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The Contourlet Transform with Multiple Cycles Spinning for Catenary Image Denoising

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Abstract

In the catenary images, noise and artifacts are introduced due to the acquisition techniques and systems, which may influence the judgement of catenary quailty and working states. In this paper, the contourlet transform (CT) with performances of multi-scale, multi-resolution and anisotropy is proposed, which can be effectively applied to image denoising. However, the CT hasn't the spinning invariance, which will lead to the Gibbs-like phenomena. In this paper, the CT with multiple cycle spinning is introduced for image denoising, which can effectively eliminate the visual artifacts due to the lack of translational invariance. Meanwhile, the different Laplacian pyramid (LP) filters and directional filter banks (DFB) are proposed to test noisy images. Finally, test the influence of cycle spinning numbers for denoising effects by using different cycle spinning times. The experiment results show that the proposed method has excellent denoising performance in terms of the signal-to-noise ratio (SNR) and the visual effects, which is also superior to some other existing methods in overcoming the Gibbs-like phenomena, background smoothing and preservation of edge sharpness and texture.

Keywords: *contourlet transform, spinning invariance, catenary image denoising*

1. Introduction

Catenary fault diagnosis under background noise is a challenging task. During the catenary fault diagnosis based on image processing, image quality is crucial. However, the catenary images are easy to be influenced by weather, light source, system and other factors, which will appear noise. In order to accurately analyze the fault type, it is important to denoise the catenary images. Image denoising is to keep the useful information and reduce the noise of the image [1]. Usually, there are two main methods for multi-focus image denoising, One is the spatial domain-based methods, another is the transform domain based methods. Among these methods, the wavelet transform (WT) has obtained good results in handling one-dimensional piecewise smooth functions [2]. However, the efficiency and sparse representation of WT are limited by spatial isotropy of the basis functions built only along with the finite directions, which has low frequency resolution and high time resolution in the high frequency parts [3]. Besides, the efficient image representation has to account for the geometrical structure pervasive in natural scenes [4]. As the catenary images contain much texture features, wavelets may not be the best sparse representation, which has the good denoising results, while the preservation of edge details isn't ideal, the artifacts marked by softness, ringings, halos, and color bleeding can be seen along edges. Recently, many mutli-scale transforms are proposed. During these transforms, the contourlet transform (CT) inherits the multi-resolution and time-frequency localization performances of WT. It provides more sparse representation at both spatial and directional resolutions which can efficiently represent images containing contours and textures [5]. Compared with WT, the CT can provide more useful performances, which can effectively capture the important information of catenary images.

The CT has the remarkable virtues in denoising two-dimensional images. However, due to down-sampling and up-sampling, the CT has the performances of shift-variant [2, 6], which will lead to Gibbs-like phenomena along with removing image noise. To overcome the Gibbs-like phenomena, many methods are introduced in some papers. In [7], interval wavelet

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transform is applied, which can generate sparser representations in the vicinity of discontinuities than classical WT. However, it is still built on the WT. In [8], Wavelet based on contourlet is a non-redundant sparse representation of image, which can effectively reflect visual characteristics of the image, while its main purpose is to reduce the redundancy; the translation variance is still exist. Recently, the nonsubsampled contourlet transform and the translation invariant contourlet transform are introduced, which have desirable feature in many imaging applications such as pattern recognition, edge detection and image denoising, while all of them are translation invariant at the cost of high redundancy [2]. In [9], R Eslami and H Radha have achieved good denoising results by employing the CT with cycle spinning to denoising. While the different Laplacian pyramid (LP) filters and directional filter banks (DFB) may have different impacts on denoising effects. Besides, the different cycle spinning numbers may influence the image denoising effects. In this paper, the CT with multiple cycle spinning method is introduced to denoise. Meanwhile, to test the influence of denoising effects, the different cycle spinning times and LP filters and DFB are employed to denoise. Experimental results show that the proposed method can effectively apply in image denoising and protect the image texture details.

2. The Proposed Method

2.1. The Contourlet Transform

The CT is a kind of multi-scale geometric analysis tool, which can take full advantage of the geometric regularity of image intrinsic structures and obtain the asymptotic optimal representation. It has the performances of multi-resolution, local and multi-directional, which can effectively represent smooth curvature details typical of the catenary images. The CT is constructed by combining the LP with DFB, which includes the sub-band decomposition and directional transform. Firstly, the LP transform iteratively decomposes a two-dimensional image into low-pass and high-pass sub-bands, and then the same scale point discontinuities are linked into linear structure by DFB [10], the DFB are applied to the high-pass sub-bands to further decompose the frequency spectrum into directional sub-bands [11], which is easily adjustable to detect details in any number (2^n) of directions [12]. Because the number of directional sub-bands can vary between scales, CT is a true two-dimensional digital image representing method. Figure 1 shows the structure of CT [13, 14].

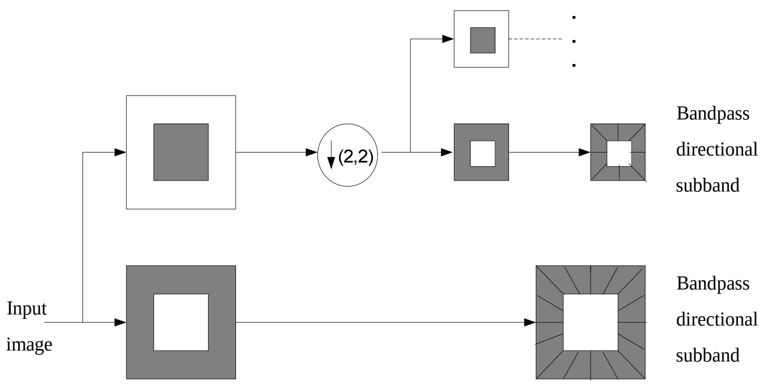

Figure 1. A Flow Graph of the Contourlet Transform

The CT consists of the following steps:

Step 1. Decompose the image with LP transform.

Step 2. Decompose the high frequency signal, synthesize the singular points distributed in the same directions as a coefficient.

Step 3. Reconstruct.

The CT has more directional sub-bands and directional information, the partitioning of the frequency spectrum diagram is shown in Figure 2.

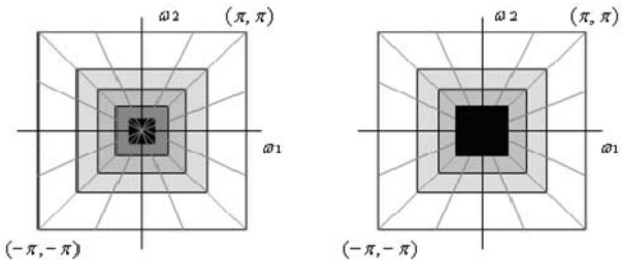

Figure 2. The Diagram of the Directional Filter Banks Frequency Spectrum Partitioning

Figure 3 is the CT of the Cameraman image using 2 LP levels and 8 directions at the finest level.

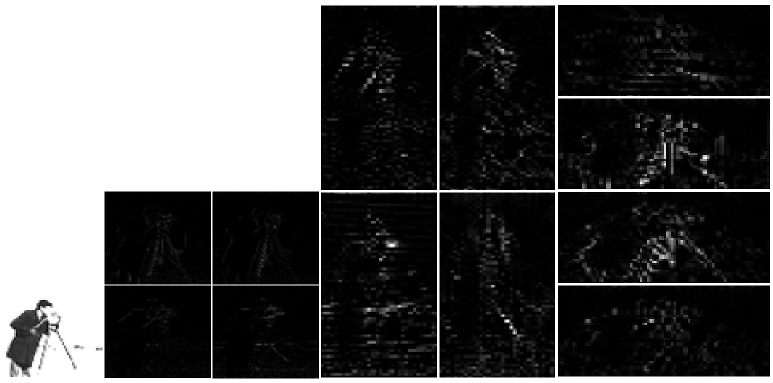

Figure 3. The Diagram of the Contourlet Transform Two Layers Decomposition

2.2. Cycle Spinning

The CT contains $2^n (n = 0,1...)$ direction basis functions, the aspect ratio of each basis function is optional, which can be used in image denoising widely. However, the CT is constructed by LP decomposition and DFB, the transform has the down-sampling, which is easy to generate the Gibbs-like phenomena due to the lack of spinning invariance. In order to suppress the Gibbs-like phenomena, the CT with multiple cycle spinning method is proposed by Coifman and Donoho.

The cycle spinning may be described as follows:

$$\hat{I} = \frac{1}{MN} \sum_{i=1, j=1}^{MN} C_{-i,-j}(T^{-1}\{h[T(C_{i,j}(I))]\}) \quad (1)$$

Where the images are of size (M, N) pixels, $C_{i,j}(I)$ and $C_{-i,-j}$ are the cycle spinning operator and inverse operator, the subscript i and $-i$ are the line direction spinning quantity to the left or right respectively, j and $-j$ are the column direction spinning quantity to the upward or downward respectively; h is the threshold operator; T and T^{-1} are the contourlet decomposition and reconstruction operator [15].

The image denoising method based on CT with multiple cycle spinning is as follows:

1. Spinning the original image.
2. Multi-scale decompose the image.

3. Obtain the adaptive threshold and denoise the image by CT.
4. Reconstruct image.
5. Inverse spinning the image to obtain the same sequence image as the original image.

The main aim of intensity image denoising algorithm is then to reduce the noise level while preserving the image features [16]. Recently, denoising with hard threshold and soft threshold technique is widely used in image denoising and has obtained some success. However, this method only concerns one point and thresholds the image term by term while neglects this important fact that the point to be thresholded is dependent on those in its neighborhood [17]. Usually, the noise of the catenary images is Gauss white noise, as the transformed Gauss white noise is still Gauss white noise, while the same scale and all directional coefficients gotten by CT are different. In this paper, the threshold according to each layer decomposition coefficients and the noise intensity is chosen, the selected threshold has self-adaptability.

3. Results and Discussion

The CT is constructed by LP decomposition and DFB. The LP filters mainly have 5-3, 9.7, Pkva, Burt, etc. the DFB mainly have Haar, 5-3, Pkva, Dmaxflat6, Cd, Sinc, etc. The choice of the LP filters and DFB has certain influence on image denoising quality. In this paper, the different LP filters and DFB are chosen to test the denoising effects. The testing Cameraman Image contains the $\sigma = 35$ Gaussian white noise.

Table 1. Cameraman + Gaussian White Noise ($\sigma = 35$)

Dfilter / Pfilter	Haar	5-3	Pkva	Dmaxflat6	Cd	Sinc
5-3	10.91	10.90	11.41	11.39	11.22	10.25
9-7	10.90	10.94	11.44	10.94	11.15	10.40
Pkva	10.50	10.67	11.01	11.08	10.81	10.35
Burt	10.84	10.89	11.41	11.43	11.12	10.60

Table 1 shows the SNR of choosing the different LP filters and DFB. Experimental results show that it could get higher SNR by combing the 9-7 filter with the Pkva directional filter. That is because the biorthogonal wavelet has the feature of linear phase, which can guarantee the transform coefficients are symmetric and solve the problem of edge effect and the coefficient expansion. No matter what LP filters are used, as long as the DFB is Haar wavelet, the denoising effects aren’t ideal, that is because the analytic properties of haar filter are relatively poor. Besides, as the operation time is long by combining the Dfilter filter, Dmaxflat6, Sinc with other Pfilters for denoising, which will affect the image denoising efficiency, the 9-7 filter and Pkva filter are chosen for the LP filter and DFB of CT. To text the effectiveness of our proposed algorithm, we denoising the noisy Cameraman and Lena images by wavelet transform (WT), contourlet transform (CT) and contourlet transform with multiple cycle spinning (MCSCT). Figure 4 and Table 2 show the experimental results.

In the Figure 4 and Table 2, MCSCT1 expresses the CT using cycle spinning one time, MCSCT2 and MCSCT3 on the analogy of this.

In the Table 2, σ is the noise variance. SNR is the signal-to-noise ratio. The higher of SNR, the better of image denoising effects.

From the Figure 4, the results of these figures indicate that the CT method works well and brings some advantages in keeping the contour textures than WT, this improvement of the denoising performance is reasonably explained by the fact that the CT can represent more directional details than WT. However, all of them still have the artifact phenomena. The proposed method is better at detail information reservation and flicker restrain than other methods. The results of Table 2 indicate that the MCSCT method can outperform the WT and CT in SNR measure, the more cycle spinning times, the higher SNR values.

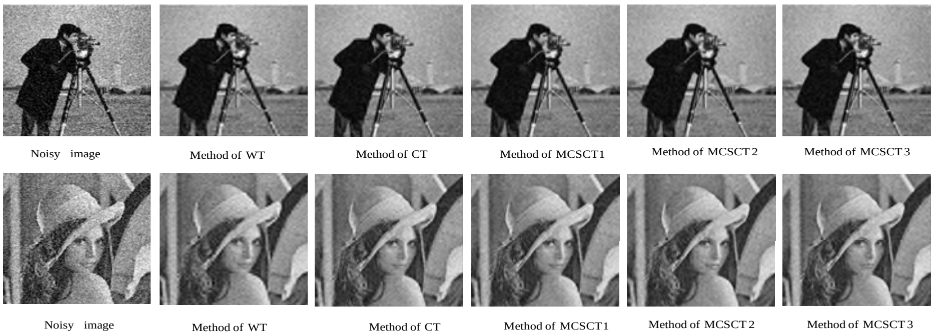

Figure 4. The Denoising Results of Different Denoising Methods with Cameraman and Lena ($\sigma = 25$)

Table 2. SNR Contrast of Different Denoising Methods

Image	σ	SNR				
		WT	CT	MCSCT1	MCSCT2	MCSCT3
Cameraman	15	12.21	12.33	12.73	12.75	12.80
	20	11.47	12.14	12.47	12.49	12.53
	25	10.89	11.78	12.18	12.22	12.27
	30	10.41	11.37	11.80	11.88	11.91
Lena	15	11.42	12.01	12.39	12.44	12.48
	20	10.82	11.66	12.09	12.14	12.20
	25	10.38	11.13	11.63	11.68	11.69
	30	9.94	10.15	10.88	10.89	10.96

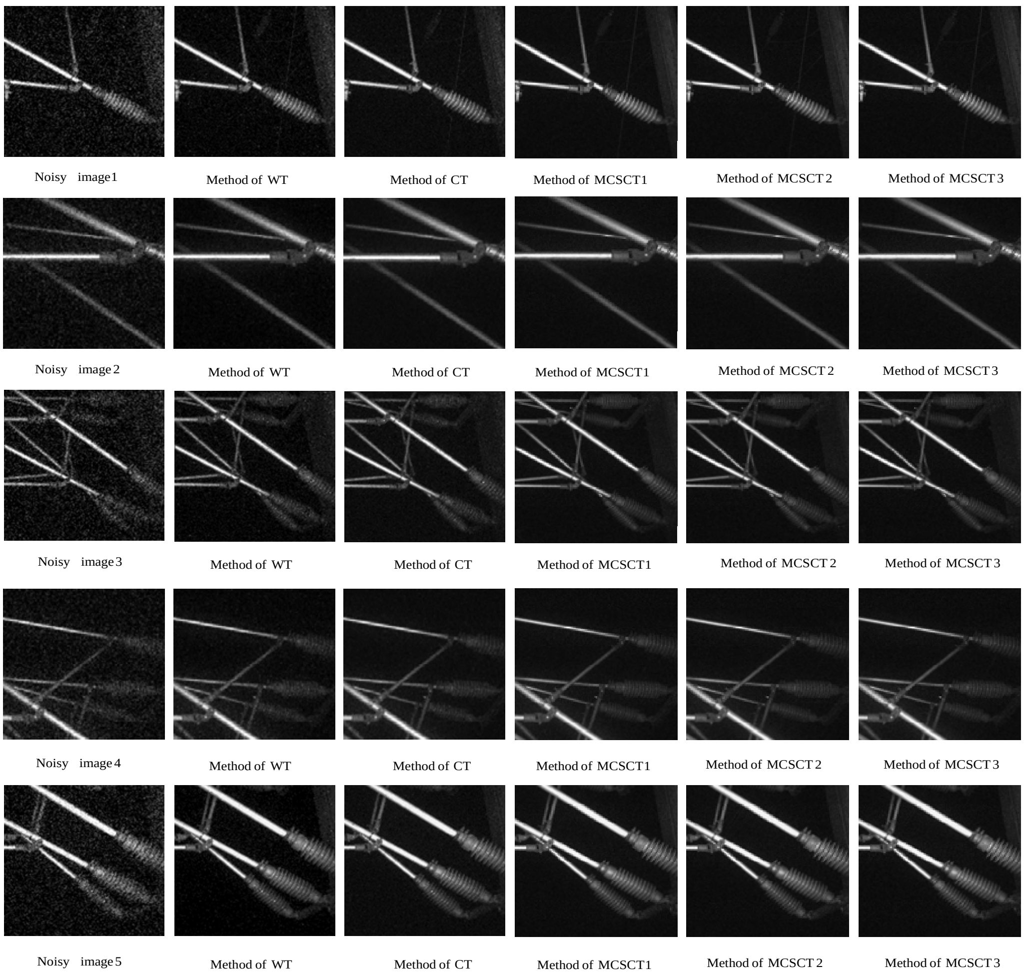

Figure 5. The Catenary Denoising Results of Different Denoising Methods

Table 3. SNR Contrast of Different Denoising Methods

Image	SNR				
	WT	CT	MCSCT1	MCSCT2	MCSCT3
Image1	9.09	10.06	10.34	10.38	10.41
Image2	9.63	10.73	11.04	11.07	11.10
Image3	9.68	10.96	11.32	11.35	11.39
Image4	7.91	9.69	10.13	10.17	10.21
Image5	13.62	13.84	14.02	14.07	14.11

The catenary image quality is vital in the fault diagnosis. In this paper, the proposed method is applied to denoise the actual catenary images, the denoising results are shown in Figure 5 and Table 3.

To text the protecting ability of the image texture details, the partial pictures of catenary denoising results based on different denoising methods are shown in Figure 6.

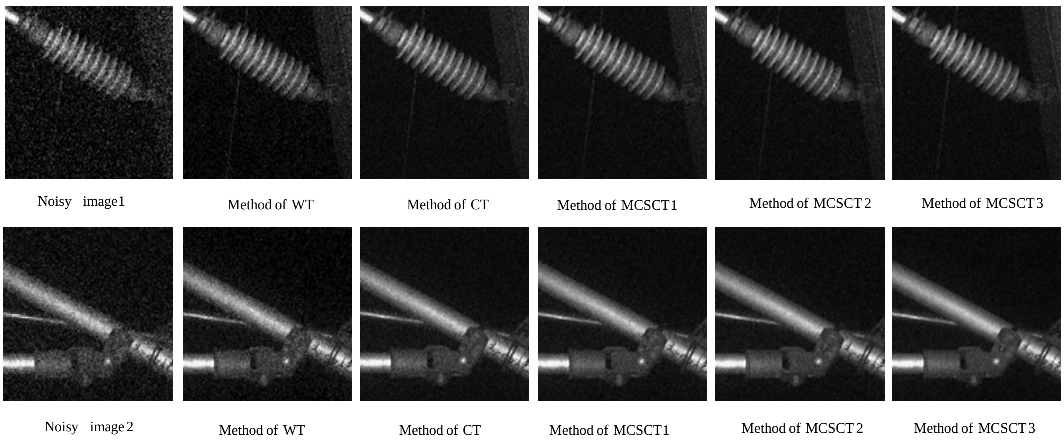

Figure 6. The Partial Pictures of Catenary Denoising Results Based on Different Denoising Methods

From the results of Figure 5, Figure 6 and Table 3, it can be seen that the catenary images denoised by WT show some blur artifacts, which have some ringing artifacts around the edges in images.

The images denoised by CT have more detail information than WT, the SNR is higher about 1dB than WT, that is because the CT has richer directional information. The MCSCT can effectively denoise the images and eliminate the Gibbs-like phenomena, which is outperforming in denoising procedures without losing the useful information such as texture details, such observation is consistent with all the denoised images, just as is the case with the objective SNR values.

Then our conclusions are as follows:

1. The CT denoising method works well and brings some advantages in keeping the contour textures than WT, although they have the Gibbs-like phenomena.

2. Use the MCSCT method for denoising, the protecting ability of the image edges and textures is more abundant than the WT and CT, which can effectively eliminate the Gibbs-like phenomena.

3. With the increasing of cycle spinning numbers, the image denoising effects are improved, while the denoising time is increased. Generally speaking, the suitable cycle spinning numbers are about three times.

4. The noise is stronger, the values of SNR are lower, the denoising effects are more decreased.

5. Use the same method to denoise the images with the same noise, the changes of the image details are less, the denoising effects are better.

4. Conclusion

According to the multi-scale, multi-resolution and anisotropy virtues of CT, reasonable selecting the LP filter and DFB, an image denoising method based on CT is applied. In addition, aim to the shortcoming of CT without the cycle invariance, the contourlet transform with multiple cycle spinning is proposed to overcome the Gibbs-like phenomena emerged in the process of image denoising. In this paper, several groups of standard images and actual catenary images are chosen to text the validity, the experiment results show that the MCSCT method can effectively suppress noise and eliminate the Gibbs-like phenomena than WT and CT, the more cycle spinning times, the better denoising effects, generally speaking, according to the cost of denoising time, the suitable cycle spinning times are about three. In short, the proposed method is an effective image denoising method owing to the values of SNR and effectively preserving details and texture information of original images.

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