Fingerprint Image Enhancement – A Survey

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Abstract

Fingerprint image enhancement is one of the most important operation in (Automated fingerprint Identification system, AFIS), and affect directly on the accuracy of the results in all other steps in fingerprint system (like feature extracting, noise removal, alignment, and matching), so the selection of suitable and efficient method is very important to avoid faulty results and to make fingerprint systems more reliable. Fingerprint images are rarely of perfect quality; they may be degraded and corrupted due to variations in skin and impression conditions. The available enhancement algorithms are based on either the local orientation field filtering scheme in space domain or the Gabor filtering scheme in the frequency domain. The local orientation could not be correctly estimated for fingerprint images of poor quality, which greatly restricts the applicability of these filtering techniques. The Gabor filters could obtain the reliable orientation estimate even for corrupted images, but it is time consuming. It is unsuitable for an on-line fingerprint recognition system such as AFIS.

Keywords: Fingerprint, Enhancement, Gabor filter.

الخلاصة

تحسين صورة بصمة الابهام واحدة من اهم العمليات في نظام تشخيص بصمة الابهام الألي (AFIS)، وله تاثير مباشر على دقة النتائج في كل خطوات نظام بصمة الابهام (مثل اختزال الخصائص، ازالة الضوضاء، المحاذاة، التطابق)، ولتجاوز النتائج الخاطئة يجب اختيار طريقة ملائمة وكفوءة لجعل نظام بصمة الابهام اكثر وثوقية. لانه نادرا ماتكون صورة بصمة الابهام ذات نوعية تامة، نتيجة للتغييرات في طبيعة الجلد و المزاجية المختلفة للشخص نفسه قد تكون صورة الابهام غير واضحة او مقطعة.

خوارزميات التحسين الموجودة حاليا تكون معتمدة اما على مجال المرشحات المحليةٍ لحساب الاتجاه في مجال الفراغ ، اوعلى مخطط فلتر كابور في المجال الترددي. في المرشحات المحليةِ ربما لانحصل على تخمين صحيح لصورة بصمة الابهام ، للحصول على تخمين صحيح واكثر تحديد يتم تطبيقَ تقنياتِ التَرشيح، بالنسبة لمرشح كابور نحصل على التخمين الحقيقي حتى لو كانت صورة البصمة مشوشة لكن من عيوب هذه الطريقة هو استهلاك وقت ا كثيرا لذلك تكون غير ملائمة لتمييز بصمة الابهام في الوقت الحقيقي on-line مثل نظام AFIS.

1. Introduction

Fingerprint images are used for personal identification for many decades because of the following reasons, very high level of reliability, fingerprint remains constant during people's life, and uniqueness property of fingerprint image, the fingerprints of identical twins are different and so the prints on each finger of the same person [1].

Fingerprint is a pattern of parallel ridges and valleys, ridges (also called ridge lines) are dark in fingerprint image whereas valleys are bright in it as illustrate in figure (1).

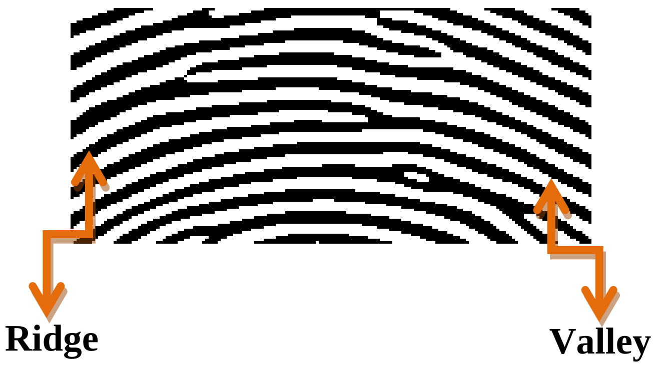
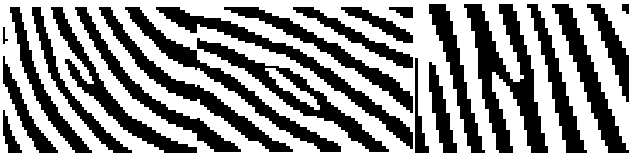


Figure (1): Ridge and valley in fingerprint image.

Features in fingerprint image can be divided into two levels:

1- Local level for minutiae detects (ending and bifurcation) minutiae are local discontinuities in the fingerprint pattern، as shown in figure (2) which used in fingerprint matching stage and the similarity between two fingerprints is determined by comparing the two sets of minutiae points .

a- Ending **b- Bifurcation** **c- Island**



d- Hook **e- Lake** **f- Bridge**

Figure (2): Local features.

2- Global level for singular points (or singularities) detect (core and delta), core and delta illustrates in figure (3).

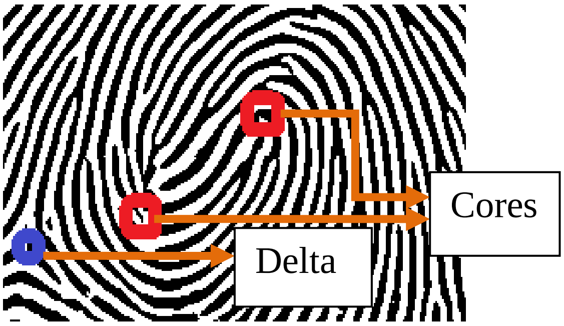
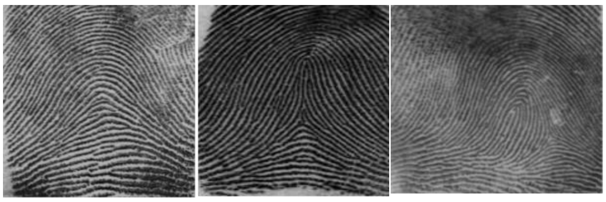
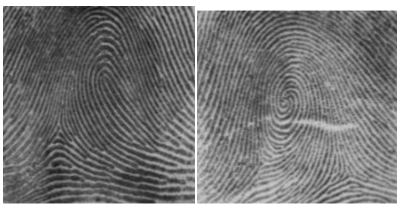


Figure (3): Global features in fingerprint image.

The detection of global features is very important task in fingerprint classification system into at most (5) classes according to its geometric properties which are Arch, Tented Arch, Left loop, Right loop [2][3],and Whorl as in figure(4).



a- Arch b- tented arch c- left loop



d- Right loop e- whorl

Figure (4): Classes of fingerprint images.

Classification of fingerprint image depends on numbers of cores, delta, and the position of delta in finger as illustrated in table (1).

Table (1): Fingerprint pattern classes.

Fingerprint pattern class	Core numbers	Delta numbers	Delta position
Arch	0	0	-
Left loop	1	1	right
Right loop	1	1	left
Tented arch	1	1	middle
Whorl	2	2	Left and right

Some of the researchers classified the fingerprint image into (6) classes in addition to above five classes they add a twin loop class as illustrates in figure (5).

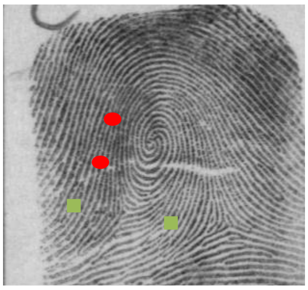


Figure (5): Twin loop.

Some permanent and semi-permanent features such as scars, cuts, bruises, cracks, and calluses are also present in a fingerprint image [4][5].

2. Fingerprint Image Enhancement

Enhancement process is the most important step in any fingerprint system and precedes all other operations in fingerprint system; many methods are suggested to enhanced fingerprint image [6]:

2.1- Fingerprint Image Normalization

Normalization process is used to standardize the intensity values of the pixels in fingerprint image within a desired range of gray-level values by applying equation (1).

$$N(i,j)=\begin{cases} M_o+\sqrt{\dfrac{V_o(I(i,j)-M)^2}{V}} & if\ I(i,j)>M \\ M_o-\sqrt{\dfrac{V_o(I(i,j)-M)^2}{V}} & otherwise \end{cases} \qquad ....(1)$$

where $M=\dfrac{1}{w x h}\sum_{i=0}^{w-1}\sum_{j=0}^{h-1} I(i,j)$, and $V=\dfrac{1}{w x h}\sum_{i=o}^{w-1}\sum_{j=0}^{h-1}\left(I(i,j)-M\right)^2$

M and *V* are the mean and variance of the fingerprint image *I (i, j)*, M_o and V_o are the desired mean and variance values.

Normalization process is used to remove the effects of sensor noise, variations in gray scale levels due to finger pressure differences, and to improve image contrast and brightness.This process is a pixel-wise operation that doesn't change fingerprint structures as shown in figure (6), and facilitates the calculation in the later processes [7].

a- Original image **b- Normalized image**

Figure (6): Normalization operation.

2.2- Ad hoc Strategy

This technique will be used to enhance the quality of a fingerprint image as follows:

$$Eimage(i,j)=\alpha+\gamma\, x\left(\frac{[image(i,j)-M]}{s}\right) \qquad ...(2)$$

Where, *Eimage (i, j)* is the enhanced image, *Image (i, j)* is the input image, *M* is the mean of input image, and *S* is the standard deviation of gray level of input image.

From empirical results $\alpha=150$ and $\gamma=55$, and *S* must be less than γ else we replace the constant γ with another number greater than *S*. Ad hoc strategy is a simple and efficient method used to enhance fingerprint image by removing noise speedy [8]. Figure (7) illustrates the result of this process.

a- Original image **b- Enhanced image**

Figure (7): Ad hoc strategy operation.

2.3- Windowed Fourier Transform (WFT)

A frequency transformation decomposes an image from its spatial-domain (bright intensities) into a frequency-domain. The frequency domain shows the frequency of brightness variations, the direction of variation patterns, and the amplitude of the waveforms representing the patterns. The process of filtering image in frequency (spectral) domain can be summarized as [9]:

- Transforming image information to the frequency domain via the Fast Fourier Transform (FFT).
- Multiplying the image's spectrum with some filtering mask.
- Transforming the filtered spectrum back to the spatial domain.

Fingerprints are first smoothed using a directional filter whose orientation is everywhere matched to the local ridge orientation. Threshold then yields the enhanced image [10]. The two-dimensional Fourier transform is defined by the relationship as illustrated in eq. 3 below:

$$G(p_1, q_1) = \sum_{p=0}^{n-1} \sum_{q=0}^{m-1} f(p,q) \; x \; \exp\left\{ -2t\pi \; x \left(\frac{p_1 p}{M} + \frac{q_1 q}{N} \right) \right\} \quad ...(3)$$

Where $p_1 = 1 \ldots w$, and $q_1 = 1 \ldots w$, w is the block size when image is divided into non overlapping blocks.

FFT of fingerprint image is block wise operation where image is divided into blocks of size 32 or 16.

In order to enhance a specific block, we multiply the *FFT* of the block by its magnitude a set of times, as eq. 4.

$$FFT = abs(G(p_1, q_1)) \quad \ldots(4)$$

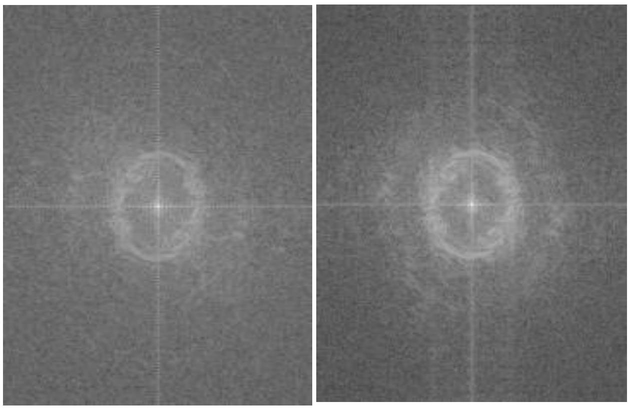
The block is enhanced according to eq. (5):

$$g(p,q) = G^{-1}\{G(p_1, q_1 \; x |G(p_1, q_1)|^{n})\} \quad \ldots(5)$$

Where $G^{-1}(G(p_1, q_1))$ is done by:

$$f(p,q)=\frac{1}{NM}\sum_{p=0}^{m-1}\sum_{q=0}^{n-1}G(p_1,q_1)\ x\ \exp\left\{2t\pi\ \ x\left(\frac{p_1\ p}{M}+\frac{q_1 q}{N}\right)\right\} \quad \ldots(6)$$

Frequency domain techniques are less efficient computationally and require more processing resources to implement [11].



a- FFT Spectrum of original image b- FFT spectrum of enhanced image

Figure (8): WFT enhanced image spectrum.

2.4- Gabor Filter

If the enhancement step uses a single filter convolution on the entire fingerprint image, it creates significant number of spurious minutiae, a large number of genuine minutiae is missed and a large number of errors in the location (position and orientation) of minutiae are introduced. Most of the fingerprint enhancement techniques use contextual filter or multi-resolution filter. The purpose of these filters is to fill the small gaps (low-pass effect) in the direction of the ridge and to increase the discrimination between ridge and valley in the direction, orthogonal to the ridge [11].

To enhance the contrast of the ridges the (W × W) blocks will be filtered with an appropriately tuned Gabor filter. An even symmetric Gabor filter has the following general form in the spatial domain, as eq. 7.

$$G(x, y, f, \theta) = Exp\left\{\frac{-1}{2}\left[\frac{x_1^2}{\delta x^2} + \frac{y_1^2}{\delta y^2}\right]\right\}\cos(2\pi f x_1) \qquad ...(7)$$

Where x_1, and x_2 is calculated in eqs. (8)(9):

$$x_1 = x\sin\theta + y\cos\theta \qquad \ldots(8)$$

$$y_1 = x\cos\theta - y\sin\theta \qquad ...(9)$$

Where, (f) is the frequency of the sinusoidal plane wave along the direction (θ) from the x-axis, and (δx, δy) are the space constants of the Gaussian envelope along x and y axes, respectively. The result of applying the Gabor filter is illustrated in figure (9).

a- Original image **b- Image after applying Gabor filter**

Figure (9): Apply Gabor filter on a fingerprint image.

To apply Gabor filter firstly, the (W×W) blocks orientation centered at each pixel will be calculated. Orientation can be calculated by using Sobel vertical and horizontal masks respectively as illustrated in figure (10).

Z1	Z2	Z3
Z4	Z5	Z6
Z7	Z8	Z9

a- Image

-	-	-
0	0	0
1	2	1

b- Horizontal Mask

-	0	1
-	0	2
-	0	1

c- Vertical Mask

Figure (10): Sobel Masks.

The magnitude of the edge in each pixel will be calculated by using the eqs. (10)(11) as below:

$$\partial x(p,q) = (Z_7 + 2Z_8 + Z_9) - (Z_1 + 2Z_2 + Z_3) \qquad \ldots(10)$$

$$\partial y(p,q) = (Z_3 + 2Z_6 + Z_9) - (Z_1 + 2Z_4 + Z_7) \qquad ...(11)$$

Then the average edge Magnitude in each block is computed in eqs. (12, 13) as follow:

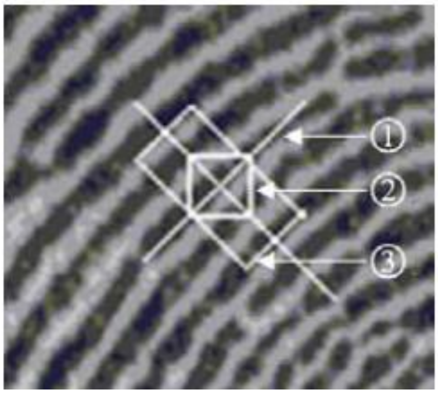
$$vy(i,j)=\sum_{p=i-\frac{w}{z}}^{i+\frac{w}{z}}\sum_{q=j-\frac{w}{z}}^{j+\frac{w}{z}} 2\partial x(p,q)\partial y(p,q) \quad \text{...(12)}$$

$$vx(i,j)=\sum_{p=i-\frac{w}{z}}^{i+\frac{w}{z}}\sum_{q=j-\frac{w}{z}}^{j+\frac{w}{z}} \partial^2 x(p,q)-\partial^2 y(p,q) \quad \text{...(13)}$$

The block gradient direction (θ) is calculated in eq. (14) below:

$$\theta(i,j)=\frac{1}{2}\tan^{-1}\frac{v_{y(i,j)}}{v_{x(i,j)}} \quad \text{...(14)}$$

The frequency of the sinusoidal plane wave along the direction (*θ*) from the x-axis (*f*) is the inverse number of pixels between two consecutive ridge centers as shown in figure (11). From empirical results, the constant values can be used for following parameters $\delta x= \delta y = 4$, $f= 0.1$ and we used $w= 17$.



Figure(11): Ridge frequency.

Where**,** 1 is local orientation, 2 is local orientation estimation block, and 3 is frequency window.

2.5- Log Gabor Filter

Log-Gabor filters are constructed in the frequency domain. The original fingerprint image is transformed to frequency domain by implementing the Windowed Fourier Transform, WFT. The frequency spectrum is filtered with a bank of Log-Gabor filters. The 2D Log-Gabor filter in polar coordinates system can be divided into two components which are the radial filter and the angular filter [12]. The radial filter has a frequency response described by eq (15):

$$G_r(r)=\exp\left(-\frac{\log\left(\frac{r}{f_o}\right)^z}{2\delta r^z}\right) \quad ...(15)$$

and the angular filter has a frequency response described by eq (16):

$$G_\theta(\theta)=\exp\left(-\frac{(\theta-\theta_\theta)^z}{2\delta_\theta^z}\right) \quad ...(16)$$

The two components are multiplied together to construct the Log-Gabor filter as shown in eq (17).

$$G(r,\theta)=G_r(r)x\ G_\theta(\theta) \quad ...(17)$$

Where (r, θ) represents the polar coordinates, f_0 is the center frequency of the filter, θ_θ is the orientation angle of the filter, δ_r determines the scale bandwidth and δ_θ determines the angular bandwidth.

2.6 Federated Filtering using Quality Factor

This method can be summaries by the following steps**:**

1- Obtaining the S [0], S [1] , … , S [l-1] by using the eq. (18), by calculating the quality factor of the image**:**

$$s[k]=\frac{1}{w}\sum_{n=0}^{w-1}n(u,v) \quad ...(18)$$

Where $K = 0, 1, 2, \dots, l-1$

$$u=i+\left[\frac{w}{2}-n\right]\sin\theta(i,j)+\left[k-\frac{l}{2}\right]\cos\theta(i,j)$$
$$v=j+\left[n-\frac{w}{2}\right]\cos\theta(i,j)+\left[k-\frac{l}{2}\right]\sin\theta(i,j)$$

$\theta(i,j)$ is the local orientation and $n(u,v)$ is the normalized image.

Let the $DI(i,j), Df(i,j), DP_d(i,j), Dv_d(i,j)$ be the variance of the amplitude, the period and the differences of the peaks and valleys, so the local quality factor is defined in eq. (19):

$$Q(i,j) = \alpha DI(i,j) + \beta DT(i,j) + \gamma DP_d(i,j) + \omega DV_d(i,j) \quad \text{...(19)}$$

Where, $0 < \omega\gamma < \beta\alpha < 1$. The local quality factor $Q(i,j)$ is the estimation of every block in the fingerprint image. Then the quality factor of the whole image is defined as:

$$Q = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} Q(i,j)}{M \, x \, N} \quad \text{...(20)}$$

2- Making decision of filtering schemes by the quality factor: if the quality factor is below the predefined threshold τ, the quality of the processed image could be accepted and the processed image could be output as the enhanced image; otherwise we consider the quality of the processed image not acceptable and performing the Gabor filter on the image [13].

2.7 Binary Fingerprint Image Enhancement

binary image may be enhanced by using the masks illustrated in figure (12) to remove small gaps or points in the ridges without affect on normal regions, this process produces good results speedy as illustrated in figure (13).

P1	P2	P3
P4	1	P5
P 6	P 7	P8

a- Mask1

P1	P2	P3	P4	P5
P6	1	2	3	P7
P8	4	5	6	P9
P10	7	8	9	P11
P12	P13	P14	P15	P16

b- Mask 2

Figure (12): Enhanced masks.

a- Binary image b- Enhanced image

Figure (13): Binary image enhancement.

$if \sum_{k=1}^{8} P_k = 8*255$ Then pixel (1) becomes (255)

$if \sum_{k=1}^{8} P_k = 0$ Then pixel (1) becomes (0)

$if \sum_{k=1}^{16} P_k = 16*255$ Then pixels (from 1 to 9) become (255) , and

$if \sum_{k=1}^{16} P_k = 0$ Then pixels (from 1 to 9) become (0)

Otherwise each pixel stays with its original color.

3- Discussion

From the results above we discuss the following steps:

1. Contextual filters are time consuming methods because of the needing for building candidate filter for each pixel in region of interest of the image, while fixed filter methods are fast.
2. Contextual filter method give perfect results for very important fingerprint system, while fixed filter methods give simple results which must be used in simple or not important systems.
3. Simple binary methods can be used as preprocessed operations for hard methods.

4- Conclusions

From this research we can be conclude the following points:

1. Methods depend on the usage of contextual filters give perfect results in damaged images as well as in accepted images.
2. Binary image contains too enough information for enhancing fingerprint images therefore enhance step can be simplified by using binary image instead of gray scale image.
3. Directional filters have an additional view of the direction in which pixels must be dense and the one in which pixels must be free to fill forger gaps and boost truth one.

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