A fingerprint recognition method based on Fourier filtering
ehancement and minutia matching

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ABSTRACT

The fingerprint (FP) provides an optimal foundation for Automatic Personal Identification Systems. Over the last two decades significant progress in Automatic Fingerprint Identification Systems (AFIS) has been achieved. However, the performance of AFIS still suffers from the FP image quality captured by FP sensors, the enhancement techniques for FP images and feature extraction, and the available approaches of feature matching. In this paper, we proposed a fingerprint enhancement algorithm based on Fourier filtering. In our algorithm the fingerprint enhancement were transformed from spatial domain to frequency domain by Fourier transforming. In addition, Fingerprint matching is one of the most important problems in AFIS. We proposed a minutia matching algorithm. In our algorithm, a simpler alignment method is used. We introduced ridge information into the minutia matching process in a simple but effective way and solved the problem of the matching of vector pairs with low computational cost.

Keywords: fingerprint, Fourier transform, filtering, Image enhancement, minutia matching

1. INTRODUCTION

Fingerprint identification determines whether two fingerprints are from the same finger or not. Fingerprint Identification is one of the most reliable and popular personal identification methods. Fingerprint recognition is a rapidly evolving technology, which is being widely used in forensics and has the potential to be used in a large range of civilian application areas such as access control, financial security, information security, etc. An automatic fingerprint identification system acts a complex process, such as fingerprint classification, fingerprint image enhancement, orientation field estimation, binarization, thinning and fingerprint matching.

Fingerprint image enhancement and minutiae matching are two key steps in AFIS. It is well known that image processing is a difficult problem in computer vision and pattern recognition while knowledge representation is a difficult problem in artificial intelligence. But unlike other images, fingerprint image has its own characteristics. In general, we have some heuristics about fingerprint images in the processing of such image. In fact, these heuristics is also the bases of orientation based fingerprint image enhancement methods. A fingerprint expert is often able to correctly recover the fingerprint topology by using such visual clues. It is also possible to represent such structure information in computer. Thus, it is valuable to introduce human knowledge into the processing of fingerprint images and simulate what an expert will do to enhance a fingerprint image.

In this paper, we used human knowledge about fingerprint in the form of rules to guide the enhancement process and develop a fingerprint image enhancement algorithm based on Fourier filtering. In practice, due to variations in impression conditions, skin conditions, acquisition devices etc., fingerprint image may be corrupted by various kinds of noise. Fingerprint enhancement is needed to recover the topology structure of ridges and valleys from the noisy image. Most of the existing enhancement algorithms are based on the local ridge direction. Like the direction oriented ridge enhancement algorithm of Douglas Hung and the algorithm of Lin Hong et.al which uses Gabor filters. The main drawback of these methods lies in the fact that false estimate of local ridge direction will lead to poor enhancement. There has a contradiction in the local ridge direction based methods. On one hand, it is in the areas where ridges and valleys are corrupted by noise that enhancement is most needed. On the other hand, it is in such areas that local ridge directions cannot be reliably estimated and the performance of local ridge direction based methods will be poor.

Many fingerprint enhancement algorithms are effective for medium or high quality fingerprint images. Therefore these existing algorithms are either not suited for low quality fingerprint images, or too slow to satisfy the real-time requirements. In this paper, we propose a fingerprint enhancement algorithm based on Fourier filtering. In
our algorithm the fingerprint enhancement are transformed from spatial domain to frequency domain by Fourier transforming. The fingerprints are enhanced by bandpass filter and directional filter in frequency domain.

Fingerprint matching is one of the most important problems in AFIS. In general, the minutia such as ridge endings and ridge bifurcation is to be used to represent a fingerprint and the fingerprint matching through minutia matching. Based on this observation and by representing the minutia as a point pattern. An automatic fingerprint verification problem may be reduced to point pattern matching (minutia matching) problem. Point pattern matching is a famous problem in the field of pattern recognition. For a good point pattern matching approach, it is able to perform the geometrical invariant quantities (translation, rotation, and scaling) efficiently. Various algorithms have been proposed for point pattern matching. For example, the relation approach handles translation difference only and the complexity of triangles approach is very high. In this paper, an algorithm for fingerprint identification using point pattern matching based on cluster approach is proposed, which effectively solves the problems of optimal matching between two fingerprint minutia images under geometrical transformation and minutiae quantity change. Process which bases on the matching of vector pairs is developed to determine the registration parameters. The experimental results show that the proposed matching algorithm is fast and has high accuracy.

2. METHODOLOGY

2.1 Fingerprint enhancement based on Fourier filtering.

The process of the fingerprint image enhancement can be completed by spatial domain and frequency domain. There are own characteristics, some fingerprint image is not suitable for enhancement in the spatial domain. For example, Background noise are consist of regular lines, If we adopt technique in proceeding of spatial domain, it will difficult to throw away noise. But if we transformed from spatial domain to frequency domain, the regular lines noise is represented bright point on amplitude spectrum diagram. Only to get rid of bright point frequencies, it is a easy way to eliminate lines noise. Fast transformation is its strongpoint. Enhancement in the spatial domain make use of all of fingerprint information, but only using of part of fingerprint information in the frequency domain.

Our process is described as below Fig 2.1.1.

![Fingerprint image enhancement flow chart](image)

Fig 2.1.1 Fingerprint image enhancement flow chart
In figure, After original image complete fast Fourier Transformation (FFT), fingerprints are enhanced by bandpass filter and directional filter in frequency domain. And then, filter images are converted into fast In-Fourier Transformation (IFFT) images. We pick up ridges from IFFT images and obtain ridges image. After ridges composing, fingerprints image are enhanced.

2.1.1 Fourier Transformation and Filter

When we get a fingerprint image, we have the width, height and the gray distributing. We define N as width and M as height, and g(i,k) is the gray value of pixel (i,k), G(u,v) is the frequency matrix.

When N is 2 power, we apdot fast Fourier Transformation method. The method can realize the online real-time proceeding. The Fourier’s Transformation is described as below:

\[
G(u,v) = \frac{1}{N \cdot M} \sum_{i=0}^{N-1} \sum_{k=0}^{M-1} g(i,k) \cdot \exp(-j2\pi\frac{ui}{N} + \frac{vk}{M})
\]  

(2.1.1)

The In-Fourier’s Transformation is described as below:

\[
g(i,k) = \sum_{u=0}^{N-1} \sum_{v=0}^{M-1} G(u,v) \cdot \exp(j2\pi\frac{ui}{N} + \frac{vk}{M})
\]

(2.1.2)

We get a fingerprint original image (Fig 2.1.2), the image of corresponding amplitude spectrum from Fourier transformation (Fig 2.1.3), and the image after filtering the spectrum by BPF (band-pass filter) in the frequency domain (Fig 2.1.4)

![Fig 2.1.2 Original image](image1)
![Fig 2.1.3 Amplitude spectrum](image2)
![Fig 2.1.4 Image after BPF](image3)

From the results of image, we can see that the information of ridges is not lost, it shows that the ridges information is really contained in the loop-area of the spectrum, the first step of our algorithm is to filter the spectrum by bandpass filter, filter some of noise, only reserve the Fourier spectrum in the loop-area.

Now we base on the above result, we filter the spectrum in eight directions. In order to prove our method is feasible and reasonable, we have three pairs image here (Fig 2.1.5).

![Fig 2.1.5 Direction of local ridges and Fourier spectrum](image4)

The pairs of image show the relationship between the direction of local ridges in the fingerprint image and the Fourier spectrum. Form the Fourier spectrum we can see the bright point line is perpendicular to the local ridges line. In other word, after we filter the Fourier spectrum in directions, we transform the spectrum back to the spatial domain, we can enhance the ridges of the fingerprint image in direction, it is our speciality, which is different from
other enhancement methods.

we must filter the Fourier spectrum in eight directions, then transform the result to the spacial domain by in-
Fourier’s Transformation, then we can get the enhanced ridges of the fingerprint image. From many experiments,
we can see the result is the best if we use the filter factor as followed.

\[
H(\varphi) = \begin{cases} 
1 & \text{if } |\varphi| < \varphi_{bw} \\
0 & \text{otherwise}
\end{cases} \quad (2.1.3)
\]

So in our algorithm, the eight directions as below (Fig 2.1.6):

\[0 \text{ direction:}(0 \sim \pi/8) \quad 1\text{st direction}:(\pi/8 \sim \pi/4) \quad \ldots \quad 7\text{th direction:}(7\pi/8 \sim \pi)\]

The image after Fourier’s Transformation is center-symmetry, so we only filter the half part (0 ~ \pi). The
domain that surrounds curve is enhance domain, the other of domain are filter process.

The direction filter is describe as followed:

\[
g(s, i, k) = \sum_{i=0}^{N-1} \sum_{k=0}^{M-1} G(u, v) \cdot H(s, u, v) \cdot \exp(j2\pi\left(\frac{ui}{N} + \frac{vk}{M}\right)) \quad (2.1.4)
\]

\[
H(s, u, v) = \begin{cases} 
1 & \text{if } \frac{\pi}{8} \cdot s < \arctan\left(\frac{v}{u}\right) < \frac{\pi}{8} \cdot (s+1) \\
0 & \text{otherwise}
\end{cases} \quad (2.1.5)
\]

where \( s \) is the ordinal number of the direction \((s = 0, 1, 27 \ldots)\).

We get 8 filter images (Fig 2.1.7, 2.18) in 8 directions including 0 direction, 1st direction, \ldots 7th direction, they
are images to obtain after band-pass filter and directional filter and In- Fourier’s Transformation. The real ridges of
original finger image is enhanced.

\[\text{Fig 2.1.7 Image after 0-4 directions filter and In- Fourier’s Transformation}\]
2.1.2 ridges picking up and ridges composing

We have had many methods to pick up the ridges from the filtered image, in our algorithm, we base on the relationship between local mean value and local mean square deviation with whole mean value and mean square deviation, use the method of threshold value, that means: for each piece of the filter image, if the mean square deviation is bigger than the threshold value (given by experience, here we make the Threshold=600), we can consider it is the real ridges and let block=1(block is defined as followed), otherwise block=0.

Here we have 8 filter images in 8 directions including 0 direction, 1st direction, ...7th direction, we can see the real ridges of original finger image is enhanced.

Now we have to divide each image up to pieces with the same side 8×8dpi (this require N,M can divide 8 exactly), so we take an image with the size of 32×32dpi for an example, that means N=M=32, and each image includes 32×32/(8×8)=16 pieces, each piece we mark as: block (s,n)

“s” is the ordinal number of the image (s=0,1 ...7)

“n” is the ordinal number of the piece of the image (n=0,1 ...15)

For each piece block (s,n), we can describe the gray-value as : g (s,n,m)

“m” is the ordinal number of the pixel of the piece (m=0,1 ... 63)

mean value is given as followed:

\[
\bar{g}(s,n) = \frac{1}{64} \sum_{m=0}^{63} g(s,n,m)
\]  

(2.1.6)

mean square deviation

\[
Var(g(s,n)) = \frac{1}{63} \sum_{m=0}^{63} (g(s,n,m) - \bar{g}(s,n))^2
\]  

(2.1.7)

Then we can determined:

\[
block(s,n) = \begin{cases} 
1 & \text{if } Var(g(s,n)) > \text{Threshold} \\
0 & \text{otherwise}
\end{cases}
\]  

(2.1.8)

When \(block(s,n)=1\): all the gray values of the pieces not changed, the piece is keep original; when \(block(s,n)=0\); the gray values of the piece evaluate 255, the piece is change to white. So we can pick the ridges up in 8 directions (Fig 2.1.9).

\[
g(s,n,m) = \begin{cases} 
g(s,n,m) & block(s,n) = 1 \\
255 & block(s,n) = 0
\end{cases}
\]  

(2.1.9)

\[
g(s,n,m) = \begin{cases} 
g(s,n,m) & block(s,n) = 1 \\
255 & block(s,n) = 0
\end{cases}
\]  

(2.1.10)
Now we compose the 8 images of ridges, the gray value of the composed image put into h(i,k), the relationship between i, j and m, n is:

\[
\begin{align*}
    n &= 4 \times \text{int}\left(\frac{i}{8}\right) + \text{int}\left(\frac{k}{8}\right); \\
    m &= 8 \times (i \mod 8) + (k \mod 8) \\
    i &= 8 \times \text{int}\left(\frac{n}{4}\right) + \text{int}\left(\frac{m}{8}\right); \\
    k &= 8 \times (n \mod 4) + (m \mod 8)
\end{align*}
\] (2.1.11) (2.1.12)

Each image includes 16 pieces, if there are superposition pieces, the gray value of the pixels in the piece must be the average value.

For example:

block (0,8) = block(1,8) = block (2,8) = block (3,8) = block (4,8) = 0
block (5,8) = block (6,8) = block (7,8) = 1

Basing on the relationship among n, m, i, k:

\[
h(8 + t, 24 + p) = \frac{g(5, 8 + t, 24 + p) + g(6, 8 + t, 24 + p) + g(7, 8 + t, 24 + p)}{\text{block}(5,8) + \text{block}(6,8) + \text{block}(7,8)}
\] (2.1.13)

\[
t = \text{int}\left(\frac{m}{8}\right); \quad p = m \mod 8; m = 0, 2, \ldots, 15
\]

then we can obtain:

\[
h(i, k) = \begin{cases} 
255 & \text{if } \sum_{s=0}^{7} \text{block}(s, n) = 0 \\
\sum_{s=0}^{7} g(s, n, m) & \text{otherwise} \\
\sum_{s=0}^{7} \text{block}(s, n)
\end{cases}
\] (2.1.14)

\[
\begin{align*}
    n &= 4 \times \text{int}\left(\frac{i}{8}\right) + \text{int}\left(\frac{k}{8}\right); \\
    m &= 8 \times (i \mod 8) + (k \mod 8) \\
    i &= 8 \times \text{int}\left(\frac{n}{4}\right) + \text{int}\left(\frac{m}{8}\right); \\
    k &= 8 \times (n \mod 4) + (m \mod 8)
\end{align*}
\] (2.1.15) (2.1.16)
2.2 Fingerprint Matching

A point pattern matching (minutia matching) problem is a well-known hard nut in the mode match identification. It deals with how to find out the relation between two different point sets \( P = \{ p_1, p_2, \ldots, p_m \} \) and \( Q = \{ q_1, q_2, \ldots, q_n \} \). Therefore, a good point pattern matching algorithm should be coordinate independence.

There are two point sets \( P \) and \( Q \) in the point pattern matching. \( P \) abstracted from 1st image consists of \( m \) points and \( Q \) abstracted from 2nd image consists of \( n \) points, namely \( P = \{ p_1, p_2, \ldots, p_m \} \) and \( Q = \{ q_1, q_2, \ldots, q_n \} \). The matching of them needs to find out a calibration function \( G(t_x, t_y, s, \theta) \), which can make two point sets have the biggest quantity points to correspond to each other. namely \( G(p) = q_b \), but in practice, there are some errors that \( G(p) \) is not completely the same as \( q_b \), therefore we generally use the error margin to describe the relation between \( Q \) and \( P \).

We use the coordinate \( x \) and coordinate \( y \) to describe the characteristic point in the point set. it means that \( P = \{(x_{p_i}, y_{p_i}) \mid i = 1, \ldots, m \} \) and \( Q = \{(x_{q_a}, y_{q_b}) \mid a = 1, \ldots, n \} \). If only one point pattern had the corresponding relation between \( P \) and \( Q \).

\[
q = G(p) \Rightarrow \begin{pmatrix} x_q \\ y_q \end{pmatrix} = \begin{pmatrix} t_x \\ t_y \end{pmatrix} + \begin{pmatrix} s \cos \theta & -s \sin \theta \\ s \sin \theta & s \cos \theta \end{pmatrix} \begin{pmatrix} x_p \\ y_p \end{pmatrix}
\]

(2.2.1)

Then calibrate function (1) have an unfixed solution. If a corresponding relation exists between points \( (p_i, p_j) \) in set \( P \) and points \( (q_a, q_b) \) in set \( Q \), while \( p_i \neq p_j \) and \( q_a \neq q_b \), then we can find out the exact calibrate function \( G \). Then we describe and prove the Theorem.

By theorem, we can see that the parameter number of calibrate function change from 4 to 2. All fingerprint images are collected by same fingerprint collecting device, so the scale parameter of the fingerprints is the same. Then we just need to determine the rotate angle parameter \( \theta \) of the calibrate function and needn’t take care of other parameters.

Generally speaking, details from the original fingerprint image consist of some fake characters. These fake characters generally come out in the process of pretreatment of the fingerprint image. So we need to modify the characters of the image and keep high reliably details. After all the steps, we put the image into fingerprint database directly contrast it with the stylebook. In the AFIS, Every character point is a fourth dimension vector \((x, y, \beta, c)\) where \( x, y \) is the coordinate of the minutia, \( \beta \) is the orientation of the minutia (the orientation of local ridge where this minutia located) and \( c \) is the genre of the minutia (bifurcation or port).

Between the matching aggregates \( P \) and \( Q \), when \( p_i \) and \( q_a \) are matching to each other and in the same calibrate function we define \( \omega_{i, a} \) as the number of \( p_i \) and \( q_a \) on the condition that these points correspond to each other. At that time, corresponding parameter is \( \theta_{i, a} \).

The algorithm, the array matchflag indicates whether point \( j \) and \( b \) can be match. And the matching of point \( j \) and \( b \) should keep to two criterions:

1) The distance between the minutia and the reference point is smaller than the given threshold value

2) The direction angle windage of minutia is limited in a given range.

In practice, considering that the reliability of ridge bifurcations are higher than ridge endings, so the \( m_1 \) and \( n_1 \) are both the number of ridge bifurcations.

If \( p_i \rightarrow q_a \) is the best matching, then \( \omega_{i, a} \) must be the max number in the aggregate \( \{ \omega_{i, a} \mid i = 1, \ldots, m ; a = 1, \ldots, n \} \). base on this, we bring forward the idea of how to decide the parameter of the calibrate function with max number of the matching points, the most critical step in this algorithm is to decide the circumrotate angle between the two fingerprint image. Its algorithm as follow

1) suppose the max number \( P_{\text{max}} = 0 \); matchflag\([i][a]=0\);
2) suppose the number of the max number of point matching point pairs that can be is \( k = \min(m_1, n_1) \);
3) For \( j = 1 \) to \( m_1 \), \( j \neq 1 \)
   - For \( b = 1 \) to \( n_1 \), \( b \neq a \)
     - \( p_i \) and \( q_a \) match
     - Delete \( q_a \) from \( Q \), \( P_{\text{match}} = P_{\text{match}} + 1; \)
4) If \( P_{\text{match}} \geq T_n \), then the match is success, \( T_n \) is the number of matching pairs setup beforehand.

In the algorithm, point \( p_i \) matches \( q_a \) is decided by 3 criterions as follow:

A. \( q_a \) is in the bound with the center \( p_i \) setup beforehand.
B. the direction angle windage of \( q_a \) is in the bound setup beforehand.
C. The style of \( q_a \) and \( p_i \) is the same.
The result of fingerprint matching is depending on the threshold value, \((P_{\text{match}} \geq T_m)\), so it is very important to select the \(T_m\) carefully. So the odds of misidentification can be described as \(P(T_m)\), when \(T_m \leq 5\), the misidentification is serious, but if the \(T_m \geq 13\), the odds of misidentification is very small. In general, we let \(T_m \geq 13\).

3. DATA

By our method, we can get enhanced image based on Fourier filtering, so we contrast the original image with the enhanced image. For the fingerprint image is very regular, its local ridges are almost parallel, the orientations of them are almost the same, so the method of direction filter enhancement is efficient, from the Fig 3.1, we can find there was some bug in the original image, but it has been eliminated in the enhanced image. We can see that the information of ridges is not lost, because image enhancement in proceeding of frequency domain will not make noise strong. It shows that algorithms are suited especially for low quality fingerprint images and has excellent enhancing performance to satisfy the real-time requirements, for example fingerprint image with scar or hole.

![Fig 3.1 Contrast original image with the enhanced image.](image)

We have 100 samples of thumbs from fingerprint database. We use photoshop to make them blurred, then we have took the fingerprint matching experiment for 100\times99 times in the Del pc (Pentium 4 2.5GHZ, 256M DDR), determined the odds of misidentification is 1.5\%, only take 25.77ms. We compare fingerprint by point pattern matching, which can reduce the processing time. It can be realized in the real-time system. In point pattern matching, we just need the information of character points, so we can store the fingerprint information with very little data.

4. CONCLUSIONS

Fingerprint image is a special kind of image and has its own characteristics. Most of the known techniques for fingerprint image enhancement are direction-oriented and rely heavily on the correct estimate of local ridge direction. But the estimate of local ridge directions is unreliable in the areas corrupted by noise where enhancement is most needed. Many fingerprint enhancement algorithms were effective for medium or high quality fingerprint images. In this paper, we proposed method based on Fourier filtering. In our algorithm the fingerprint enhancement were transformed from spatial domain to frequency domain by Fourier transforming. The fingerprints were enhanced by bandpass filter and directional filter in frequency domain. Experimental results show our algorithm for low quality fingerprints.

In addition, an algorithm for fingerprint identification using point pattern matching based on cluster approach is proposed, which effectively solves the problems of optimal matching between two fingerprint minutiae images under geometrical transformation and minutiae quantity change. Process which bases on the matching of vector pairs is developed to determine the registration parameters. The experimental results show that the proposed matching algorithm is fast and has high accuracy.

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