A Continuous Skeletonization Method Based on Distance Transform

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Abstract. A skeleton extracted by distance map is located at geometrical center, but it is discrete, on the other hand, we can get a continuous skeleton with morphological algorithm, but the skeleton is not located at the geometrical center of the object image. To get a continuous skeleton that is located at geometrical center of the object image, a continuous skeletonization method based on distance transform is proposed in this paper. At first, the distance function is calculated with respect to the object boundary, which is defined as a new indicator for the skeletonization. Then, a thinning algorithm with five deletion templates is given, which can be applied to get a continuous and centered skeleton indicated by distance map. The performance of the proposed algorithm is compared with existing algorithms, experimental results confirm the superiority of our proposed approach.

Keywords: Skeletonization, Distance map, Morphology, Thinning.

1 Introduction

Skeletonization is useful when we are interested not in the size of the pattern but rather in the relative position of the strokes in the pattern. It plays an important role in digital image processing and pattern recognition [1], especially for the analysis and recognition of binary images [2]. It has been widely used in such areas as object representation, data compression, computer vision, and computer animation [3]. Skeletons provide a simple and compact representation of a 2D shape that preserves many of the topological and size characteristics of the original. The process can be viewed as a transformation to transform the width of a binary pattern into just one single pixel. Essentially, such transformation can be achieved by successively removing points or layers of outline from a binary pattern until all the lines or curves are of unit width. The resulting set of lines or curves is called the skeleton of the pattern. As we know, the purpose of skeletonization is to reduce the amount of redundant data embedded in a binary image and to facilitate the extraction of distinctive features from the binary image thereafter. A good skeletonization algorithm should possess the following properties: (1) preserving connectivity of

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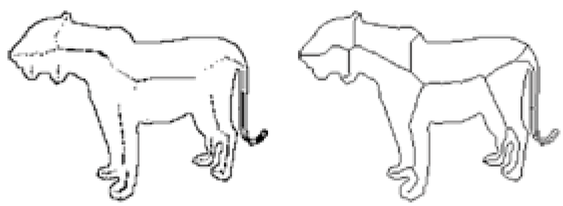
skeleton, (2) converging to skeleton of unit width, (3) preserving original topology, and (4) locating at the geometrical center of the object image.

Abundant of thinning algorithms have been proposed to obtain a thin-line representation of binary patterns [4]. Most of existing thinning algorithms can be divided into two main types. In the first category also known as “distance transform” [5]. The second category consists of “thinning algorithm” [6] which are constructed by successive removal of outer layers of pixels from an object while retaining any pixel whose removal would alter connectivity or shorten the legs of the skeleton. The aim of the first algorithm is getting distance field with European, chessboard, and so on [7], and the spine of the distance field is taken as the skeleton. Due to the extraction of the spine is difficult, so it is not easy to get a accurate spine. Generally, every point is specified by giving its distance from the nearest boundary point. The skeleton is defined as the set of points whose distance from the nearest boundary is locally maximum. As shown in Fig. 1(a), the position of the skeleton of this method is accurate, but the skeleton is made up of many discrete maximum points, so the skeleton is not a continuous one.



(a) (b)

Fig. 1. Skeletons Extracted by Distance Transform and Morphological Algorithms (a) Distance Transforms Algorithms, (b) Morphological Algorithms

Skeletonization based on morphological algorithms is the process of peeling off of a pattern as many pixels as possible without affecting the general shape of the pattern. In other words, after pixels have been peeled off, the pattern should still be recognized. There are many algorithms which were designed for this aim. Here we are concerned with one of them namely the Hilditch's algorithm [8]. This consists of performing multiple passes on the pattern and on each pass; the algorithm checks all the pixels and decide to change a pixel from black to white if it satisfies the deleting conditions. This algorithm turned out to be not the perfect algorithm for skeletonization. The result of this algorithm is shown in Fig. 1(b), the skeleton is continuous, but the position of the skeleton is not centered. Other morphological algorithms are just the same as Hilditch's algorithm; the position of the skeleton is not accurate enough.

For taking advantage of morphological algorithms and distance transform, we propose a continuous skeletonization algorithm based on the distance transform. The distance transform of the image is calculated at first, and a distance map will be gotten, then performing our morphological thinning algorithm on the image along the contour of the distance map. The performance of the proposed algorithm is compared with the existing algorithms. The result of this algorithm is centered with respect to morphological algorithms, and it is better than those generated by distance transform algorithms on continuity. Experimental results confirm the superiority of our proposed approach.

2 Distance Transform

The distance transform is a powerful tool in digital image processing. The result of this operation is called distance map. Distance transforms are important preprocessing steps in complex image analysis systems. Operations such as skeletonization, can be relied on accurate distance maps.

The distance transform labels each object element with the distance between this element and the nearest non-object element. For all elements $p \in P$, the algorithm determines

$$t(p) = \min_k \{d(p,q_k) : t(q_k) = 0 \wedge 0 \le k \le m\} \cdot \tag{1}$$

where $d(p,q_k)$ denotes a metric, and m is the total number of elements in the picture. It follows that $t(p)=0$, for all non-object elements. Obviously, the values for $t(p)$ depend on the chosen metric. Chessboard is a frequently-used distance metric, and we utilize this metric in our algorithm.

A 3×3 square element is used in chessboard distance transform, just as shown in Fig. 2, taking a point p of object shape P into account; arrange the distance value of 8 neighbours of p as a vector V

$$\begin{aligned} &\mathrm{V} = [\mathrm{t}\,(\mathrm{r}-1,\mathrm{c}), \mathrm{t}\,(\mathrm{r}-1,\mathrm{c}+1), \mathrm{t}\,(\mathrm{r},\mathrm{c}-1), \\ &\mathrm{t}\,(\mathrm{r},\mathrm{c}+1), \mathrm{t}\,(\mathrm{r}+1,\mathrm{c}-1), \mathrm{t}\,(\mathrm{r}+1,\mathrm{c}), \mathrm{t}\,(\mathrm{r}+1,\mathrm{c}+1), \mathrm{t}\,(\mathrm{r}-1,\mathrm{c}-1)\,] \end{aligned} \cdot \tag{2}$$

– 8	– 1	– 2
– 7	– p	– 3
– 6	– 5	– 4

Fig. 2. Nneighbours vector of pixel p

The distance of pixel p is the minimum of V plus 1

$$t_p(r,c) = \min(V) + 1 \cdot \tag{3}$$

The flow chart of the chessboard distance algorithm is shown in Fig. 3.

From the algorithm of chessboard distance transform, we can find that the chessboard distance field have following characteristic:1) the distance value of boundary pixel of object shape is 1, 2) from the boundary of the shape to local maximum point, the distance value increases, 3) the distance value stand for the distance between this element and the nearest non-object element, 4)if a distance value is locally maximum, then the distance value is not smaller than its neighbours', and this point is the centre of a maximal inscribed circle responding. Fig. 5 shows a distance gray-scale map of tiger image, those pixels whose gray are deeper are farther from boundary, and the lighter ones are near the boundary.

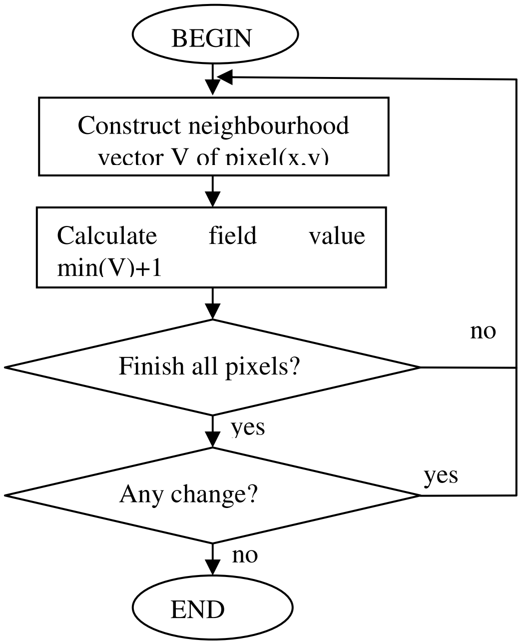


Fig. 3. Flow chart of chessboard distance algorithm

Fig. 4 is an example of chessboard distance field.

0	0	0	0	0	0	0
0	1	1	1	1	1	0
0	1	2	2	2	1	0
0	1	2	3	2	1	0
0	1	2	2	2	1	0
0	1	1	1	1	1	0
0	0	0	0	0	0	0

Fig. 4. Chessboard Distance Field

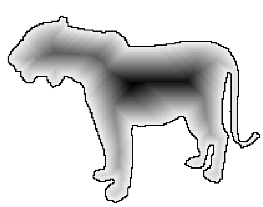


Fig. 5. Distance gray-scale map of tiger shape

Joining points of equal distance value in Fig. 5, a contour map come into being. The spine of this contour map stands for the right position of skeleton. Because the digital image is discrete, the skeleton gotten is not continuous.

3 Our Computational Scheme

Based on the discussion above, we can find that the data of distance map has a distinctive characteristic. The distance value increases from the boundary to the interior, and the gradient of distance is same at all direction. This is decided by the nature of distance calculating algorithm, every distance value calculated by its neighbours from all direction. Just because of this, the spine of distance map indicates the skeleton position accurately. Related to the continuous property of thinning algorithm, the continuous skeletonization based on distance transform is proposed in this article, the thinning process indicated by the contour of distance field. Two main steps are included in our algorithm.

1）Running the chessboard distance algorithm on the object image, getting the distance field, saving the maximum of distance to variable Max.
2）Selecting 5 deletion templates as in Fig6, changing the pixel that is satisfying these 5 deletion templates and their rotated models into background. Repeating this procedure from the boundary to the interior of given shape by the contour of distance field.

0	1	1	0	1	1	0	1	1	0	1	1	0	1	1
0	p	0	0	p	1	0	p	1	0	p	1	0	p	1
0	0	0	0	0	0	0	0	1	0	1	1	1	1	1
	(a)			(b)			(c)			(d)			(e)	

Fig. 6. Five deletion templates

As shown in Fig. 6, the pixel p is the object pixel. The deletion conditions are 1) “1” pixels are continuous in the neighbours of pixel p, 2) the number of “1” pixels is 2 to 6. When these two conditions are satisfied, turn the pixel p into background. The executed procedures as follow:

a) $i = 0$;
b) $i = i + 1$;
c) Check those pixels whose distance values are i, changing the pixel that is satisfying those deletion templates and their rotated models into background;
d) If $i < Max$, go to b);
e) If there is any change for all elements, go to b).

If there is not any change, the iteration procedure is finished.

4 Experiment Results and Analysis

Programming and running our algorithm to extract image skeleton for different kinds of planar shape, the shape of tiger is shown in Fig. 7, and Fig. 7 (a) is the original image(157×514 pixels), the Fig. 7 (b) is the skeleton extracted by our algorithm. Drawing a comparison for experimental results (Fig. 1, Fig. 5 and Fig. 7), conclusion is shown as follow: the position of skeleton in Fig. 1 (a) and Fig. 7 (b) complies with the spine in Fig. 5, which is the set of the ceter of maximal inscribed circle of the given shape, and it is in accord with the definition of skeleton. The skeleton extracted by our algorithm is continuous, as can be observed in Fig. 7 (b), and it preserves the tiger shapes, the processing result of this algorithm is better than distance transform and morphological thinning algorithms.

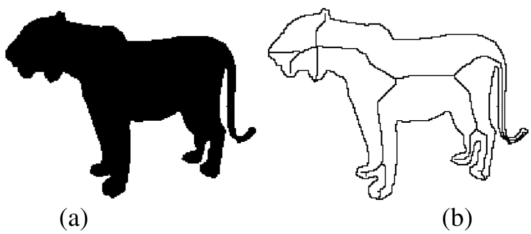


Fig. 7. Skeletonization of Tiger Shape (a) Original shape (b) the skeleton extracted by our algorithm

We also test our algorithm on horse shape; Fig. 8 shows the result of thinning when using our approach in comparison with distance transform and morphological thinning algorithm. (a) is the original shape, (b) is the distance gray-scale map, (c) is the

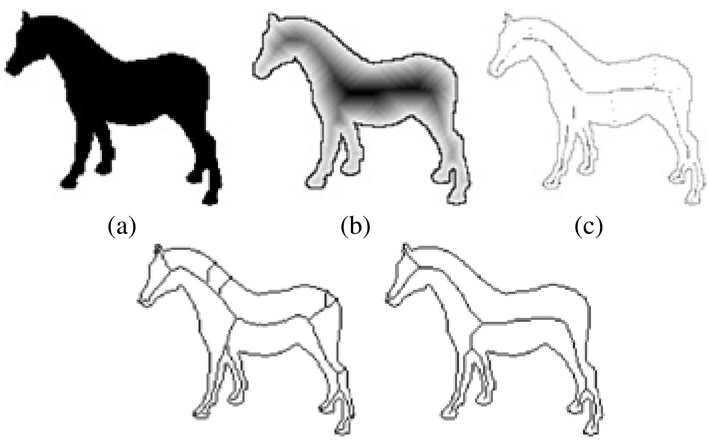


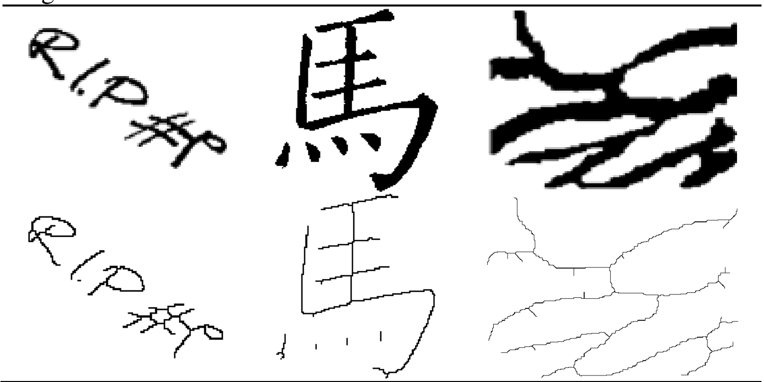
Fig. 8. Skeletonization of Horse Shape (a) Original Shape (b) Distance Gray-Scale Map of Tiger Image (c)The Skeleton Extracted by Distance Transform (d) The Skeleton Extracted by Morphological Algorithm (e)The Skeleton Extracted by Our Algorithm

skeleton extracted by distance transform, (d)is the skeleton extracted by morphological algorithm, (e)is the skeleton extracted by our algorithm. A similar conclusion can be drawn as the tiger shape: we can get a continuous and centered skeleton of horse shape, the result of our algorithm (Fig8 (e)) is better than distance transform (Fig8 (c)) and morphological thinning algorithms (Fig. 8 (d)).

A lot of other shapes have been tested on our algorithm, the results of these experiments confirm the universality of the algorithm. As can be observed in Table 1, our algorithm does an excellent job here, it preserves the image shapes. At the same time, the result skeleton is continuous and centered, keep the right angles and interconnections close in terms of the shape to the original picture. The universal performance of this algorithm proved its applications in practice.

Table 1. Results of thinning by our algorithm on different kinds of images

English words	Chinese words	Blood vessel



5 Conclusions

A very large number of algorithms in the skeletonization area have been proposed. Algorithms based on distance transform and morphology were discussed and compared. Short summaries with the available results of these two algorithms were also presented. The main points of view were the result of methodology method is not centered enough, and the result of distance transform is not continuous enough.

We presented a robust and simple method to extract an approximate skeleton for a planar image. The proposed method is based on distance transform and a methodology approach with five new deletion templates. In the first step, the chessboard distance map is calculated, then run the methodology algorithm indicated by the contour in distance map. Many different images have been tested on this method.

The proposed algorithm evolved from distance transform and methodology algorithm introduces its advantages in terms of two important characteristics:centered and continuous. The examples shown in Section 5 for graphical symbols, handwritten words and medical image demonstrate the processing quality of our algorithm. This fact proves the universal character of the algorithm.

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References

1. Komala Lakshmi, J., Punithavalli, M.: A Survey on Skeletons in Digital Image Processing. In: Proceedings. 2009 International Conference on Digital Image Processing, ICDIP 2009, pp. 260–269 (2009)
2. Srijeyanthan, K., Thusyanthan, A., Joseph, C.N., et al.: Skeletonization in a Aeal-Time Gesture Recognition System. In: Proceedings of the 2010 5th International Conference on Information and Automation for Sustainability, ICIAfS 2010, pp. 213–218 (2010)
3. Liu, X.X., Dean, M.N., Summers, A.P., et al.: Composite Model of the Shark's Skeleton in Bending: A Novel Architecture for Biomimetic Design of Functional Compression Bias. Materials Science and Engineering C 30(8), 1077–1084 (2010)
4. Rakesh, G., Rajpreet, K.: Skeletonization Algorithm for Numeral Patterns. International Journal of Signal Processing, Image Processing and Pattern Recognition 1(1), 63–72 (2008)
5. Latecki, L.J., Li, Q.N., Bai, X., et al.: Skeletonization Using SSM of the Distance Transform. In: Proceedings - International Conference on Image Processing, ICIP 2007, vol. 5, pp. V349–V352 (2007)
6. Xie, F., Xu, G., Cheng, Y., et al.: Human Body and Posture Recognition System Based on an Improved Thinning Algorithm. IET Image Processing 5(5), 420–428 (2011)
7. Xia, H., Tucker, P.G.: Finite Volume Distance Field Solution Applied to Medial Aaxis Transform. In: 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, vol. 1(82), pp. 114–134 (2010)
8. Naccache, N.J., Shinghal, R.: Investigation Into the Skeletonnization Approach of Hilditch. Source: Pattern Recognition 3(17), 279–284 (1984)