fingerprint recognition,
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GRADIENT BASED FINGERPRINT ORIENTATION FIELD ESTIMATION

Accurate estimation of ridge orientation is a critical step in image preprocessing methods used in automatic fingerprint identification systems (AFIS). Fingerprint orientation plays important roles in fingerprint enhancement, classification and recognition. The most popular is gradient-based method. This paper reviews the algorithm parameters, determining the compromise between accuracy in high-curvature areas and robustness against noise.

1. INTRODUCTION

With the continuous growing on security requirement, biometric technologies have largely been deployed in a wide range of applications. Among various biometric techniques, fingerprint based systems are regarded as most popular and reliable for automatic personal identification [15]. A long history of fingerprints use as an identification tool for forensic purposes and increased attention on automatic identity verification has caused its performance reach a high level [2]. However, there still exist critical research issues such as the low performance with poor quality images [6]. This problem can be solved by image enhancement processing. Nevertheless, critical to this step is to reliably estimate the information about local orientation of fingerprint pattern.

Fingerprint pattern consist of ridges and valleys on the surface of a fingertip. Generally, fingerprints contain two kinds of features: local features like minutia or singular points (core and delta) and global features, such as a ridge pattern orientation and frequency. The local ridge structures are commonly used to identify or verify person identity by matching two sets of minutiaes. As a global feature, orientation field describes local orientation of the ridge-valley structure in each point of fingerprint image (Fig. 1).

The values of orientation angles of fingerprint pattern have a critical impact on almost all subsequent processes in automatic fingerprint recognition systems. It can be used in fingerprint image enhancement [6],[4], singular points detection [12],[1],[14] and classification [8],[5],[10],[7]. Thus, a incorrect orientation estimation could generate faulty recognition results.

The most popular method to compute the orientation field is presented by M. Kass and A. Witkin [11] least squares algorithm (gradient-based method). Important advantage of this algorithm is the fact, that the obtained values are more accurate (continuous values) in comparison to pixel-alignment methods [1],[9]. Estimation of ridge orientation values is based on gradient relationship between neighboring pixels. Since the gradients are the orientations at the pixel scale, the orientation of the ridge is orthogonal to the average phase angle of pixels value changes, indicated by gradients. However, only ridge edge gradients are orthogonal to the ridge. Therefore the gradients averaging step is necessary.

This paper attempts to review the parameters of least squares algorithm for fingerprint orientation estimation.

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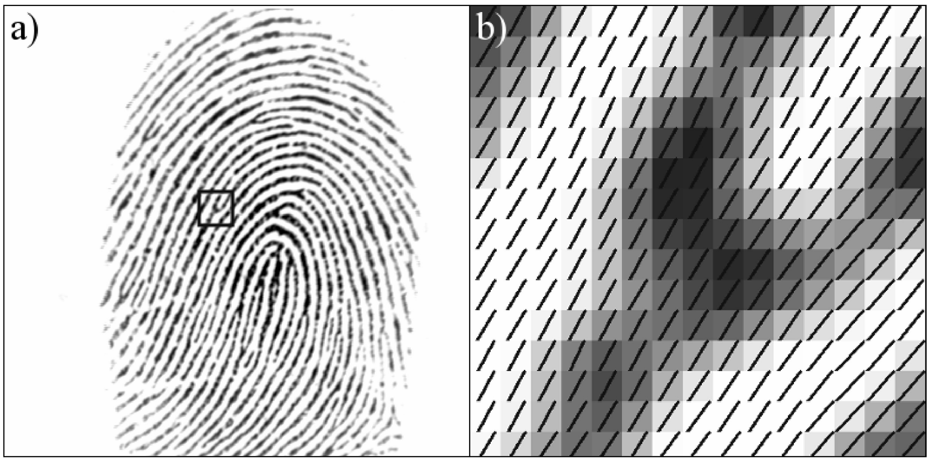

Fig. 1. a) Original fingerprint image, b) magnified area with marked dominant orientation of each pixel.

2. GRADIENT BASED ORIENTATION ESTIMATION

The main steps of the modified least mean square algorithm are as follows [13]:

1) Compute the gradients $\partial_x(x, y)$ and $\partial_y(x, y)$ at each pixel of the fingerprint image $I(x, y)$.
2) If gradient values are the same $\partial_x(x, y) = \partial_y(x, y)$ then add randomly ± 1 to one of the gradients. If one of gradients values is equal to 0 (for example $\partial_x(x, y) = 0$) then also randomly ± 1.
3) Estimate the local orientation in $\omega \times \omega$ blocks, centered at pixel (x, y) using the following equations:

$$\mathcal{V}_x(x, y) = \sum_{u=x-\frac{\omega}{2}}^{x+\frac{\omega}{2}} \sum_{v=y-\frac{\omega}{2}}^{y+\frac{\omega}{2}} 2\partial_x(u, v)\partial_y(u, v) \tag{1}$$

$$\mathcal{V}_y(x, y) = \sum_{u=x-\frac{\omega}{2}}^{x+\frac{\omega}{2}} \sum_{v=y-\frac{\omega}{2}}^{y+\frac{\omega}{2}} (\partial_x^2(u, v) - \partial_y^2(u, v)) \tag{2}$$

$$\phi(x, y) = \frac{1}{2} \tan^{-1} \left(\frac{\mathcal{V}_x(x, y)}{\mathcal{V}_y(x, y)} \right) \tag{3}$$

$$\theta_{gr}(x, y) = \phi(x, y) + k\pi \tag{4}$$

where:

$$k = \begin{cases} \frac{1}{2} & (\phi(x, y) < 0 \wedge \mathcal{V}_x(x, y) < 0) \vee (\phi(x, y) \geq 0 \wedge \mathcal{V}_x(x, y) > 0) \\ 1 \quad \text{for} & \phi(x, y) < 0 \wedge \mathcal{V}_x(x, y) \geq 0 \\ 0 & \phi(x, y) \geq 0 \wedge \mathcal{V}_x(x, y) \leq 0 \end{cases} \tag{5}$$

3. ALGORITHM PARAMETERS EVALUATION

Presented least mean square algorithm depends on two significant parameters:

- horizontal and vertical gradient operators: ∂_x and ∂_y,
- size $\omega \times \omega$ of averaging blocks.

The proposed algorithm had been applied with different parameters values on the fingerprint images database, which contains fingerprint images in 300dpi, 500dpi and 1000dpi resolution. Fingerprint images in the database were selected from NIST Special Database, FVC database samples, and captured with a livescanner. For this data set method was evaluated in accordance with the principles of Fingerprint Orientation Extraction Benchmark [16].

3.1. GRADIENT OPERATOR

The gradient operator computes an approximation of the gradient vector of the image intensity function. The gradient operator may vary from the simple Sobel or Prewitt operator to the more complex Canny operator.

To evaluate the effectiveness of gradient operators, a gradient-differentiation, Sobel operator, Prewitt operator, Sharr operator, Canny edge detector [3] and anizotropic method [13] were compared.

The Canny edge detector and anizotropic method are a multi-stage algorithms, with noise reduction step. It can be assumed that those methods provides enhancement step.

The difference $\overline{\theta}^{\varepsilon}$ between orientation estimated by the automatic method θ^A and orientation estimated by a expert θ^E, was evaluated:

$$\theta^{\varepsilon} = \begin{cases} |\theta^E - \theta^A| & \text{for} \quad \theta^E - \theta^A > \frac{\pi}{2} \\ |\pi - \theta^E + \theta^A| & \text{otherwise,} \end{cases} \tag{6}$$

The results (Fig. 2) summarized in Table 1 show that the lowest error level among the standard operators provides Sobel operator. Therefore, this operator was used in Canny edge detector and Anizotropic filtering method. The anizotropic method [13] has lowest error level in comparison to other methods.

Table 1. Mean difference $\overline{\theta}^{\varepsilon}$ between estimated orientations (Degree).

Error	Operators				Canny edge detector	Anizotropic filtering method
	Gradient	Prewitt	Scharr	Sobel		
$\overline{\theta}^{\varepsilon}$	16,56	16,38	16,21	**15,30**	14,49	**9,68**

It can be observed from the Fig. 2 that there is significant difference between standard operators and methods with enhancement step. Therefore, it can be concluded that orientation enhancement step is necessary.

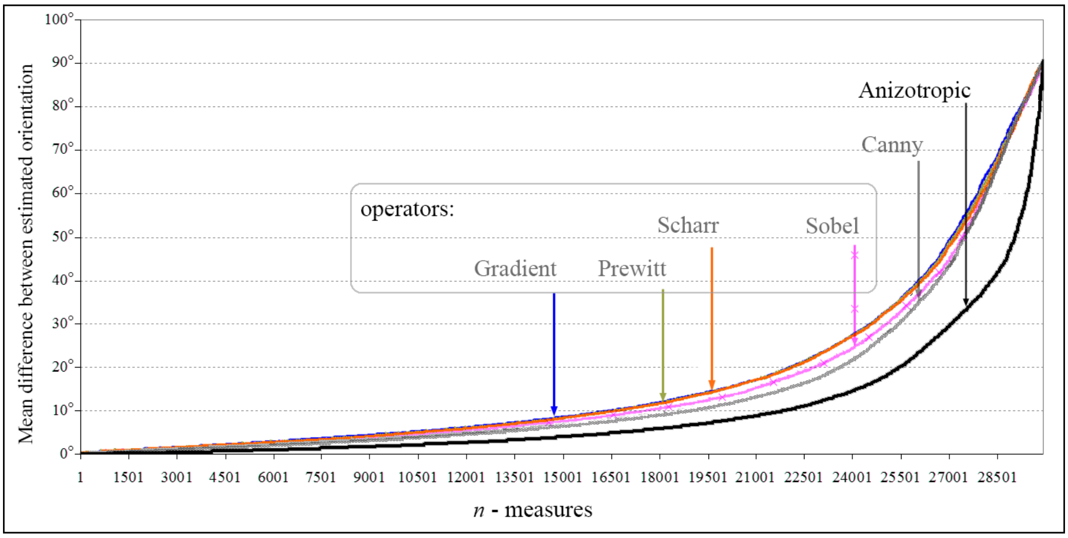

Fig. 2. Difference θ^{ε} between estimated orientations.

3.2. SIZE OF AVERAGING BLOCKS

Estimation of ridge orientation values is based on gradient relationship between neighboring pixels. Only pixel occurring on the edges of ridges provides accurate values (Fig. 3). Therefore the gradients averaging step is necessary.

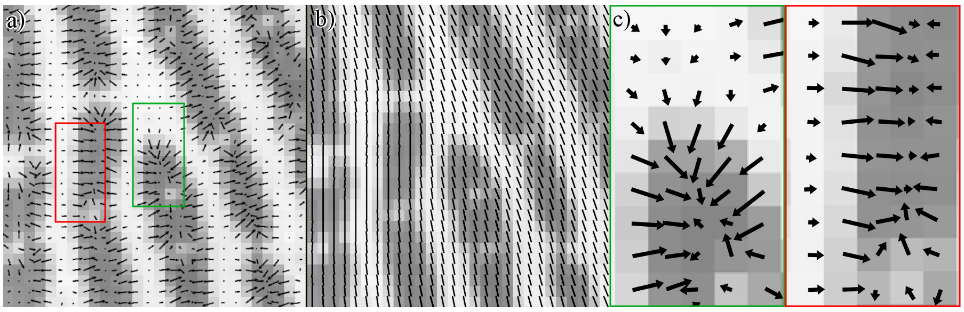

Fig. 3. a) Fingerprints with marked gradients values, b) estimated orientation, c) magnified areas of ridge edges.

The size of the $\omega \times \omega$ window must be adapted to resolution of input image and provide compromise between accuracy in high-curvature areas and robustness against noise. To evaluate the influence of the $\omega \times \omega$ window size on effectiveness of orientation estimation, a combination of different ω size and image resolution were used in the experiments.

As the minimum resolution for FBI-compliant scanners is 500dpi, it is the most popular resolution for fingerprint images. 300 dpi is the minimum resolution that allows the extraction algorithms to locate the minutiae in fingerprint. High resolution 1000dpi fingerprint images have been increasingly used in fingerprint recognition. They can provide more fine features (e.g. pores) than standard fingerprint images. For this reason, mentioned above resolutions were used in performed experiments.

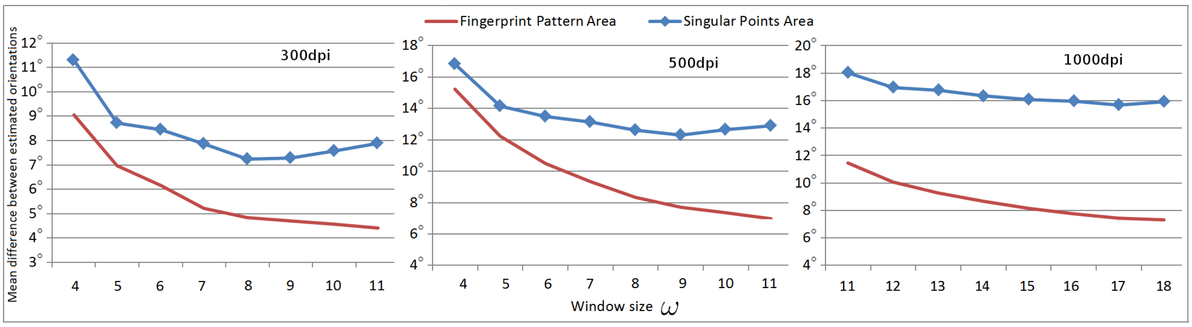

Fig. 4. Difference between estimated orientations for different resolutions and ω value.

In this study expert determined the orientations separately for high curvature singular points areas and for the rest part of image (fingerprint pattern area). Experimental results (Fig. 4) show that the too large $\omega \times \omega$ window size results in reduced effectiveness of gradient based algorithm in singular points areas. The optimal dimensions of $\omega \times \omega$ window are shown in Table 2.

Table 2. Optimal ω size for each evaluated resolution.

resolution	300dpi	500dpi	1000dpi
ω - size	8	9	17

4. CONCLUSION

In this paper a parameters evaluation of gradient-based fingerprint orientation estimation has been presented.

It can be concluded from evaluated experiments that enhancement of ridge orientation estimation significantly increases the accuracy of detected values.

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