A Stroke-density Based Double Elastic Meshing Feature Extraction Method for Chinese Handwritten Character Recognition

Wei Wei , Ning Bo
School of Computer Science and Software
Hebei University of Technology
Tianjin, China
E-mail: ningbofytx1989@163.com

***Abstract*—Stroke-density based elastic meshing method can not only absorb the deformations of stroke in different handwritings but also avoid the non-uniform width of strokes which caused by using a nonlinear normalization method. In view of existing situation that the stroke density functions do not consider the distribution of strokes in diagonal direction, the stroke-density based vertical-horizontal elastic meshing method could not effectively extract the feature of left-falling and right-falling stroke in a Chinese handwritten character image, we propose a new stroke density definition of a diagonal direction and combine it with diagonal elastic meshing technique to constitute meshes. Then, combining the vertical-horizontal elastic meshes with the diagonal's, we get the stroke-density based double elastic meshing approach. The experimental results have verified the effectiveness of this method.**

***Keywords*-stroke density; elastic meshes; feature extraction; Chinese handwritten character recognition**

I. INTRODUCTION

Text is the main carrier of human communication. With the rapid development of computer technology, processing and recognizing Chinese handwritten character by computer have become one of the research hotspots in the field of pattern recognition. How to recognize the Chinese characters quickly and efficiently has become a bottleneck which affects the efficiency of human-computer communication. So the research of off-line Chinese handwritten character recognition has profound theoretical significance and practical value.

Feature extraction is one of the most important parts in the process. Good features can not only reflect the essential characteristics of Chinese characters, but also can tolerate deformation of various writing styles of handwriting.

Due to the structure of Chinese characters themselves, every character is composed of horizontal, vertical, left-falling and right-falling strokes, extracting directional decomposition features become an effective method of Chinese handwritten character recognition. In general, the process of extracting direction decomposition feature can be demonstrated in Fig. 1.

According to the density distribution of character image, elastic mesh dynamically determines the position of mesh lines, in order to adapt to deformation of strokes which caused by different writing styles. And it can reflect the structural information of characters. Definition of stroke density is the basis of elastic mesh. Jin Lianwen and his colleagues applied the several density functions of nonlinear normalization methods to the dividing of elastic meshes, then, proposed a stroke-density based elastic meshing method to extract features [1]. However, Jin's approach didn't take the left-falling and right-falling directions into

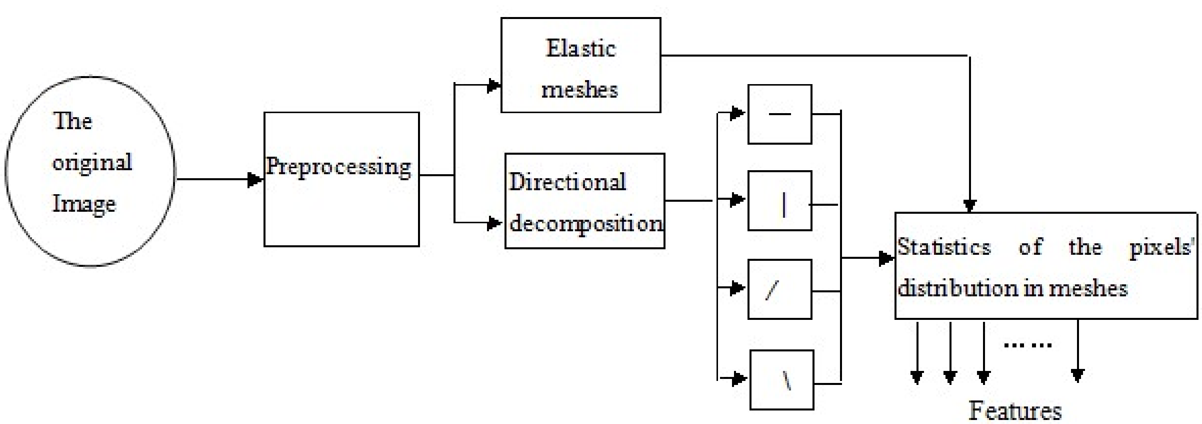

Figure 1. The process of extracting direction decomposition feature

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account when calculating the density of strokes, so that the vertical-horizontal elastic meshes neither extract the feature of left-falling strokes nor right-falling's efficiently. In view of this situation, this paper proposes a double elastic mesh feature extraction method based on stroke density. Firstly, we propose the definition of stroke density of diagonal direction. Then, according to these density functions we divide Chinese character image into several elastic diamond-shaped meshes which can overcome the disadvantage of vertical-horizontal meshes. Combining the two kinds of meshes, we get the stroke-density based double elastic meshing feature extraction method.

II. THE DEFINITION OF SEVERAL TYPICAL STROKE DENSITY FUNCTIONS

According to the structural characteristics and the distribution of stroke points and background points, several definitions of stroke density functions were proposed in paper[3,4]. Here we introduce three typical functions and then propose the new stroke density function definition of diagonal direction.

A. *The density function based on pixel point*

The function defined as:

$$d(i,j) = f(i,j) = \begin{cases} 1 & stroke \quad pixels \\ 0 & background \quad pixels \end{cases} \tag{1}$$

Where $d(i, j)$ is the stroke density function, the $f(i, j)$ is the pixel point in a Chinese character image whose size is $m \times n$. $i=1, 2,\dots,m, j=1, 2,\dots,n$.

This function is widely used in dividing elastic meshes because it is simple and easy to achieve, but it doesn't consider the distribution of background points in image.

B. *The density function based on stroke interval*

Taking the distribution of both stroke pixels and background pixels into consideration, every pixel point in this function has a horizontal density called $d_H(i, j)$ and a vertical density $d_V(i, j)$ as follows:

$$d_H(i,j) = SH \qquad if \quad f(i,j)=1 \tag{2}$$

$$d_V(i,j) = SV \qquad if \quad f(i,j)=1 \tag{3}$$

$$d_H(i,j) = \frac{1}{h(i,j)} \qquad if \quad f(i,j)=0 \tag{4}$$

$$d_V(i,j) = \frac{1}{v(i,j)} \qquad if \quad f(i,j)=0 \tag{5}$$

Where SH, SV are both very small constants, $h(i, j)$ is the maximum length of the blank segment in the horizontal scanning, similarly, $v(i, j)$ is the maximum length in the vertical scanning, as it's shown in Fig. 2.

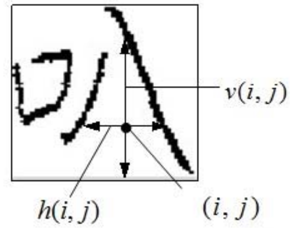

Figure 2. The definition of $h(i,j)$ and $v(i,j)$

C. *The density function based on the density of the whole line*

As it's shown in Fig. 3, the density function of the horizontal direction is defined as follows:

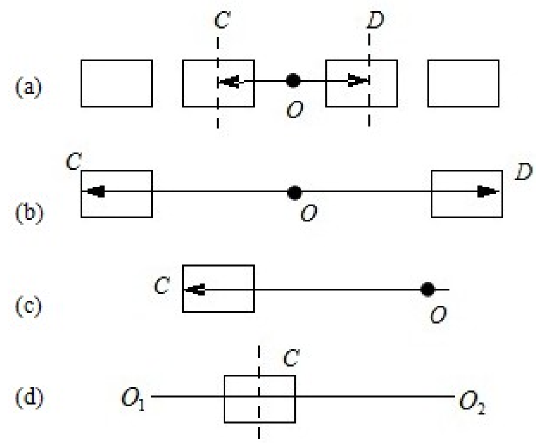

Figure 3. The definition of stroke interval in horizontal direction

1) *Situation (a) and (b):*

O is the segment center point, whose coordinate is (i, j), the coordinate of point C is (i_C, j_C) , D's coordinate is (i_D, j_D) and the distance between C and D is $|CD|$, the definition is,

$$d_H(i',j) = \frac{1}{\frac{1}{2}|CD| - |i'-i| + 1} + \alpha(i',j) \quad (i_C \le i' \le i_D) \tag{6}$$

where

$$\alpha(i,j) = \begin{cases} \alpha_1 & if\ (i,j)\ is\ a\ background \quad pixel \\ \alpha_2 & if\ (i,j)\ is\ a\ stroke \quad pixel \\ \alpha_3 & if\ (i,j)\ is\ a\ contour \quad pixel \end{cases} \tag{7}$$

usually, $\alpha_3 > \alpha_2 > \alpha_1$, and they are all constants.

2) *Situation (c):*

$$d_H(i',j) = \frac{1}{|OC| - |i'-i| + 1} + \alpha(i',j) \quad (i_C \le i' \le i) \tag{8}$$

3) *Situation (d):*

The coordinate of O_1 is (i_1, j_1), the coordinate of O_2 is (i_2, j_2), then,

$$d_H(i',j)=\frac{1}{|O_1C|-|i'-i_1|+1}+\alpha(i',j)\quad(i_1\le i'\le i_C) \tag{9}$$

$$d_H(i',j)=\frac{1}{|O_2C|-|i'-i_2|+1}+\alpha(i',j)\quad(i_C\le i'\le i_2) \tag{10}$$

Similarly, the density function of the vertical direction $d_V(i,j)$ also can be defined. The final stroke density function of point (i, j) can be defined as,

$$d(i,j)=\max\{d_H(i,j),d_V(i,j)\} \tag{11}$$

This approach takes both the background pixels and the stroke pixels into account, different pixels in character image have different densities. What' more, the density of contour pixel has been strengthened. In brief, the description of this approach is more reasonable.

D. The density function of diagonal direction

The three kinds of typical density functions above are only scanned from the horizontal and the vertical directions in the calculation of pixel's density. We will extend the density functions by scanning pixel from diagonal direction, which contains 45° and 135°, and propose the definition of stroke density function of diagonal direction.

- **The density function based on pixel point of diagonal direction:**
  For the density function based on pixel point, the definition is not changed.
- **The density function based on stroke interval of diagonal direction:**
  For the density function based on stroke interval, every pixel point has a 45° directional density called $d_L(i, j)$ and a 135° directional density $d_R(i, j)$. The function of diagonal direction can be defined as follows,

$$d_L(i,j)=SL \qquad if \quad f(i,j)=1 \tag{12}$$

$$d_R(i,j)=SR \qquad if \quad f(i,j)=1 \tag{13}$$

$$d_L(i,j)=\frac{1}{l(i,j)} \qquad if \quad f(i,j)=0 \tag{14}$$

$$d_R(i,j)=\frac{1}{r(i,j)} \qquad if \quad f(i,j)=0 \tag{15}$$

where SL, SR are both very small constants, $l(i, j)$ is the maximum length of the blank segment in the 45° direction scanning, similarly, $r(i, j)$ is the maximum length in the 135° direction scanning, as it' s shown in Fig. 4.

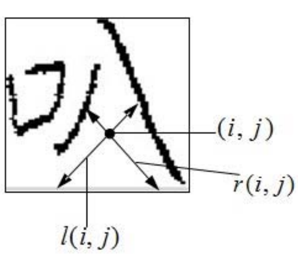

Figure 4. The definition of $l(i,j)$ and $r(i,j)$

- **The density function based on the density of the whole line of diagonal direction:**
  For the density function based on the density of the whole line of diagonal direction, as it's shown in Fig. 5, the function of diagonal direction can be defined as follows:

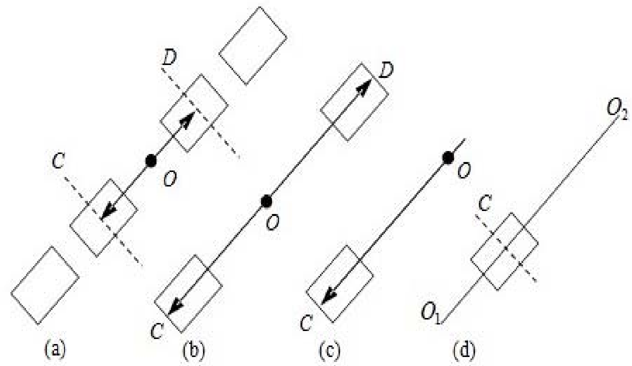

Figure 5. The definition of stroke interval in left slant direction

1) Situation (a) and (b):
O is the segment center point, whose coordinate is (i, j), the coordinate of point C is (i_C, j_C), D's coordinate is (i_D, j_D) and the distance between C and D is $|CD|$, the definition of 45° direction density is,

$$d_L(i',j')=\frac{1}{\frac{1}{2}|CD|-\sqrt{2}|i'-i|+1}+\alpha(i',j')\qquad \begin{matrix}(i_C\le i'\le i_D)\\(j_C\le j'\le j_D)\end{matrix} \tag{16}$$

where

$$\alpha(i,j)=\begin{cases}\alpha_1 & if\ (i,j)\ is\ a\ background\ \ pixel\\ \alpha_2 & if\ (i,j)\ is\ a\ stroke\ \ pixel\\ \alpha_3 & if\ (i,j)\ is\ a\ contour\ \ pixel\end{cases} \tag{17}$$

usually, $\alpha_3>\alpha_2>\alpha_1$ and they are all constants.

2) Situation (c):

$$d_L(i',j')=\frac{1}{|OC|-\sqrt{2}|i'-i|+1}+\alpha(i',j')\qquad \begin{matrix}(i_C\le i'\le i)\\(j_C\le j'\le j)\end{matrix} \tag{18}$$

3) Situation (d):
The coordinate of O_1 is (i_1, j_1), the coordinate of O_2 is (i_2, j_2), then,

$$d_L(i',j')=\frac{1}{|O_1C|-\sqrt{2}|i'-i_1|+1}+\alpha(i',j')\qquad \begin{matrix}(i_1\le i'\le i_C)\\(j_1\le j'\le j_C)\end{matrix} \tag{19}$$

$$d_L(i',j')=\frac{1}{|O_2C|-\sqrt{2}|i'-i_2|+1}+\alpha(i',j')\qquad \begin{matrix}(i_C\le i'\le i_2)\\(j_C\le j'\le j_2)\end{matrix} \tag{20}$$

Similarly, the density function of 135° direction $d_R(i,j)$ also can be defined. The final stroke density function of the point (i , j) can be defined as,

$$d(i,j)=\max\{d_L(i,j),d_R(i,j)\} \tag{21}$$

III. THE DOUBLE ELASTIC MESHING FEATURE BASED ON STROKE-DENSITY

A. The double elastic meshing technology

There are two kinds of meshing methods, namely, uniform meshing method and elastic meshing method, as it's shown in Fig. 6.

(a) (b) (c)

Figure 6. Different kinds of meshes
(a) Uniform meshes (b) Elastic meshes of vertical-horizontal direction
(c) Elastic meshes of diagonal direction

According to the pixel density function of Chinese handwritten character image, the positions of elastic mesh are determined dynamically, in order to adapt the deformation of various writing styles. According to the different directions of gird lines, elastic mesh can be divided into two classes, the vertical-horizontal and the diagonal elastic meshes [5]. Vertical-horizontal elastic mesh determines the positions of gird lines in accordance with the vertical and horizontal directions of the pixel's density distribution, while diagonal elastic mesh determines the positions of gird lines in accordance with the diagonal direction.

Assuming that the size of character image is $m\times n$, the size of elastic mesh is $M\times N$, a and b represent the grid lines in the horizontal and vertical directions respectively. The projections of stroke density function in horizontal and vertical directions are $H(i)$ and $V(j)$, then,

$$H(i)=\sum_{j=1}^{n} d(i,j) \qquad i=1,2,\cdots,m \tag{22}$$

$$V(j)=\sum_{i=1}^{m} d(i,j) \qquad i=1,2,\cdots,n \tag{23}$$

The gird lines in horizontal and vertical directions are:

$$a(s)=\min\left\{ i \mid \frac{s-1}{M}\sum_{k=1}^{m}H(k)\le\sum_{k=1}^{i}H(k)\le\frac{s}{M}\sum_{k=1}^{m}H(k)\right\} \tag{24}$$

$$b(t)=\min\left\{ j \mid \frac{t-1}{N}\sum_{l=1}^{n}V(l)\le\sum_{l=1}^{j}V(l)\le\frac{t}{N}\sum_{l=1}^{n}V(l)\right\} \tag{25}$$

$$\text{where } s=1,2,\cdots,M;\ t=1,2,\cdots,N$$

The projection of stroke density function in 45° direction has a total of $m+n$-1 projection lines. Let $L(i)$ represents the total pixel density of the i th projection line, then,

$$L(i)=\begin{cases}\displaystyle\sum_{k=0}^{i-1}d(i-k,1+k) & 1\le i\le m\\ \displaystyle\sum_{k=0}^{m+n-1-i}d(m-k,i-m+1+k) & m+1\le i\le m+n-1\end{cases} \tag{26}$$

Similarly, the projection of stroke density function in 135° direction has a total of $m+n$-1 projection lines. Let $R(j)$ represents the total pixel density of the j th projection line, then,

$$R(j)=\begin{cases}\displaystyle\sum_{k=0}^{j-1}d(m+1-j+k,1+k) & 1\le j\le m\\ \displaystyle\sum_{k=0}^{m+n-1-j}d(1+k,j-m+1+k) & m+1\le j\le m+n-1\end{cases} \tag{27}$$

Let the gird lines in 45° and 135° directions are c and d respectively, then,

$$c(s)=\min\left\{ i \mid \frac{s-1}{M}\sum_{k=1}^{m+n-1}L(k)\le\sum_{k=1}^{i}L(k)\le\frac{s}{M}\sum_{k=1}^{m+n-1}L(k)\right\} \tag{28}$$

$$d(t)=\min\left\{ j \mid \frac{t-1}{N}\sum_{l=1}^{m+n-1}R(l)\le\sum_{l=1}^{j}R(l)\le\frac{t}{N}\sum_{l=1}^{m+n-1}R(l)\right\} \tag{29}$$

$$\text{Where } s=1,2,\cdots,M;\ t=1,2,\cdots,N$$

B. The feature extraction of double elastic meshing based on stroke-density

The general stroke-density based elastic mesh only takes the horizontal and vertical directions into consideration, so that the vertical-horizontal elastic meshes neither extract the feature of left-falling strokes nor right-falling's efficiently. Based on the stroke density function of diagonal direction which is proposed in our paper, and combined with diagonal elastic mesh technique, we present an improved approach to solve this problem. The steps of feature extraction are as follows:

- **Decomposing the Chinese handwritten character image into four directional sub-patterns.** A character image was decomposed into the four directional sub-patterns, namely, horizontal stroke, vertical stroke, left slant and right slant stroke. There are several kinds of decomposing strategies to refine a Chinese character into four directional-patterns, which are shown in paper [6, 7]. Here, we use the stroke-based directional decomposition method to decompose the character image, which was proposed in paper [7]. Fig. 7 shows the result of decomposing a Chinese character "艾" with the stroke-based directional decomposing

(a) (b) (c) (d) (e)

Figure 7. (a) Original character. (b), (c), (d), (e) The four directional sub-patterns of the original character.

strategy.

- **Constructing double elastic meshes which are based on stroke density.** Firstly, according to the distribution of the horizontal and vertical stroke-density histograms, the elastic meshes of vertical-horizontal direction are constructed. Secondly, we use the diagonal stroke density which is proposed by this paper to construct the diagonal direction meshes. According to the distribution of the 45° and 135° directional stroke-density histograms, the elastic meshes of 45° and 135° direction are constructed.
- **Extracting features.** After a Chinese handwritten character is decomposed into four directional sub-patterns, the vertical and horizontal elastic meshes above are applied to the vertical stroke pattern and the horizontal stroke pattern, and the diagonal elastic meshes above are applied to the left slant pattern and the right slant pattern. The distribution of stroke pixels in each mesh is computed as the features.

IV. EXPERIMENTS

Our experiments were performed on 100 Chinese characters which are covered by the National Standard Chinese Character Set 16. Each character has 165 different writers' samples, 100 of them were used as training samples and the rest of them were used as testing samples. Fig. 8 shows 100 samples of one writer.

The experiments were carried out by the following three schemes:

- **Scheme 1:** Extracting features of vertical-horizontal direction elastic meshes which were proposed in paper [7] based on stroke-density by using the stroke density functions.
- **Scheme 2:** Extracting features of diagonal direction elastic meshes based on stroke-density by using stroke density functions which were proposed by us.
- **Scheme 3:** Firstly, use the feature extraction method in Scheme 1 to get the features of horizontal and vertical stroke sub-patterns. Secondly, use the method in Scheme 2 to get the features of left slant and right slant stroke sub-patterns. Then, combining the two features, we get the double elastic meshing features which are based on stroke density.

According to the different stroke density functions, we obtain the corresponding elastic meshes, respectively referred to the elastic mesh based on the density function of pixel point (PDM), the elastic mesh based on the density of stroke interval (IDM), the elastic mesh based on the density of the whole line (WLDM).

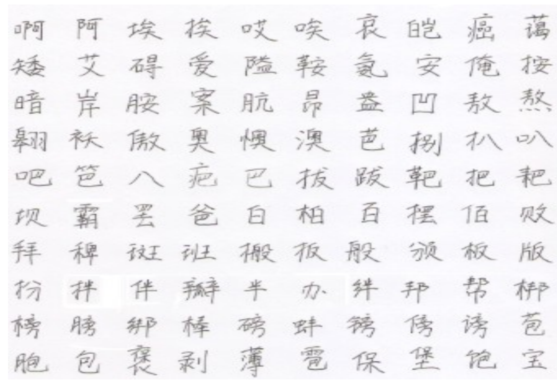

Figure 8 100 samples of one writer

LibSVM toolbox which was developed by Chih_Jen Lin and his partners was used in our experiments. It is a support vector machine tool which is widely used in SVM, classification and regression. We selected the radial basis function as the kernel function in our experiments. Experimental results with different schemes are shown in TABLE 1.

According to the experimental results shown in TABLE 1:

- With the increase of mesh number, the recognition rate of scheme 2 is generally increased. It can also be seen that the diagonal direction density elastic meshing method which used in scheme 2 had a high recognition rate as well as the vertical-horizontal direction density's which used in scheme 1. This indicates that the elastic meshing method which based on the stroke density of diagonal direction is reasonable and effective.
- Recognition rate of scheme 3 is higher than the scheme 1or 2's. It indicates that the elastic meshes of 45° and 135° directions which based on the diagonal direction stroke density can make up for the lack of elastic meshes of vertical and horizontal directions which

TABLE 1 RECOGNITION PERFORMANCE WITH DIFFERENT SCHEMES

Elastic Meshes	Recognition Rate (%)								
	Scheme 1			*Scheme 2*			*Scheme 3*		
	PDM	*IDM*	*WLDM*	*PDM*	*IDM*	*WLDM*	*PDM*	*IDM*	*WLDM*
3×3	76.68	77.21	77.69	76.34	77.05	77.10	77.26	78.01	78.23
4×4	81.41	82.61	82.78	81.01	82.05	82.11	83.23	84.09	84.21
5×5	83.25	85.38	85.21	83.20	84.87	84.90	85.07	85.78	85.62
6×6	86.64	86.92	86.56	86.72	86.97	86.57	87.52	87.81	87.94
7×7	88.25	89.36	89.48	88.61	89.37	89.51	91.40	92.06	92.11
8×8	90.16	91.53	91.57	90.85	91.62	91.70	91.51	92.17	92.23

based on vertical-horizontal direction stroke density. This is due to the fact that stroke density of diagonal direction can tolerate the distortion of left slant stroke and right slant stroke better than the stroke density of vertical-horizontal directions, and scheme 3's method has combined the two elastic meshes which have different directions.

V. CONCLUSION

In view of existing situation that the stroke density function without considering the distribution of strokes in diagonal direction, the stroke-based elastic meshing method of vertical-horizontal direction could not effectively extract the features of left slant and right slant strokes, we extend the method and propose a new definition of stroke density in diagonal direction, and use it with diagonal elastic meshing technique to constitute meshes. Then, combining the vertical-horizontal elastic meshes with the diagonal's, the stroke-density based double elastic meshing feature extraction approach is proposed for the recognition of Chinese handwritten characters. The experimental results demonstrate the effectiveness of this approach.

We get the conclusion that the feature extraction method of stroke-density based double elastic meshing can improve the recognition performance of Chinese handwritten characters effectively.

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