An Automatic Pruning Method for Skeleton Images

Jun Ma
Dept. of Infocommunication Technologies
Belarusian State University of Informatics and Radioelectronics
Minsk, Belarus
majun1313@hotmail.com

Xunhuan Ren
Dept. of Infocommunication Technologies
Belarusian State University of Informatics and Radioelectronics
Minsk, Belarus
renxunhuan@bsuir.by

Valery Konopelko
Dept. of Infocommunication Technologies
Belarusian State University of Informatics and Radioelectronics
Minsk, Belarus
volos@bsuir.by

Victor Tsviatkou
Dept. of Infocommunication Technologies
Belarusian State University of Informatics and Radioelectronics
Minsk, Belarus
vtsvet@bsuir.by

***Abstract.* Skeletons can be regarded as a compact shape representation in that each pattern can be completely reconstructed from its skeleton. One of the limitations of the application of the skeleton for object analysis and recognition is the existence of redundant skeleton branches. Skeleton pruning is an effective way to remove the redundant skeleton branches in the skeleton images. However, most of the existing pruning methods require manual tuning of the parameter to control the power of pruning, which is not convenient to use. In this paper, we have proposed a fully automatic pruning method that adjusts the power of the pruning according to the image and achieves good pruning results in the experiment.**

***Keywords:* skeleton, automatic skeleton pruning, skeletonization**

I. Introduction

Skeleton, also termed as medial axis, is an efficient and compact descriptor for pattern recognition. Skeletonization is a set of methods that extract the skeleton from the 2D shapes or patterns while preserve topology characters of the original image. After Blum [1] proposed the primitive skeletonization by simulating the fire-grass, a large amount skeletonization emerged. These methods can be majorly divided into three major groups [2], which are continuous geometric approach, continuous curve propagation approach, and digital approach.

Continuous geometric approach generate the skeleton by focus on the properties of Blum's medial symmetry axis. The most popular method under this category is the Voronoi skeletonization. These methods require many vertices to generate a proper polygonal approximation of a shape. Therefore, Voronoi skeletonization yield many unwanted skeletal branches [3] that contribute little information for overall shape.

The continuous propagation curve approach [4] is modeled using partial differential equations, in which certain singularities occur, which are referred to as shocks. The flaw of this method is that the topology of the resulting skeleton may altered.

The Digital approach of skeletonization is based on simulating Blum's grassfire propagation as an iterative erosion on a digital grid under certain predefined topological and geometric rules [2]. By adopting the parallel strategy, these methods are very fast. In addition, these methods can suppress tiny boundary noise and avoid generating unwanted branches to some extent.

One of the limitations of the use of the skeleton in the application is caused by the fact that there are many spurious skeleton branches that resulted from the small deformations along the boundary [5]. In order to overcome this problem and obtain clean skeletons, a lot of pruning algorithms have proposed by the researchers. Xiang Bai and his team have proposed a pruning method by using the techniques of contour partition with discrete curve evolution [6]. Their method is guaranteed to preserve skeleton topology, does not shift skeleton, and does not shrink the remaining branches. Wei Shen [7] proposed another pruning methods by considering significance measure of bending potential ratio (BPR), in which the decision regarding whether a skeletal branch should be pruned or not is based on the context of the boundary segment that corresponds to the branch. Since their BPR

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evaluates both local and global shape information, thus it is insensitive to local boundary deformation. HongZhi Liu and his colleagues have proposed a skeleton pruning algorithm based on information fusion [8]. They treat skeleton pruning as a multi-objective decision-making problem. They combined different measurements of branch significance including region reconstruction, contour reconstruction and visual contribution. Guo Siyu has proposed a skeleton pruning method based on saliency sorting [9]. Their method decomposes a skeleton into a number of skeletal components (SCs), and terminal SCs are removed one by one according to a saliency measure. Then SCs may be merged into a new one after each removal. The removal process continues until the desirable number of terminals are achieved.

These pruning methods are all worked well, but all of them have some parameters need to manual tuning. For examples, Bai's method need to provide the stop parameter k, Shen's method need provided the value of the filter threshold t, for Liu's method, there are more parameters rather than one need to specify. Because of these parameters are not very intuitive, a suitable parameter is hard to find. It is necessary to develop a method for automatically chose a proper parameter for pruning without any intervention of the people.

In this paper, we have proposed an automatic pruning method based on the Bai's pruning skeleton algorithm. The experiment on the images from the benchmark of MPEG-7 has proved that the proposed method can properly pruning the input skeleton for different shape image and produce a relative clean skeleton.

II. Proposed Method

A. Motivation

For Bai's pruning algorithm, which is based on the discrete curve evolution partition method [10–12], a parameter k (which should above or equal three) is required for calibrating the strength of pruning. The value of the parameter k can dramatically alter the level of completeness of the resulting skeleton. As shown in Fig. 1. Therefore, to generate a proper skeleton, It is necessary to manually select a proper k for each shape according to the real human visual perception. Whereas, the intervention of people will dramatically reduce the efficiency of the skeletonization. A complete automatic pruning method is very helpful to extract a relatively good skeleton in a high-efficiency way.

Since Bai's method can generate hierarchical skeletons, it has the potential to conduct pruning automatically. It can be noticed that in Fig. 1., when k is set as the lowest value 3, there only three skeleton branches are reserved, which is not good for representing the original star. With the increase of the k parameter, more and more skeleton branches are retained.

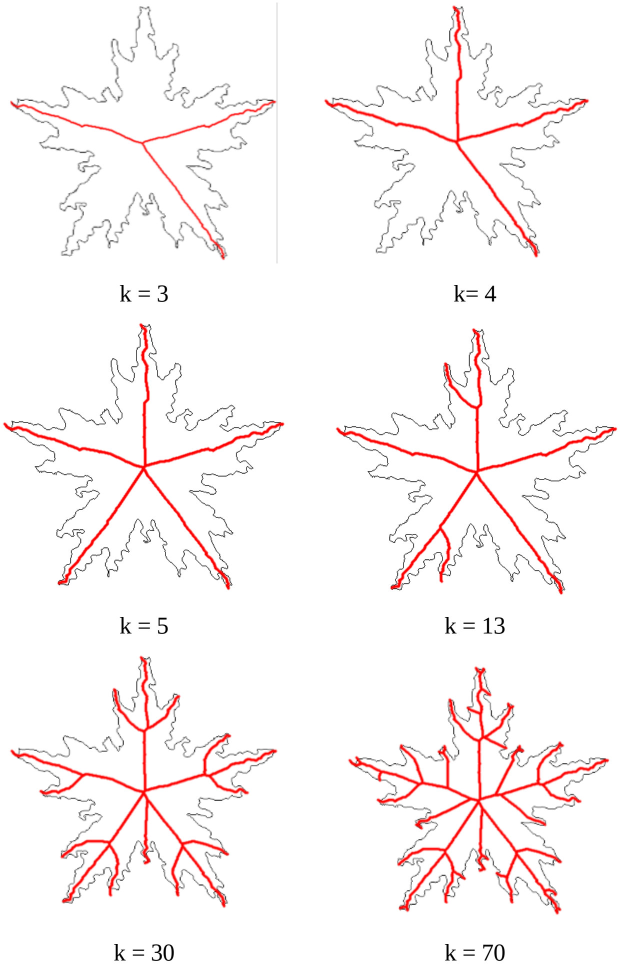

Fig. 1. The result skeleton under different parameter k

When the k is rise to 5, the extracted skeleton already can represent the original structure well. But if we continue to enlarge the value of the parameter k, many unwanted branches are also introduced. This inspires us to propose an automatic pruning method based on Bai's method.

B. Detail of the Proposed Method

Before introducing the proposed method, the original input binary image *I* should first respective processed by the skeletonization algorithm to extract the skeleton and discrete curve evolution algorithm to extract the salient points. For the skeletonization algorithm, we chose to use the algorithm proposed in [13], since it has a good performance in terms of computational speed and can suppress slight boundary noise, which can effectively reduce workload in the pruning procedure. In the discrete curve evolution algorithm, we followed Bai's method. The skeleton and salient points are denoted as *S* and *P* respectively.

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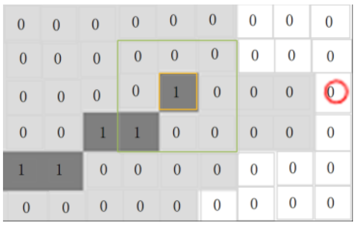

Fig. 2. The black pixels are skeletal pixels, the grey pixels are the deleted pixels during skeletonization, the yellow pixel is the endpoint, the green window is the 8-neighborhood of the endpoint, the red circle highlight the salient point

The proposed method begins with pairing all the endpoints *E* in the skeleton *S* with their nearest salient point *P*. Endpoints are referred to those foreground pixels that have only one foreground neighbor in his 8-neighborhood (See Fig. 2). Then we sort these endpoints from large to small according to the value of their paired salient points. Hereafter, we iteratively reconstruct the original image from the partial skeleton which consisted by the partial skeleton branches that directly connected to the selected endpoints. In the first iteration, we only select the top three endpoints. Next, two comparisons are conducted which are the area comparing of current reconstruction image *R* with the original image *I*, and area comparing of current reconstruction with the last reconstruction. If the reconstruction image *R* cannot cover most of area of the original image or there is obvious area increment in reconstruction images between two successive two iterations, then including more endpoints in sequence and continue iteration. We summarize the whole process into the following algorithm.

Automatic pruning method

***Input* :** Skeleton *S*, Salient Points *P*, Original image *I*

***Output*:** Pruned Skeleton *PS*

Step 0: Initialize the all the pixels in Pruned Skeleton *PS* and in the reconstruct image *R1* are backgrounds pixels, set *count* as 0.

Step 1: Search all the endpoints in *S*, paired them with the nearest *P*, and conduct the sort.

Step 2: Reconstruct the image by using top (*count+3*) endpoints along with their skeletal branches and saved it as *R2.*

Step 3: If the *area*(*R2-R1*)*/*(*area*(*R1*)*+1*) is above 0.1 **or** *area*(*I-R2*)*/area*(*I*) is less than 0.9 **then** jump to step 4, **otherwise** jump to step 5.

Step 4: *count* = *count+1, R1* = *R2*, jump to step 2.

Step 5: Pruned Skeleton *PS* are constructed by the top (*count+3*) endpoints along with their skeletal branches. Return *PS.*

III. Experiments And Comparison

In this section, we will compare the result of the proposed method and the result of the Bai's method. We have specified the proper parameter k according to our eye-level view assumption in advance. In the other hand, to enhance the contrast, we also presented the original skeleton that extracted by [13]. All the test images are come from the benchmark of the MPEG-7.

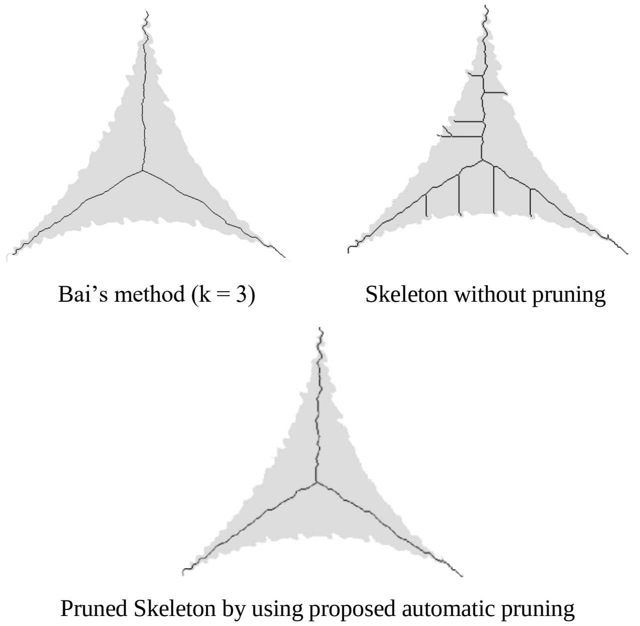

Fig. 3. Skeleton generated from the device4-17 of the MPEG-7

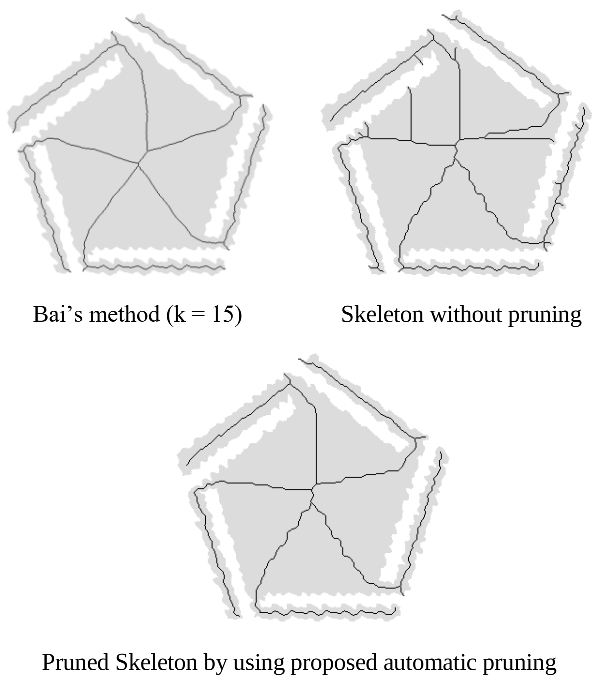

Fig. 4. Skeleton generated from the device6-18 of the MPEG-7

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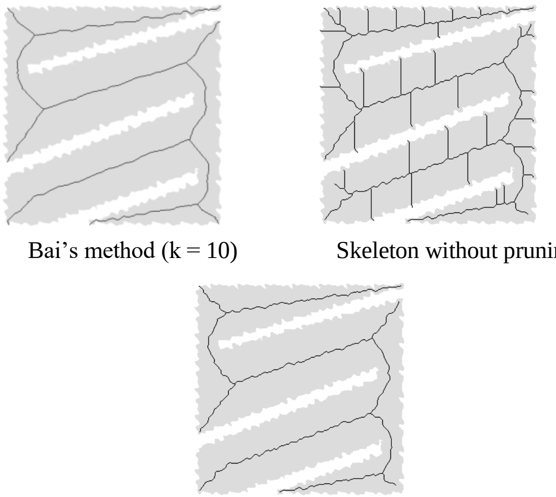

Bai's method (k = 10) Skeleton without pruning

Pruned Skeleton by using proposed automatic pruning

Fig. 5. Skeleton generated from the device3-18 of the MPEG-7

From Fig. 3 to Fig. 5, it can be noticed that for the different input images, although Bai's method generates very good skeletons, which maintained the topology component and succeeds in deleting unwanted branches that are caused by the boundary perturbation, the parameter k are different. In Fig. 3, the proper parameter of k is 3, whereas in Fig. 4 and Fig. 5, appropriate value of k is changed into 15 and 10 respectively. In the contrast, the proposed method does not need to change any parameter and can provide a relatively satisfactory result. In each figure, the image of the skeletons without pruning are the input of the proposed method. They are not the input of the Bai's method. By the way, the skeletonization method used in Bai's method is the skeleton growing algorithm [14], which is slow but more accurate. Then when we compared the result of the proposed method and its input original skeleton, it is obvious that there are a lot of unwanted branches that have been filtered. Therefore, the proposed method is a good automatic pruning method that without the need to manually tuning parameter for different images.

IV. Conclusion And Future Work

In this paper, we have proposed an automatic pruning method based on the Bai's pruning algorithm that by using the discrete curve evolution for partition contour. In the proposed method, manually tuning of the pruning parameter is not necessary, which is inevitable in many pruning algorithms. Therefore, proposed method is more convenient than others pruning algorithm to use. On the other hand, the proposed method generates an enough clean skeleton, in which many unwanted branches are removed. The result of the proposed method is close to the Bai's method, so it also has the potential to use in shape similarity, which is also one of the merits of the Bai's method.

In the future, it is interesting to further inspection the performance of the proposed method, such as comprehensive comparing the skeleton extraction with Skeleton Grafting method [15], which is an automatic extract method rather than a pruning method. Another interesting direction is to explore the shape similarity by using the result of the proposed method.

References

[1] H. Blum, "A transformation for extracting new descriptors of shape, Cambridge," MA: MIT press, 1967, pp. 362–380.

[2] P. K. Saha, G. Borgefors, G. Sanniti di Baja, "A survey on skeletonization algorithms and their applications," Pattern Recognition Letter, 76. 2016, pp. 3–12.

[3] R. L. Ogniewicz, O. Kübler, "Hierarchic Voronoi skeletons," Pattern Recognition, 28. 1995, pp. 343–359.

[4] F. Leymarie, M. D. Levine, "Simulating the grassfire transform using an active contour model," IEEE Transactions on Pattern Analysis and Machine Intelligence, 14, 1992, pp. 56–75.

[5] P. K. Saha, G. Borgefors, G. Sanniti di Baja, "Skeletonization: Theory, Methods, and Applications," Academic Press. London, 2017.

[6] X. Bai, L. J. Latecki, and W. Y. Liu, "Skeleton pruning by contour partitioning with discrete curve evolution," IEEE Trans. Pattern Anal. Mach. Intell., vol. 29, no. 3, pp. 449–462, 2007, doi: 10.1109/TPAMI.2007.59.

[7] S. Wei, B. A. I. Xiang, Y. Xingwei, L. L. Jan, "Skeleton pruning as trade-off between skeleton simplicity and reconstruction error," vol. 56, no. April, pp. 4–9, 2013, doi: 10.1007/s11432-012-4715-3.

[8] H. Liu, Z. H. Wu, X. Zhang, D. F. Hsu, "A skeleton pruning algorithm based on information fusion," Pattern Recognit. Lett., vol. 34, no. 10, pp. 1138–1145, 2013, doi: 10.1016/j.patrec.2013.03.013..

[9] G. Siyu, H. Pingping, L. Zhigang, W. He, L. Min, "A skeleton pruning method based on saliency sorting," 14th IEEE International Conference on Electronic Measurement & Instruments (ICEMI). pp. 593–599, 2019.

[10] L. J. Latecki and R. Lakämper, "Convexity Rule for Shape Decomposition Based on Discrete Contour Evolution," Comput. Vis. Image Underst., vol. 73, no. 3, pp. 441–454, 1999, doi: 10.1006/cviu.1998.0738.

[11] L. J. Latecki and R. Lakämper, "Polygon evolution by vertex deletion," Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 1682, pp. 398–409, 1999, doi: 10.1007/3-540-48236-9_35.

[12] L. J. Latecki and R. Lakamper, "Shape Similarity Measure Based on Correspondence of Visual Parts," IEEE Trans. Pattern Anal. Mach. Intell., vol. 22, no. 10, pp. 1185–1190, 2000, doi: 10.1109/34.879802.

[13] J. Ma, X. H. Ren, T. V Yurevich, "A Novel Fast Iterative Parallel Thinning Algorithm," Proceedings of the 2020 4th International Conference on Vision, Image and Signal Processing. – 2020. – C. 1–5.

[14] W. Choi, K. Lam, W. Siu, "Extraction of the Euclidean skeleton based on a connectivity criterion," Pattern Recognition, vol. 36, pp. 721–729, 2003.

[15] C. Yang, B. Indurkhya, J. See, M. Grzegorzek, "Towards Automatic Skeleton Extraction with Skeleton Grafting," in IEEE Transactions on Visualization and Computer Graphics, 2020. doi: 10.1109/TVCG.2020.3003994.

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