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A Shearlets-based Edge Identification Algorithem for Infrared Image

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Abstract

A shearlets-based edge identification algorithem for infrared image is proposed. The algorithem demonstrates the performance of edge detection based on shearlets, combines with the edge hysteresis thresholding, designs steps of edge detection, which is proper to use in infrared images.Simultaneously, with the advantage of edge geometric features provided by the shearlets, infrared image were extracted the direction information of edge of Infrared image, and classified. In computer simulations with this method for infrared image, simulation results conformed to the theory on edge detection based on shearlets. It drew the outline of edge for infrared image, and provided the edge orientation feature. The method is very eventful for target detection, identification, track in infrared image system.

Keywords: *thearlet transform; edge identification; infrared image; hysteresis thresholding*

1. Introduction

Edge are the most basic and eventful features of the image, which include the location, outline and many other useful information. They provide significant parameters of the image feature to describe or identify the target for people. The traditional edge detection algorithm is to use the edge operators. Then, edges are recognized as the local maxima of the magnitude of the gradient of the image. In order to overcome the impact of noise, the iamge has to be smoothed by the Gaussian filter before the edge detection of the image.

In the classical Canny edge detection algorithm [1], the image u is smoothed by the Gaussian filter:

$$u_a = u * G_a \tag{1}$$

Where $G_a(x) = a^{-1}G(a^{-1}x)$, $a > 0$. $G(x)$ is the Gaussian function. Edge are the local gradient maximum of u_a. The adjustable scale factor a determines the smoothness: as a increases, the detector’s sensitivity to noise decreases; however, the localization error in the detection of edges also increases. Therefore, the algorithm performance is very much dependent on the adjustable scale factor a [2, 3].

It was observed by Mallat [4] et al. that, at a single scale, the Canny edge detector is equivalent to the detection of the local maxima of the wavelets of u, for some particular choices of the analyzing wavelets. That is:

$$\tilde{N}u_a(x) = u*\tilde{N}G_a(x) = u*y_a(x) = W_y u(a,x) \tag{2}$$

This shows that, the maximum gradient of the smoothed image corresponds exactly to the maxima amplitude of wavelets. Wavelet edge detection algorithm avoids the problem that the Canny edge detection algorithm need to find the appropriate scaling factor.

However, as edges close together or cross-over, especially in the noise interference, edge detection is extremely difficult. In many cases, the above edge detection algorithm clearly

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has the following limitations [5]: edges close together to be blurred into a single curve; in the presence of sharp, leading to an inaccurate detection of edge orientation.

Edge detection of infrared Image are great significance for target detection, identification, track and so on. Meanwhile, the infrared image is inevitably mixed noise. Due to technics limitations, the image contains the non-uniformity of the infrared detector. Even after correction, with time drifting, the detector also may appears the non-uniformity. The non-uniformity still affect the edge detection as same as noise.

Shearlets is a genuinely multi-dimensional form of the traditional wavelets, which is especially designed to address anisotropic and directional information at various scales. Indeed, the traditional wavelets approach, which is based on isotropic dilations, has a very limited capability to account for the geometry of multidimensional functions [6]. In contrast, the shearlets is highly anisotropic, and is defined at various scales, locations and orientations. So, this transform provides an optimally efficient representation of images with edges.

2. The Shearlets Transform

A non-isotropic version of the wavelets transform called the shearlets transform. This is defined as the mapping [7]:

$$\mathcal{SH}_{\psi} u(a,s,t) = \langle u, \psi_{ast} \rangle \tag{3}$$

Where $\psi_{ast}(x) = |\det M_{as}|^{1/2} \psi(M_{as}^{-1}(x-t))$, and $M_{as} = [a\ \ -\sqrt{a}s;\ 0\ \ \sqrt{a}]$ for $a > 0, s \in \mathbb{R}, t \in \mathbb{R}^2$. It shows that $M_{as} = B_s A_a$, $A_a = [a\ \ 0;\ 0\ \ \sqrt{a}]$, $B_s = [1\ \ s;\ 0\ \ 1]$. Each matrix M_{as} are associated two distinct actions: an anisotropic dilation matrix A_a and a shearing matrix B_s.

Each $u \in L^2(\mathbb{R}^2)$ has the representation:

$$u = \int_{\mathbb{R}^2} \int_{-\infty}^{\infty} \int_0^{\infty} \langle u, \psi_{ast} \rangle \psi_{ast} \frac{da}{a^3} ds dt \tag{4}$$

Specifically, for $x = (x_1, x_2) \in \mathbb{R}^2$, $x_1 \neq 0$. We assume $\hat{\psi}(x) = \hat{\psi}_1(x_1)\hat{\psi}_2(x_2/x_1)$, where $\hat{\psi}_1$, $\hat{\psi}_2$ are smooth functions with supp $\hat{\psi}_1 \subset [-2, -1/2] \cup [1/2, 2]$ and supp $\hat{\psi}_2 \subset [-1, 1]$. In the frequency domain:

$$\hat{\psi}_{ast}(x_1, x_2) = a^{\frac{3}{4}} e^{-2\pi i x t} \hat{\psi}_1(a x_1) \hat{\psi}_2(a^{-\frac{1}{2}}(\frac{x_2}{x_1} - s)) \tag{5}$$

and, thus, each function $\hat{\psi}_{ast}$ is supported in the set.

$$\{(x_1, x_2) : x_1 \in [-\frac{2}{a}, -\frac{1}{2a}] \cup [\frac{1}{2a}, \frac{2}{a}], |\frac{x_2}{x_1} - s| \le \sqrt{a}\} \tag{6}$$

There are several examples of functions $\hat{\psi}_1$, $\hat{\psi}_2$ satisfying the properties described above (see References [8]).

Figure 1. Shearlet Frequency Domain Subdivision

Thus each shearlet ψ_{ast} has frequency support on a pair of trapezoids, at various scales, symmetric with respect to the origin and oriented along a line of slope s. As a result, the shearlets are a collection of well-localized waveforms at various scales a, orientations s and locations t.

Notice that the shearing variable s corresponds to the slope of the line of orientation of the shearlets $\hat{\psi}_{ast}$, rather than its angle with respect to the ξ1 axis.

It turns out that the shearlets transform can be used to describe the geometry of the singularities of a 2-dimensional image u. In fact, the decay rate of $\mathcal{SH}_\psi u(a,s,t)$ describes not only the location, but also the orientation of the singularities of u. The shearlets transform has the ability of multiscale methods to capture the geometry of multidimensional data and it is optimally efficient in representing images containing edges. The following theorem describes the edge approximation ability of the shearlets [8].

Theorem. If $t_1 + t_2 = 1$ (assuming the round represents curve) and $s = t_2 / t_1,\ t_1 \neq 0$, we have $\mathcal{SH}_\psi u(a,s,t) \sim a^{3/4}$ as $a \to 0$; In all other cases, $\mathcal{SH}_\psi u(a,s,t) \sim 0$, as $a \to 0$.

The result is the foundation for the application of the shearlets transform to the analysis of edges.

Discretization of continuous shearlets transform see References [5], [9], [10]. In accordance with the continuous wavelet transformation discretization, let $a = 2^{-2j}$, so the digital form of $\mathcal{SH}_\psi u(a,s,t)$ is $\mathcal{SH}_\psi u[j,l,k]$.

3. Edge Dection based on Shearlets Tranform

Recall that, the edge detection based on the wavelet transform think that the maxima amplitude of wavelet transform is the maximum gradient of the smoothed image. So, we will apply the idea of edge detection based on wavelet into that based on the shearlets, which can describe the orientation of the singularities. Meanwhile, taking the threshold method as the Canny edge detection algorithm.

The steps of edge detection algorithm based on shearlets tranform are as follows:

First, Given a image $u \in L^2(\mathbb{R}^2)$, $\mathcal{SH}^{[d]}u[j,l,k]$ is be the discrete shearlets transform of u, $j \geq 0$, $-2^j \geq l \geq 2^j$, $k \in \mathbb{Z}^2$, $d = 0,1$. $\mathcal{SH}^{[0]}u[j,l,k]$ is the horizontal cone; $\mathcal{SH}^{[1]}u[j,l,k]$ is the vertical cone. The edge candidates e'_j at level j are then given by:

$$e'_j u[k] = \sqrt{\left(\sum_l \mathcal{SH}^{[0]}u[j,l,k]\right)^2 + \left(\sum_l \mathcal{SH}^{[1]}u[j,l,k]\right)^2} \qquad (7)$$

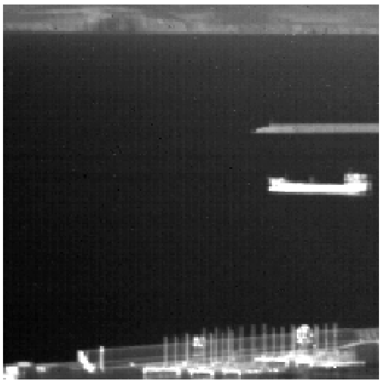
Secondly, the edge candidates e'_j are filtered by the application of hysteresis thresholding. Hysteresis uses 2 thresholds, a high T_1 and a low T_2. Each pixel in the image that has a value greater than T_1 is presumed to be an edge pixel, and is marked immediately. Then, any pixels that are connected to this edge pixel and that have a value greater than T_2 are also selected as edge pixels. Then, obtaining the edge of the image. The threshold algorithm is as same as that of the classical Canny edge detection algorithm.

At last, after obtaining the edge of the image, it may applied in target detection, identification and track in image system by the feature of the shearlets cofficients.

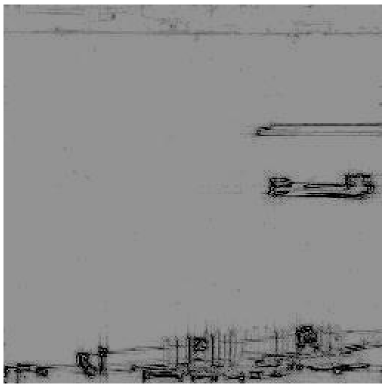
4. Edge Dection for Infrared Image

Infrared image shows in Figure 2(a), which is a 256×256 size, mid-wave infrared image. Thers are a port below the image, the clouds in the sky above the sea-sky line, a fishing boat inside the sea, which is brightest, and another port (a part) at the remote end.

Let j=2(a=2-2j), the discrete shearlets transform is $\mathcal{SH}_y u[2,l,k]$, so the index l ranges over ℓ = 1~16. Figure 2 is the original image and the edge image, which was processing by the above methods.



(a)



(b)

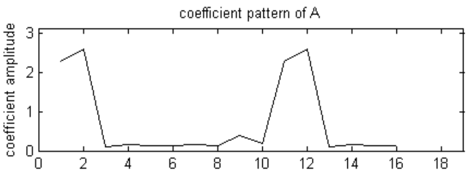
Figure 2. Infrared Image (a) and its Edge (b)

From the Figure 2(b), the edge detection algorithm based on shearlets found the outline of the sea-sky line, the fishing boats, the port and so on, meanwhile, the edge of the cloud is as same as smoke in the sky. The non-uniformity (such as vertical stripes) in infrared image didn't affect the edge detection.

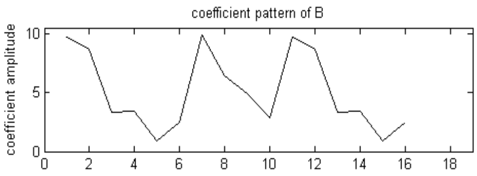
Below, let's discuss how to obtain the direction information of the edge based on the shearlets tramsform.

5. Edge Identification Strategy for Infrared Image

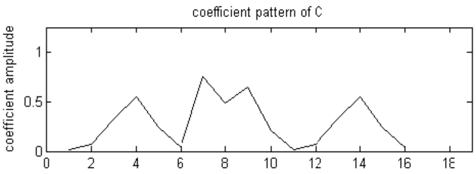
Thanks to the discrete shearlets transform directional sensitivity, for each fixed scale a, the shearlets transform will have a significant magnitude only for orientations l in a very small interval. The discrete shearlets transform can be applied to provide a very accurate description of the edge orientations.



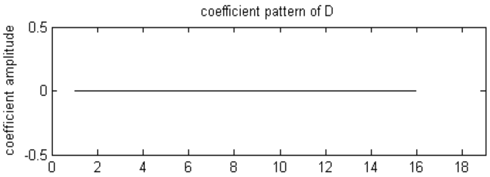
(a)



(b)



(c)



(d)

Figure 3. Shearlets Transform Pattern ℓ (or s) at j=2, l=1,···,16

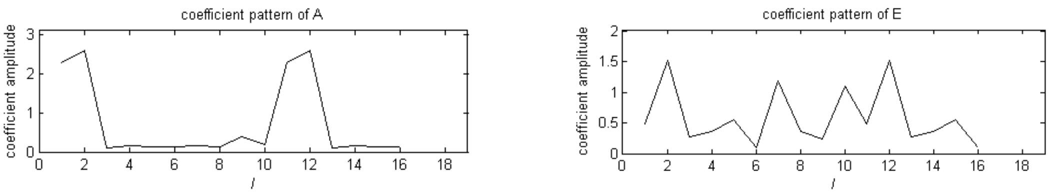
Figure 3 shows the typical coefficients of the discrete shearlets transform for Figure 2(a). The discrete shearlets transform is $\mathcal{SH}_y u[2,l,k], l = 1,\ldots,16$. Fig.3(a) is the coefficients curve of a point of the sea-sky line at coordinate (148, 20). Its coefficients have a pulse at l=11,12, which illustrates the point has a direction. Figure 3(b) is the curve of a front point of boat at coordinate (223, 129). Its coefficients have many pulses, which illustrates the point has lots of directions. Figure 3(c) is the curve at coordinate (125, 174). Thers are lots of pulses in its cofficients curve, but the magnitude is smaller compared with that of (a). Figure 3(d) is the curve at coordinate (120, 160), which is aline. Point D is at the no edge area.

The following table list the statistics about the numbe of pulses of the each point coefficients curve in the infrared image. It may reply edge type in the infrared image.

Table 1. Number of Edge Type in the Infrared Image

No. of Pulses	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No. of Points	43352	10620	3779	2420	870	391	95	8	1

Figure 4 shows the difference of the sea-sky line and other edges. Figure (a) is the state of the sea-sky line; Figure (b) is the state at the junction of the sea-sky line and cloud. The points at the junction have lots of directions, while the pixel points at the sea-sky line have clear directions.



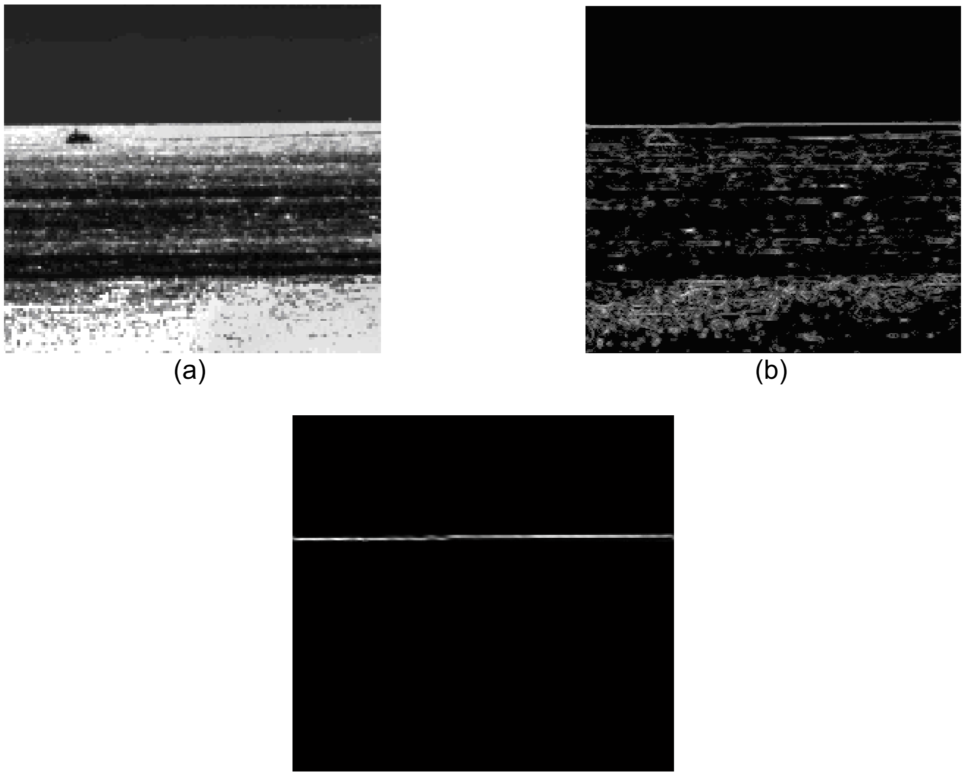
(a) (b)

Figure 4. The Comparison between Two Patten Points

This shows that the shearlets approach provides a very simple and computationally efficient framework for classifying several features of image edge. This has some advantages with respect to wavelet-based methods and other edge operators methods which do not have a specific ability to capture the directional features of an image edge.

When infrared image processing is used in the sea-sky background, the sea-sky line is an important information. Due to the interference of sunshine, it may have a sunshine band and severe sea-clutter on the sea surface sometimes. Especially in the situation that the sea-clutter and sea-line are similar, it is affected in the sea-sky line detection., it is extraced the edge direction and identified the sea-sky-line by using the shearlet edge detection theory in the section.

The scene is affected by sunlight in the infrared image Figure 5(a). There is seriously sea-clutter. Figure 5(b) shows the edge of image by the shearlet algorithm, and sea-clutter edge information is rich. Figure 6 is the curve of accumulation of each line of shearlet coefficient value. From the graph be observed, the values of line 87~88 and line 205~245 are larger than others. Then compared with the variation of the two shearlet coefficient, line 87~88 shearlet coefficient curve is consistent which is like in Figure 3(a), showed clear direction information; line 87~88 shearlet coefficient curve is similarity with Figure 3(b). In according to the prior knowledge in Figure 3, line 87~88 is sea-sky line. See Figure 5(c). The method is simple and practical.



(a) (b)

(c)

Figure 5. Sea-sky Line Detector

The data analysis shows that the shearlet can provide a simple, effective to classify the edge. This method, compared with the method of wavelet and edge operator, can obtain the direction of image features, shows the superior performance.

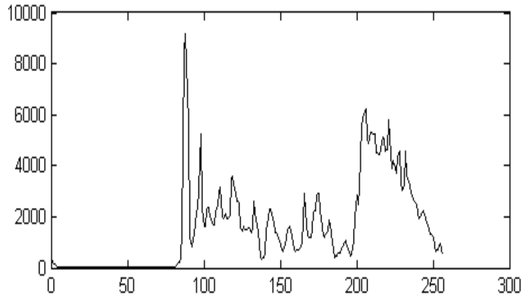


Figure 6. Cofficient Accumulated Value of each Line

6. Conclusion

The advantage of the shearlets transform is that, by decomposing an image as function of scale, location and orientation, it allows one to extract directly the information about the orientation of the edges. These information is very eventful for target detection, identification, track in infrared image system. This approach is based on a simple and rigorous mathematical theory which accounts for the geometrical properties of edges. This opens the door to a number of further research including feature extraction and recognition about infrared target. While the objective evaluation of edge detection requires a deeper proposal.

References

[1] FJ Canny. A computational approach to edge detection. *IEEE Trans. Pattern Anal. Machine Intell*. 1986; 8(6): 679-698.
[2] T Lindeberg. *Edge detection and ridge detection with automatic scale selection*. Proceedings of the IEEE Int. Conference on Computer Vision and Pattern Recognition. San Francisco. 1996: 465-470.
[3] T Lindeberg. Feature Detection with Automatic Scale Selection. *International Journal of Computer Vision*. 1998; 30(2): 79-116.
[4] S Mallat, WL Hwang. Singularity detection and processing with wavelets. *IEEE Trans. Inf. Theory*. 1992; 38(2): 617-643.
[5] D Ziou, S Tabbone. Edge Detection Techniques an Overview. *International Journal of Pattern Recognition and Image Analysi]*. 1998; 8(4): 537-559.
[6] Sheng Yi, Demetrio Labate, Glenn R, Easley, Hamid Krim. A Shearlets Approach to Edge Analysis and Detection. *Image Processing, IEEE Transactions.* 2009; 18(5): 929-941.
[7] Kutyniok G, Labate D. Resolution of the Wavefront Set Using Continous Shearlets. *Transactions of The American Mathematical society*. 2009; 361(5): 2719-2754.
[8] Guo KH, Labate D, Lim WQ. Edge analysis and identification using the continuous shearlet transform. *Applied and Comutational Harmonic Analysis*. 2009; 27(1): 24-46.
[9] Easley G, Labate D, Lim WQ. Sparse directional image representations using the discrete shearlet transform. *Applied and Comutational Harmonic Analysis*. 2008; 25(1): 25-46.
[10] Kutynioka, Gitta, Donohob, David L. *Development of a digital shearlet transform based on pseudo-polar FFT*. Proceedings of SPIE-The International Society for Optical Engineering. 2009; 7446.
[11] B G Bodmann, G Kutyniok, X Zhunag. *Coarse Qunatization with the Fast Digital Shearlet Transform*. Wavelets and Sparsity XIV (San Diego, CA, 2009), SPIE Proc. 8138, SPIE, Bellingham, WA. 2011.
[12] G Kutyniok, D Labate. Shearlets. The First Five Year. Oberwolfach Report No. 44/2010.
[13] G Kutyniok, WQ Lim. Image Separation Using Wavelets and Shearlets. *Curves and Surfaces* (Avignon, France, 2010), Lecture Notes in Computer Science 6920, Springer. 2011.
[14] Hanshan Li, Zhiyong Lei. Research on Infrared Special Facula View Measurement Method Based on Image Processing Technology. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012, 10(6): 1422-1429.
[15] Zhao Yan, Chen Hexin, Wang Shigang, Gabbouj Moncef. An improved method of detecting edge direction for spatial error concealment. *Journal of Multimedia.* 2012; 7(3): 262-268, 2012.