Multiscale Orientation Field Estimation

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Abstract- **In response to broadband wireless access need, the IEEE 802 committee set up a working group to develop such standard - IEEE 802.16. Later, an industrial association, the Worldwide Interoperability for Microwave Access (WiMAX) Forum, was formed to promote the 802.16 standard.**

The present paper aims at presenting the process of investigation of Bandwidth Request Mechanisms in 802.16 Networks under Point-to-Multipoint Mode using the simulation model created with GPSS-General Purpose Simulation System.

Keywords- **Bandwidth request, Polling system, Simulator, WiMAX networks**

I. INTRODUCTION

There exist various biometric techniques for automatic personal identification where automatic fingerprint identification system (AFIS) is most popular and also considered to be amongst most accurate and reliable ones. [1].

A fingerprint represents the image of the surface of the skin of the fingertip. Every fingerprint image consists of lines, called ridges, and interlines spaces, called valleys. Francis Galton defined ridge as a single curve segment, where combination of ridges forms a fingerprint pattern [1]. That pattern can be described as an oriented texture pattern with fixed dominant spatial frequency and orientation in a local neighborhood. The frequency is dependent on inter-ridge spacing, and orientation on flow pattern exhibited by the ridges. Region of a fingerprint where the ridge pattern makes it visually prominent are called singularities [2]. There are two types of fingerprint singularities: core and delta, and they are very useful for determining fingerprint's class.

A closer analysis of the ridges reveals some anomalies (local features) called minutiae, which can be used for manual or automatic fingerprint identification since their number and position defines fingerprint's individuality. Two most popular types of minutiae are ridge endings and bifurcations. Typical structure and basic features of fingerprints (singularities and minutiae) are shown in Fig. 1.

Fingerprints orientation field, as a global feature, is defined as the local orientation of the ridge-valley structure and is one of the basic structures of a fingerprints. The variation of orientation field is of low frequency so that it is robust with respect to various noises [3].

Fig. 1. Basic features of fingerprints: minutia- ridge ending (in square), ridge bifurcation (in circle), singularities core(X) and delta (in triangle)

There exist different methods for orientation field estimation. Essentially they can be divided in two groups: filter-bank based approaches (convolving techniques) [4, 5] and gradient-based approaches [6, 7, 8, 9, 10]. In either way, some information may be lost during the process of smoothing the orientation field. Smoothing part is necessary for obtaining correct orientation aproximation in scratchy regions. This paper considers the problem of obtaining and preserving the multiscale orientation image information in order to use it in process of spurious minutiae detection in scratchy regions.

The rest of this paper is organized as follows. Section II gives the basics about orientation field estimation. Technical background of general convolution and gradient-based approaches are described in Section III and Section IV respectively. In Section V multiscale orientation information is presented. Some examples and possible uses of that multiscale information (especially for scratchy regions detection) are shown. Finally, Section VI concludes the paper.

II. ORIENTATION FIELD ESTIMATION

Orientation field estimation is an essential module of fingerprint recognition systems. The angles of orientation fields represent the ridge flow directions on regulary spaced grids. Since they reveal the intrinsic features of ridge topologies, we may say that all subsequent processes in the fingerprint recognition systems greatly depends on accurate orientation estimation.

The ridge (or valley) orientation in two dimensional space can be represented in two ways. First way is to represent the ridge orientation by a unit vector, forming angle θ with x-axis, as shown in Fig. 2(a). The angle θ, called *direction* of the vector, is in the range $[0, 2\pi)$. The alternative way is to

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treat the ridge as nonoriented line, as shown in Fig. 2(b). In this case, the angle θ, is called *orientation* of the line and belongs to the range $[0, \pi)$. This second approach is more often useful in fingerprint analysis since it is difficult to determine the proper angle of unit vector in every pixel. In the analysis, the concept of “directional field” or “orientation field” known from differential geometry must be used. However, in the literature dealing with fingerprint analysis, as well as in this paper, both terms “direction” and “orientation” are used as synonyms to denote ridge line orientation.

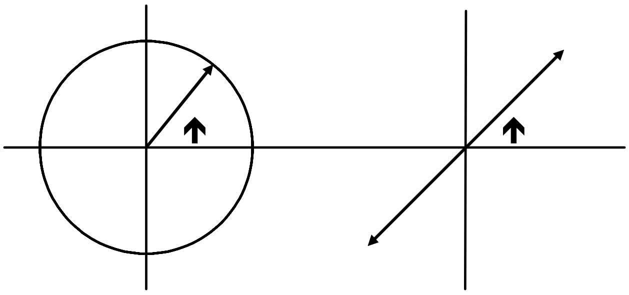


Fig. 2. Ridge orientation represented by: (a) vector, (b) orientation.

As we mentioned earlier there are two different approaches for orientation estimation: filter-bank based approaches (convolving techniques) and gradient-based approaches. First one are more resistant to noise than gradient-based, and can be executed very quickly. A disadvantage of this methods is, since they rely on a number of fixed possible templates or filters (orientations are quantised mostly to only 8 directions), that result may not be very accurate [1]. Most modern systems require a greater degree of accuracy, and therefore rely primarily on gradient-based algorithms. In fingerprint image gradients will point in the direction from ridges towards valleys as this will be the direction with the greatest rate of change in greyscale pixel values for a local area. The orientation of the ridges in that area will be perpendicular to the average gradients. Gradient-based techniques are popular due to their ability to create highly accurate results, but they also have some limitations. Since the gradients of image intensity are usually computed on pixel level, the related methods are quite sensitive to noise even after the averaging/smoothing process. There also exist some model based approaches [3, 11] where we need to know the locations and types of singularities in a ridge pattern in order to adjust the system parameters for orientation estimates. In such cases, the coarse orientation estimates are used to feed the training model as initial statistics. Therefore, it is still critical to have a good estimation of coarse orientation fields in the first place.

III. Convolution Mask Methods

The local orientation of ridges in each pixel is chosen based on criterion of maximal gray level uniformity in the neighborhood of each pixel. Usually, the orientation is estimated in 9×9 neighborhood around the examined pixel in the center [5]. Also, in order to facilitate subsequent processing only small number (typically eight) of possible orientations is allowed. One typical 9×9 mask is shown in Fig. 3. The pixel intensity values corresponding to eight possible directions (denoted $i = 0,...,7$) are summed to give eight directional sums s_i. The formation of directional sums can be interpreted as the convolution of fingerprint image with eight masks, having all elements equal to zero except in positions denoted by i where the elements have value 1.

6		5		4		3		2
7		6	5	4	3	2		1
		7				1		
0		0		*C*		0		0
		1				7		
1		2	3	4	6	6		7
2		3		4		5		6

Fig. 3. The 9×9 mask to compute directional sums.

After the computation of eight directional sums, the maximal and minimal sums are determined as:

$$s_p = \min_{0 \le i \le 7} s_i \quad , \quad s_q = \max_{0 \le i \le 7} s_i \qquad (1)$$

The direction at a pixel is defined to be *p* if the center pixel is located on a ridge (dark area), or *q* if the center pixel is located in a valley (light area). Therefore, the direction at a pixel is defined as:

$$d = \begin{cases} p, & \text{if } (4C + s_p + s_q) > \frac{3}{8}\sum_{i=0}^{7} s_i \\ q, & \text{if } (4C + s_p + s_q) \le \frac{3}{8}\sum_{i=0}^{7} s_i \end{cases} \qquad (2)$$

where *C* is the value of the central pixel.

The obtained directional image has too much elements for further processing. Therefore, it is divided into blocks which dimensions are usually 8×8 or 16×16 pixels. All directions belonging to the same block are averaged and the average direction is assigned to the block as its dominant direction. Although this block-directional image contains less data for further processing the classification accuracy remains about the same, what has been verified by a number of experiments. In order to obtain correct results, in averaging procedure doubled angles are used to represent the directions, therefore, a direction is represented by the unit vector $\mathbf{v} = (\cos 2\alpha \ \sin 2\alpha)$. After averaging inside a block, the average vector $\mathbf{v}_{av} = (x_{av} \ y_{av})$ is obtained, where x_{av} and y_{av} are the averages of cosine and sine components of all unit vectors belonging to this block. The average direction angle is easily found as $\alpha = 0.5 \arctan(y_{av} / x_{av})$. Also, as a measure of direction uniformity in a block, the modulus of the resultant vector $\sqrt{x_{av}^2 + y_{av}^2}$ can be used. If the modulus is closer to one, the uniformity of directions is better, and the result of averaging is more reliable.

This method of computing the orientation field is used widely because it is simple and fast. However, the estimated field is coarse due to the limit of number of possible directions. Systems requiring a greater accuracy should use a gradient-based method.

IV. GRADIENT-BASED APPROACH

In a fingerprint image, a gradient points to the highest variation of gray intensity which is perpendicular to the edge of ridge lines. The gradient vector $[G_x(x,y) G_y(x,y)]^T$ is defined as [6]:

$$\begin{bmatrix} G_x(x,y) \\ G_y(x,y) \end{bmatrix} = sign(G_x)\nabla I(x,y) = \\ = sign\left(\frac{\partial I(x,y)}{\partial y}\right)\begin{bmatrix} \frac{\partial I(x,y)}{\partial x} \\ \frac{\partial I(x,y)}{\partial y} \end{bmatrix}. \tag{4}$$

where $I(x,y)$ represents the original gray-scale image. Since opposite directions indicate equivalent orientations, the first element of the gradient vector has been chosen to always be positive.

Since elements of an orientation field are normal to the gradients in the local area, one method of calculating the orientation field for a given region is to set its orientation perpendicular to the average direction of its gradients. However, some care must be taken when calculating the average gradient direction because two gradients on different sides of the same ridge will point in opposite directions and cancel each other out if averaged (even though they represent the same ridge orientation). One solution to this problem is to double the angles of the gradient vectors before averaging [10].

The average squared gradient $[\overline{G_{s,x}} \overline{G_{s,y}}]^T$ in a block specified by a window size W can be calculated as [6]:

$$\begin{bmatrix} \overline{G_{s,x}} \\ \overline{G_{s,y}} \end{bmatrix} = \begin{bmatrix} \sum_W G_x^2 - G_y^2 \\ \sum_W 2G_x G_y \end{bmatrix}. \tag{5}$$

Conventional gradient-based methods divide the input fingerprint image into equal-sized blocks and average over each block independently. The direction of orientation field in a block is given by:

$$\Phi = \frac{1}{2}\tan^{-1}\left(\frac{\sum_W 2G_x G_y}{\sum_W G_x^2 - G_y^2}\right) + \frac{\pi}{2}, \; G_x, G_y \neq 0 \tag{6}$$

where G_x and G_y are the horizontal and vertical components of the gradient at each pixel.

This method is sensitive to distortions of fingerprint image such as noise and scratches, so some additional processing (smoothing) is necessary to improve the quality of the estimated field. Usually, Gaussian smoothing operator is used to smooth the orientation fields in a local neighborhood.

V. MULTISCALE ORIENTATION INFORMATION

The estimated orientation may contain some unreliable elements due to background noise and ridges and valleys damages, caused by impression lack of certain image areas (scars and ridge breaks). Orientation smoothing (low-pass filtering) is expected to further attenuate the noise of orientation field and can also be interpreted as a reduction of its scale [6]. The orientation averaging method is commonly used in orientation smoothing because of its efficiency. However it is crucial to determine the size of the averaging neighborhood.

Filtering (smoothing) the orientation image by a smoothing window of different size defines a multiscale representation of orientation image with some useful information.

In our research we used original grayscale fingerprint image available from [1], modified for test purposes with two scars in upper left corner, whose size is 512×512 pixels. Multiscale directional information is obtained through two orientation images D_s and D_l corresponding to the orientation image filtered with Gaussian window with $\sigma = 5$ and $\sigma = 20$ for smoothing. Orientation image is in the first place obtained by conventional gradient-based method.

The original fingerprint image and its orientation field obtained in that way are shown in Fig. 4(a) and 4(b) respectively. Notify that for convenience instead of presenting orientation in each pixel, we presented block-directional image overlaid at original image.

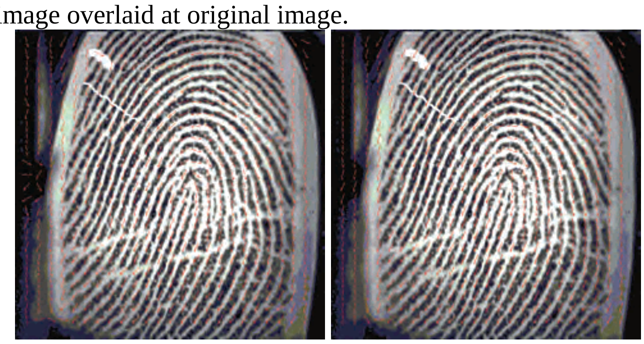
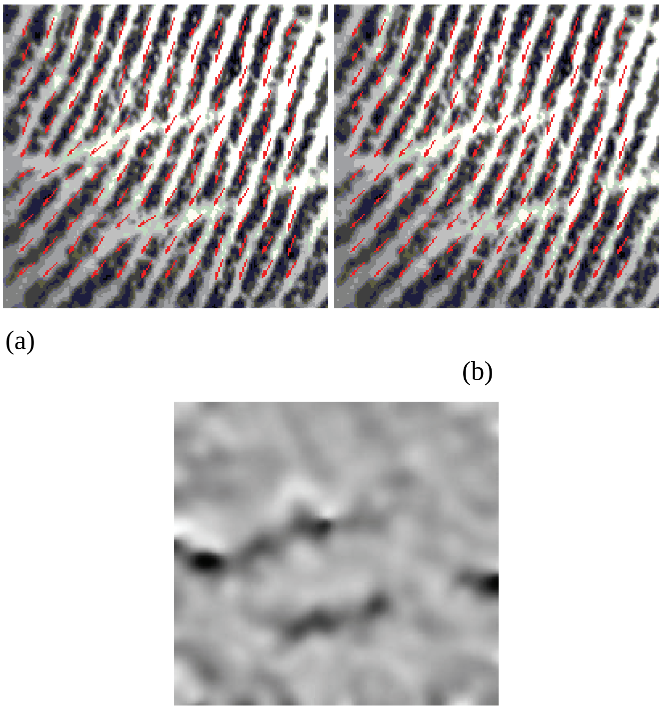


Fig. 4. Orientation image overlaid at input fingerprint image for (a) $\sigma = 5$ and (b) $\sigma = 20$ respectively

In the large regions of broken ridges (caused by scars and cuts), the detected orientation is significantly different (often perpendicular) from the actual ridge orientation. So the regions associated with the broken ridges are represented in orientation image by an abrupt change of orientation. When smoothing is performed in larger window it is more likely to obtain correct orientation information. Nevertheless, multiscale information obtained for two different sizes of smoothing window can be very helpful in detecting scratchy regions. To show this we took one segment of original fingerprint image presented in Fig. 4 which contains regions of broken ridges. Multiscale orientation information obtained with value for σ of 5 and 20 are shown in Fig. 5(a) and 5(b) respectively. In Fig. 5(c) difference between two estimated orientations is shown.

As we can see that difference caries significant information where, by applying appropriate condition, spurious minutia can be detected and eliminated from matching stage [12].



(a)

(b)

(c)

Fig. 5. Orientation image overlaid at input fingerprint image for (a) $\sigma = 5$, (b) $\sigma = 20$, (c) difference of estimated orientations

VI. Conclusion

In this paper a robust method for orientation field estimation at multiple scales is described. Traditional gradient-based method was used. Orientation field smoothing, as necessary step for correct orientation estimation in scratchy regions, results in some information loss. We showed that multiscale orientation, if preserved, contain significant information that can be helpful in minutiae validation stage for spurious minutia elimination. Although presented idea may seem rather subjective, experiments conducted in that way give promising results, and will be tested on the larger database.

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