A MINUTIAE LEVEL FUSION FOR AFIS SYSTEMS

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ABSTRACT

Minutiae correspond essentially to the termination and bifurcation of fingerprint patterns. Since the quality of fingerprint images is often low, extraction algorithms produce a large number of false alarms. A complete minutiae extraction scheme for automatic fingerprint recognition systems is presented. A great deal of work has been dedicated to fingerprint enhancement. We propose a new fusion approach to combine different extraction algorithms. The proposed method, as confirmed by simulations, allows a good overall performance to be achieved suitable for identification forensic applications.

1. INTRODUCTION

Fingerprints are today the most widely used biometric features for personal identification (50% of the biometric market). Various approaches of automatic fingerprint matching have been proposed in the literature [1, 2, 3].

Fingerprint matching techniques can be classified as being minutiae-based, image-based or correlation-based. Most of the existing Automatic Fingerprint Identification Systems (AFIS) are based on minutiae features (ridge bifurcation and ending, see Figure 1).

Figure 1 - Ridge endings (□) and ridge bifurcations (○).

Minutiae detection methods can be based on image binarization, while some others extract minutiae directly from the gray scale images [1]. When the binarization process is adopted, the feature extractor is realized as follows: *i)* ridge detection, *ii)* thinning, *iii)* minutiae extraction and a possible post-processing for imperfection removal.

A reliable extraction algorithm is a critical step for a general AFIS performance. This performance is relatively dependent on the fingerprint image quality. In practice, a significant amount of image is considered of low quality, this is generally due to: *Acquisition conditions* or *epidermal alterations*. Such cases of image distortion generate anomalies as spurious minutiae, dropped or exchanged one. Thereby, matching algorithms will be claim to failure. Consequently, an enhancement step which can improve the clarity of the ridge structures is the most challenging problem in this area.

In Section 2 of this paper, we develop three approaches for raw fingerprint enhancement. In section 3, each approach is used in an overall minutiae extraction process, getting by this way three different extractors. In section 4, we make a comparative study of them. This comparison suggests us to reinforce the robustness of minutiae template by a fusion technique presented in Section 5. Results achieved show improvement in the goodness of the template. In term of efficiency, the method is well suitable for forensic AFIS rather than online verification systems.

2. FINGERPRINT IMAGE ENHANCEMENT

Image processing techniques classically involved in typical preprocessing treatment like: histogram equalization, normalization or Wiener filtering when applied to fingerprint images can expand contrast or reduce some kind of noise. However, before any method is selected, it is initially important that the noise notion be properly defined.

Dealing of such line pattern images, noise can be expressed as breaks in the directional flow of ridges. Moreover, the non-stationary property of fingerprint images suggests the use of contextual filters locally tuned. Such contextual information has to make in advance the textured nature of fingerprint images: on a block, the gray levels of the ridges and valleys constitute a sinusoidal form along the normal direction to the orientation field (see Figure 2).

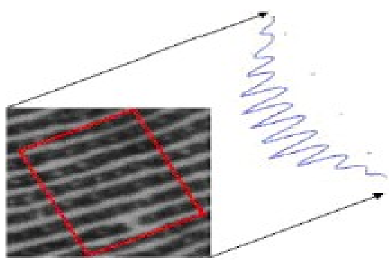


Figure 2 - Gray scale projection in an oriented block

So, the frequency end the orientation can be taken into account as the contextual parameters for each non-overlapped block. On the basis of this specification, we have selected in our implementation different filtering techniques making orientation or frequency selection.

2.1. Gabor filtering

Gabor filters have been applied to the problem of fingerprint image enhancement in [4]. Gabor filters are band-pass filters with adjustable frequency, orientation, and bandwidth parameters. A Gabor function is a sinusoidal waveform that is modulated by a rotated Gaussian envelope, and has the following form in the spatial domain:

$$G(x, y; \theta, \sigma) = \exp\left\{-\frac{x'^2 + y'^2}{2\sigma^2}\right\} \cos(2\pi f x')$$

$$x' = x\cos\theta - y\sin\theta \quad y' = x\sin\theta + y\cos\theta \qquad \textbf{(1)}$$

Where f is the sinusoidal frequency along the direction θ. σ is the standard deviation of the Gaussian envelope.

In our experiments, we set the filter frequency to the average ridge frequency $\left(1/K\right)$, where K is the inter-ridge average distance. The normalized fingerprint is then convolved with a bank of filters tuned with the dominant orientation in each WxW image block. Orientation field is obtained by the mean square orientation estimation algorithm.

2.2. Anisotropic filtering

In this section we have used a new enhancement method based on anisotropic filtering. The goal is to use the local intensity orientation to control the shape of the filter. The filer kernel applied to each point x_0 is defined as following:

$$g_\theta(x,y) = \left\{\exp\left(\frac{-(u-mean)^2}{2\sigma^2}\right)\frac{1}{\sqrt{2\pi\sigma^2}}\right\}' * \left\{\exp\left(\frac{-(v-mean)^2}{2\sigma^2}\right)\frac{1}{\sqrt{2\pi\sigma^2}}\right\}''$$

$$u = x\cos\theta - y\sin\theta \quad v = x\sin\theta + y\cos\theta \qquad \textbf{(2)}$$

The shape of the kernel is controlled through mean and σ. This formula which is a modulation of a Gaussian and it is derived behaves as a pass-band filter in the given direction. By modifying the filter with a scale c=-2 as follows:

$$h_\theta = c \times g_\sigma(x,y) \qquad \textbf{(3)}$$

We obtain better results than the classical anisotropic filtering proposed in [5] when applied to fingerprint images. For certain directions, these filters are represented by images represented in Figure 3:

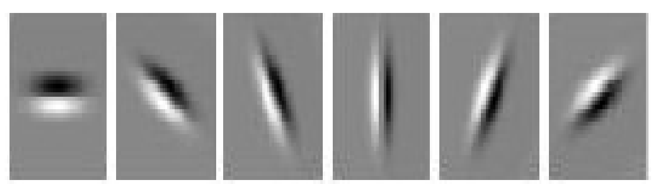


Figure 3 - Controlling anisotropy in different directions

2.3. STFT based enhancement

Although the spatial convolution of the Gabor or anisotropic filter is easily calculable in the frequency domain, explicitly filter in Fourier domain can be designed. The method we have used was proposed in [6]. The filter used F is separated in angular domain F_a and radial domain F_r. Angular and radial (frequency) information are estimated from the Fourier image spectrum in its polar form. The matlab code source for the enhancement is available at www.cubs.bufallo.edu.

3. MINUTIAE DETECTION PROCESS

The all process for minutiae detection can be resumed by the figure 4.

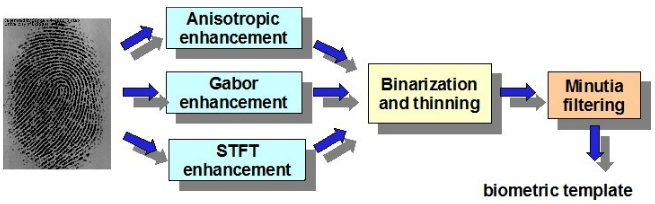


Figure 4 - Minutiae extraction process.

According to the used image enhancement technique, we obtain a different minutiae detection scheme. So, until now, we generate three different methods. The implementation of the common steps for each extraction method is given by the following pseudo-algorithms:

3.1. Binarization

For binarization, we assume that the image contains two classes of pixel. Figure 6, shows a well separation of these classes on fingerprint image after enhancement.

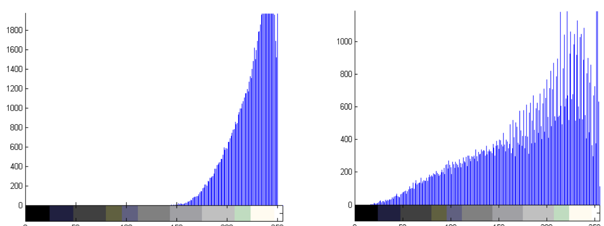


Figure 5 - Image histogram before and after enhancement

The optimal threshold th is then computed according to Otsu method. The I_{bin} image is binarized s follows:

$$I_{bin}(x,y) = \begin{cases} 1 \ \ if \ I_{old}(x,y) \geq th \\ 0 \qquad otherwise \end{cases} \qquad \textbf{(4)}$$

3.2. Thinning

We use a morphological process for ridge thinning (see Algorithm 1).

3.3. Minutiae filtering

From the thinned image, a white pixel is considered as minutia if its connexion number CN (number of 3x3 white neighbors) is greater then 2. Once the minutiae are extracted, we have to detect false ones in order to suppress them. We use the structural false minutiae filtering described by Algorithm 2.

Thinning pseudo-algorithm
I : image binarized ;
changed : booleen ;
changed = true ;
While** (changed= true) **Do
{changed = false ;
***For** i =1 to image length*
***For** j=1 to image width*
*{**If** (I[i,j] = 1)*
{Traverse the 3x3 neighbours of the pixel(i,j);
***If** one of the configurations C coincide*
{ I[i,j] = 0;
changed = true;
}
}}

/*Structural configurations C */

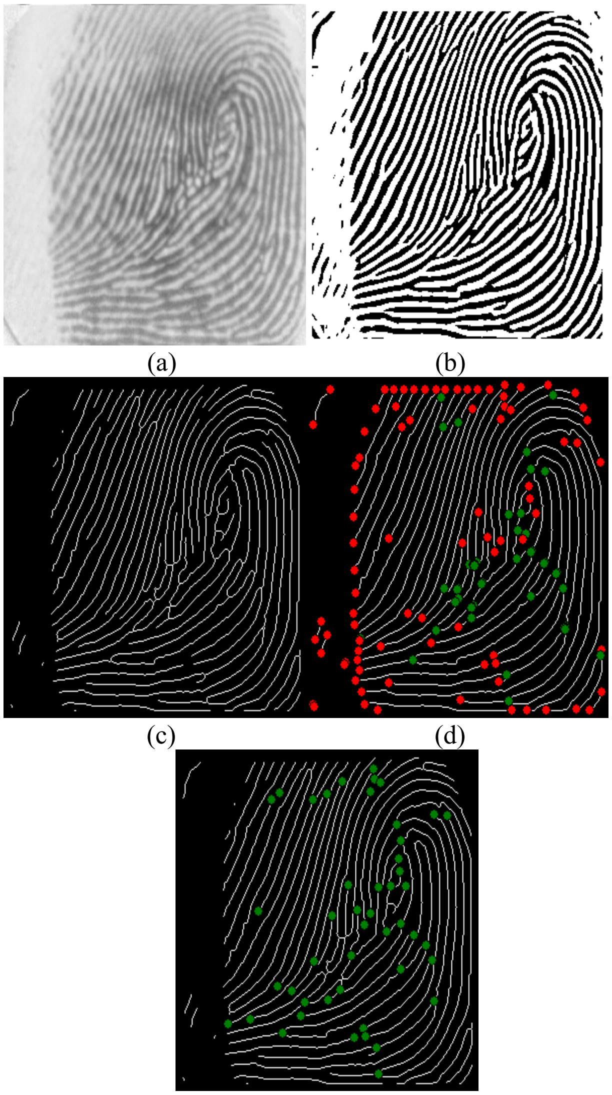
0	0	0	0	0			1			1		1	1	1	1		0
	1		0	1	1	0	1	1	1	1	0		0		1	1	0
1	1	1		1		0	0			0	0	0	0	0	1		0

Algorithm 1 – Morphological thinning

Minutiae filtering pseudo-algorithm
***For** each minutia candidate M*
{Consider a WxW image block B centred at M;
***If** (M is an end edge)*
{ Label by 1 all pixels connected to in B;
Count transition number T_{01} from 0 to 1 on the border
of the block B with a clockwise sense;
***If** (T_{01} = 0) validate the minutiae M;*
}
***If** (M is bifurcation)*
{ Label by 1,2,3 the 3 neighbours of M ;
Label all pixels of the block B connected to this trio
Count transition numbers T_{01} from 0 to 1, T_{02} from 0 to 2 and T_{03} from 0 to 3;
***If** (T_{01} = 1 and T_{02} = 1 and T_{03} = 1)*
validate the minutiae M;
}}

Algorithm 2 – Minutiae filtering

The value W corresponds to the size of the neighbourhood that is considered for the filtering process. In our test, we take W=17 and we also eliminate minutiae which are not present in the region of interest. The figure 6 shows an example of the explained process.



(a) (b)

(c) (d)

(e)

Figure 6 - (a) original image, (b) binarized image, (c) thinned image, (d) minutiae map, (e) filtered map

4. COMPARATIVE STUDY

Enhancement techniques we have implemented have generated 3 different minutiae extractor. The aim of this section is to study their behaviour. In order to do this task, we used quantitative qualifiers :

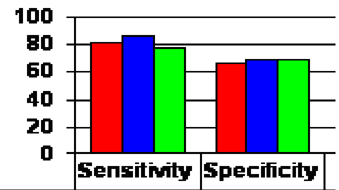
- Sensitivity S (%) : $S = 1 - \frac{D}{N}$
- Specificity P (%) : $P = 1 - \frac{F}{N}$

With N : minutiae number

D : dropped minutiae

F : false minutiae

Tests have been conducted on the NIST database as done in [1]. Sample set is composed of 40 fingerprints. The results are reported in figure 7:



	Sensitivity	Specificity
Method1	82	67
Method2	87	69
Method3	78	69

Figure 7 - Histogram of the sensitivity/specificity results

An analysis of the statistical distribution by the Q-Q diagram has proven the normality against the three methods:

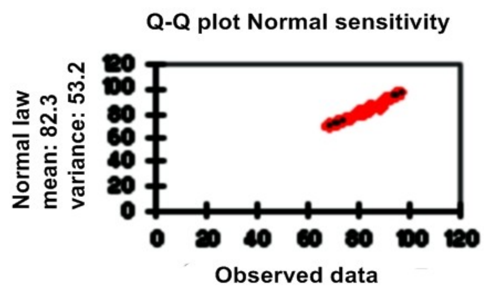


Figure 8 - Q-Q diagram of sensitivity for one extractor.

Noting that all methods have gotten the same diagram. From where we can start a comparison on the overlapping of these distributions:

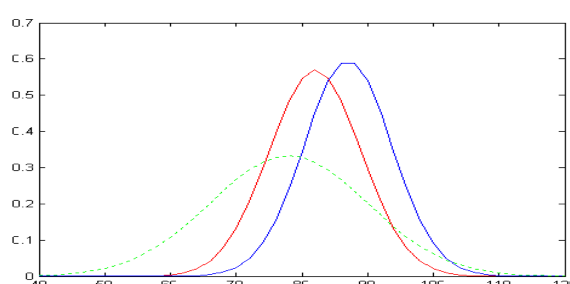


Figure 9 - Distribution overlapping between methods

This statistical study over results of the previous methods has inspired to us to imagine a possible fusion between extractor decisions. The goal is to increase the robustness of the template by keeping only minutiae with a strong probability of good detection.

5. FUSION PROCESS

We propose to confront each template generation method, to get a consensus extraction. This new extraction must make in advance information for which all the treatments agree by eliminating contradictory one. The principle is decomposed in two steps:

i- Associate minutiae coming from the three extractions by a correlation-relaxation algorithm.

ii- Associated minutiae will form a fuzzy set witch must be transformed to get a final clear minutiae template Now, we present these steps by setting:

$$S1 = \bigcup_{i=1}^{N}\left(x_i, y_i, \theta_i\right),\ S2 = \bigcup_{i=1}^{M}\left(x_i, y_i, \theta_i\right),\ S3 = \bigcup_{i=1}^{O}\left(x_i, y_i, \theta_i\right)$$

minutiae templates from method1, methd2 and method3.

Correlation-relaxation pseudo-algorithm

Put S1,S2,S3 in a list L;
While** (L is not empty) **do
{ m = pop_first(L); / $m \in Si$ */*
Put EF a set of associated minutiae as empty;
Add m to EF;
***For** all minutiae n in Sj and $j \neq i$*
If** m is correlated to n by this similarity test **{

$$\begin{cases} d(m,n) < s_d \quad \text{with } d(m,n) = \sqrt{(x_m - x_n)^2 + (y_m - y_n)^2} \\ \left|\theta_m - \theta_n\right| < s_\theta \quad s_d \text{ and } s_\theta \text{ are threshold values} \end{cases}$$

*Add n to EF; Remove n from the list L;**}***
*Add EF to the list of fuzzy minutiae LF; **}***
***If** a minutia belongs to several sets in LF at the same time*
Concatenate the two fuzzy sets;

Algorithm 3: Correlation-relaxation

The problem now is to get the minutia representing of each fuzzy set. We consider this question as a robust estimation location problem starting from a sample of very small size. We use the following position estimators: considering the observation $X=(x_1,..,x_n)$, the estimator T_n is equal to : if n=3, T_3 = median(x); If n>3, use M-estimator technique [5].

6. EXPERIMENTAL RESULTS

We compare now the results conducted at the same fingerprint sample. The graphics in Figure 10 compares the goodness index GI between the three templates alone and the template consensus. We define GI as $(Sensitivity + specificity)/2$:

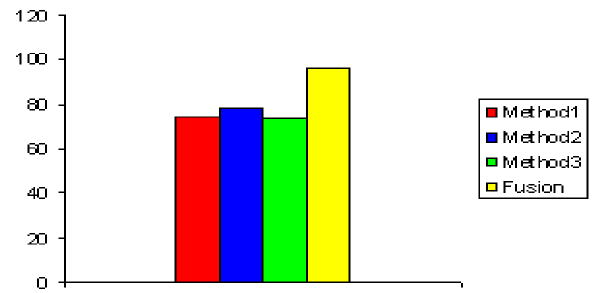


Figure 10 - A comparison of 4 extraction approaches

7. CONCLUSION

In this work, we have considered the minutiae extraction problem; we have also reported that the main difficulty is due to the image quality. With an aim of obtaining a robust minutiae template, a strategy of fusion enters the three methods has been proposed. After tests, we obtain a degree of confidence of 96% of the hybrid minutiae template. Hence we can claim that fusion has proven each initial extraction. So, the proposed minutiae fusion extraction becomes well suitable for AFIS systems in forensics applications when image quality can be much deteriorated.

8. REFERENCES

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