and Kuan et al. [7] proposed speckle denoising filters based on the multiplicative speckle model and local statistical characteristics.

On the basis of the above de-speckling algorithms, Porrilli et al. [8] proposed synthetic aperture radar block matching 3D filter by combination of the multi-scale filter with the nonlocal means filter (SAR-BM3D). In [9], the new median filter is proposed for speckle reduction. Gold et al. [10] proposed reduced-rank wiener filter based on orthogonal projections. Damodaran et al. [11] proposed speckle noise reduction algorithm using discrete topological derivative (DTD). Then in [12], the speckle reducing AD (Srad) algorithm is proposed which can process images directly to preserve useful information. In general, the methods based filters in spatial domain can remove speckle noise simply and quickly, but these methods are sensitive to the size and shape of the selected kernel. The selection of large kernel can lead to losing important details, and the selection of small kernel can also lead to insufficient speckle noise removing.

On the other hand, some algorithms based on transform domain have been proved to be more useful in the process of medical ultrasound image de-speckling. Luisier et al. [13] proposed the advanced ultrasound image de-speckling technique based on wavelet by using the intra-scale correlation. The de-speckling algorithms [14,15] based on threshold techniques are proposed in the wavelet

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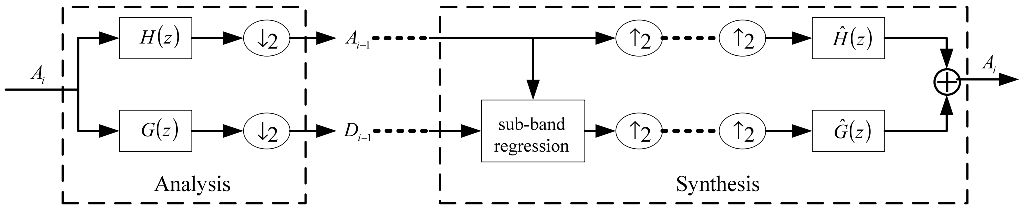

Fig. 1. Perfect reconstruction of monogenic wavelet transform.

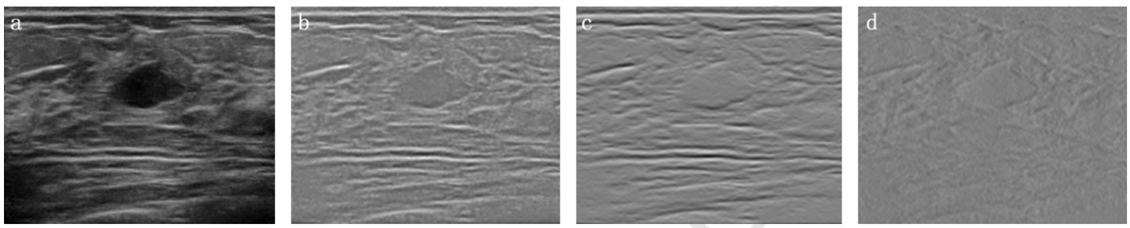

Fig. 2. Monogenic wavelet transform at the third scale. From left to right: (a) Input ultrasound image, (b) amplitude A, (c) phase angle φ, and (d) orientation angle θ.

Table 1
The Kurtoses values of each sub-band at different decomposition scales by using MWT.

Synthetic test image	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5
Brain	41.26	19.30	18.32	17.38	13.79
	68.15	97.68	54.73	30.06	20.64
	51.83	71.75	39.83	21.90	12.79
Circle	19.67	17.70	13.46	9.09	6.48
	64.88	62.82	49.95	30.57	16.13
	98.92	95.43	73.60	43.77	22.94

domain. In [16], a novel ultrasound image de-speckling algorithm is proposed by using linear Bayesian minimum mean square error (MMSE) estimation based on wavelet transform. Kingsbury applied dual tree complex wavelet transform [17] which was composed of two separate cascading orthogonal filter banks to image denoising. Then, some newly proposed image denoising algorithms based on multi-resolution analysis have been proposed such as contourlet [18], bandlets [19], and directionlets [20]. Although these directional transformation algorithms are efficient in image denoising, they are prone to producing salient artifacts and edge ringing.

Recently, Felsberg et al. [21] has proposed monogenic signal which can generalize the analytic signal to 2-D AM–FM model. In [22], the Riesz transform is used to extend the Hilbert transform to higher dimensions and construct the framework of monogenic wavelet transform by employing the hyper-complex monogenic. Soulard et al. [23] proposed non-marginal monogenic wavelet transform (MWT) by extension of the monogenic framework to vector-valued signals which had shown to be shift invariant and sparse representation. Olhede et al. [24] extended 1-D analytic wavelet transform to 2-D monogenic wavelet transform. So far, the MWT has been successfully applied to various areas such as pattern recognition [25], texture classification [26], medical image processing [27], etc.

In order to capture the statistical characteristics of decomposition sub-bands in transform domain, the statistical models are widely utilized to describe the distribution of the decomposition coefficients by using prior knowledge. Rabbani et al. [28] employed Gaussian mixture model to fit the distribution of the sub-band coefficients by using complex wavelet transform. Portilla et al. [29] proposed an medical ultrasound image de-speckling algorithm by combination Bayesian least squares with Gaussian scale mixture model. After that, the generalized Gaussian distribution [30,31] is used to fit the data distribution. In order to improve the robustness of the statistical models, several probability density functions are proposed such as normal inverse Gaussian [32,33], Laplace distribution [34], Cauchy Rayleigh distribution [35], and bounded Gaussian mixture distribution [36]. The transform domain based algorithms described above can process the speckle noise of ultrasound image at different scales and directions, but the problem is high design complexity.

In fact, the real medical ultrasound images are sensitive to speckle noise, which can decrease the ultrasound image contrast and wrap the boundaries of the tissue. Simultaneously, the speckle noise can also cause problems in medical ultrasound image processing system such as automatic segmentation, feature extraction and classification. Therefore, it is desirable to develop a method which improves the de-speckling performance and has low computational complexity.

In this paper, we analyze the statistical characteristics of subband coefficients in the monogenic wavelet transform domain. Inspired by [34], the Laplace mixture model (LM) has better fitting decomposition coefficients than the other statistical models. Therefore, the Laplace mixture model (LM) is utilized to describe the distribution of MWT coefficients of noise-free log-transformed data which can exploit the inter-scale and intra-scale dependencies of the MWT coefficients. The Rayleigh probability density function is applied to model the speckle noise in the MWT domain. Finally, we propose a novel medical ultrasound image de-speckling algorithm in the MWT domain by combination LM with linear Bayesian MMSE technique. The advantages of our main work are as follows: on the one hand, the proposed algorithm can seek a good tradeoff between the feature preservation and speckle suppression. On the other hand, the proposed algorithm not only has strong speckle suppression ability but also maintains the image details such as the edge information of the medical ultrasound images.

The rest of the paper is organized as follows. In Section 2, we give a brief introduction to the monogenic wavelet transform, and statistical characteristics of its decomposition coefficients. LM model and Rayleigh model are used to describe the noise-free domain's coefficients and speckle noise, and the detail of medical ultrasound image de-speckling algorithm based on linear Bayesian MMSE estimator is given in Section 3. In Section 4, we present the experimental results of the proposed algorithm comparing with some existing popular de-speckling algorithms. Finally, the conclusions are given in Section 5.