Advanced Materials Research *Online: 2010-12-06*
ISSN: 1662-8985, Vols. 171-172, pp 73-77
doi:10.4028/www.scientific.net/AMR.171-172.73

Application of Mathematical Morphology on Touching or Broken Characters Processing

Liu Yingjie, You Fucheng
Information & Mechanical Engineering School
Beijing Institute of Graphic Communication Beijing, China
liuyingjiea@hotmail.com, youfucheng@yahoo.com.cn

Keywords: Mathematical Morphology; Binarization; Touching Characters; Broken Characters
Abstract. It is difficult to process touching or broken characters in practical applications on optical character recognition. For touching or broken characters, a method based on mathematical morphology of binary image is put forward in the paper. On the basis of the relative theories of digital image processing, the overall process is introduced including separation of touching characters and connection of broken characters. First of all, character image is pre-processed through smoothing and threshold segmentation in order to generate binary image of characters. Then character regions which are touching or broken are processed through different operators of mathematical morphology of binary image by different structuring elements. Thus the touching characters are separated and broken characters are connected. For higher recognition rate, further processes are done to achieve normal and individual character regions.

Introduction

Touching or broken characters processing plays an indispensable role in optical character recognition and influences the recognition results to a great extent. During the research of optical character recognition, the segmented character samples are used mostly for experiments, only algorithm of character recognition is evaluated, therefore touching or broken characters processing is ignored usually. Currently, however, individual character recognition has achieved higher accuracy. Results of practical recognition system demonstrate that the reason for wrong recognition is wrong character segmentation to a great extent [1]. It has become a main problem in practical applications. However traditional approaches can not solve the problem in a more appropriate way [2].

Under this background, an approach based on mathematical morphology is proposed in the paper after experiments on many touching or broken characters. By constructing different structuring elements, different operators of mathematical morphology are selected to separate touching position and connect broken regions. Also typical touching or broken characters are selected as examples to introduce the whole process. The approach has referenced value for research of touching or broken characters processing in the fields of optical character recognition.

Character Image Pre-processing

Generally, character images need to be pre-processed, which aims at acquiring clearer character regions. It mainly includes image smoothing and threshold segmentation to generate binary image of characters for further morphological processes.

Character Image Smoothing

In most situations, character image contains some noises. Higher quality of pre-processed image is the important premise for higher recognition accuracy. Therefore, smooth character image firstly so that the noises could be suppressed by smoothing filter. Among all smoothing filters, the linear Gaussian filter is more optimal not only because it could suppress high frequencies, i.e., noises, in the image but also it is rotation-invariant, i.e., isotropic [3]. Let row and column of image be denoted by r and c. Let σ be denoted by standard deviation. Then the Gaussian filter in two dimensions is defined by Eq. 1.

$$g_\sigma(r,c) = \frac{1}{2\pi\sigma^2} e^{-(r^2+c^2)/(2\sigma^2)} . \quad (1)$$

Character Image Binarization

It is fairly important to generate binary image through threshold segmentation in image processing and character recognition. Results of threshold segmentation have direct influence on final recognition. Therefore, appropriate threshold segmentation according to practical condition is key point. If smoothed character image by Gaussian filter is specified as local background, character regions could be distinguished by being locally darker than their local background. So optimal binarization could be achieved by dynamic threshold segmentation and character regions could be extracted easily. Dynamic threshold segmentation compares image to its local background. Let character image be denoted by $f_{r,c}$ and smoothed image be denoted by $g_{r,c}$. Then dynamic threshold segmentation for dark regions, i.e., character regions, is defined by Eq. 2. From the binary image generated by dynamic threshold segmentation, character regions are segmented obviously.

$$S = \{(r,c) \in R \mid f_{r,c} - g_{r,c} \le -g_{diff}\} . \quad (2)$$

Mathematical Morphology Processing

Because of inhomogeneous illumination and so on, character regions are not individual in practical applications, but touching between some characters as well as broken within some characters. Mathematical morphology of binary image can be used to process touching or broken characters.

Mathematical Morphology of Binary Image

Mathematical morphology of binary image is based on set theory. For the purpose of image analysis and recognition, it is a tool for extracting image components that are useful in the description of region shape. Fundamental principle of mathematical morphology is shown in Fig. 1. Structuring element is treated as set which can be translated in original binary image. Mathematical morphology operations can be implemented through transposition, intersection and complement when structuring element translating in original binary image.

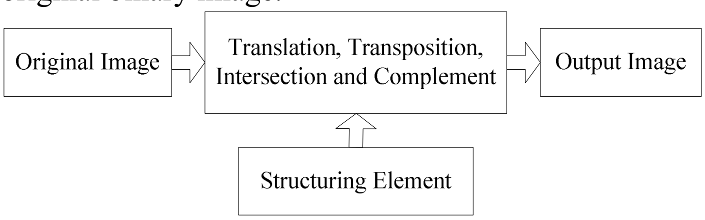

Fig. 1 Fundamental principle of mathematical morphology

Morphological operations mainly include dilation, erosion, opening, closing, region filling and skeleton extraction and so on. Dilation and erosion are the most fundamental operations. And many other morphological algorithms are all based on these two primary operations. Suppose A denotes a region, B denotes a structuring element. Specify an origin of B as the reference of morphological operation. Then dilation of region A by structuring element B, denoted A⊕B, is defined by Eq. 3, which is based on obtaining the reflection of B about its origin and shifting this reflection by x. Dilation of A by B is the set of all displacements, x, such that reflection of B and A overlap by at least one element [4].

$$A \oplus B = \{x \mid [(\hat{B})_x \cap A] \subseteq A\} . \quad (3)$$

Erosion of A by B, denoted A⊖B, is defined by Eq. 4, which indicates that erosion of A by B is the set of all points x such that B, translated by x, is contained in A.

$$A \ominus B = \{x \mid (B)_x \subseteq A\} . \quad (4)$$

Thus dilation expands a region and erosion shrinks it. If the same structuring element is used in combination of dilation and erosion, the operations are called opening and closing. Opening generally smoothes the contour of a region, breaks narrow connections, and eliminates thin protrusions [5]. Opening of region A by structuring element B, denoted $A \circ B$, is defined by Eq. 5.

$$A \circ B = (A \ominus B) \oplus B . \quad (5)$$

Closing also tends to smooth region contours but, as opposed to opening, it generally fuses narrow breaks and long thin gulfs, eliminates small holes, and fills gaps in the contour. Similarly, closing of A by B, denoted $A \bullet B$, is defined by Eq. 6.

$$A \bullet B = (A \oplus B) \ominus B . \quad (6)$$

Region filling operation, based on dilation, complement and intersection, fills region A beginning with a pixel within boundary of A. Let complement of A be denoted by A^c, region filling can be implemented by Eq. 7. If $X_k = X_{k-1}$, region filling ends on step k.

$$X_k = (X_{k-1} \oplus B) \cap A^c \qquad (k = 1,2,3\cdots) . \quad (7)$$

Suppose S(A) denotes the skeleton of region A. Then skeleton extraction can be described by erosion and opening as shown in Eq. 8. Let $(A \ominus kB)$ denote erosion A by B for k times, then $S_k(A) = (A \ominus kB) - (A \ominus kB) \circ B$. Step K is last erosion before A becomes empty, i.e., $K = \max\{k| \ A \ominus kB) \neq \phi\}$.

$$S(A) = \bigcup_{k=0}^{K} S_k(A) . \quad (8)$$

Processing on Touching Characters

Firstly eliminate holes in touching character regions by region filling operation. Then construct a structuring element, which can break touching between characters, according to touching position and direction. Thus opening operation on filled touching region separates touching characters. Let the result intersect with original touching region. Then individual characters are obtained.

Processing on Broken Characters

Construct a structuring element, which could fuse break of character, according to broken position and direction. Thus closing operation on broken character connects the break. Then complete and connected region of character is obtained for further processing.

Characters Normalization Processing

Size and shape of character obtained through above operations are usually irregular, which can influence feature extraction and recognition. Therefore characters need to be normalized to impair the adverse influence for higher recognition accuracy. Firstly, extract skeletons of character regions. Then dilate character skeletons by appropriate structuring element.

Experiment and Result Analysis

Typical images of touching or broken characters are selected from experiments as examples, touching characters shown in Fig. 2, broken characters shown in Fig. 3 and Fig. 4 respectively.

Fig. 2 Touching characters

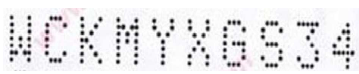

Fig. 3 Broken characters Ⅰ

Fig. 4 Broken characters Ⅱ

Character Image Pre-processing

Smooth character image by Gaussian filter, then binarization by dynamic threshold segmentation. Binary images of touching and broken characters are obtained as shown in Fig. 5, Fig. 6 and Fig. 7.

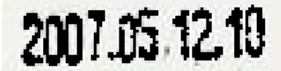

Fig. 5 Touching characters

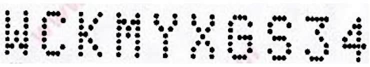

Fig. 6 Broken characters Ⅰ

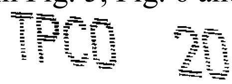

Fig. 7 Broken characters Ⅱ

Processing on Touching Characters

In Fig. 5, character 00 and 05 are touching. Extract touching regions respectively according to region features firstly, and then morphological algorithms are used to process touching characters. Thus the individual characters are obtained for final recognition.

Extract character 00 from Fig. 5 as shown in Fig. 8. Then apply region filling operation on touching character 00, holes in character 00 are eliminated and filled character 00 is shown in Fig. 9. According to touching position and direction in Fig. 9, construct a rectangle structuring element shown on the right of opening operator in Fig. 10, and then apply opening operation on filled character 00 as shown in Fig. 10. So touching region is separated after opening operation by appropriate structuring element.

Fig. 8 Character 00

Fig. 9 Filled character 00

Fig. 10 Opening operation on character 00

Intersect between separate regions (opening operation result of Fig. 10) and original character 00 (Fig. 8), as shown in Fig. 11. It can be seen that touching character 00 are separated already.

Fig. 11 Intersection on character 00

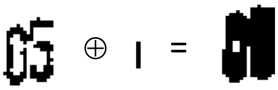

Fig. 12 Dilation on character 05

Then extract character 05 from Fig. 5 as shown on the left of dilation operator in Fig. 12. Construct a rectangle structuring element shown on the right of dilation operator in Fig. 12. Apply dilation operation on character 05 as shown in Fig. 12. Then apply region filling operation on the dilation operation result of Fig. 12, so filled region of character 05 can be obtained as shown on the left of opening operator in Fig. 13. It can be seen that holes in character 05 are eliminated. According to touching position and direction, construct a rectangle structuring element shown on the right of opening operator in Fig. 13, and then apply opening operation on character 05 as shown in Fig. 13. It can be seen that touching character 05 are separated after above morphological operations.

Intersect between separate regions (opening operation result of Fig. 13) and original character 05 (shown on the left of dilation operator in Fig. 12), as shown in Fig. 14. It can be seen that touching character 05 are separated and individual characters are obtained.

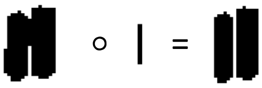

Fig. 13 Opening operation on character 05

Fig. 14 Intersection on character 05

From intersection operation result of Fig. 14, it is obvious that individual character 0 and 5 are broken respectively. Therefore the breaks need to be fused. According to broken position and direction, construct two rectangle structuring elements shown on the right of closing operator in Fig. 15 and Fig. 16 respectively. Then apply closing operation on the broken region of character 0 and 5 as shown in Fig. 15 and Fig. 16 respectively. Thus the breaks are connected after closing operation by appropriate structuring elements.

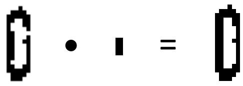

Fig. 15 Closing operation on character 0

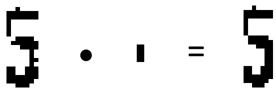

Fig. 16 Closing operation on character 5

Touching character 00 and 05 have been processed to form individual complete characters by morphological algorithms and can be used for final recognition.

Processing on Broken Characters

There are different breaks in character regions shown in Fig. 6 and Fig. 7, which need to be fused. According to broken position and direction, construct circle structuring element and apply dilation operation on broken character regions shown in Fig. 6. Then connected characters are generated and dilation result with circle structuring element is shown in Fig. 17. Construct rectangle structuring element and apply dilation operation on broken character regions shown in Fig. 7. Then connected characters are obtained and dilation result with rectangle structuring element is shown in Fig. 18.

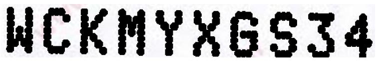

Fig. 17 Dilation result Ⅰ

Fig. 18 Dilation result Ⅱ

Remaining problem is character normalization for higher recognition accuracy. It can be implemented by skeleton extraction. After skeleton extraction operation on characters shown in Fig. 17 and Fig. 18, skeleton of characters are generated as shown in Fig. 19. Then apply dilation operation on skeleton of characters, so connected characters are obtained as shown in Fig. 20. Broken characters have been processed to be clear and connected by morphological algorithms for final recognition.

Fig. 19 Skeleton of characters

Fig. 20 Connected characters

Conclusion

In this paper, better results have been achieved from the experiments on practical character images with touching or break, which are based on the relative theories of mathematical morphology of binary image. By constructing different structuring elements and selecting different morphological operators, touching characters are separated and broken characters are connected for final recognition. Therefore another referenced approach on touching or broken characters processing is provided for practical applications on optical character recognition.

Acknowledgment

This paper is supported by Beijing Higher Institute Research Center of Printing Equipment and the Funding Project for Academic Human Resources Development in Institutions of Higher Learning under the Jurisdiction of Beijing Municipality.

References

[1] ZHU Xiao-Yan, WANG Song: Application of Fourier Transform on Segmentation of Connected Character, Chinese J.Computers, Vol. 22, No. 12(1999), p.1246-1252.

[2] YIN Xu-Cheng, LIU Chang-Ping: A Segmentation and Recognition System for Touching and Broken Numeral Strings Based on Viterbi Algorithms, ACTA AUTOMATICA SINICA, Vol. 33, No. 3 (2007), p.315–322.

[3] Carsten Steger, Markus Ulrich, Chritian Wiedemann: Machine Vision Algorithms and Applications, Tsinghua University press (2008), p.47–124.

[4] ZHANG Yu-jin, Image Engineering (Ⅱ), Second Edition, Tsinghua University press (2007), p.367–380.

[5] Rafael C. Gonzalez, Richard E. Woods: Digital Image Processing, Second Edition, Publishing House of Electronics Industry (2007), p.522–550.