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CATENARY IMAGE ENHANCEMENT METHOD BASED ON CURVELET TRANSFORM WITH ADAPTIVE ENHANCEMENT FUNCTION

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Abstract

In the process of catenary failure diagnosis system based on image processing technique, some catenary images present low contrast, which need to be enhanced. Curvelet transform has the high directional sensitivity and anisotropy, which is suitable for image enhancement because of its optimal sparse representation of image with rich details and edges. First, the catenary image is decomposed by Curvelet transform to get its high and low frequency coefficients, then adjust the high frequency coefficients using the enhancement function. Afterwards, combine the high frequency coefficients and low frequency coefficients by the inverse Curvelet transform, and thus to get the enhanced catenary image. In this paper, Curvelet transform is compared with the traditional enhancement methods. The experimental results show that the proposed method can effectively enhance the low contrast catenary images, the catenary insulator, arm, hanger, pillar and locator part become visible, the details become more obvious. Moreover, as for the online application of catenary failure diagnosis system, efficiency is another important consideration. The experimental results also show that the cost time of catenary image enhancement is within a few tens of seconds, which meets the requirements of catenary failure diagnosis system.

Keywords: catenary image; enhancement; Curvelet transform; coefficient structure; adaptive function

1. INTRODUCTION

With the rapid development of the railway construction, the failure diagnosis problem of railway is becoming more and more prominent. The electric locomotive gets the electric energy through the catenary, it is necessary to focus on detecting the working state of the catenary in order to ensure its good operation. Usually, in catenary failure diagnosis system, there are some faults such as insulator defect, suspension device damage, broken accessory equipment, loosening of positioning and supporting devices, et al. At present, there are several failure diagnosis methods, such as manual detection, laser detection and ultrasonic detection. Among these methods, some have low detection accuracy, some affect the operation of locomotives, and some detection devices are complex. Recently, with the development of image processing technique, catenary failure diagnosis system based on image processing technique is a non-contact detection method, which has the characteristics of high intelligence, high detection accuracy, low missing detection rate, easy installation and so on. Usually, due to the influence of natural environment, the contrast of some catenary image is low, and the relevant components of catenary are not obvious. These factors will affect the accuracy of catenary failure diagnosis. Therefore, it is necessary to enhance these low contrast catenary images before they are further processed.

Image enhancement is improving the visual effect, highlighting the detail and effective information of image, and suppressing noise, which makes the enhanced image more suitable for human and machine vision. Thus it is propitious to further analyze and understand image. The traditional image enhancement methods include spatial domain analysis and frequency domain analysis. The spatial domain analysis includes gray level transform and spatial domain filtering. Gray level transform includes contrast enhancement and histogram correction, while spatial domain filtering includes image smoothing and image sharpening. Besides, frequency domain analysis includes frequency domain sharpening, band-pass, band-resistance filtering, homomorphic filtering and frequency domain smoothing. Due to the influence of environmental factors, the contrast of some catenary images is low, the texture details are complex and blurred, and the traditional image enhancement method is not effective for these low contrast catenary images. For example, histogram equalization technique is suitable for the standard test image, while for catenary image, the enhancement effect is unsatisfactory. In order to effectively detect the working state of the catenary, the catenary components in the image should be highlighted. So, it is necessary to select a reasonable enhancement method to enhance catenary image for getting clearer catenary components in image.

Wavelet has good time-frequency localization ability, which has gradually focused on any detail of the object, and effectively described the local information of image, so that it is suitable for image enhancement. However, wavelet transform is isotropic, which reflects the singularity of the signal. It cannot express the edge multi-direction and detail of the image accurately, nor can it achieve sparse representation of image. Subsequently, Ridgelet transform is proposed to effectively represent the characteristics of line singularities. Ridgelet transform is a non-adaptive high dimensional function representation method. It has the ability of good direction selection, and it can effectively represent the directional singular feature of image. The transform maps the one-dimensional singularity of the image to a point, and then uses one-dimensional wavelet to detect singularity, which effectively overcomes the shortage of wavelet transform in processing two-dimensional image. Ridgelet transform has good approximation performance for multivariable functions with linear singularity. However, the contrast of catenary image is very low, and image details and edges are more complex. As for complex image, Ridgelet transform has rich redundancy which restricts its application in many fields. Curvelet transform is a signal processing technique based on Ridgelet transform, which solves the sparse approximation problem of multivariate functions with singular curves. The transform includes scale, direction and displacement parameters. It has multi-scale and multi-directional characteristics, and it has excellent direction identification for multi-dimensional signal. This makes it more effective in processing image edges, texture and other geometric features than conventional algorithms. As for now, Curvelet transform has been used in many fields such as denoising [1, 2], detection[3, 4], recognition[5,6], diagnosis [7, 8], enhancement [9], compression[10], watermarking [11], estimation [12], steganography [13], segmentation[9,14], classification [9, 15,1 6], etc. Moreover, many combination methods based on Curvelet transform and other methods have been proposed in many areas. In Ref. [2], a method based on the Curvelet transform and neural network is presented to reduce speckles in SAR image, which shows good achievement. In Ref. [7], a method for classification of abdomen diseases is introduced. The result shows that the presented method is suitable for diagnosis abdomen diseases of various sizes. In Ref. [13], Curvelet transform based image steganography technique is presented and a new cover selection method is demonstrated. This method has many virtues such as imperceptibility, robustness and security. In Ref. [15] and Ref. [16], Curvelet transform is combined with the machine learning technique to classify the texture and brain tumour images, respectively. The results indicate the validity of Curvelet transform. In Ref. [17], a profile face detection algorithm based on Curvelet features and SVM, which can detect profile faces in colour images with low mis-detection rate and high detection rate was presented. In Ref. [18], a technique is introduced to extract discriminative features of masked gait energy image based on fast discrete Curvelet transform and PCANet. The result demonstrates that the method can obtain good recognition accuracy. Besides, in Ref. [3] and Ref. [4], the performance evaluation of Curvelet transform is compared with wavelet and colour texture moments, respectively. In the above-mentioned methods, most of them are discussed based on the standard experimental images. However, as for actual catenary images, they show very low contrast due to the impact of special environments such as very severe weather, electromagnetic interference, etc. Many algorithms are not useful for enhancing these actual catenary images. In addition, many introduced algorithms have no good self-adaptability. In this paper, Curvelet transform with adaptive function is presented to enhance actual catenary images. The proposed method not only have the virtues of multi-resolution and multi-direction but also has the self-adaptability. The experimental results show that the proposed method is more effective in processing the exceptionally low contrast image than other traditional image processing methods.

2. CURVELET TRANSFORM

Curvelet transform is a multi-resolution, multi-direction, stable and efficient image representation method, which includes continuous Curvelet transform and discrete Curvelet transform [19]. Continuous Curvelet transform is a combination of filtering and multi-scale Ridgelet transform. Which needs sub-band decomposition, smooth block and normalization. Although it improves the ability of dealing with complex lines, but it has redundancy and the speed is low. Besides, it is difficult to digitalize. Subsequently, the fast discrete Curvelet transform is proposed. Compared with the continuous Curvelet transform, the fast discrete Curvelet transform simplifies the operation process and greatly improves its efficiency. The implementation of discrete Curvelet transform is in the frequency domain, which is simple and fast. Besides, it greatly reduces the redundancy of the traditional algorithm such as wavelet transform and Ridgelet transform, etc. For discrete Curvelet transform, in order to improve the speed of algorithm, fast Fourier transform USFFT algorithm and Wrapping algorithm based on special sampling in frequency domain can be used. These two algorithms have the different space grid selection in each direction. Generally, the Wrapping algorithm is more accurate and efficient in image processing technique. So, this paper uses the Wrapping algorithm to realize the discrete Curvelet transform.

In the following description, Curvelet transform means the discrete Curvelet transform.

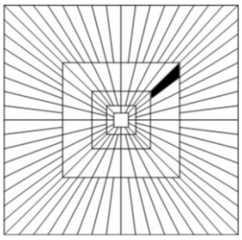


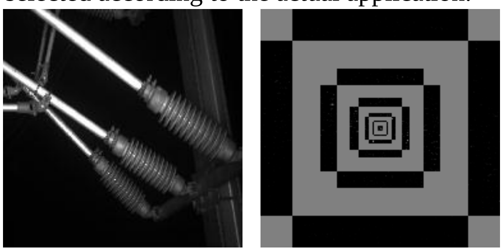
Fig. 1. Distribution diagram of discrete Curvelet transform frequency bands

Fig. 1 shows the scale and angle distribution diagram of discrete Curvelet transform, where the gray region is a wedge of Fourier domain with parabolic scale.

The discrete Curvelet transform is expressed as[19]:

$$cv(s,d,l)=\sum_{0<t_1,t_2<n} f[t_1,t_2]\overline{\varphi_{s,d,l}[t_1,t_2]} \qquad (1)$$

Curvelet transform includes critical parameters such as scale and direction. In Eq.1, $f[t_1,t_2]$ is the input, s is the scale parameter, d is the direction parameter and l is the position parameter. s is related to image enhancement effect. Usually, s is too small, the data contain more redundant information, and s is too large, it will lose part information of image. So these parameters should be selected according to the actual application.



(a) Image (b) Coefficient diagram

Fig. 2. Coefficient diagram of each sub-layer based on Curvelet transform

Curvelet transform offers a good directional representation. It decomposes an image into several sub-bands with a given orientation and scale. So, it can capture detail and edge information of image.

Fig. 2 shows the coefficients of each sub-band based on Curvelet transform. As for frequency distribution, the Curvelet transform divides the image into three parts: coarsest layer, detail layer and finest layer. In Fig. 2(b), the middle part of the innermost layer corresponds to the coarsest layer, that is the low frequency information of image, the outermost part corresponds to the finest layer, that is the high frequency information and noise, and the detail layer corresponds to the intermediate part, that is the medium high frequency coefficient that contains the strong edge information of image. The anisotropy property of Curvelet transform is shown in Fig. 2.

There is a close relationship between image pixel N and image frequency domain scale s, both of them satisfy $s=\log_2(n)-3$. The image size is 256×256, so $n=256$, $s=5$. Table.1 shows the coefficient structure of Curvelet transform.

Table 1. Coefficient structure of Curvelet transform

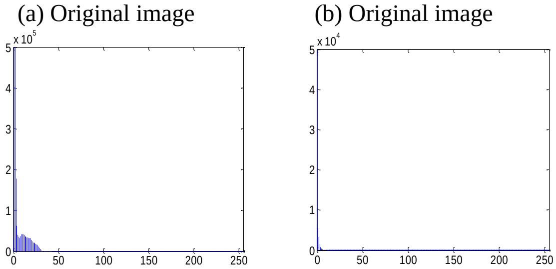
layer	Scale	Directional number	Matrix format			
Coarsest layer	C{1}	1	21*21			
Detail layer	C{2}	16(4*4)	19*23	23*19	19*23	23*19
	C{3}	32(4*8)	35*23	23*35	35*23	23*35
	C{4}	32(4*8)	67*43	43*67	67*43	43*67
Finest layer	C{5}	64(4*16）	131*43	43*131	131*43	43*131

For the coefficients of Curvelet transform, the large coefficients correspond to the texture, details and line contour of image, while small coefficient corresponds to the blank or interference signal of image.

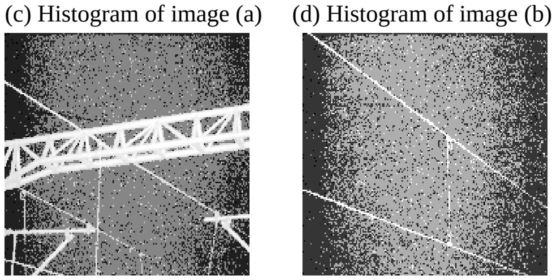
3. EXPERIMENTS AND RESULTS

Some acquired catenary images have low contrast. Fig. 3 shows the original images(a),(b) and their histogram(c),(d), respectively. In Fig. 3, it is clear that the catenary images are a little fuzzy, the gray distribution of images are not uniform, the signal is in the left of histogram and theirs gray distributions are concentrated in a narrower range, so that the details of the image are not clear enough, and they need to be enhanced to a certain degree.

(a) Original image (b) Original image



(c) Histogram of image (a) (d) Histogram of image (b)



(e) Histogram equalization of (a) (f) Histogram equalization of (b)

Fig. 3. Images and their histogram

Of course, as far as standard images are concerned, histogram equalization method can obtain good results. However, as for the actual catenary images, the contrast is not obvious, and the distribution of light and darkness is extremely uneven. These lead to unsatisfactory enhancement effects by using the histogram equalization method. As are shown in Fig. 3(e) and Fig. 3(f), the histogram equalization method leads to serious distortion.

Curvelet transform has the characteristics of multi-scale and multi-direction. It can decompose the image into different scale layers, and each scale layer can represent the different frequency information. The catenary image enhancement process based on the Curvelet transform is shown in Fig. 4.

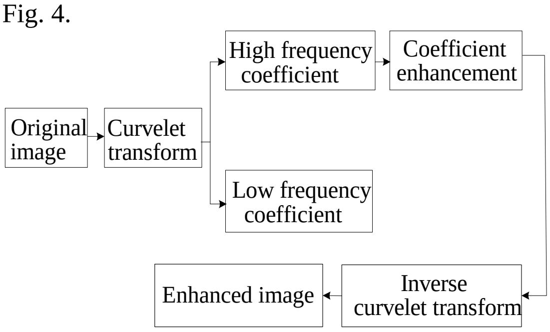


Fig. 4. Block diagram of image enhancement

The algorithm includes the following steps:

(1) Curvelet transform is performed to obtain the high frequency and low frequency coefficients of image, where the Curvelet transform adopts Wrapping algorithm.

(2) According to the Curvelet transform theory, the high frequency information corresponds to the texture details of the image. So the high frequency coefficients should be processed. In order to improve the speed of the algorithm, it only deals with the coefficients that determine the image quality, and abandons the smaller ones.

The coefficients of Curvelet transform is processed based on Eq.(2) and Eq.(3).

$$k=\frac{|cv_H(x)|_{\max}}{|cv_H(x,y)|}\sin\left(\frac{\pi}{2}*\frac{|cv_H(x,y)|-t}{|cv_H(x)|_{\max}-t}\right) \qquad (2)$$

$$cv(x,y)=\begin{cases} cv_H(x,y)*k & |cv_H(x,y)|\geq t \\ 0 & |cv_H(x,y)|<t \end{cases} \qquad (3)$$

Where, (x, y) is the dimension of the original image, $t=\frac{4}{3}\delta\sqrt{2\log(X*Y)}$, δ is the standard deviation, and $1<x<X, 1<y<Y$, $cv_H(x,y)$ is the high frequency sub-band coefficient of Curvelet transform, $|cv_H(x)|_{\max}$ is the maximum value of the m line high frequency sub-band coefficient absolute value of Curvelet transform, $cv(x,y)$ is the enhanced high frequency sub-band coefficient of Curvelet transform.

(3) After the high frequency information is processed, the enhanced image is obtained by combining the processed high coefficients with the low frequency coefficients.

(4) Analyze and evaluate the enhancement effects.

In Fig. 5, Fig. 6, Fig. 7 and Fig. 8, image (a) are the acquired catenary images. Using the Retinex method-(b), homomorphic filtering method-(c), dark channel method-(d), logarithmic transform method-(e), piecewise linear method-(f), wavelet transform-(g) and Curvelet transform method-(h) to enhance the low contrast catenary images, respectively. The experimental results are shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8, respectively.

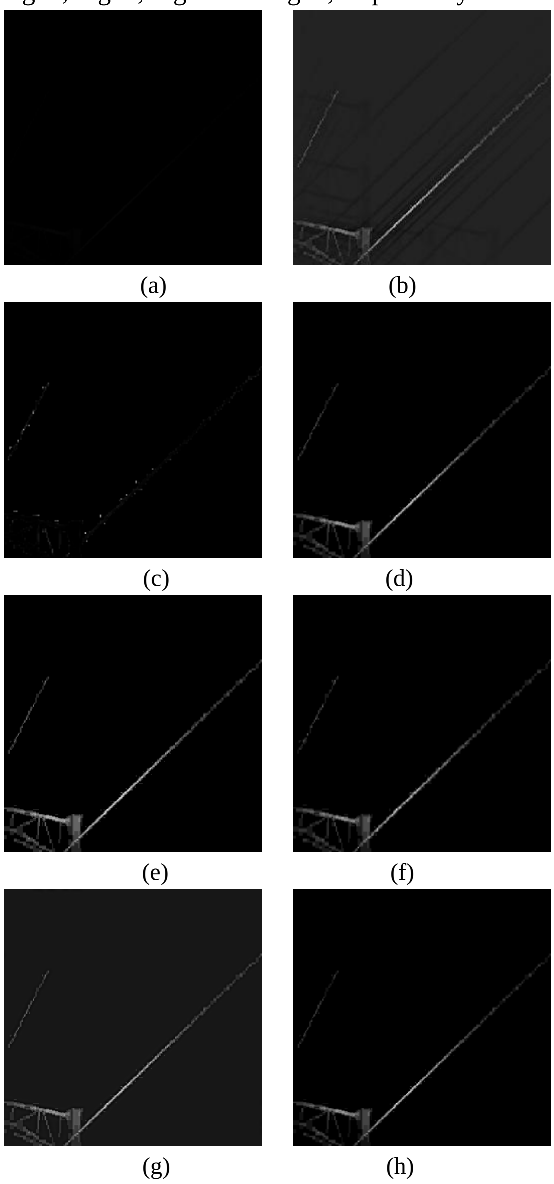


Fig. 5. Experiment of catenary image enhancement (1)

In Fig. 5, the contrast of the original image is low. The bearing cable, support device, contact line, hard cross and other devices are almost invisible. Using the Retinex method to enhance image [20], components of catenary are enhanced, while the background is also enhanced simultaneously. The reason is that Retinex method is generally used for enhancing colour image, defogging and restoring colour image. Using the homomorphic filtering method to enhance catenary image, the effect is not prominent, many components of catenary are not displayed, the contact line and bearing cable are not detected continuously. Wavelet transform is used to enhance the catenary image, although the parts of catenary are effectively highlighted, the background is also enhanced synchronously. Several other methods such as dark channel, logarithmic transform, piecewise linear and Curvelet transform methods are effective in enhancing the low contrast image, which can clearly enhance the related parts of catenary and the effects are encouraging.

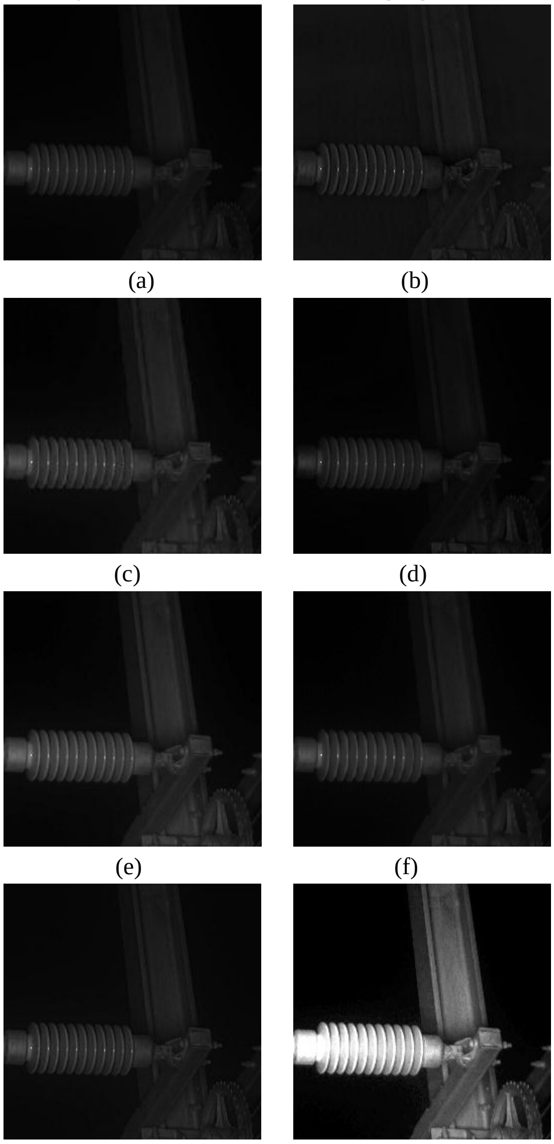


Fig. 6. Experiment of catenary image enhancement (2)

In the original image of Fig. 6(a), insulators and props are visible, while they are not obvious enough. Uses the same 7 methods as Fig. 5 to enhance catenary image, the enhancement effect based on Curvelet transform is best among these methods. In the enhanced image, the insulator becomes bright, pillar of brightness is also improved synchronously. However, for the other six methods, although the contrast of the enhanced images compared with the original image has little change, the effects are not obvious. It can get conclusion that using Curvelet transform can get the best enhancement effect in the case that the contrast of the image is not particularly low.

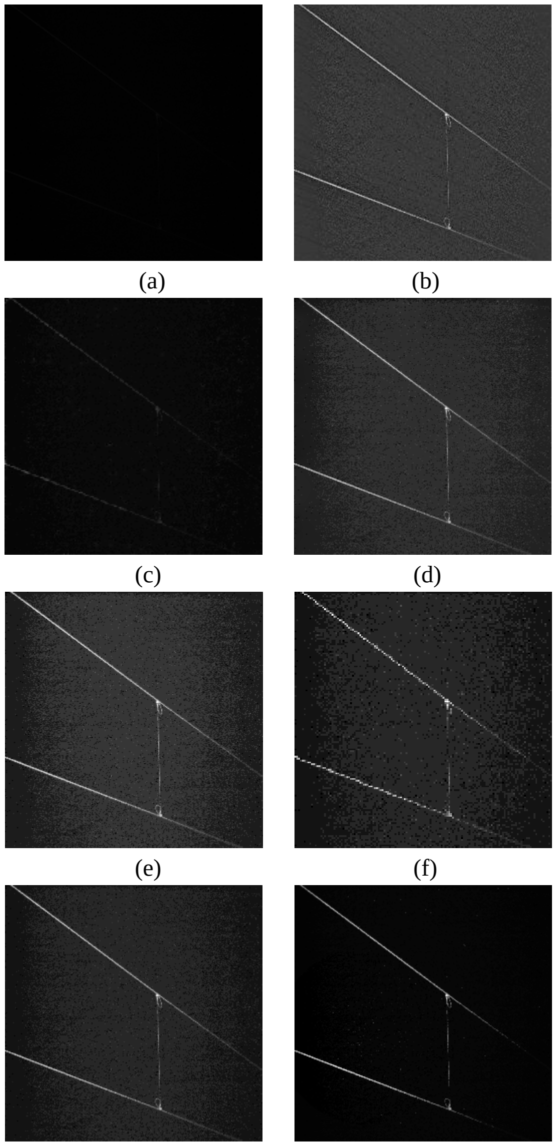
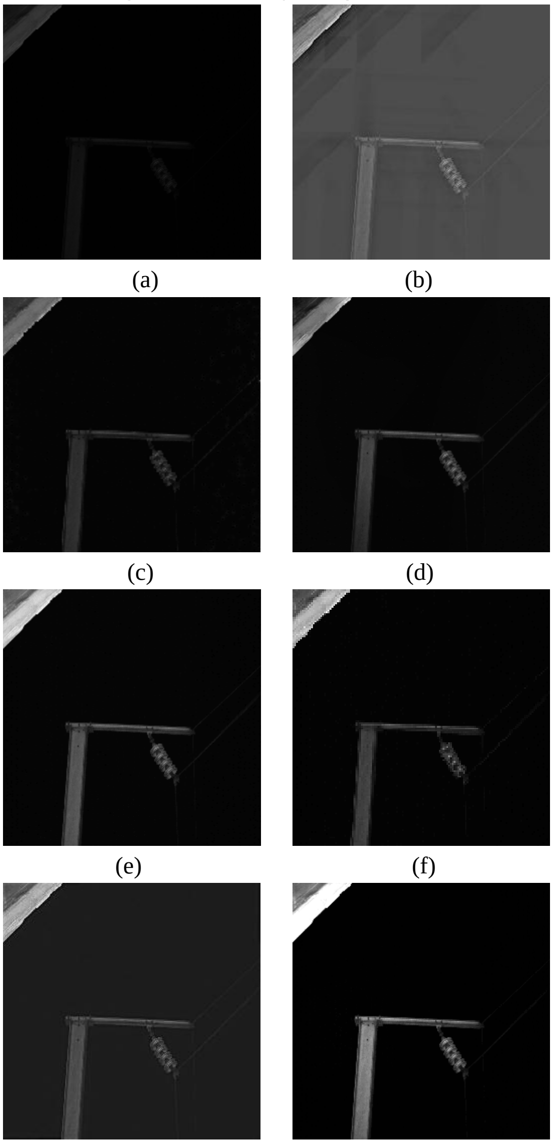


Fig. 7. Experiment of catenary image enhancement (3)

In Fig. 7(a), the contact wire, messenger wire and the dropper are almost invisible. Use the same 7 methods as Fig. 5 to enhance image, in addition to the effects are good based on the homomorphic filtering and Curvelet transform methods, the contrast of enhanced image is not obvious based on the other 5 methods, the parts of catenary and image background are enhanced simultaneously, the enhancement effects of catenary devices are unsatisfactory. Besides, when use the homomorphic filtering method to enhance image, although the effect is good, and the catenary devices are brightening, as for the visual aspect, the enhancement effect is significantly weaker than the Curvelet transform. Of course, the contact line and the hanger are clearly visible in the enhanced image based on the Curvelet transform. So, the Curvelet transform is the best method among these methods in enhancing these catenary images.

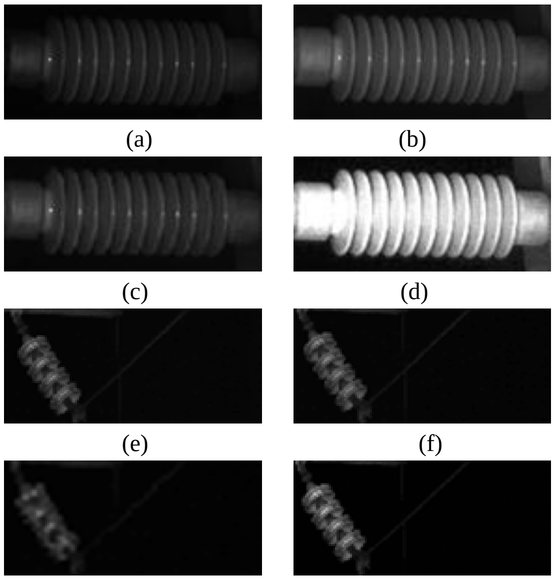


(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 8. Experiment of catenary image enhancement (4)

In Fig. 8, as for the enhancement effect, the Retinex method is the most unsatisfactory. Besides, except the Curvelet transform, although several other methods can improve the parts of catenary to a certain extent, but the contrast is not obvious. As for Curvelet transform, the enhancement effect is the best among these enhancement methods.

As shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8, it is clear that it can obtain relatively better results based on dark channel method-(d), logarithmic transform method-(e), piecewise linear method-(f) and Curvelet transform method-(h). To clearly and intuitively observe the results, the local zoomed images are shown in Fig. 9.

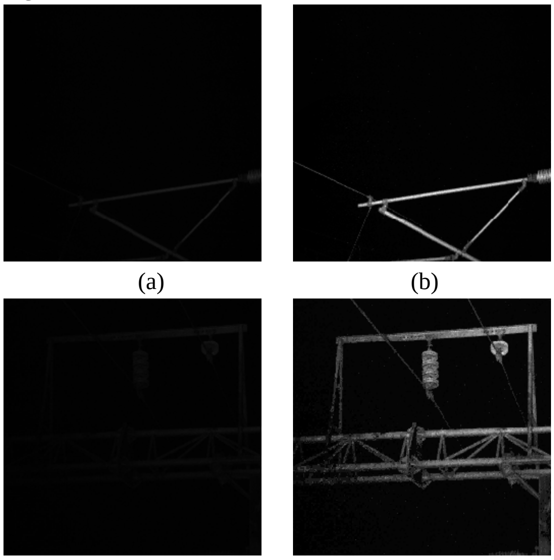


(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 9. The local zoomed images

In Fig. 9, the enhancement results are presented based on the dark channel method-(a) and (e), logarithmic transform method-(b) and (f), piecewise linear method-(c) and (g), Curvelet transform method-(d) and (h), respectively. From the Fig. 9, it can be found that the enhanced images by Curvelet transform method keep better details. The contrast of catenary components becomes more obvious. It obtains encouraging result based on the proposed method.

In order to further test the effect of enhanced image based on the Curvelet transform, a group of low contrast images are enhanced using Curvelet transform. The experimental results are shown in Fig. 10.



(a) (b) (c) (d)

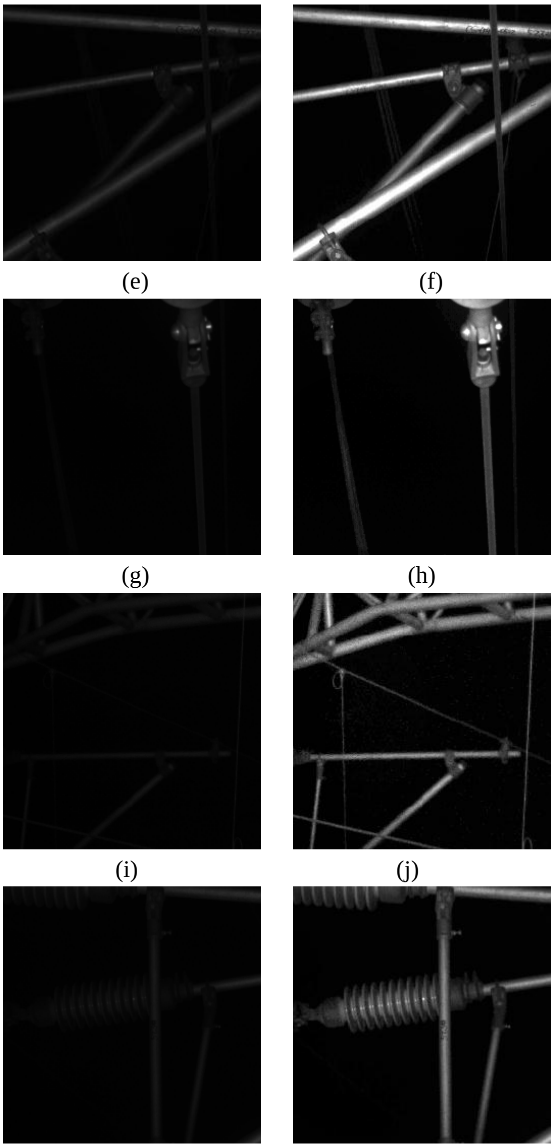


Fig. 10. Experiment of catenary image enhancement based on Curvelet transform

In Fig. 10, (a), (c), (e), (g), (i), (k) are original images, and (b), (d), (f), (h), (j), (l) are enhanced images based on Curvelet transform. It is clear that the enhancement effects are obvious. Many devices of catenary such as location device, support device, catenary suspension, rod insulator and cantilever are enhanced evidently. The results are encouraging.

Furthermore, the efficiency of image processing is another important factor which needs to be considered. Image enhancement is the crucial step of catenary condition detection, the speed of method needs to meet the real-time requirement. Curvelet transform not only has the virtues of multi-scale and multi-direction but also has fast speed. As for the catenary images in Fig. 10, the cost time of enhancement process based on Curvelet transform is shown in Fig.11.

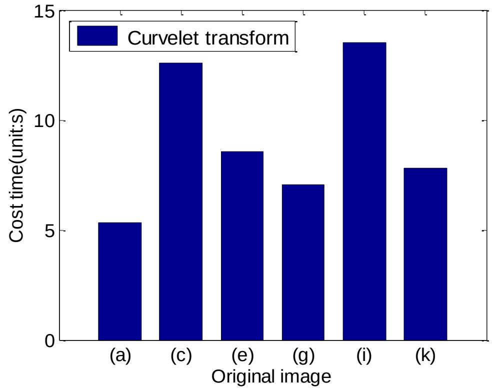


Fig. 11. Cost time of catenary image enhancement

As for acquired catenary images in the field of electrified railway, the cost time of catenary image enhancement based on Curvelet transform is shown in Fig. 11. For images in Fig. 10(c),(i), the parts of catenary have rich edges and details, and they cost time 13.51s and 12.59s, respectively. While for image of Fig. 10(a), there are only few parts of catenary, it costs the shortest time 5.34s. That is to say, enhancing the complex image will cost longer time than the simple image. According to a large number of experiments, the cost time of catenary image enhancement is within a few tens of seconds, which meets the requirements of catenary failure diagnosis system.

4. CONCLUSION

In the process of catenary failure diagnosis system based on image processing technique, some catenary images have the low contrast, which are very unfavorable for catenary condition diagnosis. Therefore, they should be enhanced for further analysis and processing. Curvelet transform is very effective in enhancing catenary images because of its multi-scale and multi-directional characteristics. Especially for images with extremely low contrast, the enhancement effects are obviously better than the traditional image enhancement methods, and the cost time also meets the actual needs of the detection system. Experimental results show that this method based on Curvelet transform with adaptive enhancement function is a fast, stable and efficient method of catenary image enhancement.

5. ACKNOWLEDGEMENT

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