An Anisotropic Diffusion Filter for Reducing Speckle Noise of Ultrasound Images Based on Separability

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Abstract— **Anisotropic diffusion is being widely used in reducing speckle noise of ultrasound images. However, the traditional anisotropic diffusion algorithms are poor at preserving edges and usually make the image edges blurred when denoising, which negatively affects the following image analysis. In this paper, we modify the standard speckle reducing anisotropic diffusion to increase its ability of detecting edges and suppress the smooth at edge by using the separability of images. We extract contours from the original images, denoised images by SRAD and the images denoised by our proposed method, respectively. We analyze and compare the accuracy of these three kinds of contours. The result shows the proposed method performs better in edge-preserve and gets better images of high quality than SRAD, which can contribute to get more accurate contours.**

INTRODUCTION

Ultrasound imaging technology has the advantage of convenient, safe, fast, real-time, which is widely used in clinic. As with X-ray, CT, MRI(magnetic resonance imaging), Ultrasound imaging technology is one of the four major medical imaging techniques. However, due to the particularity of the imaging mechanism, ultrasound images have serious speckle noise. This kind of noise can be regarded as the multiplicative noise, and has complex stochastic properties. Speckle noise not only decreases the quality of ultrasound images, but also makes the following image-analyzing becomes more difficult. Therefore, before analyzing and using ultrasound images, we must reduce speckle noise. However when denoising, we should keep the details of the ultrasound image, such as image contour information.

At present, there are a number of algorithms for ultrasound images denoising including the Lee [1], Frost Filter [2] and PM [3]. Based on PM, Lee Filter and Frost Filter, Yu and Acton proposed SRAD [4] in 2002, a modified AD filter. SRAD can preserve edges well for ultrasound images when reducing speckle noise in homogenous regions.

In this paper, we modify the standard SRAD. We extract contours from the original images, the denoising results by SRAD and the proposed method, respectively. And we analyze and compare the three different contours.

The paper is organized as follows. In section 2, we review the standard SRAD, separability [5] and introduce the proposed method. In section 3, we present the experiments and analyze the result. The conclusions are given in Section 4.

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ANISOTROPIC DIFFUSION

A. *Speckle reducing anisotropic diffusion*

SRAD is very fit for speckle reducing. SRAD can not only preserve edges but also enhances edges. Given an intensity image $I_0(x,y)$ having finite power and no zero values over the image support Ω, the output image $I(x,y;t)$ is evolved according to the following PDE [4]:

$$\begin{cases} \partial I(x,y;t)/\partial t = div\ (c(q)\nabla I(x,y;t)) \\ I(x,y;0) = I_0(x,y),\ \ (\partial I(x,y;t)/\partial \vec{n})|_{\partial\Omega} = 0 \end{cases} \quad (1)$$

Where t represents diffusion time, $\partial\Omega$ denotes the borders of Ω, $\vec{n}$ is the outer normal to the $\partial\Omega$, and

$$c(q) = \frac{1}{1+[q^2(x,y;t)-q_0^2(t)]/[q_0^2(t)(1+q_0^2(t))]}. \quad (2)$$

Where $q(x,y;t)$ is the instantaneous coefficient of variation determined by

$$q(x,y;t) = \sqrt{\frac{\left(\frac{1}{2}\right)(|\nabla I|/I)^2-(1/4^2)(\nabla^2 I/I)^2}{[1+(1/4)(\nabla^2 I/I)]^2}}. \quad (3)$$

And $q_0(t)$ is the scale factor of speckle. For our images in the experiment we can define $q_0(t)$ with

$$q_0(t) \approx q_0 exp[-\rho t]. \quad (4)$$

So the proposed iteration formula of diffusion is defined with:

$$I_{i,j}^{n+1} = I_{i,j}^n + \frac{\Delta t}{4} d_{i,j}^n. \quad (5)$$

and $d_{i,j}^n$ is defined with:

$$\begin{aligned} d_{i,j}^n = {} & c_{i+1,j}^n\left(I_{i+1,j}^n - I_{i,j}^n\right) + c_{i,j}^n\left(I_{i-1,j}^n - I_{i,j}^n\right) \\ & + c_{i,j+1}^n\left(I_{i,j+1}^n - I_{i,j}^n\right) + c_{i,j}^n\left(I_{i,j-1}^n - I_{i,j}^n\right). \end{aligned} \quad (6)$$

Where ρ is a constant to slow down the decrease of q_0 while the algorithm is iterating.

SRAD can preserve edges even enhance edges; however this character or function highly depends on the precision of edge detecting. If the edge is not detected, the edge will not be enhanced and even smoothed. And if the noise is detected as edges, the noise will not be smoothed and even enhanced. So the performance of SRAD is sensitive to the selection of threshold value. Although SRAD has a dynamic threshold value, its precision of edge detecting is not so good in experiment. What's more, the diffusion coefficient cannot be zero at any edge; hence some edge in the image will be blurred.

B. Separability of ultrasound images

According to the fact that the performance of SRAD is sensitive to the selection of threshold value and the edge may be blurred. The proposed method uses the image separability based on statistics to improve the edge preserving during denoising. The separability is robust to blurred edges caused by noise and sensitive to detect an edge between different texture regions [6]. As the images have separability characteristics, we use the image characteristics to help SRAD detect the edges of the ultrasound images.

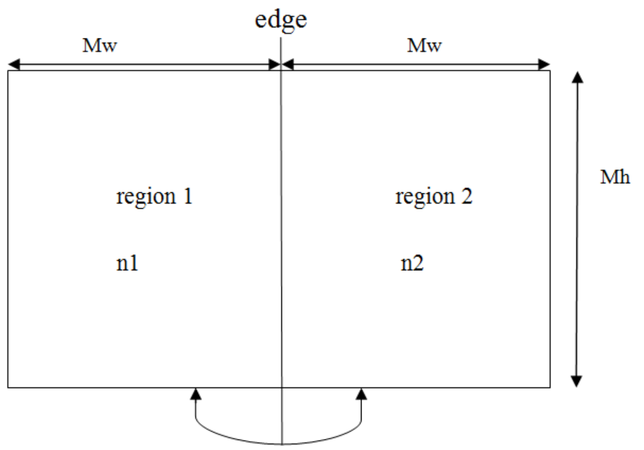

Fig. 1 define an edge based on separability

As Fig. 1 shows, a *2Mw×Mh* region consists of region 1 and 2. Separability η can be calculated by linear discriminant analysis using information from region 1 and region 2. The definition is:

$$\eta = \frac{\sigma_b^2}{\sigma_T^2}. \tag{7}$$

$$\sigma_b^2 = n_1(\overline{P_1} - \bar{P})^2 + n_2(\overline{P_2} - \bar{P})^2. \tag{8}$$

$$\sigma_T^2 = \sum_{i=1}^{n_1+n_2}(\overline{P_i} - \bar{P})^2. \tag{9}$$

Where P_i is the image intensity of an image at a pixel i, and $\overline{P_1}$ and $\overline{P_2}$ are the means of the image intensity in region 1 and region 2. $\bar{P}$ is the mean of image intensity for the combined region. n_1 and n_2 are the numbers of pixels in region 1and region 2 [5].

From the definition, we can conclude that η is $0 \le \eta \le 1$. At an ideal step edge, $\eta = 1.0$. When the egde becomes dull, the separability η will decrease. If the intensity changes linearly, η is a constant value $\bar{\eta}$ independent of the gradient θ of the slope. And

$$\bar{\eta} = 0.75\,\frac{1}{1-{}^{1}/_{4{M_w}^2}}. \tag{10}$$

If the change of the image intensity is little, $\eta \approx 0$.

C. The proposed method

We propose a novel anisotropic diffusion method based on the standard SRAD. In SRAD model, the diffusion coefficient $c(q)$ detects edges and controls the amount of smooth. Hence we modify the diffusion coefficient $c(q)$ of SRAD with separability η to help SRAD enhance precision of detecting edges and control the amount of smooth. The PDE of the proposed method is:

$$\begin{cases} \partial I(x,y;t)/\partial t = div\,(c(q)\nabla I(x,y;t)) \\ I(x,y;0) = I_0(x,y),\ \ (\partial I(x,y;t)/\partial\vec{n})|_{\partial\Omega} = 0 \end{cases} \tag{11}$$

And the diffusion coefficient $c(q)$ is:

$$c(q) = \frac{1-\eta}{1+[q^2(x,y;t) - q_0^2(t)]/[q_0^2(t)(1+q_0^2(t))]}. \tag{12}$$

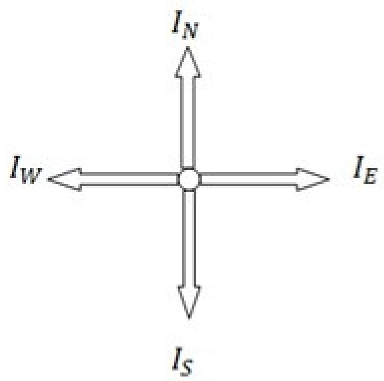

Fig.2 The four neighborhood operating window

So the proposed iteration formula of diffusion is defined with [7]:

$$I_s^{t+\Delta t} = I_s^t + \frac{\Delta t}{4}(1-\eta)[(c_N\nabla I_N + c_S\nabla I_S + c_W\nabla I_W + c_E\nabla I_E)]_s^t. \tag{13}$$

and:

$$\nabla I_E = I_E - I\,, \nabla I_W = I_W - I$$
$$\nabla I_N = I_N - I\,, \nabla I_S = I_S - I. \tag{14}$$

here

$$I_N = I(i-1,j)\,, I_S = I(i+1,j) \qquad (15)$$
$$I_W = I(i,j-1)\,, I_E = I(i,j+1).$$

These pixels are used to calculate the gradient magnitude $|\nabla I|$ of the diffusion coefficient

$$|\nabla I|^2 = (\nabla I_E)^2 + (\nabla I_W)^2 + (\nabla I_N)^2 + (\nabla I_S)^2. \qquad (16)$$

and the Laplacian:

$$\nabla^2 I = I_E + I_W + I_N + I_S - 4I. \qquad (17)$$

In our proposed method, at the edges, the diffusion becomes sluggish because of the separability η is high. And in the homogeneous regions, the diffusion is encouraged because the separability η is low.

Due to separability, the proposed method is able to detect edges more precisely and less smooth at the edges than SRAD.

EXPERIMENT AND RESULT

The images we used in the experiment are real ultrasound images. The images are obtained from the ultrasound machine Terason T3000. The size of the images is 640×480.But many sections of the images do not contain any useful information. So before denoising the images, we cut the image and modify the size to 400×240. This can reduce the computation when denoising the images. In the all experiments, q_0=1, ρ =0.166, *Mw*=30, *Mh*=3. Set η = 0 when η is smaller than $\bar{\eta}$ in equation (10) .

A. *Experiment with Sobel filter*

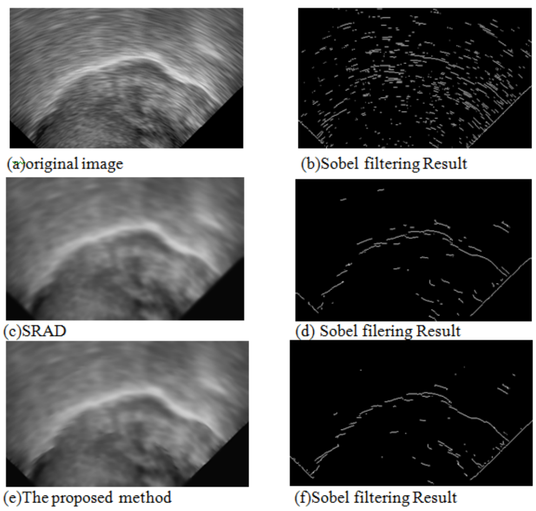

Fig. 3 the denoised results and extracted results of one sample image (a) The original image to be processed. (b) Sobel filtering result for (a). (c) denoising result by SRAD for(a). (d) Sobel filtering result for (b). (e) denoising result by proposed method for(a). (f) Sobel filtering result for (e).

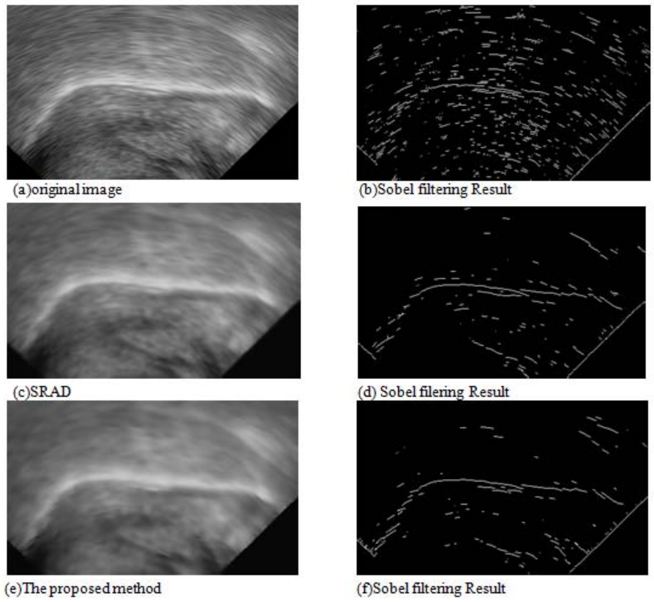

Fig.4 the denoised results and extracted results of one sample image (a) The original image to be processed. (b) Sobel filtering result for (a). (c) denoising result by SRAD for(a). (d) Sobel filtering result for (b). (e) denoising result by proposed method for(a). (f) Sobel filtering result for (e).

We use Sobel filter to extract contours from the original images, the denoising results by SRAD and the proposed method, respectively. Fig. 3 and Fig. 4 show the denoising and extracting results of two images derived from Terason T3000. Fig. 3 and Fig. 4 (b), (d) and (f) show that it is necessary to denoise images before detecting the edges with Sobel filter. Moreover, compared (d) and (f) of each figure, it is seen that the proposed method can get more precise and complete edge from real ultrasound images. So the proposed method is better than SRAD for Sobel filter to detect edges.

B. *Experiment with AAM*

We use the Pratt's figure of merit (FOM) [8] to compare edge preservation performance between the proposed method and SRAD. And the FOM is defined by

$$FOM = \frac{1}{max(I_I, I_E)} \sum_{i=1}^{I_E} \frac{1}{1+\frac{1}{9}d^2(i)}. \qquad (18)$$

Where I_I and I_E are the number of ideal and actual edge pixels. $d(i)$ is the Euclidean distance between the ith detected edge pixel and the nearest ideal edge pixel. We can see that FOM is between 0 and 1.

Before calculating FOM, we should extract the contours. In our experiment, we use Mikkel B. Stegmann's aam-api [9] based on AAM [10] to extract contours.

We have 3 different training sets and 3 different test sets. Each training set is 80 images, which we use to build a model. We use the model to extract the contours of the test set, which includes 6 images. So we get 6 contours for each test set. Then we annotate the 6 images to get 6 ideal contours. Now we can calculate FOM.

TABLE I
THE VALUE OF FOM

Org	0.0735	0.0701	0.0522	0.0700	0.0426	0.0332
SRAD	0.0815	0.0985	0.0600	0.0922	0.0572	0.0353
The Proposed Method	0.2796	0.3084	0.1740	0.3638	0.1008	0.1121

From the data in the Table I, it is seen that the proposed method perform much better than SRAD for AAM to extract contours. Moreover, the proposed method can help AAM get more accurate contours. So the proposed method improved edge preservation comparing with standard SRAD method.

For the proposed method, the iteration number is one of the most important facts that affect the denoising result. So it is significant to optimize the iteration number (*n*). In the experiment, we change the *n* from 30 to 100 with step 10. And Fig. 5 shows partial results of the image Fig.3 (a), for which the denoised images with 30, 40, 50 and 60 iterations have been shown in different panels respectively.

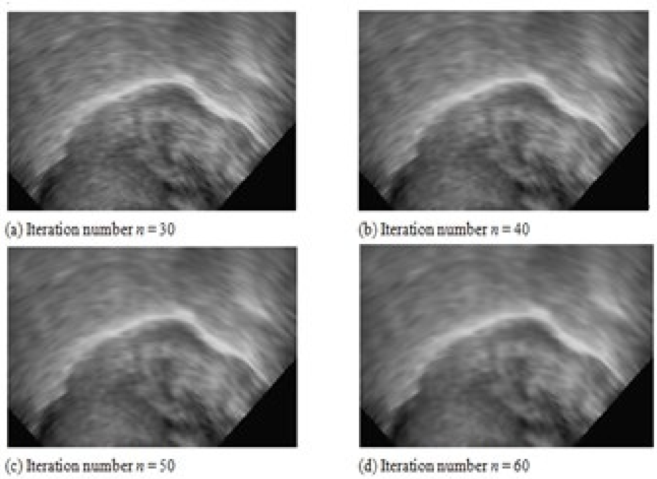

Fig.5 The denoised images with 30, 40, 50 and 60 iterations
(a) Iteration number n=30. (b) Iteration number n=40.
(c) Iteration number n=50. (d) Iteration number n=60.

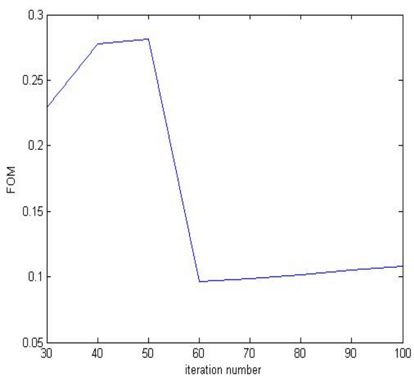

Fig.6 FOM of different iteration numbers of the image Fig.3 (a)

We evaluate the results for different iterations by FOM for the sample image. The FOM value changed along with different iteration numbers that have been shown in the Fig.6.

Fig.6 shows when *n*=50, the FOM is the highest. So we get the best iteration number 50 of this sample image.

CONCLUSIONS

In this paper, we have proposed a novel denoising method for ultrasound images. The present method is based on Yu and Acton's SRAD algorithm. The proposed method not only reduces speckle noise, but also performs better in edge-preserve by take image separability into account. The evaluation result show that the FOM value improved from 0.07 to 0.22 averaged over all test set images. This result indicate that our method significantly outperform the standard SRAD method. The proposed method is very useful for reducing speckle noise before detecting edges from real ultrasound images. In the future research, we need to evaluate the proposed method to investigate if important information is being lost in the filtering.

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