Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

Ribbon-like skeletonization based on contour reconstrction on intersection regions

Melody Z. W. Liao
School of Computer Science
Sichuan Normal University
Chengdu, China
liaozhiwu@163.com

S X Hu
School of Automation Engineering
University of Electronic Science and Technology of China
Chengdu，China

X Q Huang
Suzhou Non-ferrous Metal Research Institute
Suzhou, China

W F Chen
School of Automation Engineering
University of Electronic Science and Technology of China
Chengdu, China

***Abstract*—According to the requirments of "good" skeletons, we present a skeletonization based on repairing the contours, especially for intersection regions. The motivation of this method is each of chinese character is composed by some strokes, and the "good" skeletons can be extracted easily from these strokes using existing methods. Therefore, the contours on intersection regions can be reconstructed correctly by repairing strokes. In this paper, the contour lines and corner points will be detected firstly; and then the strokes are recovered by repairing the contour lines detected on step 1 according to convex and concave natures of distinct points ; Finally, the skeletons are extracted using strokes. Experimantal results show the good performance of our method.**

Keywords—Skeletons; skeletonization; contour; stroke; contour repaired

I. INTRODUCTION

Skeletonization becomes an important subject of character recognition either for its abilities of reducing computation complexity or robustness in noise and distortion. But skeletonization based on symmetrical analysis can not extract skeletons which conform human perceptions on intersection regions of characters correctly. Especially for chinese characters, which have more intersection regions, skeletonization becomes a very difficult problem.

Thus, method which has good performance on intersection regions would be a resonable choose and becomes a research spot on pattern recognition [3, 7-8]. In [3], the authors proposed a skeletonization scheme based on singularity and regularity analysis. Since the scheme is designed on the the constrained Delaunay triangulation technique, its comuptation burden can not be afforded for complex shapes. [7-8] proposed skeletonization based on primary skeletons and types of different feature points. Since there are so many human experimental value in this kind method, they can not be generalized easily.

We argue the main difficulty for skeletonization is it is based on contuors, which leads to lost some useful information. In this paper, we propose a new skeletonization scheme. The main contribution of our skeletonization scheme is converting skeletonization to two procedures: one is contour reconstruction based on stroke repaired and the other is stroke skeletonization. We also propose a simple and powerful stroke-repaired method.

The remainder is arranged as follow: in order to explain our scheme more clearly, we will introduce the motivation of the new scheme on section 2; and on section 3, contuor repaired method will be presented; then based on the discussion of section 2 and 3, the whole framework is given on section 4. Finally, the experimental results and related discussion will be given on section 5.

II. MOTIVATION

According to the introduction of the previous section, skeletonization can be accomplished by two steps: one for contour reconstruction and the other for skeletonization for strokes.

The motivation for this new scheme is firstly based on the fact that it is very easy for extraction skeletons of the three type strokes. The three type basic strokes are vertical line, horizontal lines and points. Since each character can be represented by the combination of these three type strokes, the strokes are called basic strokes (see fig. 1).

- *Definition 1 (Basic Strokes) Three type strokes: vertical line, horizontal line and point are called Basic Strokes.*

Observing Fig. 1, skeletonization of basic strokes is very simple and direct, while skeletonization on intersection regions is very difficult. The reason is that skeletonization is based on contours, whose stroke information is lost on intersection regions.

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Figure 1. Three basic strokes and their skeletons

Therefore, the second motivation for new scheme is that repairing contuors on intersection regions will help extract skeletons, which is close to human perceptions.

Summary above facts, the motivations can be expressed as: each character can be considered as a combination of basic strokes, whose skeletons can be extracted easily and correctly.

III. CONTOUR REPAIRED

On this section, we will discuss the contour repaired method on intersection regions based on feature lines and points. The main motivation for this method is that corner points of basic strokes is convex (see figure 1). Thus contours can be repaired by finding all concave corner points and mending them to convex points or flat points. The main procedures are as follow:

TABLE I. MAIN PROCEDURES OF CONTUOR REPAIRED

1. Edge detection using wavelet maxima [10]
2. Distinct points localization using Harris detector [12]
3. Finding all concave points detected on procedure 2
4. Extending two lines of each concave point until they meet other contour points

Contour repaired method will be discussed according to this four procedures.

A. Edge detection using wavelet maxima[10]

The image f(x, y) is one differentiable, and its gradient vector is defined as:

- *Definition 2 (Gradient Vector) If f (x, y) is one differentiable, its Gradient Vector can be defined as*

$$\nabla f(x,y) = (W_x f(x,y), W_y f(x,y)) \quad (1)$$

where Wxf(x,y) is the wavelet coefficient of (x,y) in x direction and Wyf(x,y) is the wavelet coefficient in y direction.

- *Definition 3 (Gradient Direction) If f is one differentiable, the Gradient direction can be defined as*

$$Af(x,y) = \arctan(W_y f(x,y) / W_x f(x,y)) \quad (2)$$

- *Definition 4 (Modulus) If f is one differentiable, the Modulus can be defined as*

$$|\nabla f(x,y)| = \sqrt{(W_x f(x,y))^2 + (W_y f(x,y))^2} \quad (3)$$

Singularity points which correspond to edges or other singularities can be detected as the maximum modulus of gradient. Then we give the strict definition of maximum modulus of gradient

- *Definition 5 (Maximum Modulus of Gradient direction) If f is one differentiable, N is a neighborhood of (x, y). If ∀(x1, y1)∈N and arctan(y-y1, x-x1)=Af(x, y), satisfy*

$$|\nabla f(x, y)| > |\nabla f(x1, y1)| \quad (4)$$

$|\nabla f(x, y)|$ is called maximum modulus of point (x, y).

TABLE II. ALGORITHM OF WAVLET MAXIMA

1. Decide the scale s and threshold value k
2. Compute the Gradinet Vector according to (1)
3. Compute the Gradinet Direction according to (2)
4. Compute the wavelet modulus according to (3)
5. If |∇f(x, y)|-|∇f(x1, y1)|>k in direction Af(x,y), |∇f(x, y)| is maximum modulus
6. Repeat 1-5 until all points are computed←

B. Harris detector[12]

The Harris detector is a well known method for combing edge and corner detection. On this subsection, we used Harris detector only for corner points location.

For an image I(x,y), we firstly define the following terms:

$$A = X^2 \otimes W$$

$$B = Y^2 \otimes W$$

$$C = XY \otimes W$$

where $X = \frac{\partial I}{\partial x}, Y = \frac{\partial I}{\partial y}$ and $W_{u,v} = \exp^{-\frac{u^2+v^2}{2\sigma^2}}$. Here, u and v are the cprresponding distances between x and the considered point in x and y directions.

Then, compute $R=AB-C^2-k(A+B)^2$, finding points with R>T, where T is a positive number. These points are required distinct points.

C. Convex and concave nature of distinct point

On this subsection, we will dicuss convex and concave nature of each distinct point detected on subsection 3.2. The goal of this discussion is to find all concave points in corner points, which will be used for contour repaired. To our knowledge, we still do not find an existing way useful for this task. In this paper, we propose a simple and powerful way for location the concave points based on gradient directions of contour points. The explaination is almost self-contained and gives both definition for general case and algorithm for this special target.

Firstly, we will give the definition of convex set from Wikipedia [14].

- *Definition 6 (Convex set and concave set [14]) Let C be a set in R2 space. C is said to be convex if, for all x* *and y in C and all t in the interval [0,1], the point (1 − t) x + t y is in C. Otherwise, C is concave.*

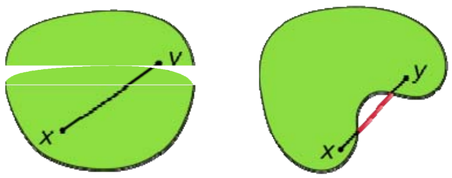

Figure 2. A convex set (left) and a concave set (right)

This implies that a convex set in R2 is path-connected. Fig. 2 gives examples of convex set and concave set.

Then based on convex set, convex ploygon will be defined.

- *Definition 7 (Convex polygon [14]) A convex polygon is a simple polygon whose interior is a convex set.*

The following properties of a simple polygon are all equivalent to convexity:

- Every internal angle is less than 180 degrees.
- Every line segment between two vertices remains inside or on the boundary of the polygon.

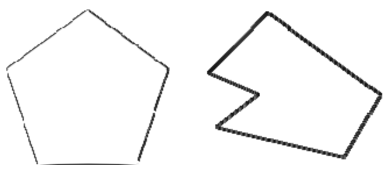

Figure 3. An example of convex polygon (left) and an example of concave polygon (right)

- *Definition 8 (Concave polygon [14]) A polygon that is not convex is called concave.*

A concave polygon will always have an interior angle with a measure that is greater than 180 degrees.

Fig. 3 gives examples of convex polygon and concave polygon. The definition of concave polygon can be stated as: A polygon that has at least one internal angle is more than 180 degrees is called concave, we also call one of this angle as concanve corner and related vertex is called as a concanve point.

In order to select concanve points from all corner points, we should propose a method to decide the convex and concanve nature of each of distinct point. Since the gradient direction can be decided by (2), a method to judge the nature of a corner point will be presented based on its the gradient direction. However, gradient directions of some contour points may be affected seriously by noise. A new method ,which is similar to voting, is proposed to reduce the effect for noise. The whole method is as follows:

1. Decide convex and concave nature of each distinct point using its gradient direction:

Two example regions are shown in Fig. 4. Black arrows indicate the directions of gradient while dashed lines represent the straight lines for directions of gradient. Observing Fig. 4, we can see one obvious difference between two regions-the intersection of two straight lines on convex region is in the region while its on concanve region is outside the region. It infers us the convex and concave nature can be specified as this rule.

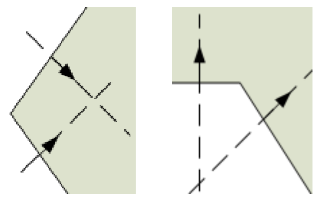

Figure 4. A convex region (gray) (left) and a concave region (gray) (right)

Theorem 1. If intersection of two straight lines, whose directions are their gradient directions and pass through the edge points near a corner point, is in the region, the corner point is convex; while is outside the region, is concave.

The demonstration of theorem is quite obvious under the situation that edge points is very close to the distinct points.

2. Voting method:

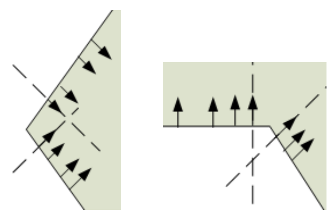

Figure 5. Voting method of a convex region (gray) (left) and a concave region (gray) (right)

In order to decreasing the effect of noise, a voting method is proposed based on gradient directions of contour points on two sides (see figure 5). The gradient direction of edge points is computed using (2). Then from this results, we can find the majority of gradient directions of contour points on each side of a corner point, which is called major direction. For each of a corner point, two straight lines should be decided by major directions of two sides of the corner point and two closest edge points to the distinct point. If the intersection of two straight lines is in the region, the distinct point is convex; otherwise, it is concanve.The whole method is summaried as:

TABLE III. FIND ALL CONCANVE POINTS:

1. Compute major directions of whole corner points using voting method
2. For each distinct point, decide two straight lines using major direction and two closest edge points
3. Find intersection of two straight lines,
4. Denote the intersection, which is outside the region
5. repeat 2-4, until all corner points are discussed

IV. THE NEW FRAMEWORK

On this section, we describe the new framework step by step. In order to show our ideas more clearly, we firstly describe how to skeletonization using repaired contuors according to [5] in detail; then we will give the whole framework.

A. Skeletonization

Following the discussion on section 3, the edge points in a digital image can be detected by wavelet maxima. Using the skeletonization method proposed by us [5], multi width skeletons can be extracted simultaneously. The steps are as follow:

TABLE IV. SKELETON LOCATION ALGORITHM:

1. Edges points are detected using wavelet maxima (subsection 3.1);
2. The edge points and their gradient directions are written down;
3. For each of edge point goes along his gradient direction until finding another edge point, writes down the coordinates of two edge points;
4. Compute the mid point of (i, j) and (i1, j1) as a skeleton point
5. Repeat 2-4, until all edge points is computed.←

B. The New Framework

The new framework of skeletonization is based on two steps: contour repaired and skeletonization of basic strokes. In order to obtain good performance, these two procedures is woven in whole new framework. The Steps of new framework are:

1. Extract contours using wavelet maxima
2. Locate corner points using Harris detector
3. Extract primary skeletons using gradient directions [5]
4. Find all concave points
5. Extending two sides of each concave point until they meet other contour or primary points
6. Repeat 4-5, until can not find concave points
7. Skeletonization using gradient [5]

V. EXPERIMENTAL RESULTS

In order to compare our new method with the existing methods, two state of art methods, method proposed in [5] and morphologically operation, will be discussed on this section. We also give some discussions about wavelet maxima, which is very important for our motivation.

For wavelet maxima, the detection results dependent seriously on the scale. The scale must coincide to the width of strokes. If this assumption does not meet, the skeleton points can not be located. This makes its detection must be in the images with same width strokes and the detection will be lost on intersection regions.

The morphologically operation will produce some artifact in skeleton (see Fig. 6).

Method proposed in [5] also has some artifacts in skeletons, but its number is smaller than the morphologically operation's and it very easy to locate and delete. Besdies this, some broken trokes also occur on intersection regions (Fig. 7).

Our new method is very close to human perceptions (Fig 8).

Figure 6. Skeleton by morphologically operation

Figure 7. Skeleton by method in [5]

Figure 8. Skeleton by our new method

VI. SUMMARY AND FUTURE WORK

This paper presents a new scheme for skeltonization. The main advantages of this technique is skeletons extracted by our new method has good performance both in computation complexity and conforming huaman percrptions .

The future work on this direction will be two sides

1. We will consider the noise and broken strokes.
2. The method how to combine with stochastic techniques to obtain better performance.

ACKNOWLEDGEMENTS

This paper is supported by the National Science Foundation of China (No 60873102), China Postdoctoral Science Foundation (No 20070410843) and Key Foundation of Sichuan Education Office (No 07ZA090, 2006A066).

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