A Chord Curvature Model for Silhouette Curvature Calculation

Bi-Tao Fu

Abstract Silhouettes contain abundant shape information of image objects, which have advantages ranging from invariance to rotation and scale changes, and interference immunity against illumination and noise. Curvature calculation models are applied to detect contour feature points sequentially along silhouette curves. The normal curvature calculation method is often disturbed by coordinate perturbation of adjacent points in a support domain, which is usually caused by rotation transformation and noise interference. We therefore propose a novel curvature calculation method, termed a Chord Curvature Model, which has characteristics consisting of simple calculations, rotation invariance and robustness. Experiments demonstrate that this model can detect contour feature points from complex discrete curves.

Keywords Silhouette curvature calculation · Chord curvature · Contour feature point

1 Introduction

Although contour feature points (CFP) only account for a small percentage of all silhouette points, they can describe silhouette's overall structure accurately. Existing CFP detection methods include polygonal approximation algorithm, corner detection operator and curvature calculation method. According to certain principles, the polygonal approximation algorithm adds feature points successively between two original endpoints to approximate the original curve [1, 2]. The corner detection operators include Moravec, Forstner, Hanna, Harris, Patch-Duplets [3], anisotropic Gaussian kernel [4, 5], etc. Unfortunately, their results are unordered points. While the curvature calculation method can detect points arranged sequentially along

B.-T. Fu (✉)
School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
e-mail: fubitao@163.com

A. Hussain (ed.), *Electronics, Communications and Networks V*,
Lecture Notes in Electrical Engineering 382, DOI 10.1007/978-981-10-0740-8_2

silhouette curves, which includes classic curvature algorithm [6–8], L-curvature [9, 10], U chord length curvature [11, 12], visual curvature [13], etc.

The curvature value is apt to be disturbed by coordinate perturbation of adjacent points in support domain, which is caused by scale transformation, rotation transformation or noise interference [9, 11]. To solve it, the author proposed a chord curvature (CCUR) model about CFP detection in this paper.

2 Methodology

2.1 Definition of CCUR

A chord in length of $2L$, midpoint laid on a point p_i on a curve f(x, y) (Fig. 1a), is rotated clockwise at intervals of a small angle $\Delta\theta$. There is a prerequisite that adjacent points p_{i-1} and p_{i+1} must locate on the same side of the chord, in other words, its rotation range locates in the angle θ in Fig. 1b. The gray area enclosed by the curve, chord's perpendicular on two endpoints, and the chord is $A = A_1 + A_2$. It should be noted that the gray area must locate at the same side of the chord. That of the j th rotation is $A_j = A_{j1} + A_{j2}$, j = 1, 2, …, m, m is total rotation times. The CCUR is defined as

$$K = \frac{\min(A_j)}{L^2} \tag{1}$$

Suppose an equal-area transformation from $\min(A_j)$ in Fig. 1a to the gray area in Fig. 2. There are two equal included angles α between two symmetrical lines $p'_{i-1}p_i$, $p_ip'_{i+1}$ and chord, so the gray area in Fig. 2 is

$$\min(A_j) = 2 \times L \times L \tan \alpha/2 = L^2 \tan \alpha \tag{2}$$

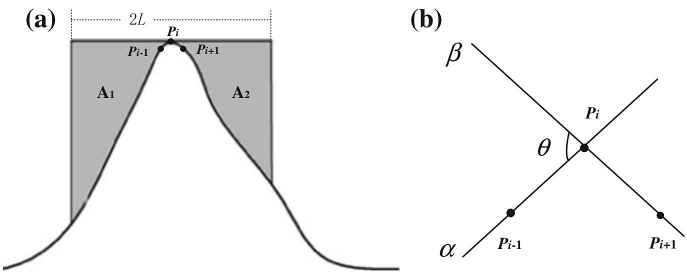

Fig. 1 The diagram of CCUR calculation. **a** CCUR, **b** rotation range of chord

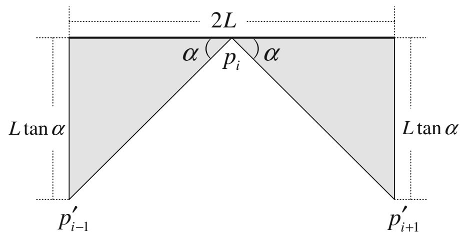

Fig. 2 The diagram of CCUR's physical meaning

and

$$\kappa = \frac{\min(A_j)}{L^2} = \tan\,\alpha \tag{3}$$

So CCUR is the slope of $p'_{i-1}p_i$ for chord as x-axis, in fact it is the synthetic curvature near p_i. Its physical meaning is simple and clear: The more protruding the p_i, the larger α becomes, and the larger κ becomes. When both p_{i-1} and p_{i+1} locate on chord, p_i, p_{i-1} and p_{i+1} are collinear and κ = 0.

2.2 Calculation Procedures of CCUR

Preprocessing procedures are necessary to simplify silhouette curves and reduce calculation amount:

1. Image preprocessing. It includes image enhancement, image denoising, image filtering, image deblurring, image smoothing, etc.
2. Edge preprocessing. Many existing edge detection operators can be adopted, but before that, the edge preprocessing procedures is necessary. In fact, there are always plenty of disconnected edge, double edge, jagged edge, and massive short fragmental contours.
3. Coordinate transformation. The Cartesian coordinate system is convenient to calculate area and the pedal coordinates of point to the curve, whereas the polar coordinate system or polar coordinates is convenient to process rotation, so the coordinate transformation is necessary. In polar coordinates for the pole with p_i, $\theta + \Delta\theta$ and constant ρ mean the rotation of chord. While in Cartesian coordinates, rotated chord becomes x-axis, and the distance between curve points to chord is *y* coordinate, so the calculation of area A_j becomes a simple thing. Set $M \approx 5L$, the neighborhood point set of p_i is $p_{i-M}, \ldots, p_{i-1}, p_i, p_{i+1}, \ldots, p_{i+M}$. To speed up above calculation, the author substituted the point set for all curve points in the calculation.
4. Filter preprocessing by included angle. The calculation of included angle is much easier than that of CCUR, so it can decrease calculation time markedly. Simple loop computation is applied to calculate the included angle cluster $\angle p_{i-s}p_ip_{i+t}$, among of which, $1 \le s \le 5$, $1 \le t \le 5$. If there is an included angle between $0.95\pi \sim 1.05\pi$, p_i is not a CFP certainly and does not need subsequent calculation.

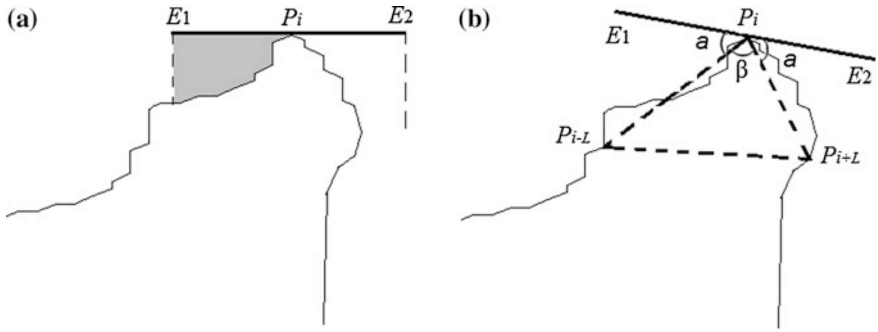

Fig. 3 The diagram of dangle points. **a** dangle point, **b** CCUR of dangle point

2.3 Dangle Endpoints

Perhaps there are dangle endpoints when the chord lay on the sharp turn points as shown in Fig. 3a. The endpoint E2 is a dangle endpoint, that is to say, there isn't an intersection between perpendicular line and the neighborhood point sets of p_i, so the closed area can't be calculated, and the formula 1 is unsuitable for it.

The author designed an alternative simplified method to solve it. As shown in the Fig. 3b, the included angle $\beta = \angle p_{i-L}p_ip_{i+L}$ can be calculated by their coordinates, and $\alpha = (\pi - \beta)/2$, and then $\kappa = \tan\alpha$, which can be seen as the CCUR of p_i.

3 Experiment and Conclusion

3.1 Experiment I—CCUR Values

The experiment data I is a giraffe image (Fig. 4a). The author compiled the corresponding MATLAB program to realize above model and algorithms. When the sampling scale is $L = 5$, the detected points are CFPs.

By a series of statistical analysis experiments, threshold $th = \tan\alpha_0$ is ascertained. When $\kappa > th$, p_i is judged as a CFP. Too small α_0 will result in overmuch CFPs; otherwise too big α_0 will lead to CFP lack. Three corresponding threshold is: when $L = 5$, $th = 0.8$; when $L = 10$, $th = 0.6$; when $L = 20$, $th = 0.45$.

There are too many CFPs on the same section of curve (Fig. 4b), so non-maximum value suppression is necessary. In this paper a simple algorithm is

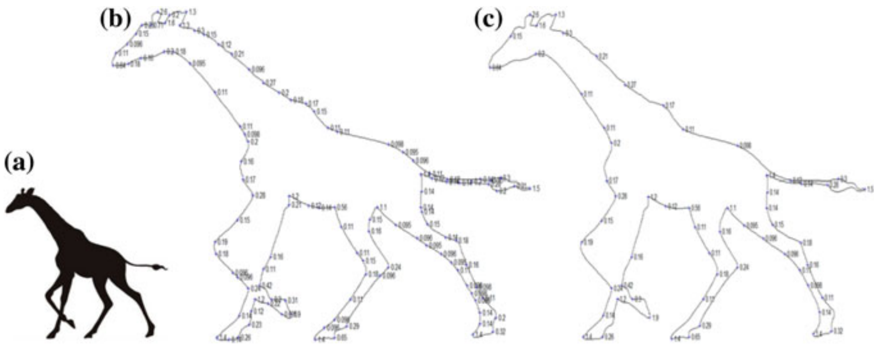

Fig. 4 The CFPs of giraffe image. **a** Original image, **b** *th_dis* = 10, **c** *th_dis* = 20

designed to screen CFPs by their distance: if the distance between two CFPs is less than a given distance threshold *th_dis*, the smaller CFP will be eliminated (Fig. 4c).

3.2 Experiment II—Robustness of CCUR

The experiment II is designed to compare the CCUR and the classic mathematics curvature method, and verify their anti-interference performance against coordinate perturbation of adjacent points. The experiment data is the discrete point set of a unit circle (Fig. 5a).

A comparison method adopted here is a classic mathematics curvature calculation after discrete curve fitting [7]. Obviously the mathematics curvature of a unit circle is $K = 1.0$, exactly the reciprocal of radius, but CCUR is no longer equivalent to it. CCUR values have no longer any actual physical implications, and the only significance is their relative sizes, which reveal the possibility of CFP. CCUR values vary with chord length: when $L = 1.0$, $\kappa = 0.429$; $L = 0.5$, $\kappa = 0.174$; $L = 0.2$, $\kappa = 0.067$; $L = 0.1$, $\kappa = 0.0334$.

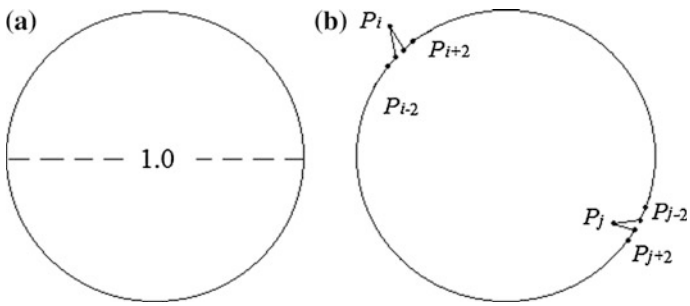

Fig. 5 The experiment data II-unit circle

There are two noise points to verify their anti-interference performance, among them, p_i is a protruding point, and p_j is a concaving point (Fig. 5b). And p_{i-2}, p_{i+2}, p_{j-2}, p_{j+2} are their neighborhood points. In contrast to Fig. 5a, their mathematics curvatures change sharply: $K_{i-2} = 3.07$, $K_{i+2} = 4.16$, $K_{j-2} = 0.82$, $K_{j+2} = 0.74$. Their change rate is 207, 316, −18, −26 %. When $L = 0.2$, the CCUR is $\kappa_{i-2} = \kappa_{i+2} = 0.064$, $\kappa_{j-2} = \kappa_{j+2} = 0.071$, change rate is −4.48, −4.48, 5.97, 5.97 %. Obviously change rate of the CCUR is far less than that of the former. The reason is that the area disturbance is far less than the shape disturbance of fitted curves, so curvature model by calculation of closed area is more robust.

4 Conclusion

CCUR calculation merely requires the minimum area closed by chord and curve, so it costs a small calculation amount. It has the properties of rotation invariance, noise immunity, robustness, and suitability of various discrete curves. It can detect CFPs on various scale silhouette by altering chord length.

Acknowledgements This work was supported by the Fundamental Research Funds for the Central Universities, HUST: No. 2015TS155.

References

1. Wang, J.W.: Research on shape contour analysis and matching based on combined global and local information. Ph.D. thesis. Huazhong University of Science and Technology, Wuhan (2012)
2. Carmona-Poyato, A., Madrid-Cuevas, F.J., Medina-Carnicer, R.: Polygonal approximation of digital planar curves through break point suppression. Pattern Recogn. **43**, 14–25 (2010)
3. Johansson, B., Moe, A.: Patch-duplets for object recognition and pose estimation. In: The 2nd Canadian Conference on Computer Vision Proceedings, pp. 444–451. IEEE Computer Society, Piscataway, NJ, USA (2005)
4. Zhang, W.: Image edge and corner detection based on anisotropic Gaussian kernels. Ph.D. thesis. Xidian University, Xian (2012)
5. Akagunduz, E.: Shape recognition using orientational and morphological scale-spaces of curvatures. IET Comput. Vision **9**, 750–757 (2015)
6. Kronenbergera, M., Wirjadib, O., Freitag, J., Hagen, H.: Gaussian curvature using fundamental forms for binary voxel data. Graph. Models **6**, 1–14 (2015)
7. Worring, M., Smeulders, A.: Digital curvature estimation. CVGIP: Image Understanding **58**, 366–382 (1993)
8. Koenders, R., Lindenbergh, R.C., Storms, J.E., Menenti, M.: Multiscale curvatures for identifying channel locations from DEMs. Comput. Geosci. **68**, 11–21 (2014)
9. Zhong, B.J.: Research on algorithms for planar contour processing. PhD. thesis. Nanjing University of Aeronautics and Astronautics, Nanjing (2006)
10. Zheng, R.L., Zhong, B.J., Xu, D.S.: Scale-space shape analysis based on L curvature. J. Nanjing univ. (Nat. Sci.), **48**(2), 172–181 (2012)

11. Guo, J.J., Zhong, B.J.: U-Chord curvature: a computational method of discrete curvature. Pattern Recog. Artif. Intell. **27**(8), 683–691 (2014)
12. Chen, B.B., Deng, X.P., Yang, J.G.: Orientation-invariant generalized Hough transform algorithm based on U-chord curvature. J. Comput. Appl. **35**(9), 2619–2623 (2015)
13. Liu, H.R.: Curvature representation and decomposition of shape. Ph.D. thesis. Huazhong University of Science and Technology, Wuhan (2009)

Springer

http://www.springer.com/978-981-10-0738-5

Electronics, Communications and Networks V
Proceedings of the 5th International Conference on Electronics, Communications and Networks (CECNet 2015)
Hussain, A. (Ed.)
2016, IX, 426 p. 187 illus., 95 illus. in color., Hardcover
ISBN: 978-981-10-0738-5