

RESEARCH AND APPLICATION OF IMAGE DENOISING METHOD BASED ON CURVELET TRANSFORM

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ABSTRACT:

The images usually bring different kinds of noises in process of receiving, coding and transmission. The curvelet transform is one kind of new multi-scale transform after 1999 that is based on wavelet transform, whose structural elements include the parameters of dimension and location, and orientation parameter more, which let curvelet transform has good orientation characteristic. Therefore, curvelet transform is superior to wavelet in the expression of image edge, such as geometry characteristic of curve and beeline, which has already obtained good research results in image denoising. This paper puts forward an improved method based on curvelet transform because certain regions of the image have the ringing and radial stripe after curvelet transform. The experimental results indicate that the improved curvelet transform has a abroad future for eliminating the noise of images. It suits not only the ordinary visual image, but also remote sensing image.

1. INTRODUCTION

The image usually has noise which is not easily eliminated in image processing. According to actual image characteristic, noise statistical property and frequency spectrum distribution rule, people have developed many methods of eliminating noises, which approximately are divided into space and transformation fields. The space field is data operation carried on the original image, and processes the image grey value(Gao Zhing,2004), like neighborhood average method, wiener filter, center value filter and so on. The transformation field is management in the transformation field of images, and the coefficients after transformation are processed. Then the aim of eliminating noise is achieved by inverse transformation, like wavelet transform(Donoho.D.L,1994; Pan Quan,1999). These methods generally have a dilemma, namely the noise smoothness and holding of image edge and detail information. If noise smooth effect is good, image illegibility is inevitably caused, and if the image outline is clear, the noise smooth effect is inevitably bad, which consider one aspect but lose another.

In recent years, one kind of new multiscale transform based on wavelet transform --curvelet transform has developed rapidly (E.J.Candes,1999). The structural elements of curvelet transform include the parameters of dimension and location, and orientation parameter more, which let it has good orientation characteristic. Therefore, curvelet transform is superior to wavelet in the expression of image edge, such as geometry characteristic of curve and beeline, which has already obtained good research results in image denoising. This paper puts forward a improved method based on curvelet transform because certain regions of the image have the ringing and the radial stripe after curvelet transform.

2. SECOND CURVELET TRANSFORM

2.1 Wrapping_based Curvelet

Curvelet transform develops from 1999 until now, already has transformed from the first generation(J.L.Starck,2002) to the second generation theory(E.J.Candes,2005). Based on this, overseas research scholars realize the conversion process more simply and quickly, they develop another new algorithm. The first method is based on unequally-spaced fast Fourier transforms(USFFT) and the second is based on the wrapping of specially selected Fourier samples. The two implementations essentially differ by the choice of spatial grid used to translate curvelets at each scale and angle. The ‘wrapping’ approach use in this article assumes the same digital coronization as digital curvelet transform theory, but makes a different, somewhat simpler choice of spatial grid to translate curvelets at each scale and angle.

Instead of a tilted grid, we assume a regular rectangular grid and define ‘Cartesian’ curvelets in essentially the same way as before,

$$c(j,l,k) = \int \hat{f}(\omega) \tilde{U}_j(S_{\theta}^{-1}\omega) e^{i\langle b,\omega \rangle} d\omega \quad (1)$$

Discrete curvelet transform formula

$$c(j,l,k) = \int \hat{f}(\omega) \tilde{U}_j(S_{\theta}^{-1}\omega) e^{i\langle S_{\theta}^{-1}b,\omega \rangle} d\omega \quad (2)$$

Notice that the $S_{\theta}^{-T}b$ has been replaced by $b = (k_1 2^{-j}, k_2 2^{-j/2})$, taking on values on a rectangular grid. As before, this formula

for b is understood when $\theta \in \left(-\frac{\pi}{4}, \frac{\pi}{4}\right)$ or $\theta \in \left(\frac{3\pi}{4}, \frac{5\pi}{4}\right)$.

Wrapping round origin point is the core of Wrapping_based curvelet. Figure 1 shows that it realizes one to one through the periodization technology in the affine region.

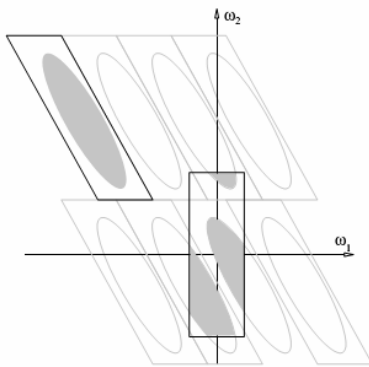


Figure 1. Wrapping data in a parallelepiped by periodicity. Equipped with this definition, the architecture of the FDCT via wrapping(E.J.Candes,2005) is as follows:

1. Apply the 2D FFT and obtain Fourier samples $\hat{f}[n_1, n_2]$, $-n/2 \leq n_1, n_2 < n/2$;
2. For each scale j and angle, form the product $\tilde{U}_{j,l}[n_1, n_2] \hat{f}[n_1, n_2]$;
3. Wrap this product around the origin and obtain $\tilde{f}_{j,l}[n_1, n_2] = W(\tilde{U}_{j,l} \hat{f})[n_1, n_2]$, $0 \leq n_1 < L_{1,j}, 0 \leq n_2 < L_{2,j}$, $\theta \in (-\pi/4, \pi/4)$;
4. Apply the inverse 2D FFT to each $\tilde{f}_{j,l}$, hence collecting the discrete coefficients $c^D(j, l, k)$.

2.2 Improved Arithmetic

Curvelet transform develops based on ridgelet transform. The researches indicate that though the second generation of curvelet transform has been separated from ridgelet transform and realizes simply, its digit realization process still exist a transformation question between polar coordinate and the Cartesian coordinate in Radon transform. People proposed several interpolation methods, but the enhancement of transformation precision takes the computation of complexity and redundancy increase as the price. Radon transform existence causes curvelet transform ratio has inborn relevance. The change of a coefficient value in curvelet region will cause all values change of a straight line. Of course, whether to getting rid of the relevance can't attribute one kind of transformation good or bad. The key is how to use it as well as use in whatever situation.

Through experiments analysis it is discovered that curvelet transform itself will not have the ringing and the radial stripe, but will appear in the threshold value denoising process. So this article proposed an improved algorithm is as follows:

Define original noise image is `noisy_img`, denoising image is `restored_img`, curvelet transform is $C(t)$, two-dimensional steady wavelet transform is $F(t)$, N is odd number:

```

For i = 1 to N
    restored_img = C(noisy_img); %Direct and inverse
    curvelet transform, threshold value denoising
    if (i mod 3 = 0)
        restored_img = F(restored_img); % Direct and inverse SWT
    end
end
    
```

The improved algorithm mainly aims at assuming threshold value denoising. One time curvelet transform becomes many times they can decrease the ringing and radial stripe. Then a combination of curvelet and wavelet transform will obtain quite good denoising effect.

3. EXPERIMENTS

3.1 Emulational Experiments

In order to confirm the validity of curvelet transform improved denoising method, take Lenna gray image and Barbara color image as the examples. They are increased random noise separately ($\sigma = 20$ and $\sigma = 40$). Table1 shows curvelet improved denoising effects in comparison with others.

method \ noise size		SWT	Curvelet	Improved
		Lenna	$\sigma = 20$: 21.2089	22.0424
	$\sigma = 40$: 15.1327	16.0928	15.9275	
Barbara	$\sigma = 20$: 22.0811	21.1102	23.8692	
	$\sigma = 40$: 15.8579	15.7676	16.3089	

Table 1. Comparison of denoising results

To show effects clearly, we display the hat region of Lenna($\sigma = 20$) denoising images and the face region of Lenna($\sigma = 40$) denoising images, e.g. Figure 2 and Figure 3.

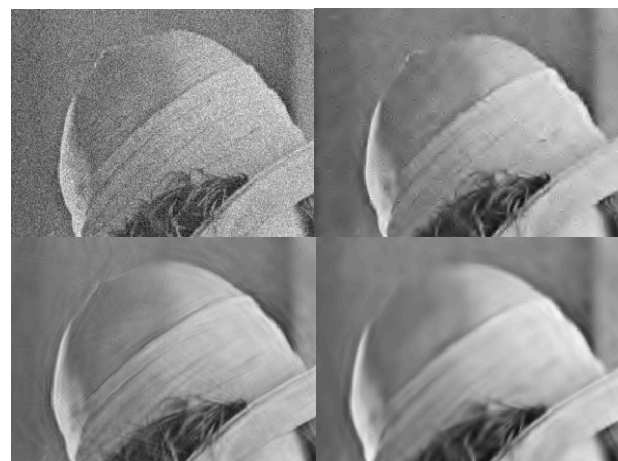


Figure 2. The figure displays the $\sigma = 20$ noisy image Lenna's hat region (top left), and the restored images after denoising by means of SWT(top right), curvelet transform(bottom left) and the improved curvelet transform (bottom right).



Figure 3. The figure displays the $\sigma = 40$ noisy image Lenna' face region (top left), and the restored images after denoising by means of SWT(top right),curvelet transform(bottom left) and the improved curvelet transform (bottom right).

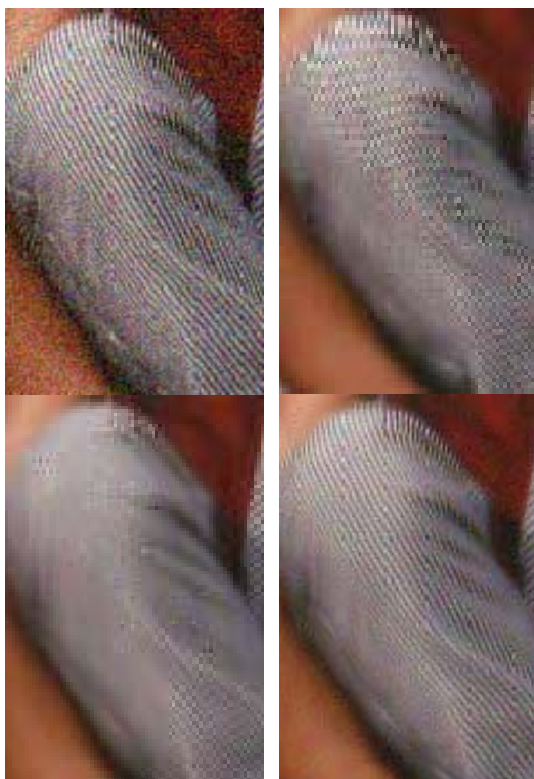


Figure 4. The figure displays the $\sigma = 20$ noisy image Barbara 'knee region (top left) and the restored images after denoising by means of SWT(top right),curvelet transform(bottom left) and the improved curvelet transform (bottom right).

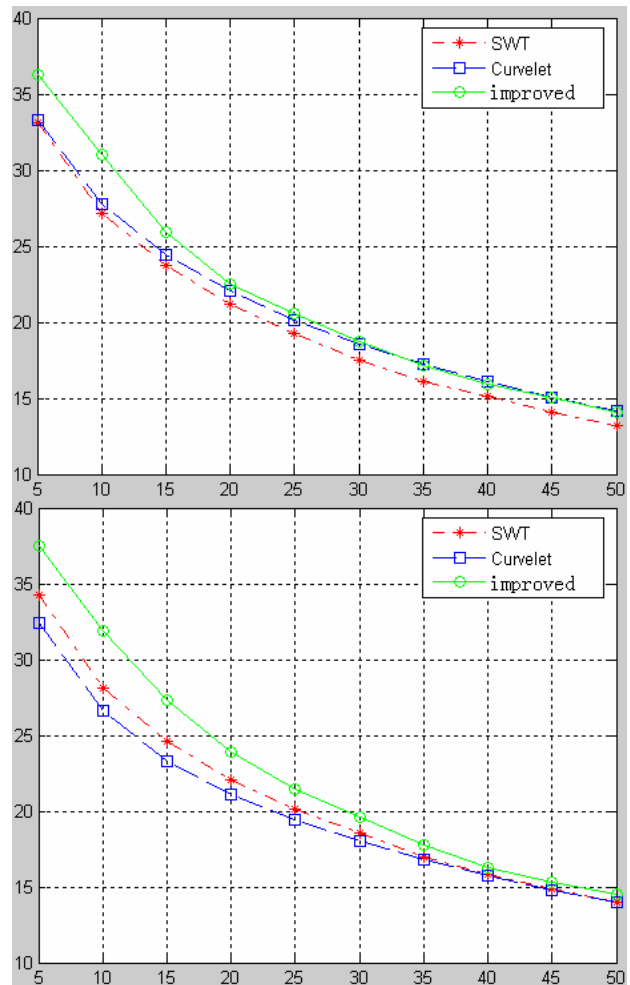


Figure 5. PSNR versus noise standard deviation for different denoising methods. The three methods based on SWT, curvelet and the improved curvelet. The left panel corresponds to Lenna, and the right to Barbara.

From Figure2 and Figure3 we found that the curvelet transform denoising effects were good, but meanwhile produced more radial stripes. By contrast, curvelet improved method changed this situation, but the denoising process correspondingly lost a part of edge characteristic and detail information due to adding wavelet transform to improved method. On the whole, the improved method obtained better denoising results than curvelet transform and two-dimensional stationary wavelet transform.

Similarly, we selected the knee region of $\sigma = 20$ Barbara color noisy image. Compare their results of above three denoising methods. From Figure4, we could see that curvelet transform improved method is truly more effective than the other two methods.

As shown in Figure5 , Lenna and Barbara images were increased separately random noise $\sigma = 5, 10, \dots, 50$, in all 10 groups data. Analyze the PSNR value change tendency of denoising image among SWT, curvelet transform and curvelet improved method. Lenna image in the situation of $\sigma < 35$, PSNR value of curvelet transform improved method denoising is relatively high. With the noise size increasing, PSNR value of curvelet improved method is gradually consistent with curvelet transform, but still surpassed the wavelet transform. Barbara image in the situation of $\sigma \leq 50$, PSNR value of curvelet

improved method denoising always surpassed other two methods.

3.2 SAR Image Denoising

The experiments select Leica Corporation's example image of Erdas Imagine software. It is a size of 512×512 loplakebed image, sub-image of an aerospace craft imaging radar SIR-A experiment. The resolution of L wave band is 25 meters and is suitable for penetrating the desert, drift sand and dune. This image is Lop Nor area in Xinjiang province of China. Looked from the image that the speckle noise is very obvious.

The experiment adopts average value filter, median value filter, Lee-sigma filter, Frost auto-adapted filter, two-dimensional

steady wavelet transform, curvelet transform and curvelet transform improved method to remove noises separately. Compare denoising effects and from Table2 discover that curvelet improved method may achieve good denoising effects, and has the widespread serviceability. Using curvelet transform denoising speckle noise of SAR image is small breakthrough to traditional method. It improved the question that image's edge feature, detail information and the noises were smoothed together. After the curvelet improved method denoising, image residual speckle noises are few, the interpretation is good, meanwhile retained the edge feature and detail information and maintained the high radiation resolution. This is which several other methods are unable simultaneously to give dual attention, see Figure 6.

Denoising methods	Speckle index	Smooth index	ENL	Radiates resolution	PSNR
Original image	0.5838	1.7129	2.9339	1.9970	
Average value filter	0.4533	2.2062	4.8661	1.6236	15.5013
Median value filter	0.4871	2.0530	4.2149	1.7234	15.2918
Lee-sigma filter	0.4956	2.0178	4.0709	1.7482	18.7656
Frost auto-adapted filter	0.4985	2.0060	4.0240	1.7566	18.2058
SWT	0.4718	2.1195	4.4933	1.6784	18.3574
Curvelet	0.4978	2.0088	4.0359	1.7545	19.2106
Improved curvelet	0.4844	2.0644	4.2623	1.7154	21.1076

Table 2 The Comparison of different filtering methods

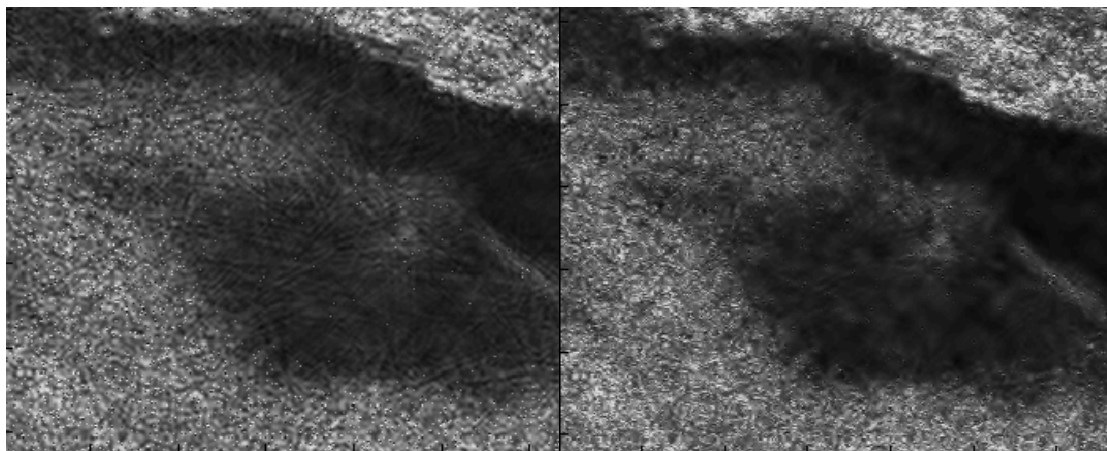


Figure 6. Denoising results for part of SAR image. Left:curvelet transform.Right:the improved curvelet transform method.

4. CONCLUSIONS

By massive experiments this article compares and contrasts wavelet and curvelet transform denoising methods' good and bad points, then proposes curvelet transform improved denoising method. The main conclusion includes:

1. This article proposes the improvement algorithm in view of the curvelet transform denoising method's shortcoming. Take Lenna gray image and Barbara color image as the examples. They are increased random noise separately ($\sigma = 20$ and $\sigma = 40$). Applies two-dimensional steady wavelet transform, curvelet transform and the curvelet transform improved method respectively denoising.

After two-dimensional steady wavelet transform, edge and detail information lost mostly. After curvelet transform, detail information retained better than wavelet transform, meanwhile in denoising process emerged the ringing and radial stripe. The curvelet improved method changed this situation, but the denoising process correspondingly lost a part of edge characteristic and detail information due to adding wavelet transform to improved method. On the whole, the improved method obtained better denoising results than curvelet transform and two-dimensional stationary wavelet transform.

2. The curvelet improved method can achieve good denoising effect and has the widespread serviceability for remote sensing image. Using curvelet transform denoising speckle noise of SAR image is small breakthrough to traditional method. It

improved the question that image's edge feature, detail information and the noises were smoothed together.

The above results were merely preliminary experiments about the curvelet transform improved denoising method. There will also have some other factors not to be considered, for instance, the resolution factor in remote sensing image denoising process. In the experiment to the SAR image denoising, the methods which the traditional filters and this article proposed will appear the identical contradiction. That is noise elimination at the same time, the image resolution will also reduce. In addition, the improved algorithm also has the deficiency. This method eliminated the ringing and the radial stripe emerged into the curvelet transform denoising process, but the improved algorithm caused to lose a small part of edge feature and the detail information correspondingly in the denoising process. How to make a deeper algorithm improvement in this foundation, to retain more edges and the detail information, waits for us further exploring.

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