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AN IMPROVED PARALLEL THINNING ALGORITHM

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Abstract:

Thinning algorithms often cause stroke distortions at the crosses or intersections of strokes, which lead to bad results in pattern recognition tasks. In order to overcome these drawbacks, this paper proposes an improved thinning algorithm. By considering the eight-neighbors of the contour pixels of an image, it can produce a skeleton with good symmetry, control the large deformation at the crosses or intersections of strokes, and make a better skeleton more quickly. Moreover, it is practically immune to noise.

Keywords:

Skeleton; Thinning; Distortion; Pre-thinning; Parallel thinning; Sequential thinning

1. Introduction

In many recognition systems, such as character recognition, handwritten numeral recognition, fingerprint identification [1], quantitative metallography [2], printed circuit boards [3], biomedical systems [4] and so on, thinning is an important preprocessing step. Putting the patterns into a single pixel width is useful, and pattern analysis will be more easily performed on a single pixel width.

When keeping the connection of the original patterns, the pixels belonging to the boundary of an image will be deleted in the thinning process. The process of deleting boundary pixels is not stopped until the lines or curves have a single pixel width, and the last thinning image is defined as the skeleton of the original image.

As for the definition of skeleton, Blum gave the "grass-fire analogy" definition in 1967 [5]: given a forest in the plane polygon fields, let the fire burn from the edges of the forest at the same time and speed, the fire goes out when intersecting each other, then the set of points at which the fire goes out is denominated the skeleton of the fields (see Fig. 1). Afterwards, Pavlidis gave a standard definition [6]: Let R denote a set which contains all the points in a plane polygon field and Γ_R denote the set of its edges. $\forall P \in R$, suppose M denotes the closest point from Γ_R to P, namely, $\forall T \in \Gamma_R, |PM| \leq |PT|$. If the number of point M satisfying $|PM| \leq |PT|$ is larger than 1, i.e., $|\{M \in \Gamma_R : |PM| \leq |PT|, \forall T \in \Gamma_R\}| > 1$, then P is called a skeleton point of the plane polygon field R. The set of all the skeleton points is called the skeleton of the plane polygon field R.

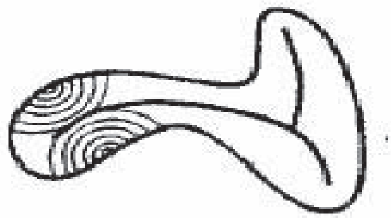

FIGURE 1. Blum's "grass-fire analogy" definition for skeleton.

There are mainly two types of skeletonization algorithms: non-iterative algorithms [7, 8] and iterative algorithms. The non-iterative algorithms yield the skeleton only once, for example, distance analysis is generally used to derive the media axis of a pattern, and the commonly used distances are City Block Distance [9], Euclidean Distance [10], Chessboard Distance, Chamfer Distance [11] and so on. Another non-iterative algorithm is the constrained Delaunay triangulation technique [12]. The iterative algorithms delete boundary pixels of a pattern successively. Besides, the deletion of a black pixel p relies on the configuration of the neighbor pixels of p. In general, thinning algorithms are iterative algorithms. They include parallel algorithms and sequential algorithms. As for parallel

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algorithms, the boundary pixels satisfying certain conditions are flagged, they are deleted simultaneously when the iteration process is over [13, 14, 15]. On the contrary, in sequential algorithms, if a boundary pixel satisfies certain conditions, it will be deleted immediately and then the iteration process continues [16, 17, 18].

So far, many thinning algorithms have been developed and applied to many kinds of patterns for distinct purposes [19, 20, 21, 22, 23]. In 1981, Davies et al. indicated that the skeleton of an image is not sole. But the final skeleton should have the same characteristics as follows:

(i) It should be thinned to a line (one-pixel wide);

(ii) It makes connectivity be maintained and makes end points be preserved;

(iii) It approaches medium axis of an original image;

(iv) It is practically immune to noise;

(v) It has a good symmetry and stability.

However, thinning algorithms often cause stroke distortions at the crosses or intersections of strokes. If they are used for pattern recognition, they may have a negative effect on the recognition result, such as misrecognition and so on. To overcome the drawbacks of thinning algorithms, the paper proposed an improved thinning algorithm by considering the eight-neighbors of the contour pixels of an image. It can produce a skeleton with a good symmetry, control large deformations at the crosses or intersections of strokes, and generate a better skeleton more quickly. Moreover, it is practically immune to noise.

2 The Improved parallel thinning algorithm

2.1 Image binarization

Binarization is a crucial step to be performed in the preprocessing system of gray scale images. The process converts $0 \sim 255$ values to 0 and 1. In fact, it affects skeleton extraction, character recognition and so on. Thresholding is a commonly used method in image binarization, as well as other methods, such as Hadamard multi-resolution analysis, Markov random field model, neural network methods and so on [24, 25, 26, 27, 28]. Whatever methods we use, although they remove excessively useless information and centralize characteristics, some information is lost. For character images, they probably break or lose the stroke and result in "small inner hole" phenomenon and so on.

The quality of binarization will affect the future thinning results.

2.2 Brief description of several parallel thinning algorithms

Before the description, let us describe some commonly used notations proposed by Rutovitz in [20] as follows.

- *The crossing number of* p: $X_R(p) = \sum_{i=1}^{8} |p_{i+1} - p_i|$, where $p_9 = p_1$.
- *The number of 0-1 patterns of* p: $S(p)$ is defined as the number of 0-1 pattern in the ordered neighbors: $p_1, p_2, \cdots, p_8, p_1$.
- *The number of nonzero neighbors of* p: $B(p) = p_1 + p_2 + \cdots + p_8$.

2.2.1 Rutovitz's thinning algorithm

In the thinning algorithm proposed by Rutovitz [20], the input pattern is scanned from left to right and from top to bottom, a dark point, p, is deleted if it satisfies the following conditions at the same time:

R_1**:** $2 \leq B(p) \leq 6$,

R_2**:** $X_R(p) = 2$,

R_3**:** $p_1 \times p_3 \times p_5 = 0$ or $X_R(p_3) \neq 2$,

R_4**:** $p_1 \times p_3 \times p_7 = 0$ or $X_R(p_1) \neq 2$.

This is a one-sub-iteration algorithm, which uses information from a 4×4 window, and the iteration will continue until no pixel is removed.

2.2.2 Deutsch's thinning algorithm

Deutsch proposed a thinning algorithm by using iteration A and iteration B in [22]. In iteration A, a dark point, p, is deleted if it satisfies the following conditions:

D_1**:** $X_R(p) = 0, 2$ or 4,

D_2**:** $B(p) \neq 1$,

D_3**:** $p_1 \times p_3 \times p_5 = 0$,

D_4**:** $p_1 \times p_3 \times p_7 = 0$,

D_5**:** if $X_R(p) = 4$, then following condition (a) or (b) holds:

(a) $p_1 \times p_7 = 1, p_2 + p_6 \neq 0$, and $p_3 + p_4 + p_5 + p_8 = 0$,

(b) $p_1 \times p_3 = 1, p_4 + p_8 \neq 0$, and $p_2 + p_5 + p_6 + p_7 = 0$.

In iteration B, a dark point is deleted if it satisfies the following conditions:

D_1**:** $X_R(p) = 0, 2$ or 4,

D_2**:** $B(p) \neq 1$,

D_6-D_8 are 180 degree rotations of D_3-D_5.

The iteration will continue until no pixel is removed.

2.2.3 Zhang and Suen's thinning algorithm

The algorithm proposed by Zhang and Suen in [21] includes two iterations C and D. In iteration C, a dark pixel, p, is deleted if it satisfies the following conditions:

Z_1**:** $2 \leq B(p) \leq 6$,

Z_2**:** $X_R(p) = 2$,

Z_3**:** $p_1 \times p_3 \times p_7 = 0$,

Z_4**:** $p_1 \times p_5 \times p_7 = 0$.

In iteration D, a dark pixel p is deleted if it satisfies conditions Z_1, Z_2, Z_5: $p_1 \times p_3 \times p_5 = 0$, and Z_6: $p_3 \times p_5 \times p_7 = 0$. The iteration stops when no more pixel is removed.

	p_3	
p_5	p	p_1
	p_7	

FIGURE 2. Points under consideration and their locations

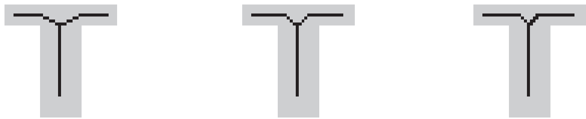
Although the above mentioned algorithms yield connected skeletons, they usually result in excessive erosion (see Fig. 3), and often cause stroke distortions at the crosses or intersections of strokes (see Fig. 4(a)(b)(c)). To improve skeleton results, a novel improved algorithm is developed based on the above methods in the next section.

2.3 The specific improved algorithm

The proposed algorithm includes three steps: pre-thinning, the first sub-iteration, the second sub-iteration.

0	0	0	0
0	1	1	0
0	1	1	0
0	0	0	0

FIGURE 3. excessive erosion example



(a) (b) (c)

FIGURE 4. Thinned results of intersecting strokes: (a) result of Rutovitz' algorithm, (b) result of Deutsch's algorithm, (c) result of Zhang and Suen' algorithm.

2.3.1 Pre-thinning

Pre-thinning is a crucial and essential step to produce a good skeleton. For a binary image with the value 1 for black pixels, the foreground pixels and 0 for white pixels, the background pixels, this paper carries out the following pre-thinning.

The binary image is scanned from the upper left corner to the lower right hand corner. For each pixel p in the image, let p_1 to p_8 be its 8 neighbors, starting from the east neighbor and counted in an anti-clockwise fashion (see Fig. 5). Let $B_{odd}(p) = p_1 + p_3 + p_5 + p_7$.

If $B_{odd}(p) < 2$, the value of p is set to 0;

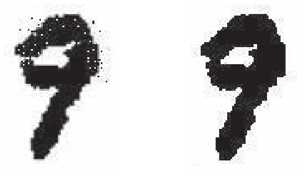
Else If $B_{odd}(p) > 2$, the value of p is set to 1;

Else, keep the value of p unchanged.

p_4	p_3	p_2
p_5	p	p_1
p_6	p_7	p_8

FIGURE 5. p and its 8 neighbor pixels

After such pre-thinning, excessive burr is removed and broken points are filled in the binary image. Consequently, the pre-thinning step removes the noise and connects the binary image. Fig. 6 shows an example of such pre-thinning.



(a) (b)

FIGURE 6. Binary image pre-thinning: (a) original image, (b)pre-thinned image.

0	1	0
0	1	0
0	0	0

(a)

0	1	0
0	1	0
0	1	0

(b)

1	1	0
1	1	0
1	1	0

(c)

1	1	1
1	1	1
0	0	0

(d)

0	0	0
0	1	1
0	1	1

(e)

0	0	0
1	1	1
1	1	1

(f)

0	1	1
0	1	1
0	1	1

(g)

1	1	0
1	1	0
0	0	0

(h)

FIGURE 7. Skeleton computation of binary image.

2.3.2 The First sub-iteration

In this iteration, a border point p (i.e. $B(p) \leq 7$) is flagged if all the following conditions are satisfied:

I_1: $2 \leq B(p) \leq 6$,

I_2: $X_R(p) = 2$,

I_3: $p_1 \times p_3 \times p_7 = 0$,

I_4: $p_1 \times p_5 \times p_7 = 0$.

Then, the flagged border points are deleted simultaneously.

By I_1, the endpoints of the stroke are preserved (see Fig. 7(a)) since each endpoint does not satisfy Condition I_1, while Condition I_2 prevents the deletions of skeleton points (see Fig. 7(b)) and maintains the connectedness of the original pattern.

The conditions I_3 and I_4 remove only south-east boundary pixels and north-west corner pixels, as well as these pixels don't belong to an ideal skeleton. Namely, the solutions to the set of equations I_3 and I_4 are $p_1 = 0$ (see Fig. 7(c)) or $p_7 = 0$ (see Fig. 7(d)) or $p_3 = p_5 = 0$ (see Fig. 7(e)).

2.3.3 The second sub-iteration

In this iteration, a border point p ($B(p) \leq 7$) is flagged if all the following conditions are satisfied:

I_1: $2 \leq B(p) \leq 6$,

I_2: $X_R(p) = 2$,

I_5: $p_1 \times p_5 \times p_7 = 0$,

I_6: $p_3 \times p_5 \times p_7 = 0$.

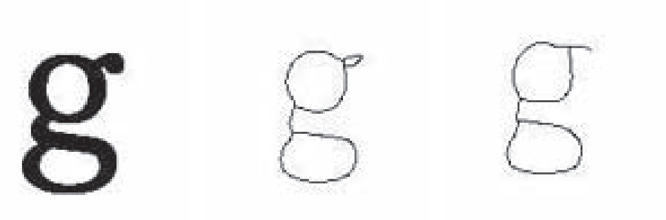
Then, the flagged border points are deleted simultaneously.

The conditions I_5 and I_6 remove only the south-west boundary pixels and the north-east corner pixels, as well as these pixels don't belong to an ideal skeleton. Namely, the solutions to the set of equations I_5 and I_6 are $p_7 = 0$ (Fig. 7(d)) or $p_5 = 0$ (Fig. 7(g)) or $p_1 = p_3 = 0$ (Fig. 7(h)).

Then, the flagged border points are deleted simultaneously. The iteration stops when no more pixel is removed.

3 Experiments and comparison

The proposed algorithm yields good skeleton concerning connectivity and noise immunity. At the same time, it preserves a good symmetry, and mostly controls the large deformations at the intersections of strokes, moreover, the seeking conditions of the boundary pixels which will be deleted from the image are simple. In order to evaluate the performance of the proposed algorithm, Rutovitz's thinning algorithm [20], Deutsch's thinning Algorithm [22], and Zhang and Suen's thinning algorithm [21] are chosen for comparison. By comparison, it is shown that the proposed thinning algorithm leads better results, especially at the crosses or intersections of strokes (Fig. 8,9 and Fig. 10).



(a) (b) (c)

FIGURE 8. Comparison of results: (a) original image, (b) result of Zhang and Suen's algorithm, (c) result of proposed algorithm.

4 Conclusions

Thinning algorithms have been researched extensively in image processing and pattern recognition.

By the improved parallel thinning algorithm proposed in this paper, the obtained skeletons approach medium axis of an original image, and good symmetry has been preserved. At the

(a)

(b)

(c)

FIGURE 9. Comparison of results: (a) original image, (b) result of Zhang and Suen' algorithm, (c) result of the proposed algorithm.

same time, the proposed parallel thinning algorithm maintains the connectivity of strokes and preserves the end points of the skeleton. It is practically immune to noise, and the large deformations at the crosses or intersections of strokes have mostly disappeared, so a better skeleton is obtained.

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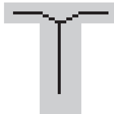
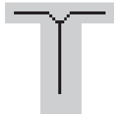
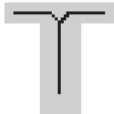


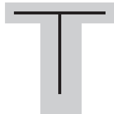
(a)



(b)



(c)



(d)

FIGURE 10. Comparison of results: (a) result of Rutovitz's algorithm, (b) result of Deutsch's algorithm, (c) result of Zhang and Suen's algorithm, (d)result of the proposed algorithm.

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