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Conference Paper · January 2004

DOI: 10.1109/ICICS.2003.1292551 · Source: IEEE Xplore

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ICICS-PCM 2003
15-18 December 2003
Singapore

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***Abstract*— This paper presents a multiscale corner detection method based on continuous wavelet transform (CWT) of contour images. The corner points are detected from the local wavelet transform modulus maxima (WTMM) of the contour orientation. To reduce the side effects of the discretization and smoothing that are introduced by the preprocessing steps, we adopt a simple but efficient post processing algorithm: non-maximum suppression. The proposed method detects sharp corners as well as subtle corners. Simulation results illustrate the better performance of the proposed corner detector compared to the other methods.**

Index Terms – Corner Detection, Continuous Wavelet Transform, Non-maximum Suppression.

I. Introduction

Corner points, which have high curvature on the contour, are sparse and robust features of an image. Being sparse, they provide useful information and give important clues for shape representation and analysis [1]. Being robust, they are invariant to the changes of translation, rotation and scaling. They provide reliable clues regarding objects even under occlusion and varying background [2], [3]. Corner detection has wide applications such as object recognition, shape representation, image interpretation and motion analysis [2], [4].

Since corners are high curvature points on the contour, most of the corner detectors find corner points on a contour image. This contour image is obtained by using edge detection on the original image. Therefore, we focus on corner detection of contour images in this paper.

A few corner detectors are summarized to detect the corners on 2-D planar curves in [5]. All of those methods detect corner points by measuring either the angles or the curvatures of discrete curves from a chain code. Among them, the algorithm called as IPAN has the best performance. Therefore, we have compared the results obtained by the proposed method and IPAN method in Section IV.

Generally speaking, corner points have the following characteristics: first, they are local features of an image; second, they may belong to structures of different sizes in an image. On the other hand, wavelet transform (WT) is a tool that can provide multiscale analysis while analyzing the local behavior of a signal. Due to the above analysis, it is attractive to apply WT in corner detection. Because different wavelets have different properties, the selection of wavelet bases is of great importance.

In recent years, the multi-scale wavelet-based corner detection techniques in 2-D planar curves have been proposed in [6], [7]. Both of them decompose the orientation profile using dyadic wavelet transform. The basic idea behind those papers is as follows: they use the local wavelet transform modulus maxima (WTMM) of the orientation profile to locate the singular points, i.e. corners [8], [9]. However, in [6], huge computational costs are required to use the property of Lipschitz exponent in the post processing.

In [7], SVD is used to identify the largest natural scale. A global threshold is applied in the post processing. In the scale-space domain, the natural scales are defined as the most significant scales that contain all important information about the structures of different sizes in the curve without overhead redundant representation of the curve [14]. In the Quddus-Gabbouj's corner detection algorithm [7], natural scales refer to the scales from the first scale up to the largest natural scale. SVD technique has been used to decompose the coefficients in the WT domain. If the first singular value is much larger than the other singular values, then the corresponding scales can detect the most dominant behavior among wavelet coefficients. Thus these scales are used as natural scales. But the used dyadic wavelet transform provides a low resolution of scale especially at the coarser scale. Therefore subtle corners will be missed after the threshold is applied.

Both dyadic wavelet transform and continuous wavelet transform (CWT) are shift-invariant. CWT has more redundancy than dyadic wavelet transform, but it is the redundancy that makes the method more stable and accurate [11]. Considering that the accuracy is more important than the computational speed in corner detection, we think CWT is suitable for it.

In this paper, we propose a continuous wavelet based algorithm to obtain a more accurate analysis. The decomposition of high scale resolution is obtained. The high scale resolution and stability of CWT make us detect the subtle corners as well as the sharp corners. Non-maximum suppression method is also applied as the post processing to remove the discretization and smoothing effects introduced in the preprocessing steps. Comparisons between the proposed method, Quddus-Gabbouj's corner detector [7] and IPAN method [5] are also presented. Better results show the improved performance of our proposed method.

The organization of this paper is as follows. Section II describes the multiscale wavelet transform (MSWT) based corner detection. In section III, the proposed corner detection method using multiscale continuous wavelet transform (MCWT) is presented in detail. Section IV shows the simulation results and the conclusion is given in Section V.

II. Multiscale Wavelet Transform Based Corner Detection

The preprocessing steps (contour extraction, boundary tracking and orientation computation) are the same for all the multiscale wavelet transform (MSWT) based corner detection techniques (see [6], [7]).

For these techniques, the contour image is extracted from the gray image first, then the 2-D planar curve (or we can call it the boundary) is expressed as

$$S(t) = (X(t), Y(t)), \tag{1}$$

where t is the arc length [10]. The orientation function (the angle between the tangent line and the positive x-axis) of the boundary is defined as

$$f(t) = tan^{-1}((dY/dt)/(dX/dt)). \tag{2}$$

For the digital image, the orientation resolution is $\pi/4$ if we replace the derivative above by the first-order difference. We can improve the orientation resolution by defining

$$f(i) = tan^{-1}\frac{Y(i+d) - Y(i-d)}{X(i+d) - X(i-d)}, \tag{3}$$

for $d > 1$. Here, i denotes the index of the chain code. In this context, the chain code is defined as a 1-d sequence that contains position information for the pixels of the contour image. According to Eq. (3), we then obtain a smoothed version of the orientation profile.

The WT of the function $f(i)$ at the scale s and position u is then defined by

$$Wf(s,u) = f(u) \otimes \psi_s(u), \tag{4}$$

where $\otimes$ denotes the convolution and $\psi_s(u) = s^{-1/2}\psi(u/s)$ is the wavelet function.

The corner points (with high curvature) of the contour image are those points having the large rate of change of the orientation. Here, these points correspond to the WTMM of the orientation profile [6], [7].

III. The Proposed Corner Detection Algorithm Using Continuous Wavelet Transform

The preprocessing steps of the proposed algorithm is the same as described in Section II.

In the proposed method, we have used CWT to decompose the orientation profile. CWT can transform the signal at any scale and any translation. It has great redundancy, but we know that the redundancy method is more stable and accurate [11]. In [12], Quddus and Fahmy present that the wavelets with one vanishing moment are more suitable for corner detection. Consequently, we have applied the bi-orthogonal spline wavelet 1.3 [13] that has one vanishing moment.

In the Quddus-Gabbouj's corner detection algorithm, they use the average of the decomposition information from the first scale up to the largest natural scale as follows:

$$W^d_{2^*}f = \frac{1}{L}\sum_{j=1}^{L} W^d_{2^j}f, \tag{5}$$

where $W^d_{2^*}f$ denotes the average. $W^d_{2^j}f$ denotes the dyadic wavelet coefficients of the discrete orientation profile f at level 2^j. L is the largest natural scale. This average will remove the noise while strengthening the WTMM points. The dyadic wavelet transform is applied in the Quddus-Gabbouj's multiresolution wavelet based methods, consequently the scales adopted are $\{2^1 \leq 2^j \leq 2^L\}$. Because the scale resolution is very low especially at coarse levels, less coarse levels has been used in determining the corner points. We know that the subtle corners correspond to relatively large wavelet coefficients at coarser scales. In Eq.(5), the averaging of the coefficients smoothes out the subtle corners. To solve the above problem, we use the CWT to achieve a more accurate analysis. In our case, we use the scales $\{j = 1, 2, \cdots, L\}$, making the scale resolution of one. Thus the high scale resolution and the stability of CWT make the algorithm detect the subtle corners as well as sharp corners.

Because of the discretization and the smoothing with Eq. (3) in the preprocessing steps, more than one local WTMM will appear around each corner. We call this phenomenon as multi-responses. At the same time, some local WTMM may correspond to the noise. In [6], the suppression of false detection and multi-responses is obtained by isolating each candidate and further selecting the singular points using Lipschitz property that results in high computational cost. In [7], the suppression of false detection and multi-responses is achieved by applying a global threshold. Due to the large threshold, some subtle corners will be missed. To address this problem, we set a relatively small global threshold to suppress the false corner detection responding to the noise. The threshold should be small enough to remain the subtle corner points. Since the multi-responses are local behaviors of the MSWT corner detection, a local post processing step seems to be more suitable. To guarantee the single response to each true corner points while keeping the subtle corners, we have introduced a non-maximum suppression algorithm [15] based on a local operator. By applying this suppression algorithm, only the maximum points should remain within the fixed window length. This post processing step, which requires small amount of extra computational load, is able to remove those side-effects, as mentioned earlier, introduced by the preprocessing steps.

The steps of the proposed algorithm is as follows.

1. Preprocessing steps that have been described in Section II:

   (a) Track the boundary and obtain the chain code of it;
   (b) Compute the orientation profile according to Eq. (3).

2. Transform the orientation profile with the continuous wavelets.

3. To detect both the sharp and subtle corner points, the scales $\{1 \leq j \leq L\}$ are used to compute the wavelet coefficients as

$$W_*^c f = \frac{1}{L}\sum_{j=1}^{L} W_j^c f, \tag{6}$$

where $W_*^c f$ denotes the average. $W_j^c f$ denotes the continuous wavelet coefficients of the discrete orientation profile f at level j. L is the largest scale used in the corner detection. As the scales adopted are $\{1 \leq j \leq L\}$ using CWT, the scale resolution is constant for all the levels. Thus, we can use more coarse scales in the proposed algorithm and more subtle corners can be detected.

4. Determine the normalized modulus of $W_*^c f$.

5. Detect the corners by selecting the local WTMM. The modulus maximum is a point whose absolute value is more than one of the neighborhood and not less than the other neighborhood [8].

6. Suppress the false corner points by setting a threshold to the result obtained in step 5.

7. Further suppress the multi-responses by applying the non-maximum algorithm [15].

IV. Illustrative Results and Comparisons

In this section, we have compared the performance of the proposed method with Quddus-Gabbouj's corner detector [7]. The results from the IPAN method [5] is also referred for comparison. A set of standard contour images [5] are used to verify the performance of the proposed corner detector.

In the experiment, we set $d = 3$ in Eq. (3) and $L = 16$ in Eq. (6) that give us the best results. In Fig. 1, the results of Quddus-Gabbouj's corner detector are shown. The corresponding results of the proposed method are presented in Fig. 2. As we can see, some subtle corners are missed by the Quddus-Gabbouj's detector in Fig. 1, whereas the detected subtle corners by our method are marked by ellipse in Fig. 2. These results verify our earlier analysis in Section III: the proposed corner detector has the ability to detect the sharp corners as well as the subtle corners. Although both these two methods detect a few false corner points in contour images as shown by Fig. 1(b) and Fig. 2(b). It may happen due to the presence of boundary noise in the contour image.

A set of standard contour images is used in Fig. 3 [5] and Fig. 4. Fig. 3 shows the results of IPAN method. The corresponding results of the proposed method are presented in Fig. 4. Comparing the results shown in Fig. 3 and Fig. 4, we can see that the proposed method detects more corners while has less false detections than the IPAN method.

V. Conclusion

In this paper, we have considered the multiscale wavelet transform (MSWT) technique for corner detection. An efficient corner detection scheme based on continuous wavelet transform is introduced. This multiscale continuous wavelet transform (MCWT) method is found suitable for the contour images at hand. Better performance is demonstrated through simulation examples in terms of detecting both the sharp and subtle corners.

VI. Acknowledgment

The authors would like to thank Dr. Sadegh Abbasi, Dr. Farzin Mokhtarian and Dr. Josef Kittler for providing the test images used in fig. 2.

REFERENCES

[1] F. Chabat, G.Z. Yang, and D.M. Hansell, “A corner orientation detector,” in *Image and Vision Computing*, vol. 17, pp. 761–769, 1999.

[2] A. Quddus, F. A. Cheikh, and M. Gabbouj, “Content-based object retrieval using maximum curvature points in contour images,” in *Proc. of SPIE/EI’2000 Symposium, On Storage and Retrieval for Media Databases*, San Jose, California, USA, pp. 23–28, January 2000.

[3] P. L.Rosin, “Note measuring corner properties,” *Computer Vision and Image Undrestanding*, vol. 73, pp. 291–307, 1999.

[4] F. Shen and H. Wang, “A local edge detector used for finding corners,” in *Proc. of Third Conference on Information,Communications and Signal Processing (ICICS’2001)*, Singapore, 2001.

[5] D. Chetverikov and Z. Szabo, “A simple and efficient algorithm for detection of high curvature points in planar curves,” in *Proc. 23rd Workshop of the Australia Pattern Recognition Group*, Steyr, Australia, pp. 175–184, 1999.

[6] J.-S. Lee, Y.-N. Sun, and C.-H. Chen, “Multiscale corner detection by using wavelet transform,” *IEEE Trans. on Image Processing*, vol. 4, pp. 100–104, 1995.

[7] A. Quddus and M. Gabbouj, “Wavelet-based corner detection technique using optimal scale,” *Pattern Recognition Letters*, vol. 23, pp. 215–220, 2002.

[8] S. Mallat and W. L. Hwang, “Singularity detection and proessing with wavelets,” *IEEE Trans. on Information Theory*, vol. 38, pp. 617–643, March 1992.

[9] S. Mallat and S. Zhong, “Characterization of signal from multiscale edges,” *IEEE Trans. on Pattern Anal. and Mach. Intell.*, vol. 14, pp. 710–732, July 1992.

[10] H. Liu and M. Srinath, “Partial shape classification using contour matching in distance transformation,” *IEEE Trans. on Pattern Anal. and Mach. Intell.*, vol. 12, pp. 1072–1079, November 1990.

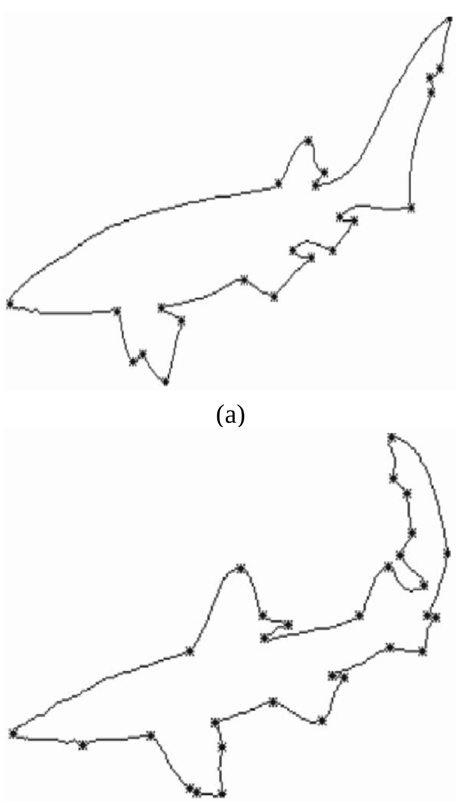
[11] S. Mallat, *A Wavelet Tour of Signal Processing*. Academic Press, 1999.

[12] A. Quddus and M. M. Fahmy, “Corner detection using various wavelets,” in *Second International Conference on Information, Communications & Signal Processing (ICICS’99), Singapore*, Dec. 1999.

[13] A. Cohen, I. Daubechies, and J.C. Feauveau,“Biorthogonal basis of compactly supported wavelets,” in *Comm. Pure Appli. Math.*, vol. 45, pp. 485–560, 1992.

[14] P. L. Rosin, “Determining local natural scales of curves,” *Pattern Recognition Letters*, no. 19, pp. 63–75, 1998.

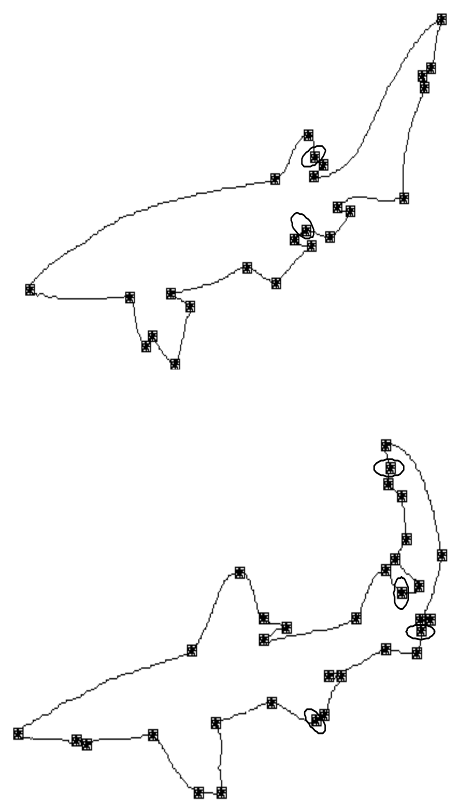
[15] Z. Wu and A. Rosenfeld, “Filtered projections as an aid to corner detection,” *Pattern Recognition*, vol. 16(31), 1983.



(a)

(b)

Fig. 1. The simulation results of Quddus-Gabbouj’s corner detector [7].



(b)

Fig. 2. The simulation results of the proposed corner detectors.

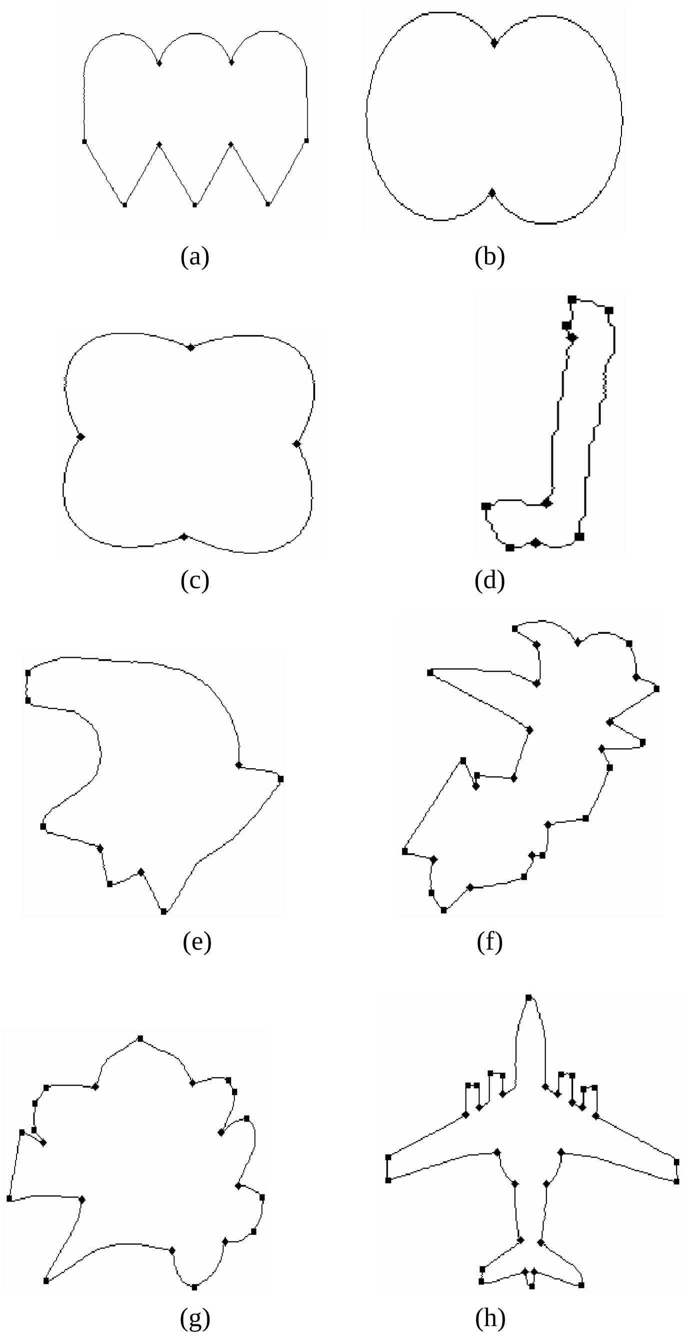


Fig. 3. The simulation results of the IPAN method [5].

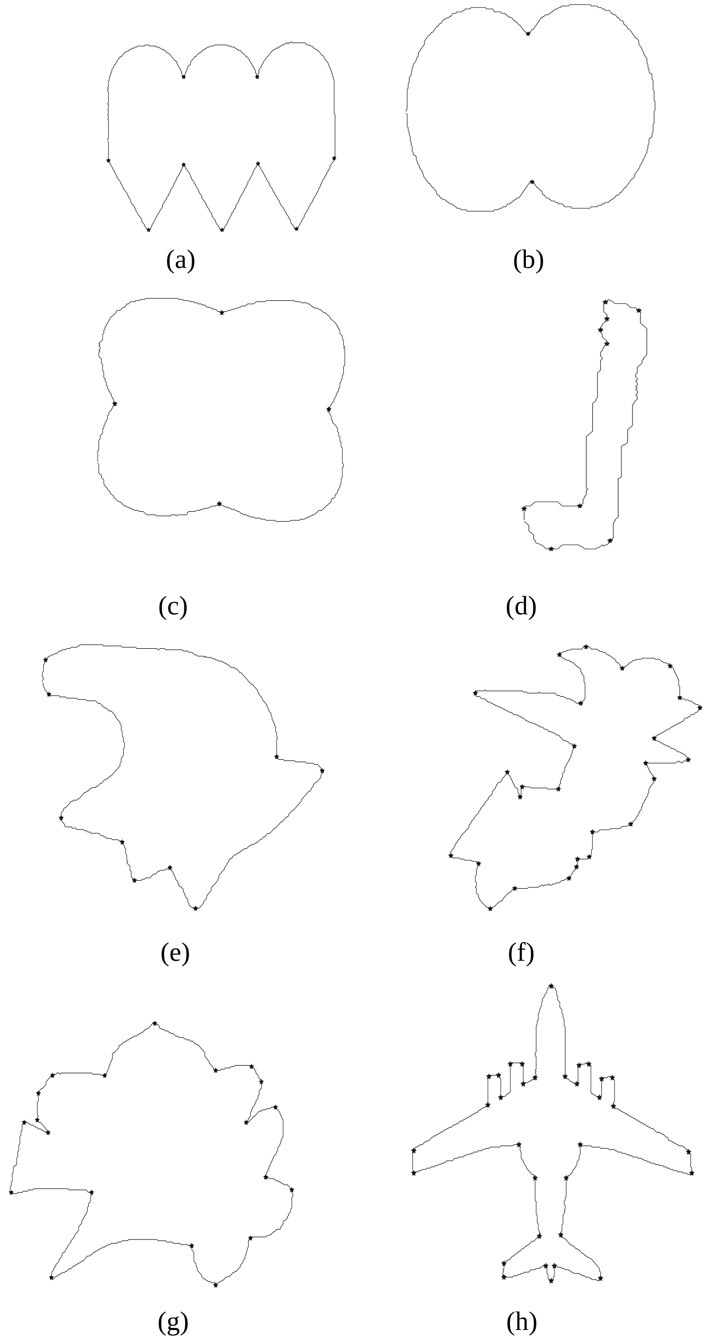


Fig. 4. The simulation results of the proposed corner detectors.