A HYBRID THINNING ALGORITHM FOR
BINARY TOPOGRAPHY MAP

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ABSTRACT  A hybrid thinning algorithm for binary topography maps is proposed on the basis of parallel thinning templates in this paper. The algorithm has a high processing speed and the strong ability of noise immunity and preservation of connectivity and skeleton symmetry. Experimental results show that the algorithm can solve the thinning problem of binary maps effectively.

1 Introduction

The thinning of binary images is an important technology in images processing. It is often used to extract the skeletons of binary images for recognizing binary objects. It has been widely applied in map digitizing, characters recognition, advanced analysis of images and so on.

The thinning algorithms so far developed can be classified into two classes. One is sequential algorithms. The other is parallel algorithms. Both algorithms extract the skeletons of objects by removing the outer layer pixels of objects. They usually have two steps. The first step is to identify boundary pixels; the second step is to remove non-critical boundary pixels. Sequential algorithms remove the non-critical boundary pixels while identifying the boundary pixels. Parallel algorithms remove the boundary pixels after identifying all the boundary pixels. Hence a sequential thinning is substantially faster than a parallel thinning. Since in real time environment fast processing is required, the parallel algorithms cannot meet the demand especially if the image size is large. Unfortunately, again, sequential thinning algorithms may have difficulty in preserving the connectivity and skeleton symmetry. On the other hand, parallel algorithms have advantages of preserving the connectivity and skeleton symmetry. For reasons given above, parallel algorithms such as Hilditch algorithm and Rosenfeld algorithm are mainly used in map digitizing systems. However, with the increase of maps size, the shortage of the parallel algorithms becomes more and more obvious. Therefore, in order to improve the thinning speed, it is necessary to improve present parallel algorithms.

A. Datta presented a new parallel algorithm in 1994. The algorithm removes the boundary pixels with four simple templates. It has properties of a good skeleton, connectivity, noise immunity, and good medial axis representation. But its thinning speed is low because it only removes one type of boundary pixels in each thinning pass. On the basis of the parallel algorithm by A. Datta, this paper presents a hybrid thinning algorithm. The algorithm combines the feature of high speed of sequential algorithms with the robust feature of parallel algorithms. It can solve the contradiction between efficiency and robustness of thinning algorithms.

2 The hybrid thinning algorithm

2.1 Definitions and theorems

We shall now list the definitions that will be used
in different contexts of our discussion. For any object pixel \( P \) there are four 4-neighbouring pixels (4-neighbours) namely \( P_2, P_4, P_5 \) and \( P_7 \); and eight 8-neighbouring pixels (8-neighbours) namely \( P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8 \) (Fig. 1(e)).

In this paper we have considered the object (denoted by 1, unless specifically mentioned otherwise) to be 8-connected and hence the background or hole (denoted by 0) are 4-connected.

**Definition 1** The boundary of an object is defined by the set of the object pixels each having at least one non-object pixel as its 4-neighbour.

**Definition 2** The 4-connected component of non-object pixels which contains the top and bottom rows and the rightmost and leftmost columns of the image is the background; and any other four component of non-object pixels is a hole.

**Definition 3** A pixel \( P \) is called critical if its removal causes any disconnectivity or formation of a hole.

**Definition 4** A skeletal leg is a limb of thickness with one end not connected to anything. The pixel not connected to anything is called an end pixel. In other words, the end pixel has exactly one 8-neighbour.

**Definition 5** A pixel \( P \) is said to be removable if it is neither an end nor a critical pixel.

Consider the \( 3 \times 3 \) window around pixel \( P \), call it \( W \). Let \( S \) be the set of 8 pixels in the window (Fig. 1(e)) excluding the pixel \( P \). That is,

\[
S = (P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8)
\]

If we concentrate only onto the window \( W \), then we have the following theorems:

**Theorem 1** If \( P \) matches (in the middle of) any of the four templates (Fig. 1(a) ~ (d)) then the following are true respectively:

1. \( P \) is critical if \( P_2 = 0 \) and \( P_3 = 1 \) or \( P_7 = 0 \) and \( P_8 = 1 \);
2. \( P \) is critical if \( P_4 = 0 \) and \( P_1 = 1 \) or \( P_5 = 0 \) and \( P_3 = 1 \);
3. \( P \) is critical if \( P_2 = 0 \) and \( P_1 = 1 \) or \( P_7 = 0 \) and \( P_6 = 1 \);
4. \( P \) is critical if \( P_4 = 0 \) and \( P_6 = 1 \) or \( P_5 = 0 \) and \( P_8 = 1 \).

**Theorem 2** If \( P \) matches the template in Fig. 1(e) then \( P \) is an end pixel if \( P_1 + P_2 + P_3 + P_6 + P_7 + P_8 = 0 \) (equivalently, \( P_1 + P_2 + P_3 + P_6 + P_7 + P_8 = 0 \)). Similar conditions hold for the other three templates.

**2.2 The hybrid thinning algorithm**

The algorithm proposed here is iterative in nature. It goes on removing the boundary pixels in each iteration. The removal of pixels is done in sequence. To remove boundary pixels in different directions, the scanning direction is alternative. In other words, the scanning direction in odd iterations is from left to right, and the scanning direction in even iterations is from top to bottom (Fig. 2). In addition, in order to prevent the skeleton non-symmetry caused by sequential thinning, a couple of templates are used in each iteration. Fig. 1(a) and (c) are for odd iteration, and Fig. 1(b) and (d) are
for even iteration. Fig. 1(a), (b), (c) and (d) correspond to the right, top, left and bottom boundary pixels respectively.

Like traditional sequential thinning algorithms, processing an object pixel consists of two steps. The first step is to identify whether the object pixel is a boundary pixel or skeleton leg. Using Fig. 1(a) – (d) and a 3 x 3 windows, four types of boundary pixels and skeleton legs can be identified. The second step is to remove unnecessary boundary pixels (not critical ones) according to theorem 1.

However, the difference from traditional sequential algorithms is that the proposed algorithm alternatively uses a couple of templates to identify object pixels. When a present object pixel is identified, the used template is the opposite template which was used to identify the previous non-critical boundary pixel. In other words, if the previous non-critical boundary pixel matches Fig. 1(a) or (b), the present object pixel should be identified with Fig. 1(c) or (d). This method can only remove the couple of the outer most layer pixels of an object so as to reserve the skeleton symmetry. Moreover, it can speeden the thinning process.

Take Fig. 3 for example. A and B are two objects. Pixels a, b and c are three pixels in object A. Pixels a and c are boundary pixels. Pixel b is an inner pixel. Pixel d is a boundary pixel in object B. Assume the scanning direction is from left to right. Firstly, pixel a is removed because it matches Fig. 1(c) and does not meet the critical condition (Theorem 1(5)). Using the above method, pixel b is identified with Fig. 1(a) which is opposite to Fig. 1(c). From Fig. 3, it is clear that pixel b does not match Fig. 1(a), so pixel b is reserved. Pixel c is also identified with Fig. 1(a). According to Fig. 3, it matches Fig. 1(a) and does not meet the critical condition (Theorem 1(5)). Therefore, pixel c is removed. Because pixel c is not a critical boundary pixel and matches Fig. 1(a), pixel d is identified with Fig. 1(c) which is opposite to Fig. 1(a).

From Fig. 3, pixel d is not a critical boundary pixel (Fig. 1(c)) and is removed. Similar processes hold for other pixels. The bold pixels in Fig. 3 are the thinning results. This example shows that the proposed algorithm can reserve the symmetry of the object skeletons by removing left and right boundary pixels sequentially with alternative templates. Comparing the algorithm with A. Datta’s algorithm, the former only removes one type of boundary pixels in each iteration because of only using one template, but the later remove two types of boundary pixels in each iteration because of using two templates. Therefore, the thinning speed of the proposed algorithm is about twice as fast as that of A. Datta’s algorithm.

If scanning direction is from top to bottom, Fig. 1(b) and (d) are used as the alternative templates. The processes are similar to the case of the above horizontal scanning.

On the basis of the theorems and definitions mentioned above, the thinning algorithm consists of following steps:

A. Setting up flags

Set up template selection flags namely m and n.

Let m = 0, then n = 0. (If m = 0, Fig. 1(c) is selected to identify left boundary pixels; if m = 1, Fig. 1(a) is selected to identify right boundary pixels. If n = 0, Fig. 1(b) is selected to identify up boundary pixels; if n = 1, Fig. 1(d) is selected to identify bottom boundary pixels.)

B. Thinning operation

In each odd iteration, the thinning operation in each row can be done as follows.

(1) From left to right, search boundary pixels with Fig. 1(a) and (d). Once find the boundary pixel which matches Fig. 1(a) or (c) and is not critical, remove the boundary pixel and set m = 0 or
3 Experimental results

The proposed algorithm has been tested on characters and a topography map, and the results are compared with Rosenfeld's algorithm and A. Datta's algorithm.

Fig. 4 (a) - (c) show two digits containing noises and their thinning results by Rosenfeld's algorithm and the proposed algorithm. From this figure, we can see that the original object "4" is changed into a clearer digit "4" by the proposed algorithm, but it is changed into a triangle "Δ" by Rosenfeld's algorithm.

Table 1 is the results of comparing the thinning speed by the proposed algorithm with that by A. Datta's algorithm. It shows that the iteration times by the proposed algorithm are less than that by A. Datta's algorithm, and the thinning time is about half of that by A. Datta's algorithm.

| Methods                  | Thinning time | Iteration times |
|--------------------------|---------------|-----------------|
| A. Datta algorithm       | 46 seconds    | 8 times         |
| the proposed algorithm   | 24 seconds    | 6 times         |
4 Conclusion

The proposed algorithm here uses four 1×3 and 3×1 templates and alternative matching method to prevent the disconnectivity and non-symmetry caused by traditional sequential algorithms and noises. This algorithm combines the feature of high speed of sequential algorithms with the robust feature of parallel algorithms. It is practical for the thinning of binary maps.

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(Continued from Page 56)

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