Segmentation of Fingerprint Images Using the Gradient Vector Field

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***Abstract*—In this paper, the properties of the fingerprint image gradient are discussed and their application to segment the fingerprint image is presented. The algorithm proposed here uses the magnitude of gradient and the variance of gradient vector's direction. The method takes advantage of the two prominent properties of fingerprint, i.e., the clarity of ridge to valley and the slow change of fingerprint texture orientation. This technique can not only segment the fingerprint images but also measure the quality of sub-block or overall fingerprint segmented. This algorithm is tested for a large number of fingerprint images with the variation of quality, and is found to be effective and robust. The results of segmentation of fingerprint images using our method proposed here are presented.**

***Index Terms*—Fingerprint Image; Image Quality; Fingerprint Segmentation.**

I. Introduction

An important step in an automatic fingerprint recognition system is to identify the foreground and background regions. The foreground is the component that originated from the contact of a fingertip with the sensor. The noisy area is called the background. It is desirable that the background and foreground regions should be identified at the earliest stage possible, so that the subsequent processing can effectively concentrate on only the foreground region of the fingerprint image. Thus, it saves processing time and cost. In addition, accurate segmentation is especially important for the reliable extraction of features like orientation, minutiae and singular points. Most feature extraction algorithms extract a lot of false features when applied to the noisy area, which may degrade the performance of identification algorithms. Therefore, accurate segmentation algorithm can improve the accuracy of systems.

Several approaches to fingerprint image segmentation are known from literature. In [1], the fingerprint is segmented using the statistics derived from the directional image. In [2] this method is extended through combining the variance criterion wherever the directional method fails. In [3] the gray-scale variance in the direction orthogonal to the orientation of the ridges is used to classify each 16×16 block. In [4], the output of a set of Gabor filters is used as input to a clustering algorithm that constructs spatially compact clusters. In [5], fingerprint images are segmented based on the coherence, while morphology is used to obtain smooth regions. In [6], Three pixel features, the coherence, the mean and the variance, are used to segment fingerprint images.

To develop a fast and efficient segmentation algorithm, we propose a new fingerprint segmentation method based on the gradient of image, which is commonly used to obtain the fingerprint orientation [7], [3], [9] and to enhance image contrast [10], [11]. The gradient of fingerprint image characterizes not only the contrast of image but also the structure of ridges and furrows. Therefore, the gradient of image is suitable for fingerprint image segmentation. The computation of gradient doesn't need any prior information except for the pixel gray level value and is very fast. In addition, the different quality scores are assigned to each block segmented and the overall fingerprint quality score also be given. Experimental results demonstrate that our algorithm proposed here is efficient.

The paper is organized as follows. The computation of image gradient is described in Section 2. In Section 3, the proposed segmentation algorithm is presented. The results based on the proposed algorithm are discussed in Section 4 and conclusions described in Section 5.

II. Gradient of fingerprint image

The gradient is a measure of change in a function, and an image can be considered to be an array of sample of some continuous function of image intensity. By analogy, significant change in the gray values in an image can be detected by using a discrete approximation to the gradient [12]. The gradient is the two-dimensional equivalent of the first derivative and is defined as the vector

$$G[f(x,y)] = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}. \quad (1)$$

There are two important properties associated with the gradient: (1) the vector $G[f(x,y)]$ points in the direction of the maximum rate of increase of the function $f(x,y)$, and (2) the magnitude of the gradient, given by

$$M = \sqrt{G_x^2 + G_y^2}, \quad (2)$$

equals the maximum rate of increase of $f(x,y)$ per unit distance in the direction G. From vector analysis, the direction of the gradient is defined as:

$$\alpha(x,y) = \arctan\left(\frac{G_y}{G_x}\right) \quad (3)$$

[1]This work is supported by Natural Science Foundation of China with grant number 60605007 and Youth Foundation of UESTC

a_0	a_1	a_2
a_7	$[i,j]$	a_3
a_6	a_5	a_4

Fig. 1. The labeling of neighborhood pixels used to explain the Sobel operator.

where the angle α is measured with respect to the x axis.

For digital images, the derivatives in Equation (1) are approximated by differences. There exist many operators to approximate the gradient, one of which is the most commonly used Sobel operator. The Sobel operator uses a 3×3 neighborhood for the gradient calculations as shown in Fig. 1. The magnitude of the gradient is computed by

$$M(x,y) = \sqrt{G_x^2 + G_y^2}, \tag{4}$$

where the partial derivatives are computed by

$$G_x = (a_2 + ca_3 + a_4) - (a_0 + ca_7 + a_6) \tag{5}$$

$$G_y = (a_0 + ca_1 + a_2) - (a_6 + ca_5 + a_4) \tag{6}$$

with the constant $c = 2$.

G_x and G_y can be implemented using convolution masks:

$$G_x = \begin{array}{|c|c|c|}\hline -1 & 0 & 1 \\ \hline -2 & 0 & 2 \\ \hline -1 & 0 & 1 \\ \hline \end{array} \qquad G_y = \begin{array}{|c|c|c|}\hline 1 & 2 & 1 \\ \hline 0 & 0 & 0 \\ \hline -1 & -2 & -1 \\ \hline \end{array} \tag{7}$$

Suppose that a fingerprint image I is divided into N $w \times w$ blocks. For each block $B_n, n = 1, 2, \ldots, N$, we can obtain P $(P = w \times w)$ gradient vectors $G_m^n, m = 1, 2, \ldots, P$ using Sobel operator described above with the zero-padded edges.

III. Image Segmentation

After obtaining P gradient vectors G_m^n of each block B_n, the magnitude M_m^n and the direction a_m^n of gradient vector G_m^n can be calculated according to the equation (2) and (3) respectively. The normalized average magnitude of gradient $\overline{M_n}$ for block B_n is computed as follows:

$$\overline{M_n} = f \frac{1}{P} \sum_{m=1}^{P} M_m^n, \tag{8}$$

where f is a normalizing factor which normalizes the value of $\overline{M_n}$ in the range from 0 to 1. Here f equals to $1/\sqrt{(255 \times 4)^2 + (255 \times 4)^2}$ due to 256 gray levels used. The normalized variance V_n of the gradient directions α_m^n for each block B_n is calculated by

$$V_n = g \frac{1}{P} \sum_{m=1}^{P} (\alpha_m^n - \overline{\alpha_n})^2, \qquad \overline{\alpha_n} = \frac{1}{P} \sum_{m=1}^{P} \alpha_m^n \tag{9}$$

where $\overline{\alpha_n}$ is the average gradient direction for block B_n and g a normalizing factor which normalizes the value of V_n in the range from 0 to 1. Here g is set to the value $1/\pi^2$ because the value of α_m^n is from $-\pi/2$ to $\pi/2$

Because the magnitude of the gradient characterizes the contrast of the fingerprint image [10], [11] and the direction of the gradient shows the information on the direction of the texture image [3], [9], it is reasonable to combine the magnitude with the direction of the gradient for segmenting the fingerprint image. In general, experience suggests that for each ideal fingerprint image block B_n, the average gradient $\overline{M_n}$ is large and the variance V_n is small, and vice versa. It should be noted that the direction variance V_n in singular block may be large and the block may be falsely regarded as background block if only depend on the direction variance information. However, we know that singular block is generally surrounded by foreground blocks and we can use this condition to distinguish singular block from background blocks easily by simple post-processing method. Thus, we establish a quality criterion Q_n for each fingerprint image block B_n as the weighted sum of the magnitude $\overline{M_n}$ and variance V_n by

$$Q_n = w_1.\overline{M_n} + w_2.(1 - V_n), \tag{10}$$

where w_1 and w_2 are weight coefficients satisfying $w_1 + w_2 = 1$.

We compute the value of Q_n for each block B_n. If Q_n is less than a threshold value T_b, the block is considered as a background block. Otherwise the block is marked as a foreground block. A quality criterion Q for the overall fingerprint image is defined as the average of the foreground block quality scores Q_n by

$$Q = \frac{\sum_{n=1}^{N_f} Q_n}{N_f}, \tag{11}$$

where N_f is the total number of foreground blocks and Q_n is calculated according to equation (10). For each fingerprint image, we can give a quality score Q according to equation (11) which characterizes the structure of ridges and valleys in the fingerprint image.

In summary, our segmentation algorithm can be stated as follows:

1) Divide the fingerprint image into N blocks of size $w \times w$.
2) Compute the gradient vectors (G_x, G_y) for each block B_n according to the equations (5) and (6).
3) Compute the average gradient magnitude $\overline{M_n}$ and the direction variance V_n by equations (8) and (9) respectively.
4) Calculate the block quality score Q_n with equation (10). Set the suitable value of the threshold T_b. If the quality score Q_n is greater than T_b, the block B_n is foreground. Otherwise, the block B_n is background.
5) Obtaining the overall image quality score Q using equation (11).

IV. Experimental Results

The public domain fingerprint database, DB3 Set A in FVC 2002, is used in the experiment which consists of 800 fingerprint images from 100 different fingers with 8 impressions per finger. The image size is 300×300 with resolution of $500dpi$. The fingerprint images are captured using capacitive sensor "100SC" by Precise Biometrics and quantified into 256 gray levels.

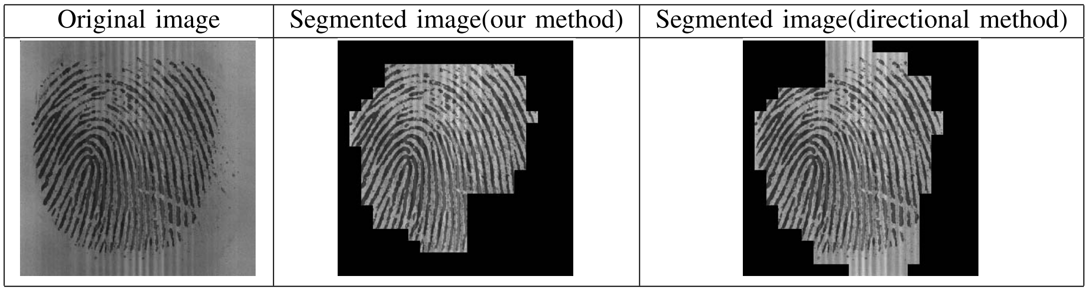

Fig. 2. Comparison of our method (gradient based) with directional method

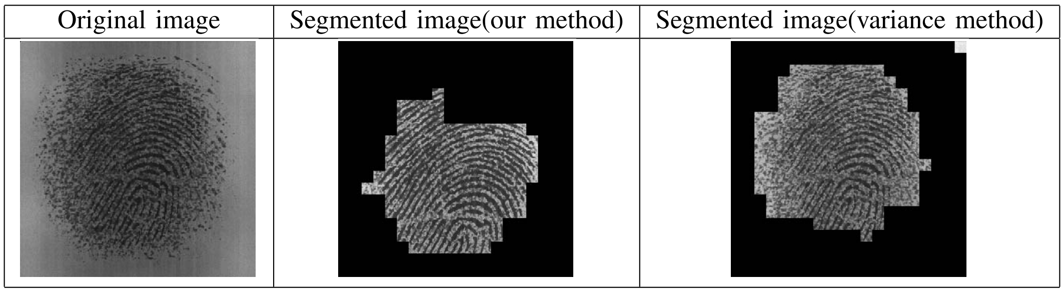

Fig. 3. Comparison of our method (gradient based) with variance method

Our proposed segmentation algorithm in this paper is implemented and applied to the above described fingerprint image database. The fingerprint image is divided into 400 $(400 = 20 \times 20)$ blocks each of which is 15×15 size. In order to avoid the border problem, we use Sobel operator to calculate the images gradients with the zero-padded edges. The normalizing factor f and g are set according to the values described in Section III. The weight coefficients w_1 and w_2 are set to the value 0.5. For comparison, other two methods, using directional method [1] and variance method [3], have also been tested for the 800 fingerprint images in the database mentioned above. Our proposed algorithm is found to work consistently well. The figures shown here in the paper represent the cases where the directional method and the variance method fail, and our method give good results. Fig. 2 shows the original image and the segmented images using directional method and our method. The directional method doesn't perform well in the (peripheral) regions where noisy texture exists. But our gradient-based algorithm does a good job. In Fig. 3, the original image and its segmented images using the variance method and our gradient-based method are shown. The variance method do a bad job in the area where the noisy area shows the relatively high contrast. On the contrary, our method has a good performance in the area. We can see that our method can work well for segmenting fingerprint images in all cases.

V. Conclusions

We have proposed an efficient and fast fingerprint image segmentation algorithm based on the image gradient. The gradient vector characterizes not only the contrast of fingerprint image but also describes the direction of fingerprint texture. From the sense of the used information, our algorithm is suitable for characterizing the structure of ridges and valleys of fingerprint and is more efficient than the algorithm only based on the image contrast [3] or the algorithm only based on the direction image [1]. The experimental results demonstrate the efficiency of our algorithm.

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