fingerprints,
orientation field,
directional field

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A REVIEW ON FINGERPRINT ORIENTATION ESTIMATION METHODS

As a global feature of fingerprint, orientation field plays important roles in most of image preprocessing methods used in automatic fingerprint identification system (AFIS). Many algorithms have been proposed for orientation field estimation. This paper reviews the advantages and disadvantages of existing fingerprint orientation estimation methods. Issues on possible directions of further development have been presented.

1. INTRODUCTION

With the pervasive growth of security requirement, it is highly desired to have reliable system of personal identification or verification. In many high safety demanding applications, the password based authentication is not secure enough. Therefore over the past few years, the biometrics based applications has experienced massive growth. Among all biometric techniques, automatic fingerprint based systems are most popular and promising for automatic personal identification. Long history of use fingerprints as a identification tool for forensic purposes caused its performance has reached a high level [7]. Now, it is not only used by police but also received wide attention commercially. However, there still exist critical research areas, such as the low performance with low quality fingerprint images [6]. This problem can be solved by specialized image processing [4, 5]. Most of these algorithms requires an information about local orientation of fingerprint pattern. Fingerprint pattern consist of ridges and valleys on the surface of a fingertip. On typical fingerprint image, the ridges are black and the valleys are white. Generally, fingerprints contains two kinds of features: global features such as ridge pattern orientation and frequency, and local features like minutia or singular points (core and delta). As a global feature, orientation field describes local orientation of the ridge-valley structure in each point of fingerprint image (Fig.1). It has been widely used for fingerprint image enhancement [4, 5], singular points detection [9, 10, 11] and classification [2, 3]. Reliable estimation of orientation field is a nontrivial issue. A lot of techniques have been proposed to deal with the problem. Generally, there are three categories of methods to compute the orientation field (also called directional field or directional image):
pixel–alignment based [1, 2, 8], gradient based methods [4, 12] and model–based method [14, 15, 16].

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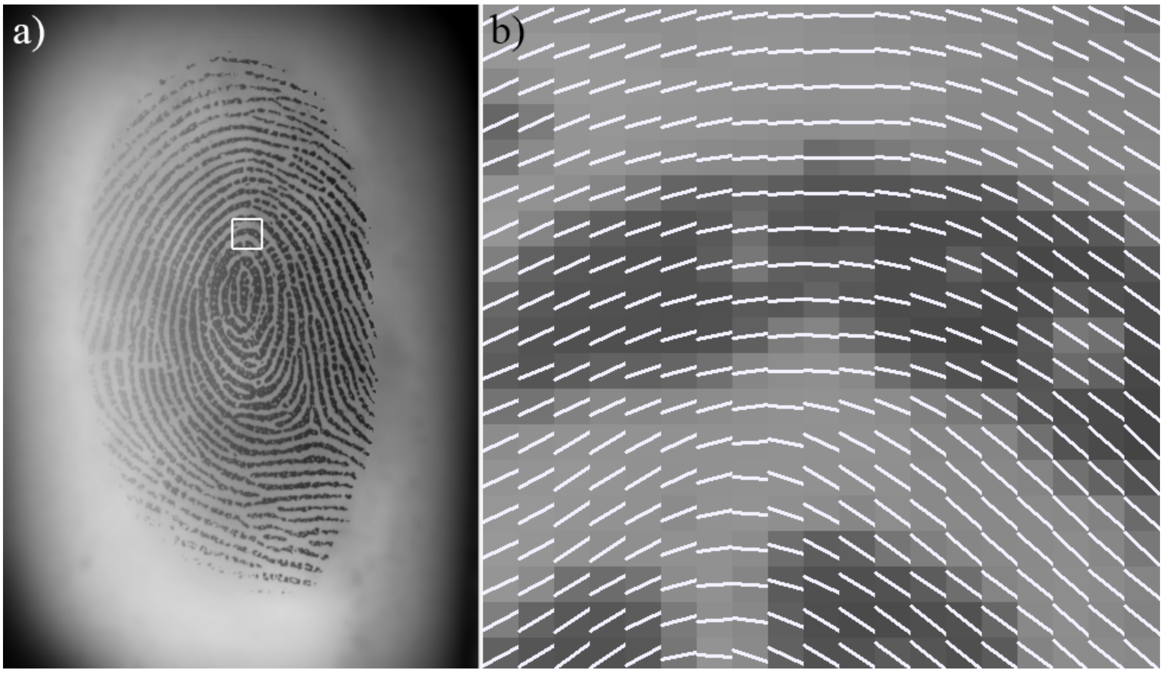

Fig. 1. a) Original fingerprint image, b) magnified area with marked dominant orientation of each pixel.

2. PIXEL-ALIGNMENT BASED METHOD

Typically, the pixel–alignment-based methods compute the local ridge orientation of each pixel on the basis of the neighboring pixel alignments with respect to a fixed number of reference orientations. Differentiation (fluctuation) of neighboring pixels grey level values is expected to be the smallest along the local ridge orientation and the largest along its orthogonal orientation. The accuracy of the estimated orientation in the pixel-alignment-based method is limited because to the fixed number of reference orientations.

The differentiation is computed by mask of eight oriented sampling scopes. Structure of this 9×9 mask (Fig. 2) was presented in [8] and was used to obtain dominant direction of fingerprint ridge–valley structure. Estimated values were limited to fixed number of eight discrete values. Greater number of sampling ranges requires bigger size of the mask, at the expense of increased computational complexity of the method.

The differentiation (fluctuation) of neighboring pixels values, in each direction, can by computed by:

$$Df_j(x,y) = \sum_{i=1}^{5} \left| S_j(x,y) - p_i^j \right|, \quad j = 0,1,\ldots,7 \tag{1}$$

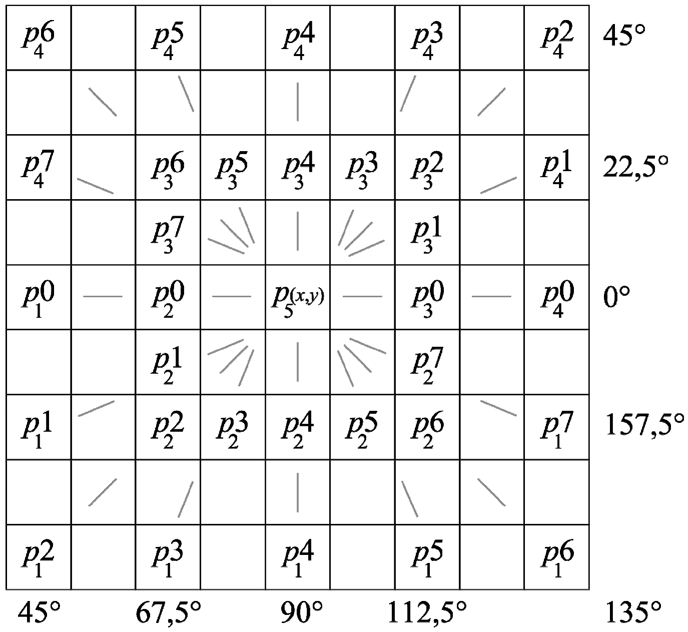

Fig. 2. The 9×9 mask to compute the differentiation of pixel values.

where S_i is the means of pixel values in eight direction:

$$S_j(x,y) = \frac{1}{5}\sum_{i=1}^{5}\frac{1}{p_i^j}, \quad j = 0,1,...,7 \tag{2}$$

and:

p_i^j – value of i pixel in j direction,

$j = 0,1,...,7$ – discrete direction values (respectively from 0° to 157,5°, with 22,5° step),

p_5 – central pixel of the mask located in *x*,*y* position of fingerprint image.

Due to the presence of some unreliable elements, resulting from heavy noise, corrupted ridge and furrow structures, minutiae and low gray value contrast, estimated differentiation values may not always be correct. The orientation smoothing stage is expected to reduce the noise and compute a reliable values. The averaging is computed for each pixel, separately in each *j* direction, respectively:

$$\overline{Df}_j(x,y) = Df_j(x,y) * fm, \quad j = 0,1,...,7 \tag{3}$$

where:

$$fm = \begin{bmatrix} 2 & 4 & 5 & 4 & 2 \\ 4 & 9 & 12 & 9 & 4 \\ 5 & 12 & 15 & 12 & 5 \\ 4 & 9 & 12 & 9 & 4 \\ 2 & 4 & 5 & 4 & 2 \end{bmatrix} \tag{4}$$

The orientation of smallest value, from all eight oriented averaged differentiation values, is expected to be the most close to the dominant orientation of that pixel:

$$\theta_{dsc}(x,y) = \frac{\pi}{8} z_{\min}(x,y) \tag{5}$$

where:

$$z_{\min}(x,y)=\arg_j(\min\{\overline{Df}_j(x,y),\ \ j=0,1,...,7\}) \tag{6}$$

Computed directional values can be presented as gray-scale image (Fig. 3). Black color corresponds to the skin ridges inclined at an angle of 0°, and the next discrete direction values correspond to increasingly lighter shades. Color white corresponds to the angle of 157.5°.

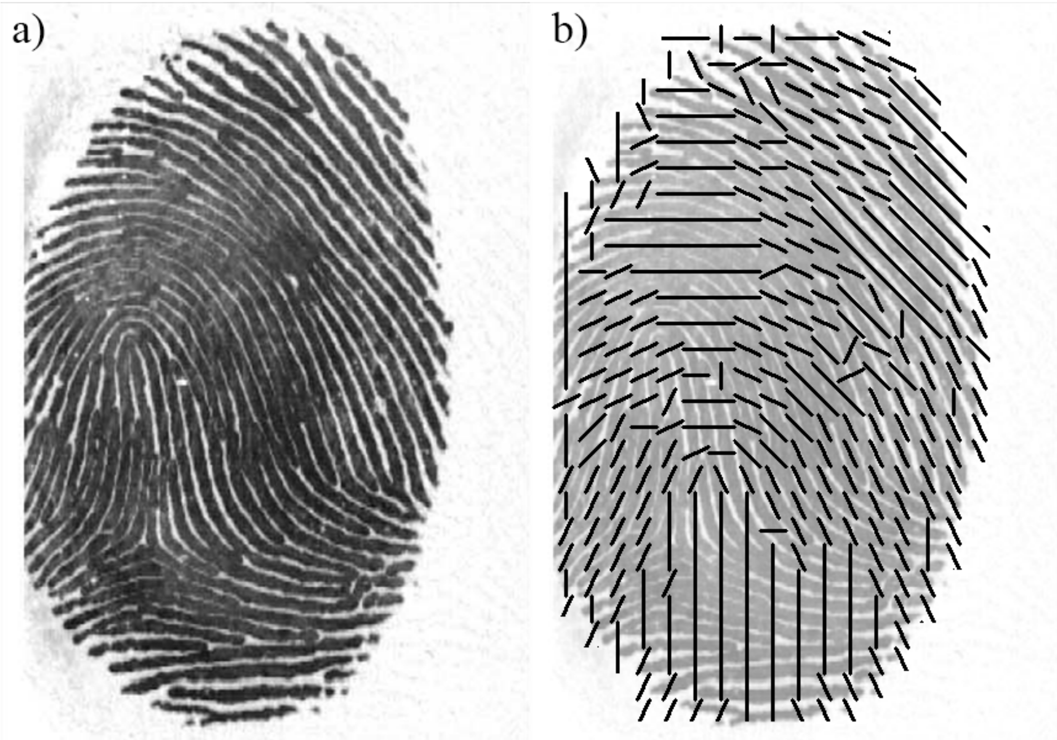

Fig. 3. a) Original fingerprint image, b) orientation field θ_{dsc}.

3. GRADIENT BASED METHOD

The most popular gradient–based method is presented by M. Kass and A. Witkin [12] least squares contour alignment method. The most important advantage of this algorithm is the fact, that the obtained values are continuous.

Since the gradients are the orientations at pixel scale, the orientation of ridge is orthogonal to average phase angle of changes pixels value indicated by gradients. The orientation of an image block is estimated by averaging the squared gradients to avoid the orientation ambiguity.

The main steps of the modified least mean square algorithm are as follows:

1. Compute the G_x and G_y gradients at each pixel of fingerprint image, where gradient operator is estimated as Sobel operator:

$$S_x=\begin{bmatrix}-1 & 0 & 1\\ -2 & 0 & 2\\ -1 & 0 & 1\end{bmatrix}_{G_x},\quad S_y=\begin{bmatrix}-1 & -2 & -1\\ 0 & 0 & 0\\ 1 & 2 & 1\end{bmatrix}_{G_y} \tag{7}$$

If computed gradient values are equal and non-zero, then randomly increase one of them by 1:

$$\forall_{G_x,G_y}\left(G_x\neq 0\wedge G_y\neq 0\wedge(G_x=G_y):G_x=G_x\pm 1\right) \tag{8}$$

2. Estimate the local orientation in $\omega \times \omega$ blocks, centered at pixel (x, y) using the following equations:

$$\overline{G}_{sy}(x,y) = \sum_{i=-\omega/2}^{\omega/2} \sum_{j=-\omega/2}^{\omega/2} 2G_x(x+i, y+j)G_y(x+i, y+j) \tag{9}$$

$$\overline{G}_{sx}(x,y) = \sum_{i=-\omega/2}^{\omega/2} \sum_{j=-\omega/2}^{\omega/2} \left(G_x(x+i, y+j)^2 - G_y(x+i, y+j)^2\right) \tag{10}$$

$$\overline{\phi}(x,y) = \frac{1}{2}\tan^{-1}\frac{\overline{G}_{sy}(x,y)}{\overline{G}_{sx}(x,y)} \tag{11}$$

$$\theta_{gb}(x,y) = \overline{\phi}(x,y) + k\pi \tag{12}$$

where:

$$k = \begin{cases} \frac{1}{2} & \text{when } \left(\overline{\phi}(x,y) < 0 \wedge \overline{G_{sy}}(x,y) < 0\right) \vee \left(\overline{\phi}(x,y) \geq 0 \wedge \overline{G_{sy}}(x,y) > 0\right) \\ 1 & \text{when } \overline{\phi}(x,y) < 0 \wedge \overline{G_{sy}}(x,y) \geq 0 \\ 0 & \text{when } \overline{\phi}(x,y) \geq 0 \wedge \overline{G_{sy}}(x,y) \leq 0 \end{cases} \tag{13}$$

Conducted experiments show that the size of $\omega \times \omega$ blocks should be at least twice the average distance between the fingerprint ridges [13]. Computed orientation field θ_{gb} can be presented as color hue values (Fig. 4).

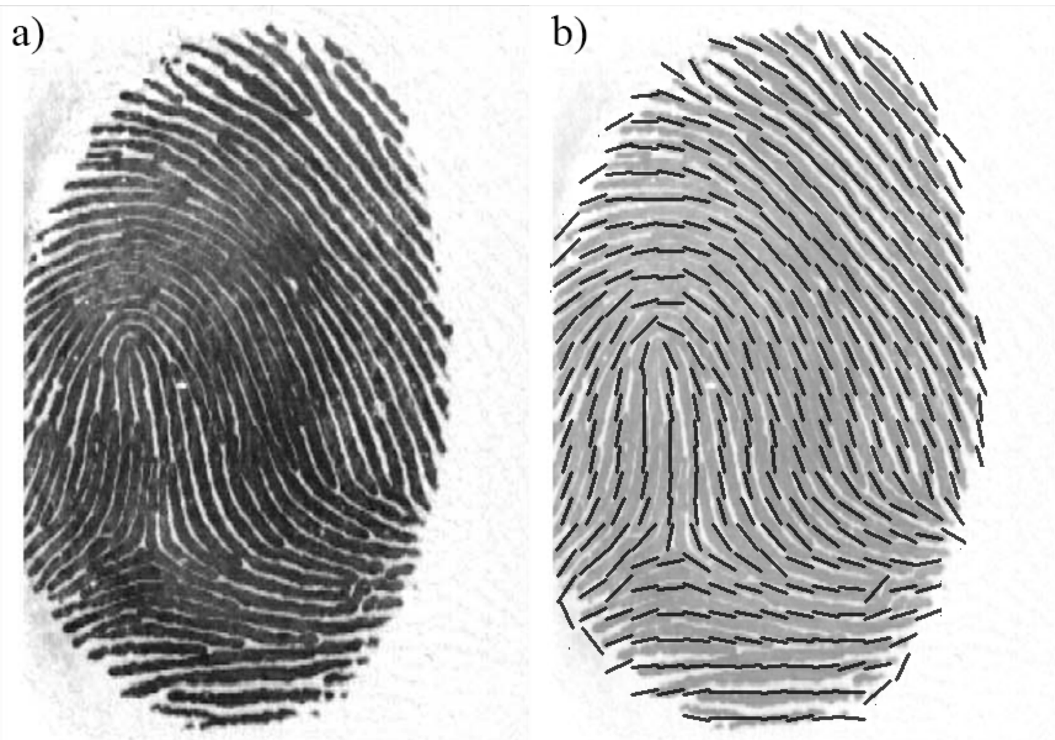

Fig. 4. Original fingerprint image, b) orientation field θ_{gb}.

4. MODEL BASED METHOD

Most advanced orientation field estimation method is model–based method [15], which rely on the global regularity of orientation values around the singular points. First work in this direction was the zeropole model presented by Sherlock and Monro [14]. An improvement of this model was made by Vizcaya and Gerhardt [16]. These two models do not consider the distance from singular points and the influence of a singular point is the same as any point on the same central line, whether near or far from the singular point, serious error will be caused in the modeling of the regions far from singular points [15]. As a result, Zhou and Gu [15, 17] proposed a combination model to represent the fingerprint orientation field.

Since the orientation field is smooth except singular points areas, it can be established a polynomial model to globally represent the orientation field and by using a point-charge model it is possible to improve the local accuracy of estimation at each singular point. When the coarse field is computed by using conventional gradient-based algorithm, the model is utilized to compute the finer field. Since the noise can be discarded in the approximation step, the final estimated result of orientation field has a robust performance while preserving the accuracy [17].

The value of a orientation field is always defined within $[0,\pi)$, therefore the orientation field cannot be modeled directly. A solution to this problem is to map the orientation field to a continuous complex function [16]:

$$U = R + iI = \cos 2\theta + i\sin 2\theta \tag{14}$$

where R and I denote the real part and image part of the unit-length complex, U.

A model named Point-Charge is added at each singular point. The influence power of a standard (vertical) core at the point (x, y), is defined as:

$$PC_{core} = (H_1, H_2) = \begin{cases} \left(\dfrac{y-y_0}{r}, \dfrac{x-x_0}{r}\right)Q & \text{when} \quad r \le R \\ 0 & \text{when} \quad r > R \end{cases} \tag{15}$$

where (x, y) is this core's position, Q is the quantity of electricity, R denotes the radius of its effective region, $r = \sqrt{(x-x_0)^2 + (y-y_0)^2}$. For standard delta respectively:

$$PC_{delta} = (H_1, H_2) = \begin{cases} \left(\dfrac{y-y_0}{r}, -\dfrac{x-x_0}{r}\right)Q & \text{when} \quad r \le R \\ 0 & \text{when} \quad r > R \end{cases} \tag{16}$$

To combine the polynomial model (*PR*, *PI*) with Point-Charge smoothly, a weight function is defined. For Point-Charge, its weight at (x, y) is defined as:

$$\alpha_{PC}^{(k)}(x, y) = 1 - \frac{r^{(k)}(x, y)}{R^{(k)}} \tag{17}$$

where $(x_0^{(k)}, y_0^{(k)})$ is the coordinate of the *k*-th singular point, $R^{(k)}$ is its effective radius, and $r^{(k)}$ is set as $\min\left(\sqrt{(x-x_0^{(k)})^2 + (y-y_0^{(k)})^2}, R^{(k)}\right)$. For polynomial model, its weight at (x, y) is:

$$\alpha_{PM}(x, y) = \max\left\{1 - \sum_{k=1}^{K} \alpha_{PC}^{(k)}, 0\right\}, \tag{18}$$

where K is the number of singular points.

Finally, the combination model for the whole fingerprint's orientation field θ_{md} (Fig. 5) can be formulated as:

$$\begin{pmatrix} R(x,y) \\ I(x,y) \end{pmatrix} = \alpha_{PM} \begin{pmatrix} PR \\ PI \end{pmatrix} + \sum_{k=1}^{K} \alpha_{PC}^{(k)} \begin{pmatrix} H_1^{(k)} \\ H_2^{(k)} \end{pmatrix} \quad (19)$$

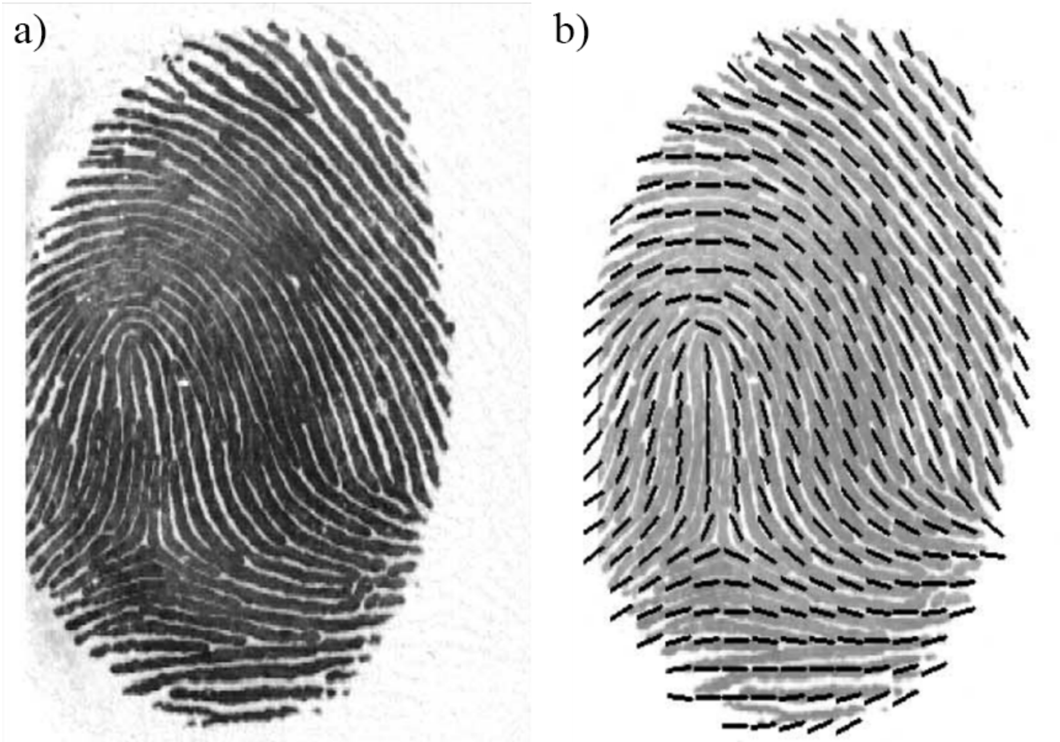

Fig. 5. a) Original fingerprint image, b) orientation field θ_{md}.

5. CONCLUSIONS

The experiments presented at [13] shows that most simple but less accurate pixel–alignment based methods are more robust to image noise than gradient based method.

Experimental results of comparison model based method with gradient based method shows that performance in the regions with strong noise or near the singular points (or outside boundary) is much better in model-based method due to the global approximation [17].

Gradient based methods are most accurate only with high quality fingerprint images [16].

It can be concluded, that the possible further work can be carried out in the direction of hybrid model combining model-based methods with more robust to noise pixel-alignment methods.

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