New Approach for the Skeletonization of Handwritten Characters in Gray-Level Images

Amer Dawoud and Mohamed Kamel
Department of Systems Design Engineering, University of Waterloo, Canada
E-mail address:{dawoud,mkamel}@watfast.uwaterloo.ca

Abstract

Existing skeletonization methods operate directly on the binary image ignoring the gray-level information. In this paper we propose a new method for the skeletonization of handwritten characters that uses gray-level information and capitalizes on their elongated pattern properties. The method controls the development of the skeleton while iteratively binarizing the gray-level image. Two types of iterations are performed: the iterative skeletonization and deletion of boundary pixels, which is nested within the iterative binarization of the gray-level image. Detailed analysis of the skeletonization process is presented to show its superior performance related to the prevention of "flooding water" and end point shrinkage and to noise immunity.

1 Introduction

Skeletonization has been a part of image processing for a wide variety of applications [9]. The usefulness of reducing patterns to thin line representation can be attributed to the need to process a reduced amount of data as well as to the fact that shape analysis can be more easily made on thin-line patterns. The thin-line representation of certain elongated patterns, like handwritten characters, would be closer to the human perception of these patterns; therefore, they permit a simpler structural analysis and more intuitive design of recognition algorithms. Many skeletonization algorithms (or modifications of existing ones) have been proposed over the years [1] [3] [7] [11] [13]. A comprehensive survey of these methods is contained in reference [9]. Lam and Suen [10] evaluated, from an OCR prospective, 10 parallel skeletonization algorithms that represented a wide spectrum of modes of operation. Lee *et. al* [12] systematically evaluated 20 algorithms based on the criteria of reconstructibility, quality of skeletonization, connectivity and degree of parallelism. Recently, Fan *et. al* [5] proposed a skeletonization algorithm that uses block decomposition and contour vector matching. Kegl and Krzyzak [8] developed a piecewise linear skeletonization algorithm that uses principal curves.

One disadvantage of the existing skeletonization algorithms is that they totally ignore gray-level information. Actually all the algorithms reported in Lam *et. al*'s survey [9] operate directly on the binary image, by iteratively deleting successive layers of pixels on the boundary until only a skeleton remains. The deletion or retention of a pixel p would depend on configuration of pixels in a local neighborhood containing p in the binary image. According to the way they examine pixels, these algorithms can be classified as sequential or parallel. The deletion/retention of a pixel in a sequential algorithm is more unpredictable, because the result depends partly on the order in which the pixels are processed. Since parallel algorithms examine all pixels simultaneously using the same set of conditions for pixel deletion, the results could be more isotropic.

There are few algorithms that use the gray-level information in skeletonization, and they are summarized in Verwer's survey [15]. Recently, Chen and Shin [2] developed an algorithm that measures the degree of membership of each ridge point with respect to the skeleton.

We propose a new skeletonization approach that capitalizes on the elongated pattern properties of the handwritten characters. It uses information from two sources: the original gray-level image and the binary image resulting from the binarization operation. We assume that the binarization operation was successfully executed at an earlier stage. We will show that the skeletonization decisions regarding deleting/retaining pixels can be relaxed by utilizing gray-level information. As a result, problems of flooding water, shrinkage of end points, and noise sensitivity are eliminated. The two underlying principles of the approach are the following: first, the medial pixels of a handwritten stroke are always darker than its side pixels, as illustrated in

Proceedings of the Seventh International Conference on Document Analysis and Recognition (ICDAR 2003)
0-7695-1960-1/03 $17.00 © 2003 IEEE

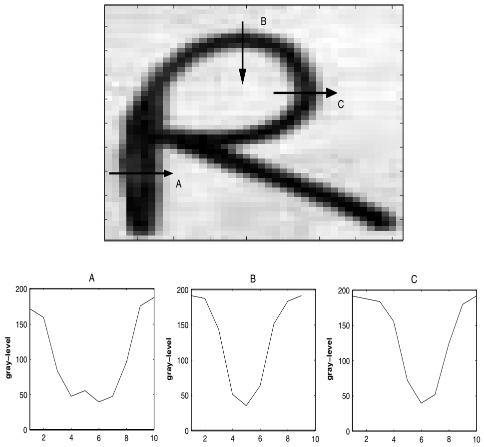

Figure 1: Gray-level profiles.

gray-level profiles B and C in Figure 1. This means that darker pixels have higher probability of being skeleton pixels. Second, the increase in gray-level from the medial pixels towards the side pixels of a single handwritten segment is monotonic. The increase in profile A in Figure 1 is not monotonic because the profile actually passes through two close lines. As we will see later on, this is important because it prevents the iterative binarization from producing holes, which will simplify the skeletonization part of the process.

2 New Skeletonization Approach

Skeleton-growing, SG, is a thinning process that controls the growth of the skeleton while iteratively binarizing the gray-scale image at a sequence of equally spaced thresholds. SG performs two types of iterations: the iterative skeletonization and deletion of boundary pixels, which is nested within the iterative binarization.

We will use Figure 2 as an example to illustrate the implementation of SG steps. Let G and B be the gray-level and binary images of the handwritten characters, respectively. We will not be concerned with the binarization method that produced the binary image, and will assume it was successfully preformed at an earlier stage. G is binarized at a sequence of thresholds, T_i, where T_1 is the lowest possible threshold in gray-scale histogram. The difference between two successive Ts was chosen to be 4 gray-levels, which we found to be satisfactory. Let BE_i be the set of pixels extracted in iteration i, or the set of pixels with gray-level less than Ti. It is clear that

$$BE_{i-1} \subseteq BE_i \tag{1}$$

Column A in Figure 2 shows the binarization outputs, where the black pixels are the ones that were extracted in the previous iterations, and the gray pixels are the ones that were added in the current iteration. In the initial iterations, the characters will be thin and broken, and as the number of iteration increases, the broken characters will become thicker and more connected. After a certain number of iteration the characters will be fully connected and the newly added pixels will be adding thickness only. One important property of this iterative binarization is that it does not create holes, which simplifies the following skeletonization step.

Our objective, in each iteration, is to distinguish between pixels that add thickness and pixels that expand the characters, and to exclude those that add thickness from the skeletonization process. To identify the pixels that add thickness we first locate the End-Nodes of the skeleton of the previous iteration. Let SK_i be the set of skeletal pixels in iteration i. Set of End-Nodes, EN_i, is a subset of SK_i of pixels that have one or less 8-connected neighbors. In each iteration, the following set of pixels is selected for the skeletonization implementation:

1. SK_{i-1} skeleton pixels of previous iteration.
2. BE_i pixels according to the following rules:
   - delete BE_i pixels that don't belong B.
   - delete BE_{i-1}.
   - delete BE_i pixels that is 8-connected with BE_{i-1}. This step will exclude pixels that add thickness.
   - then, include BE_i pixels that are connected with the End-Nodes EN_{i-1} according to the directions shown in Figure 3. This step will include pixels that will extend the skeleton in the logical elongated direction.

Column B in Figure 2 shows the pixels selected for the skeletonization, where the black pixels are the skeleton of the previous iteration, the dark gray pixels are previous iteration's End-Nodes, and the light gray are those added in current iteration. The skeletonization is applied on these newly added pixels, elongating the pervious iteration's skeleton as shown in column C of Figure 2. The skeletonization step is performed using Tsuruoka's algorithm [14]. We selected this particular thinning algorithm based on survey [12],

Proceedings of the Seventh International Conference on Document Analysis and Recognition (ICDAR 2003)
0-7695-1960-1/03 $17.00 © 2003 IEEE

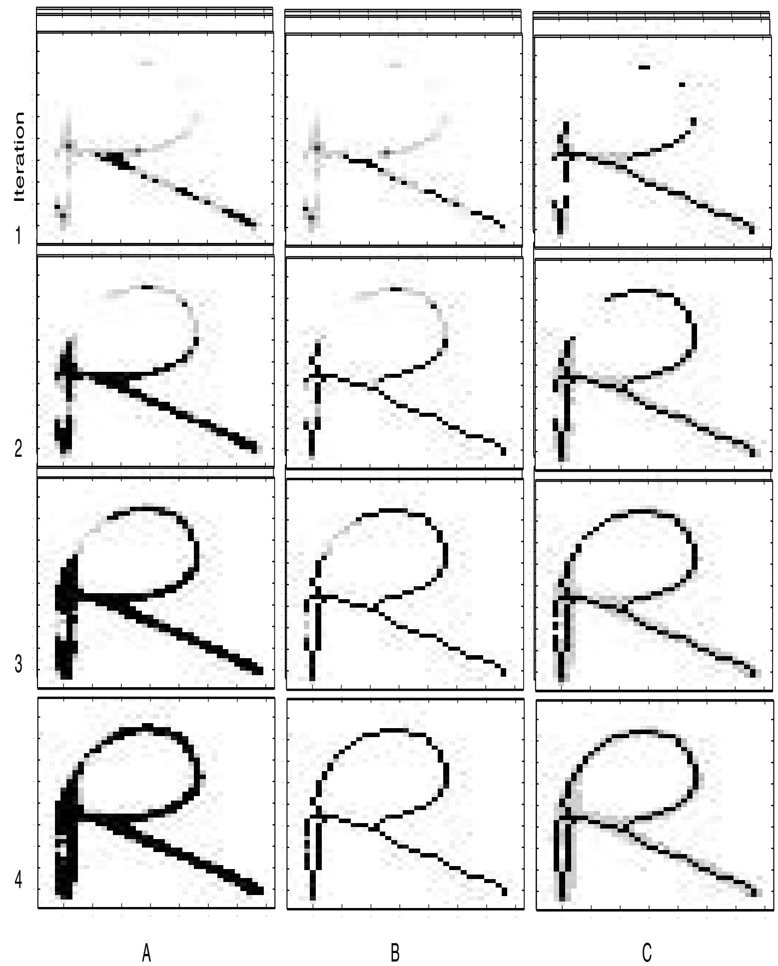

Figure 2: Example illustrating the implementation of SG's steps. A- Binarization outputs at successive iterations (black pixel: pixel extracted in previous iterations, gray pixel: pixel extracted in current iteration. B- Pixels selected for skeletonization implementation (black pixel: skeleton pixel in previous iteration, dark gray pixel: End-Node pixel of previous iteration's skeleton, light gray pixel: pixel selected skeletonization implementation in current iteration. C- Skeletonization result in current iteration.

which used several criteria to systematically compare 20 skeletonization algorithms. From among the algorithms that preserve connectivity, we chose Tsuruoka's algorithm [14] due to its simplicity, ability to prevent end points shrinkage and convergence to unit width. Other properties, such as reconstructability and parallelism are less important. This iterative process continues till B is fully included in BE_i, i.e., $B \subseteq BE_i$.

3 Discussion and results

Sensitivity to noise: One of the desired properties of SG is its insensitivity to noise. To prove that, we allowed the iterations of SG to continue till background noise started to interfere, as shown in Figure 4. We can see that SG prevented the boundary pixels from developing small bumps and extraneous branches, some of which may seriously affect the recognition process. This insensitivity to noise is attributed to the efficient exclusion the boundary pixels that add thickness, and to the limitations imposed on the directions of the skeleton growth, which allows it to grow only in its elongated directions. The importance of this insensitivity is that it relaxes the skeletonization's dependence on the shape and quality of the binarization operation, by relying more on the original gray-level information.

"Flooding water" effect: In Figure 5, SG is compared with other algorithms that were selected for their applicability to OCR. Hilditch's algorithm [6], Zhang and Suen's algorithm [17] and Wu and Tsai's algorithm [16] performed well in Lam and Suen's evaluation [10]. Figure 5 shows the skeletonization outputs of gray-level images that were binarized using Dawoud and Kamel's method [4]. All skeletonization algorithms except SG

Proceedings of the Seventh International Conference on Document Analysis and Recognition (ICDAR 2003)
0-7695-1960-1/03 $17.00 © 2003 **IEEE**

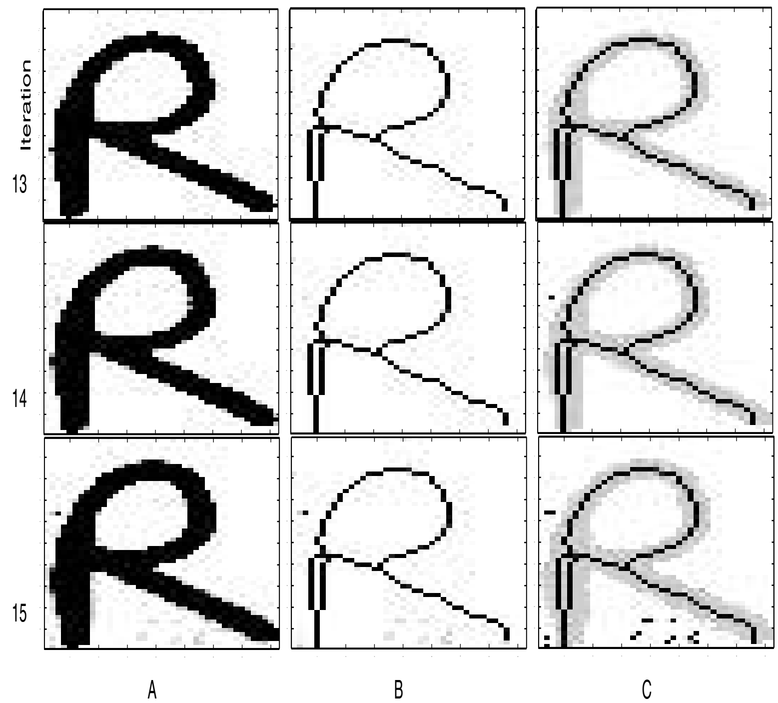

Figure 4: Continuation to the illustrative example of Figure 2.

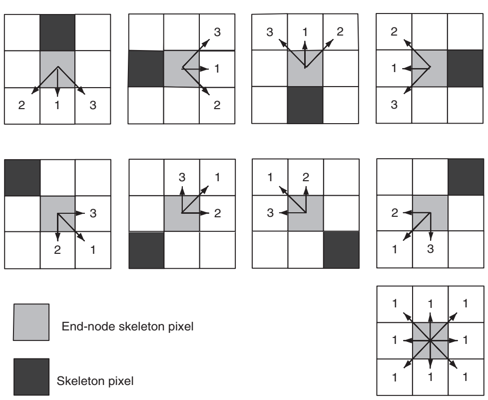

Figure 3: Directions of skeleton growth.

did not require the gray-level image. *SG* prevented the flooding water effect; it separated lines that are touching or very close to each other. However, there should be at least one-pixel separation between the centers of the lines. The other methods, which directly operated on the binary image, failed to achieve that.

4 Conclusions

We presented a new method of skeletonization of handwritten characters that capitalizes on their elongated pattern properties. The method controls the development of the skeleton while iteratively binarizing the gray-level image. Two types of iterations are performed: the iterative skeletonization and deletion of boundary pixels, which is relaxed by and nested within the iterative binarization of the gray-level image. Experimental results showed its superior performance related to the prevention of "flooding water" and endpoint shrinkage and to noise immunity in comparison with other well-established algorithms.

References

[1] C. Arcelli and G. Baja. "A one-pass two operations process to detect the skeletal pixels on the 4-distance transform." *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol.11, pp.411-414, 1989.

[2] S. Chen and F.Y. Shin. "Skeletonization for fuzzy degraded character images." *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol.15, pp.1481-1485, 1996.

[3] Y.-S. Chen and W.-H. Hsu. "A comparison of some one-pass parallel thinnings." *Pattern Recognition Letters,* Vol.11, pp.471-477, 1990.

Proceedings of the Seventh International Conference on Document Analysis and Recognition (ICDAR 2003)
0-7695-1960-1/03 $17.00 © 2003 **IEEE**

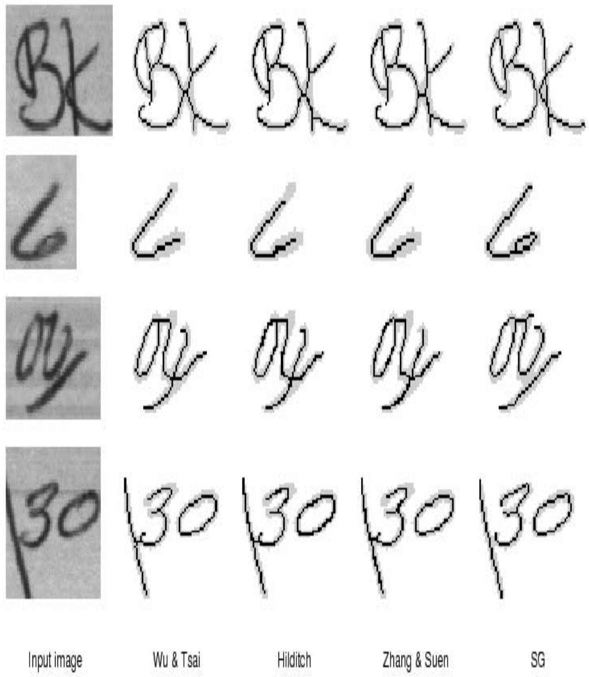

Figure 5: Skeletons obtained from 4 algorithms.

[4] Amer Dawoud and Mohamed Kamel. "Iterative model-based binarization algorithm for cheque images." *International Journal of Document Analysis and Recognition,* Vol.5, pp.28-38, 2002.

[5] K. Fan, D. Chen and M. Wen. "Skeletonization of binary images with nonuniform width via block decomposition and contour vector matching." *Pattern Recognition,* Vol.31, pp.823-838, 1998.

[6] C.J. Hilditch. "Comparison of thinning algorithms on a parallel processor." *Image Vision Computing,* Vol.1, pp.115-132, 1983.

[7] B. Jeng and R. Chin. "One-pass parallel thinning: analysis, properties, and quantitative evaluation." *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol.14, pp.1120-1140, 1992.

[8] B. Kegl and Adam Krzyzak. "Piecewise linear skeletonization using principal curves." *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol.24, pp.59-74, 2002.

[9] L. Lam, S.W. Lee and C.Y. Suen. "Thinning methodologies- A comprehensive survey." *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol.14, pp.869-885, 1992.

[10] L. Lam and C.Y. Suen. "An evaluation of parallel thinning algorithms for character recognition." *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol.17, pp.914-919, 1995.

[11] B. Lee and C.Y. Suen. "A knowledge-based thinning algorithm." *Pattern Recognition,* Vol.24, pp.1211-1221, 1991.

[12] S.-H. Lee, L. Lam and C.Y. Suen. "A Systematic evaluation of skeletonization algorithms." *International Journal of Pattern Recognition and Artificial Intelligence,* Vol.7, pp.1203-1226, 1993.

[13] T. Pavlidis. "A thinning algorithm for discrete binary images." *Computer, Graphics and Image Processing,* Vol.13, pp.142-157, 1980.

[14] S. Tsuruoka, F. Kimura, M. Yoshimura, S. Yokoi and Y. Miyake. "Thinning algorithm for digital pictures and their application to handprint characters recognition." *Tranactions of Institute of Electronics, Information and Communication Engineers,* Vol.J66-D, pp.525-532, 1983.

[15] B. Verwer, L. Van Vliet and P. Verbeek. "Binary and Grey-Value skeletons." *International Journal of Pattern Recognition and Artificial Intelligence,* Vol.7, pp.1287-1308, 1993.

[16] R.-Y. Wu and W.-H. Hsu. "A new one-pass parallel thinning algorithm for binary images." *Pattern Recognition Letters,* Vol.13, pp.715-723, 1992.

[17] T.Y. Zhang and C.Y. Suen. "A fast parallel algorithm for thinning patterns." *Comm. ACM,* Vol.27, pp.236-239, 1984.

Proceedings of the Seventh International Conference on Document Analysis and Recognition (ICDAR 2003)
0-7695-1960-1/03 $17.00 © 2003 IEEE