Proceedings of the 2012 International Conference on Machine Learning and Cybernetics, Xian, 15-17 July, 2012

OPTICAL COHERENCE TOMOGRAPHY HEART TUBE IMAGE DENOISING BASED ON CONTOURLET TRANSFORM

QING GUO[1], SHUIFA SUN[1], FANGMIN DONG[1], BRUCE Z. GAO[2], RUI WANG[2]

[1]Institute of Intelligent Vision and Image Information, China Three Gorges University, Yichang, Hubei 443002 China
[2]Department of Bioengineering, Clemson University, Clemson, SC, 29635, USA
E-MAIL: watersun@ctgu.edu.cn

Abstract:

Optical Coherence Tomography(OCT) gradually becomes a very important imaging technology in the Biomedical field for its noninvasive, nondestructive and real-time properties. However, the interpretation and application of the OCT images are limited by the ubiquitous noise. In this paper, a denoising algorithm based on contourlet transform for the OCT heart tube image is proposed. A bivariate function is constructed to model the joint probability density function (pdf) of the coefficient and its cousin in contourlet domain. A bivariate shrinkage function is deduced to denoise the image by the maximum a posteriori (MAP) estimation. Three metrics, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and equivalent number of look (ENL), are used to evaluate the denoised image using the proposed algorithm. The results show that the signal-to-noise ratio is improved while the edges of object are preserved by the proposed algorithm. Systemic comparisons with other conventional algorithms, such as mean filter, median filter, RKT filter, Lee filter, as well as bivariate shrinkage function for wavelet-based algorithm are conducted. The advantage of the proposed algorithm over these methods is illustrated.

Keywords:

Optical Coherence Tomography (OCT); Heart Tube image; Denoising; Contourlet transform; bivariate shrinkage

1. Introduction

Optical Coherence Tomography (OCT) is used to image the structure and function of the developing embryonic heart in avian models [1] and is an ideal technology to study the formation of heart tube of the chick for its noninvasive, nondestructive and real time imaging properties [2]. However, since OCT uses coherent detection to detect the weak single in the wide dynamic range, the signal is subject to the speckle noise: the image quality is poor for the grainy appearance, obscuring small-intensity features [3]. The noise can influence the application of the OCT heart tube image, such as image segmentation, registration and restoration. So image denoising methods are needed to improve the image quality.

The methods of image denoising are usually classified as space domain methods and frequency domain methods. In the space domain methods, the classic mean filter and median filter are performed on OCT heart tube image and improve the image quality to some extent while making the edge sharpness blurred. In 1980, J.S.Lee proposed an algorithm based on the local statistics of the synthetic aperture radar (SAR) image to reduce the noise while preserving edge sharpness [5]. Comparing with the mean filter, the method denoises the image while preserving edge sharpness, but the effect is not satisfied. The method based on the Rotating Kernel Transformation (RKT) [4] is performed to reduce the noise of the OCT heart tube image. And the result of the algorithm is worse than that of median filter and mean filter for reducing contrast of the image and making the edge sharpness blurred. In the frequency domain, the wavelet transform is an important method in image denoising field because of its excellent time-frequency character. In 2002, L.Sendur and I.W.Selensnick proposed a bivariate shrinkage function for wavelet-based denoising by exploiting inter-scale dependency, and the algorithm realize a good effect [6]. In 2004, D.C.Adler proposed an algorithm based on combining the wavelet-based method with the spatial structure of the OCT image (most of the OCT images are made up of horizontal edge structures) to reduce the noise of OCT image [7]. In 2009, Deng used the bivariate shrink function for wavelet-based denoising algorithm and the space structure of OCT image which are described in [6] and [7] to reduce the noise of OCT image [8]. However, the OCT heart tube image doesn't contain the space structure which most of OCT images have, so the method mentioned in the [7] can't help to reduce noise of OCT heart tube image. Using the wavelet-based denoising algorithm with the bivariate shrink function mentioned in the [6] and [8] to

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reduce the noise of OCT heart tube image can achieve better denoising effect than mean filter, median filter and RKT filter. Comparing with the Lee filter, the method does better in preserving edge sharpness. However, the wavelet transform represents image without direction and anisotropy, and this limits its ability in image expansion and image denoising.

In 2002, M.N.Do and M.Vetterli proposed the contourlet transform to realize image expansion based on the Multiscale Geometry Analysis [9]. Comparing with the wavelet transform, contourlet transform has direction and anisotropy and does better in image expansion. There are lots of applications using the contourlet transform to realize image denoising. The application objects include general images and some special images such as SAR images. According to the review of the OCT image speckle reduction algorithm reported by A.Ozcan in 2007[10] and some related algorithms reported in recent years, there are few papers involve the OCT image denoising method based on contourlet transform. In 2003, D.D.Y.Po and M.N.Do revealed the strong inter-direction dependency of contourlet coefficients based on the statistics of the coefficients [11]. According to above reports, the paper proposed a new image denoising algorithm based on the contourlet transform and inter-direction dependency of the coefficients to reduce the noise of the OCT heart tube image. The results show that the proposed algorithm outperforms wavelet-based algorithm, the flat area is smoother and the edges are preserved.

2. Contourlet shrinkage function and corresponding denoising algorithm

According to the method of constructing bivariate shrinkage function for wavelet-based denoising exploiting inter-scale dependency mentioned in [6], the joint empirical coefficient-cousin(the coefficients at the same scale and spatial location but in different directions[11]) histogram is discussed , and a non-Gaussian pdf of the current coefficients and its cousin is constructed. Finally, a bivariate shrinkage function is obtained and used to reduce the noise of OCT heart tube image.

2.1. Joint distribution model of contourlet coefficients

We assume the noise of the OCT heart tube image is n, and value of the image pixels can be written as

$$y=xn \tag{1}$$

where y is the noisy pixels, x is the true pixels, n is the noise.

Logarithmic transformation and contourlet transform is performed on (1), and the OCT heart tube image can be written as

$$y_1=w_1+\varepsilon_1 \tag{2}$$

$$y_2=w_2+\varepsilon_2 \tag{3}$$

where y_1 and y_2 are noisy observations of the current coefficient and its cousin; w_1 and w_2 are corresponding noise-free contourlet coefficienst; ε_1 and ε_2 are corresponding noise coefficients.

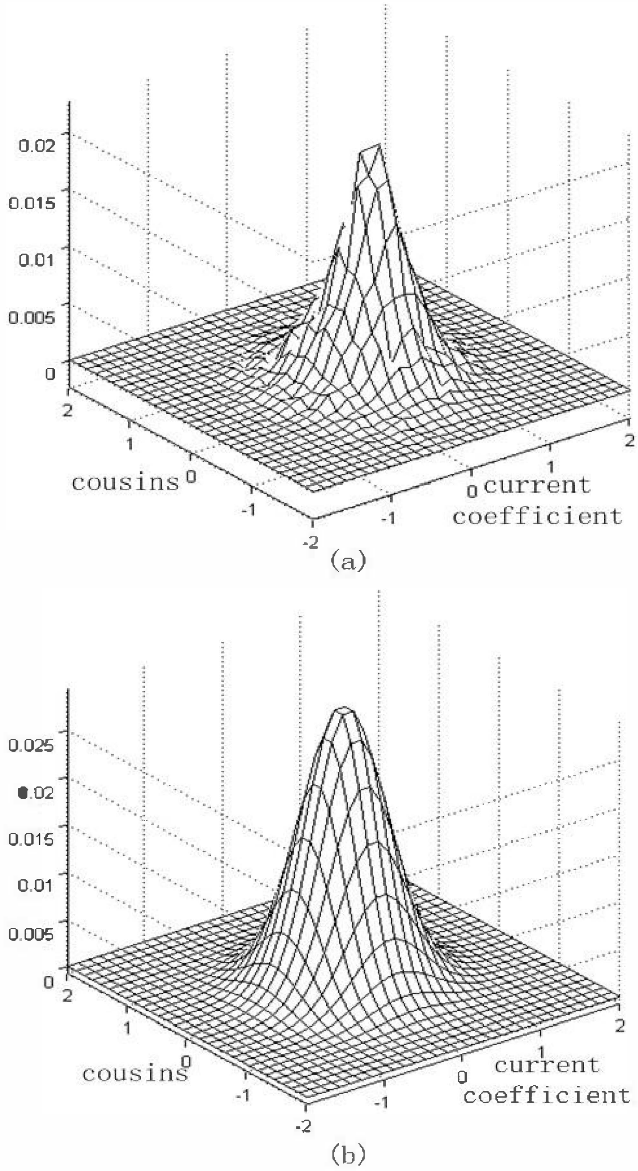

Figure 1. (a) Empirical joint coefficient-cousin histogram of contourlet coefficients. (b) bivariate pdf proposed to fit (a).

According to the method mentioned in [7], the conditional distribution of the coefficient and its cousin is discussed and indicates the dependency of them. With further discussion about the joint distribution of the two kinds coefficient, Figure 1.(a) can be obtained and indicates that the joint distribution has high peak value and long trailing and doesn't come up to the Gaussian distribution model. Figure 1.(b) can be obtained by the equation (4) to simulate the joint distribution based on the non-Gaussian pdf.

$$p_w(w) = \frac{K}{2\pi\sigma^2}\exp\left(-\frac{\sqrt{3}}{\sigma}\sqrt{w_1^2 + w_2^2}\right) \tag{4}$$

2.2. Inter-direction dependency based shrinkage function

Equation (2) and (3) can be rewritten as

$$y = w + \varepsilon \tag{5}$$

where $y=(y_1,y_2)$, $w=(w_1,w_2)$, $\varepsilon=(\varepsilon_1,\varepsilon_2)$.

The standard MAP estimation for w given y is

$$\hat{w}(y) = \arg\max_w p_{w|y}(w \mid y) \tag{6}$$

According to the Bayesian chaining rule, this equation can be written as

$$\begin{aligned}\hat{w}(y) &= \arg\max_w p_{y|w}(y \mid w)p_w(w) \\ &= \arg\max_w p_\varepsilon(y - w)p_w(w)\end{aligned} \tag{7}$$

As it shown in the equation, in order to get the estimated w, the pdf of noise is required. From assumption on the noise in contourlet domain, $p_\varepsilon(\varepsilon)$is zero mean Gaussian with variance of $\hat{\sigma}_n$ and can be written as

$$p_\varepsilon(\varepsilon) = \frac{1}{2\pi\hat{\sigma}_n^2}\exp\left(-\frac{\varepsilon_1^2 + \varepsilon_2^2}{2\hat{\sigma}_n^2}\right) \tag{8}$$

and $\hat{\sigma}_n$ can be obtained by using the method mentioned in [4]. The logarithm of (7) is taken. And let us define $f(w)=ln(p_w(w))$. By using (2) and (3), (7) becomes

$$\hat{w}(y) = \arg\max_w\left[-\frac{(y_1 - w_1)^2}{2\hat{\sigma}_n^2} - \frac{(y_2 - w_2)^2}{2\hat{\sigma}_n^2} + f(w)\right] \tag{9}$$

If $p_w(w)$ is assumed to be strictly convex and differentiable, the derivative of $f(w)$ with respect to w_1 and w_2 can be obtained.

$$\frac{y_1 - \hat{w}_1}{\hat{\sigma}_n^2} + f_1(\hat{w}) = 0 \tag{10}$$

$$\frac{y_2 - \hat{w}_2}{\hat{\sigma}_n^2} + f_2(\hat{w}) = 0 \tag{11}$$

where $f_1(\hat{w})$ and $f_2(\hat{w})$ are the derivative of $f(w)$ with respect to w_1 and w_2. Equation (10) and (11) are added into (8) and (9), an equation set is obtained. Solving the equation set, the bivariate shrinkage function can be written as

$$\hat{w}_1 = \frac{\left(\sqrt{y_1^2 + y_2^2} - \frac{\sqrt{3}\sigma_n^2}{\sigma}\right)_+}{\sqrt{y_1^2 + y_2^2}}y_1 \tag{12}$$

where

$$\left(\sqrt{y_1^2 + y_2^2} - \frac{\sqrt{3}\sigma_n^2}{\sigma}\right)_+ = \begin{cases}0, & if\sqrt{y_1^2 + y_2^2} < \frac{\sqrt{3}\sigma_n^2}{\sigma} \\ \sqrt{y_1^2 + y_2^2} - \frac{\sqrt{3}\sigma_n^2}{\sigma}, & if\sqrt{y_1^2 + y_2^2} >= \frac{\sqrt{3}\sigma_n^2}{\sigma}\end{cases} \tag{13}$$

2.3. The denoising algorithm based on the bivariate shrinkage function

Using the shrinkage function deduced above to reduce the noise of the OCT heart tube image in coutourlet domain, the steps are given as follows:

a. Perform logarithmic and contourlet transform on OCT heart tube image in turn to get the contourlet coefficients.
b. Get the cousin y_2 according to the current coefficient y_1.
c. Calculate $\hat{\sigma}_n$ using the method mentioned in [4]. And using equation $\hat{\sigma} = \sqrt{(\hat{\sigma}_{y_1}^2 - \hat{\sigma}_n^2)_+}$ to get the standard deviation of the noise-free coefficients, where $\hat{\sigma}_{y_1}$ is the variance of the local window.
d. Add the above parameters into (10) and get the $\hat{w}_1$ of every contourlet coefficient.
e. Perform the inverse contourlet transform and get the denoised image.

3. Experiments and Results

In this section, the signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR) and equivalent number of look (ENL) are used to evaluate the denoising effect.

3.1. Three evaluation metrics

$$SNR_m = 20\lg\frac{\mu_m}{\sigma_b} \tag{14}$$

$$CNR_m = 10\lg \frac{\mu_m - \mu_b}{\sqrt{\sigma_m^2 + \sigma_b^2}} \quad (15)$$

$$ENL_m = \frac{\mu_m^2}{\sigma_m^2} \quad (16)$$

where u_m and σ_m are the mean and variance of the mth ROI, respectively. u_b and σ_b are the mean and variance of the background of the image, respectively. CNR measures the contrast between an image feature and an area of background noise and ENL is a measure of the smoothness of a

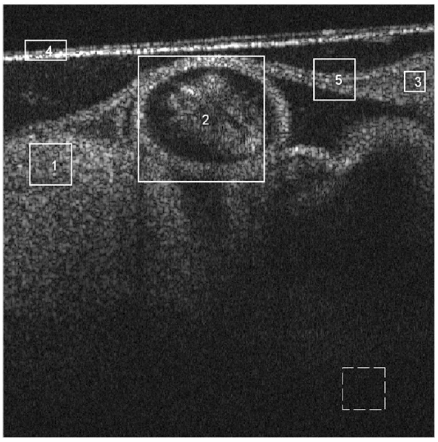

Figure 2. Regions of Interesting (ROIs) are chosen from the OCT heart tube image and labeled by solid line box. The noise region is labeled by dotted line box.

homogeneous region of interest [7]. Figure 2 shows the ROIs chosen from the OCT heart tube image.

3.2. Comparison and analysis

Using mean filter, median filter, RKT filter, Lee filter, bivariate shrinkage function for wavelet-based algorithm and the algorithm proposed by this paper to reduce the noise of OCT heart tube image, the denoising results are obtained and shown in Figure 3. The size of window used in the space domain algorithms is 3*3. Using the three evaluation metrics to evaluate the denoising effect, the results are shown in Figure 4.

As shown in Figure 3, bivariate shrinkage for wavelet-based algorithm and the algorithm proposed in this paper do well in OCT heart tube image denoising. And the evaluation metrics shown in Figure 4 illustrate that the SNR, CNR and ENL of the flat area of the OCT heart tube image increase based on the algorithm proposed in this paper, because the algorithm makes use of the direction and anisotropy of the contourlet transform and takes the inter-direction dependency of contourlet coefficients into account.

4. Conclusion and Prospect

The paper discusses the contourlet transform of OCT heart tube image and constructs a non-Gaussian pdf model based on inter-direction dependency of contourlet coefficients. A bivariate shrinkage function is obtained by using MAP and used to reduce the noise of OCT heart tube image in contourlet domain. The result of the experiment indicates that the algorithm proposed in the paper significantly reduces noise of the OCT heart tube image and increases the signal-to-noise ratio, while preserving strong edges.

A basic assumption of the algorithm is that the noise of OCT heart tube image is a single Gaussian multiplicative noise. However, [12] indicates that the speckle is not only noise source but also signal vehicle. So the next job should discuss the noise in detail in different parts to obtain accurate noise model.

Acknowledgements

This project is supported by National Natural Science Foundation of China (60972162, 61102155), Outstanding Young and Middle-aged Innovative Research Team Plan of Hubei Province of China (T201002), the Young and Middle-aged Science Funding of Hubei Provincial Department of Education (Q20111205).

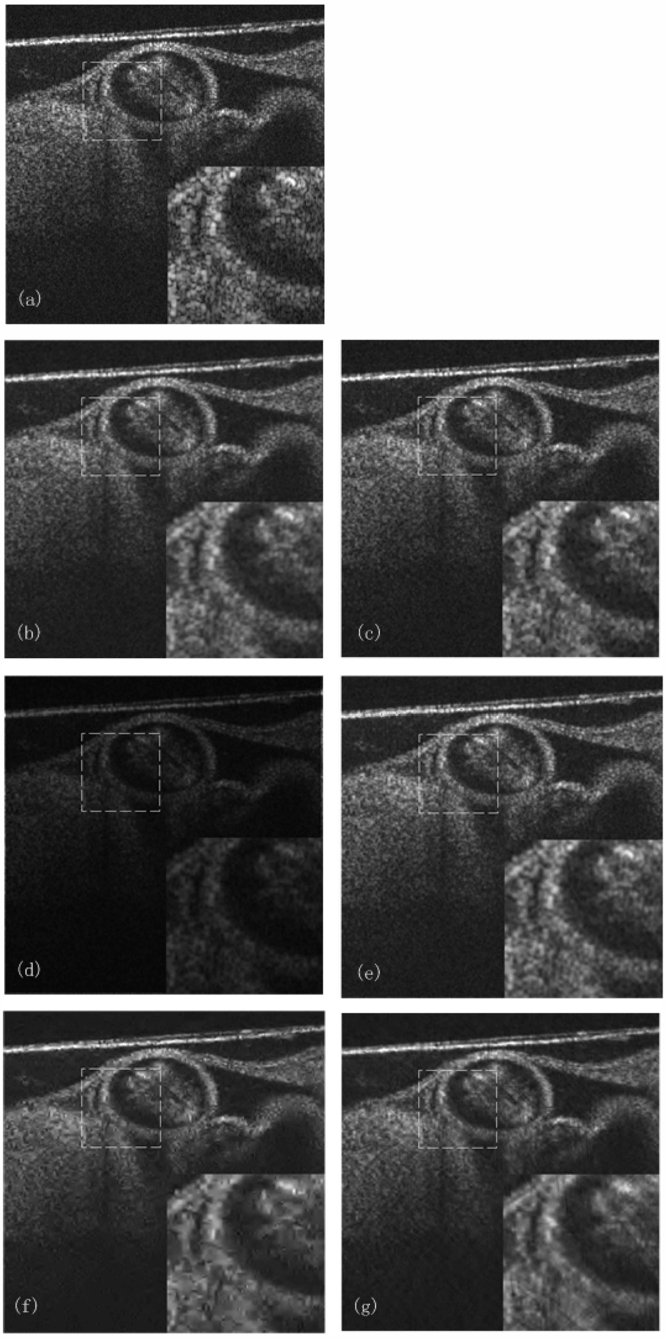

Figure 3. (a) Original image. (b)-(g) are denoised image with mean filter, median filter, RKT filter, Lee filter, wavelet shrinkage filter and the algorithm proposed in this paper, respectively.

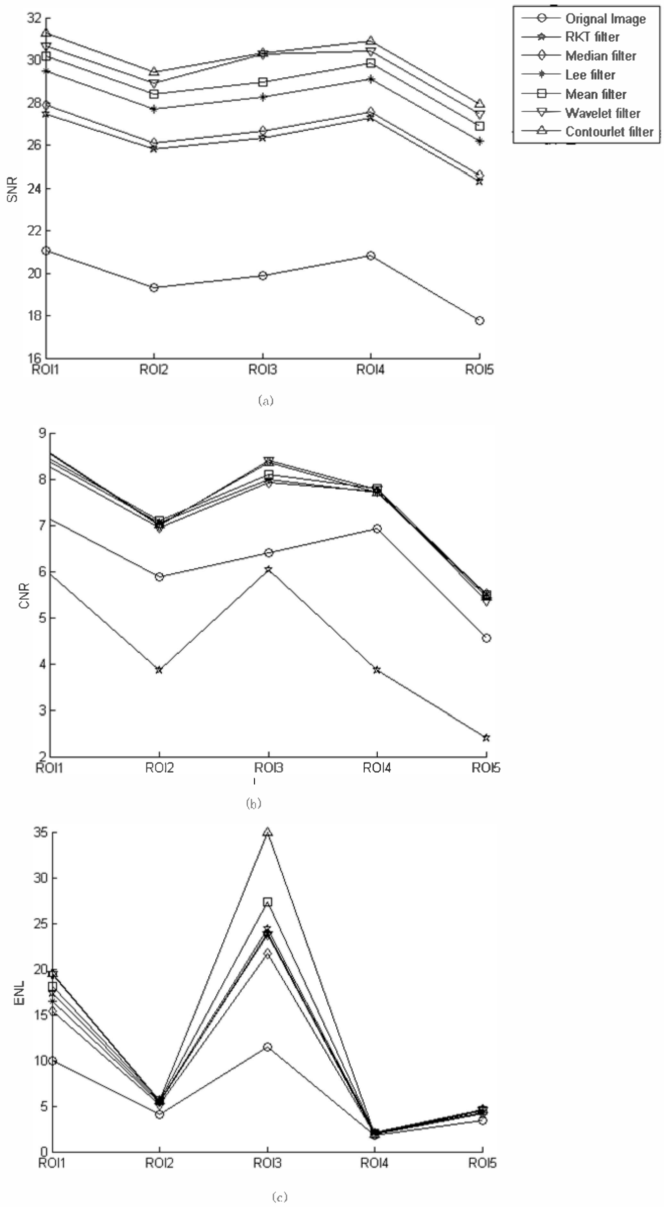

Figure 4. (a) SNR of different methods. (b) CNR of different methods. (c) ENL of different methods.

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