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Fingerprint Minutiae Filtering Based on Multiscale Directional Information

Brankica M. Popović and Ljiljana Mašković

Abstract: Automatic identification of humans based on their fingerprints is still one of the most reliable identification methods in criminal and forensic applications, and is widely applied in civil applications as well. Most automatic systems available today use distinctive fingerprint features called minutiae for fingerprint comparison. Conventional feature extraction algorithm can produce a large number of spurious minutiae if fingerprint pattern contains large regions of broken ridges (often called creases). This can drastically reduce the recognition rate in automatic fingerprint identification systems. We can say that for performance of those systems it is more important not to extract spurious (false) minutia even though it means some genuine might be missing as well. In this paper multiscale directional information obtained from orientation field image is used to filter those spurious minutiae, resulting in multiple decrease of their number.

Keywords: biometrics, fingerprint image filtering, minutiae detection, orientation field, post processing.

1 Introduction

Accurate automatic person identification is becoming very important to the operation of our increasingly electronically inter-connected information society. Biometrics, as rapidly evolving technology which identifies people based on their physiological or behavioral characteristics, is becoming dominant over traditional means of authentication such as knowledge-based (password) and token-based (key) authentication. As powerful tool of law enforcement agencies and forensics, biometrics is recently widely adopted in a very broad range of civil applications. In another

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The authors are with Academy of Criminalistic and Police Studies, Cara Dušana 196, 11080 Belgrade (e-mail: cica@ptt.yu).

words, biometrics is becoming a necessary component of any ID management system. Amongst available biometric characteristics such as face, retina, iris, voice, hand ..., fingerprints are, due to their characteristics, one of the most researched, used and mature method of authentication [1–3].

An automatic fingerprint identification system (AFIS), in general, consists of 4 fundamental stages [4]: data acquisition, feature extraction, matching module and decision module.

A number of operations are applied in order to extract features later used in matching process. The goal of feature extraction in pattern recognition system (in general) is to extract information from the input data that is useful for determining its category. In the case of fingerprints a natural choice are features based directly on the fingerprint ridges and ridge-valley structure, so most AFIS are based on minutiae matching. However, the effectiveness of a feature extraction depends greatly on the quality of the images. Even high quality images can yield false minutiae, for example, when there are cuts and scars in fingerprint image. Consequently, to solve this problem, fingerprint image enhancement is usually the first step in most AFIS, and a minutia filtering (post processing) is necessary before matching algorithm is applied.

This work considers the problem of filtering spurious minutiae in regions where creases exists. The rest of this paper is organized as follows. In Section 2 we briefly describe fingerprint structure. In Section 3 multiscale directional information is presented, and minutiae extraction algorithm is described in Section 4. Some results and conclusions are shown in Section 5 and Section 6 respectively.

2 Fingerprint Structure

A fingerprint represents the image of the surface of the skin of the fingertip. A typical structure of a fingerprint consists of ridges (black lines) separated by valleys.

The ridge pattern in a fingerprint 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. The global pattern of fingerprint is used to determine the class [5]. Region of a fingerprint where the ridge pattern makes it visually prominent are called singularities [6]. There are two types of fingerprint singularities: core and delta, and they are very useful for determining fingerprints class.

A closer analysis of the fingerprint reveals some anomalies of the ridges, such as ridge endings, bifurcations, crossovers, short ridges, etc. These local features of fingerprints, called minutiae, can be used for manual or automatic fingerprint identification. The most important ones are ridge ending and ridge bifurcation.

These basic features of fingerprints (singularities and minutiae) are shown in Fig. 1.

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

There exist a variety of enhancement techniques for improving the clarity of the ridge structure in the fingerprint image [7,8]. Since in local area, the ridges and valleys have well-defined frequency and orientation, it is natural to use oriented filters. There was some research in directional filtering in spatial [2], and in frequency domain [7–9].

Although noise content is reduced, enhancement process can also introduce false ridges, resulting in false or missing minutiae. A number of minutiae filtering approaches have been presented, applied to binary [10–12] or gray-scale image [13].

If there exists regions of broken ridges in input fingerprint image, enhancement thru directional filtering can be very helpful. If crease is narrow ridges can be reconnected, but wide creases remain resulting in spurious minutia detection. Since for enhancement by directional filtering (both in spatial and frequency domain) dominant ridge orientation must be used, and therefore previously obtained, in our work we try to analyze if and how this information can be used in minutiae filtering algorithms.

3 Multiscale Directional Information Estimation

Multiscale directional information estimation is based on orientation field estimation and filtering at a different scale. No extra time is spent, since most image enhancement algorithms (directional filtering) already use information about dominant ridge orientation to perform.

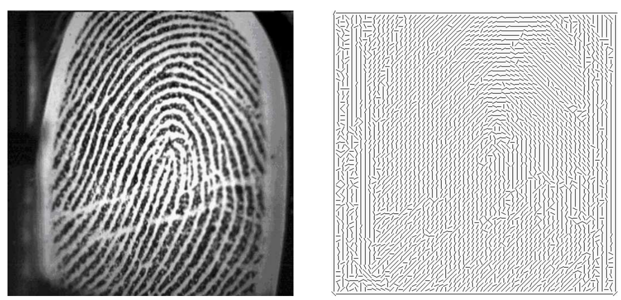
3.1 Computing orientation field

We need to know information about dominant ridge orientation in every pixel of fingerprint image. There are a number of techniques for the estimation of ridge orientation [2, 7, 14]. In this paper the local orientation in the pixel is computed in block of size $w \times w$ centered at given pixel, using the maximal uniformity criterion [12] given by:

$$\theta_d = \frac{1}{2}\tan^{-1}\frac{\sum_{i=1}^{w}\sum_{j=1}^{w} 2G_x(i,j)G_y(i,j)}{\sum_{i=1}^{w}\sum_{j=1}^{w}[G_x^2(i,j) - G_y^2(i,j)]}, \quad G_x\, G_y \neq 0 \tag{1}$$

where G_x and G_y are the horizontal and vertical components of the gradient at each pixel obtained by the use of Sobel gradient operator. Since the angle of gradient is perpendicular to the ridge orientation, the result obtained from (1) must be corrected for 90°. Finally, the obtained dominant orientations are quantized to 16 possible values in the range $[0, \pi)$. The dimension of blocks we used in our experiment was $w = 8$.

The final result of the algorithm for orientation field estimation, when applied to a fingerprint image in Fig. 2(a), is shown in Fig. 2(b). Notify that for convenience instead of presenting orientation in each pixel, we presented block-directional image.



(a) (b)

Fig. 2. (a) Input fingerprint image, (b) orientation image.

3.2 Filtering the orientation field image

As some pixels may have locally uncorrelated values, we may have a noisy version of the directional information. One of a commonly used approach is to split the image into blocks of size $w \times w$, and to replace each pixel of a block with the orientation exhibiting the highest frequency inside the block. However this yield to abrupt direction changes from one block to another, and requires additional smoothing.

In order to obtain a finer directional information, we centered a block of size $w \times w$ at a given pixel, and attributed to it the highest direction frequency inside the block. We call that block as a smoothing window Ω.

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

We use this multiscale directional information to estimate regions of broken ridges as follows:

- Define two images d_s and d_l corresponding to the orientation image filtered with small (Ω_s) and large (Ω_l) smoothing window, where $s < l$;
- For given number of 16 discretized orientations, define the pixel (x,y) a member of set X that represent broken ridge region as follows:

$$(x,y) \in X, \text{ if } \frac{5\pi}{16} \leq |d_l(x,y) - d_s(x,y)| \leq \frac{11\pi}{16} \qquad (2)$$

4 Minutiae Extraction

For minutiae extraction method we use one presented in [15]. It consists of several steps:

- Segmentation;
- Enhancement;
- Binarization;
- Thinning (skeletonization) and
- Minutiae detection;

which are going to be briefly described.

4.1 Segmentation

Segmentation is basically dividing of image to regions with similar attributes. Background of fingerprint image is uniform with no useful information (all the important details minutiae are to be found on ridges), and is useful to be excluded from further processing.

Since there is large variance of intensity in regions of ridges, opposite to uniform background, for segmentation we used variance calculation in block due to formula

$$V(k) = \frac{1}{N}\sum[I_k(i,j) - M(k)]^2 \tag{3}$$

where $V(k)$ is variance for block k, $I_k(i,j)$ intensity in the pixel (i,j) of block k, $M(k)$ is mean of intensity for block k, and N is total number of pixels in block.

If the value of variance is greater from previously determined threshold T, block is considered to be in ridge region, else it is labeled as background and is excluded from further processing.

4.2 Image enhancement

Enhancement may be viewed as a process of improving the clarity of the ridge structure in the fingerprint image [7, 8]. It is an optional step and should it be used varies greatly from the quality of input image. Although noise content is reduced, enhancement process can also introduce false ridges resulting in false or missing minutiae.

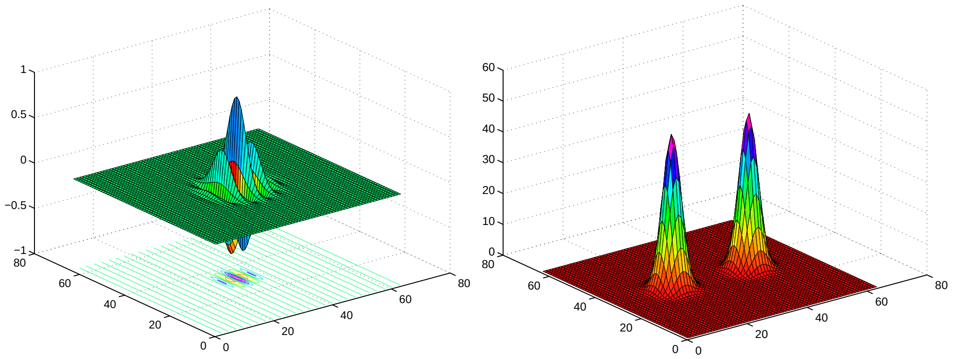
The Gabor filters are recognized as a very useful tool in computer vision and image processing applications. Gabor filters ere very useful both in frequency and spatial domain, due to their frequency-selective and orientation-selective properties [16, 17]. Impulse responses of these filters, which are by the way band-pass filters, are very similar to impulse response of receptive fields in the brains visual cortex [18]. By simple adjustment of mutually independent parameters, Gabor filters can be configured for different shapes, orientations, different width of band pass and different central frequencies. Properly tuned, Gabor filter can filter an image, maintaining only regions of a given frequency and orientation, and this has profound implications for research in fingerprint image analyze and enhancement using this filter.

An even symmetric Gabor filter general form in the spatial domain is described by formula [8]:

$$h(x,y,\phi,\omega) = e^{-0.5[(\frac{x\cos\phi}{\delta_x})^2+(\frac{y\sin\phi}{\delta_y})^2]}\cos(\omega(x\cos\phi + y\sin\phi)) \tag{4}$$

where ϕ is orientation of the Gabor filter, ω is frequency of sinusoidal wave along x axes, δ_x and δ_y are space constants of the Gaussian envelope along x and y axes, respectively. Fig. 3. shows an example of Gabor filter and its response in spatial and frequency domain.

Parameters for optimal Gabor filter ω, δ_x and δ_y, depend from average distance among ridges of fingerprint image. For our database and image of dimension 512×512 pixels, $\omega = 2\pi 60/512 = 0.736$, $\sigma_x = \sigma_y = 4$ is found to be optimal.



(a) (b)

Fig. 3. (a) The Gabor filter and its response in spatial and (b) frequency domain .

We applied method of enhancement by filtering input fingerprint image with bank of oriented Gabor filters (with 16 different orientations $\phi = i\pi/16$) in frequency domain [8].

First information about dominant ridge direction (orientation) has to be obtained as was previously described in Section 3.1. Filtering is performed in frequency domain resulting in set of 16 filtered images, where each of them emphasizes one ridge orientation (namely $\phi = i\pi/16$). Those filtered image are combined in order to get enhanced image. In enhancement process, pixels in one block of enhanced image take the value of pixels on the same position from the filtered image which emphasizes determined orientation for corresponding block.

4.3 Image binarization

For binarization process we apply *LoG* operator:

$$h_{LoG}(x,y) = \frac{1}{4\pi\sigma^2}\left(1 - \frac{x^2+y^2}{2\sigma^2}\right)e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{5}$$

We set threshold value to 127, and all pixels with value greater than threshold are set to value 1, the rest are set to 0.

4.4 Thinning process

Thinning (skeletonization) of binary image is performed in order to simplify extraction of minutiae, since ridges obtained in previous step are a few pixels wide. We use line thinning by line following method [19]. As in case of ridge bifurcations it is possible that ridge remains wider from 1 pixel, as addition we apply classical OPTA or parallel thinning algorithms [20].

4.5 Minutiae detection

It is a trivial task to determine minutiae from thinned image, simply by analyzing 3×3 neighborhood of pixel. Let (x,y) denote a pixel in a thinned ridge, and N_0, N_1, N_7 denote its eight neighbors. Then

- if $\sum_{i=0}^{7} N_i = 1$, pixel (x,y) is minutiae type ridge ending;
- if $\sum_{i=0}^{7} N_i = 3$, pixel (x,y) is minutiae type bifurcation;
- if $\sum_{i=0}^{7} N_i = 0$, pixel (x,y) is isolated and should be erased;
- if $\sum_{i=0}^{7} N_i = 2$, pixel (x,y) is on the ridge;

Simple minutiae post processing is performed in way that pairs of minutiae in a short distance (less than 8 pixels) are considered false and therefore removed from minutiae list.

5 Results

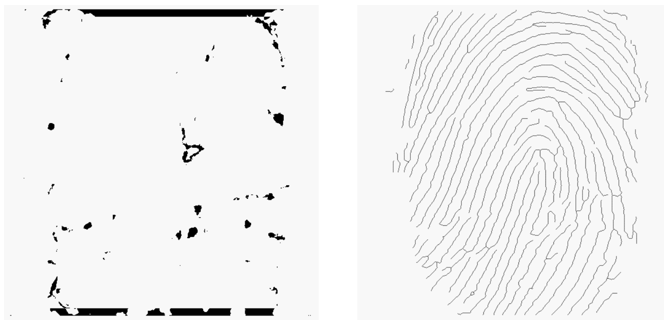
Although enhancement by orientation field can make some ridge breaks caused by narrow creases to connect, some broad creases remains. It should be noted that automatic systems usually determine greater number of minutiae than the expert, because of poor quality of image and noise in fingerprints. Because of that some minutiae filtering (post processing) must be performed in order to remove short lines, connect endings and remove bifurcations at short distance.

We use multiscale directional information obtained in 3.2 to filter spurious minutiae in following manner:

- We assume that every extracted minutiae with coordinates (x,y) belonging to set X (calculated in (2)) is false;
- Since position of extracted minutiae can vary in a small range from the real one, we split the multiscale directional image to windows of size 8×8. Then for every pixel from set X belonging to a certain block, all pixels from the block are set to belong to set X. In that way all extracted minutiae with position inside those blocks are considered false.

For our experiment we have set of 12 fingerprint images, where 11 are original $512 \times 512 \times 8$ bits containing some broken ridges, and 1 is modified in such a way that we added some white bars to create creases.

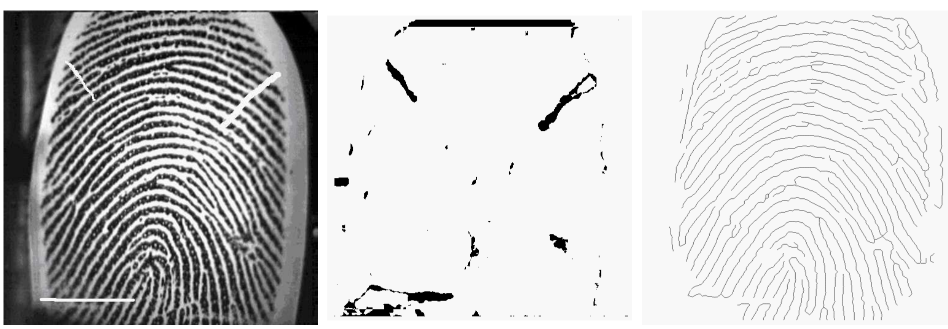
Fig. 4(a). illustrates the result obtained when Ω_s of size 15×15 and Ω_l of size 39×39 on fingerprint in Fig. 2(a) are used. Result of minutiae extraction algorithm is shown on Fig. 4(b).



(a) (b)

Fig. 4. For input fingerprint image 2(a): (a) Extracted regions of possible broken ridges; (b) Result of minutiae extraction algorithm.

Fingerprint we modified in order to test our algorithm is shown in Fig. 5(a). Extracted regions of possible broken ridges and result of minutiae extraction algorithm are shown in Fig. 5(b) and 5(c) respectively.



(a) (b) (c)

Fig. 5. (a) Input modified fingerprint image; (b) Extracted regions of possible broken ridges; (c) Result of minutiae extraction algorithm.

In order to analyze effectiveness of presented minutiae filtering method, we compared number of false minutiae extracted from fingerprint image before and after applying described filtering method. As basic fingerprint minutiae extraction method we used the one presented in [15] (briefly described in Section 4). Results for two presented fingerprint images are shown in Table 1. M represents number of minutiae determined by the expert; N is the number of automatically extracted minutiae; P is the number of matched minutiae; I is number of missing minutiae and L is the number of false minutiae.

Table 1. Comparison of number of minutiae before and after applying proposed minutiae filtering method.

	N		P		I		L		M	
	Fig. 2(a)	Fig. 5(a)	Fig. 2(a)	Fig. 5(a)	Fig. 2(a)	Fig. 5(a)	Fig. 2(a)	Fig. 5(a)	Fig. 2(a)	Fig. 5(a)
Method [15]	82	93	23	23	8	7	59	70		
After proposed filtering method	56	55	19	20	12	10	37	35	31	30

We can see that there is a significant decrease of number of false minutiae (for the whole set of tested images it varies from 30% to 55%), but we lost some genuine as well (varies from 10% to 20%), mostly around singular points. Similar results were obtained for other tested images, as we expected.

Although presented minutiae filtering method is working well, still an improvement to minutiae extraction algorithm must be achieved. For instance, there are 56 automatically extracted minutiae compared to 31 detected from the expert for fingerprint presented in Fig.2(a); 19 of them are correctly matched (23 before minutiae filtering); 12 are missing (8 before minutiae filtering); and 37 are false minutiae (59 before minutiae filtering). Relatively high number of false minutiae is mostly result of binarization and thinning algorithms applied in minutiae extraction algorithm, and should be the subject of further improvement.

6 Conclusion

Performance of automatic fingerprint identification systems greatly depend on accurate minutiae detection. Spurious minutiae must be filtered to maximal extent possible. One way to do it is to use some enhancement technique. Although enhancement by directional filtering can reconnect some ridge breaks caused by narrow creases, some broad creases remains. In this paper, we presented a new method for fingerprint minutiae filtering based on multiscale directional information. This information is used to detect and eliminate spurious minutiae in fingerprint regions of broken ridges.

Although preliminary results on small database are presented, some benefit in using presented method can be noticed. It will be a subject of further improving, and testing on a larger fingerprint database. Our future work will be focused on effort not to filter true minutiae (especially around singular points). Also we will try to improve minutiae detection algorithm in order to extract more genuine minutiae from the input fingerprint image.

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