Measuring Fingerprint Image Quality Using the Fourier Spectrum

Qing-Rong Li and Mei Xie

Abstract—The fingerprint image quality has a significant effect on the performance of automatic fingerprint identification system. A method for measure of fingerprint image quality based on Fourier spectrum is proposed. First the band frequency which corresponds to the global average period of ridge is searched. Then the quality score of the fingerprint image is computed by measuring relative magnitude of the band frequency components. The method is verified to have good performance by experiments.

Index Terms—Fingerprint image, Fourier transform, measure, quality.

1. Introduction

Recently, the need for person identification is increasing more and more in the business world for transactions and industrial security. Fingerprint identification is one of the most reliable methods for the identification of individuals since there are no two persons having the same fingerprint and for each fingerprint, it remains unchanged over a lifetime and is easy to acquire. Because of the large amount of fingerprints and recent advances in computer technology, there has been increasing interest in automatic fingerprint identification system (AFIS)[1]-[3].

Most classical AFIS take the minutiae characteristics as the distinctive features to represent the fingerprint in the matching process.[4],[5]. Minutiae characteristics are local discontinuities in the fingerprint pattern which represent ridge terminations and bifurcations. Since poor quality fingerprint image cause AFIS can not reliably extract the ridge characteristics from it, the performance of AFIS depends heavily on the fingerprint image quality which is affected by many physical factors, such as dirty finger, dirty sensor face, scar, etc. If the quality of input fingerprint image can be identified at first, the AFIS can take some measurement to improve the performance. For example, with this information, the AFIS can reject the image with very poor quality or improve the fingerprint database by replacing the poor quality image with better quality image. Thus, measuring the quality of fingerprint image becomes an important factor in AFIS.

Several papers related with fingerprint image quality measure can be found in various publications. Boll et al[6] qualified fingerprint image quality by the ratio of the directional area to other non-directional area. However, it is difficult to judge if the area which includes singular point is directional area or is non-directional area. Shen et al[7] measured the fingerprint image quality by using the output of a Gabor filter bank with a frequency parameter defined empirically to each image sub-blocks. However, in practice, the frequency of ridge structure may be changed in a widely range for various fingerprint image even if the same sensor is used. Thus, the performance of this method will be poor while a unsuitable frequency parameter is used. Hong et al[8] used the sine wave to model the ridge and valley pattern of fingerprint and qualified the quality by computing the variance of gray levels in the direction orthogonal to the local ridge orientation for each block. Chen et al. [9] (fingerprint image quality analysis) computed quality measure by using the overlapping region of the distribution of ridge and valley. The above two methods are based on the orientation field. However, the orientation field can not be computed accurately if the image is very noisy and it is difficult to use this method on the subimage where the orientation of ridges changes quickly.

In addition, the above methods compute global fingerprint image quality by using local quality. Thus, they may classify some images with good quality even though the images only partially good. In order to overcome this problem, we propose a method for measuring fingerprint image quality directly from global image. This method is based on Fourier spectrum.

2. Fourier Spectrum of Fingerprint Image

The Fourier transform is a powerful tool of linear system analysis. For discrete functions (images) of two dimensions, the direct and inverse discrete Fourier transform is respectively defined as[10]...
\[ F(u, v) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) \exp[-j2\pi(ux/M + vy/N)] \]  

(1)

\[ f(x, y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u, v) \exp[j2\pi(ux/M + vy/N)] \]  

(2)

where \( f(x, y) \) is a image of size \( M \times N \). The Fourier spectrum of images is defined as

\[ |F(u, v)| = \sqrt{R(u, v)^2 + I(u, v)^2} \]  

(3)

where \( R(u, v) \) and \( I(u, v) \) are the real and imaginary parts of Fourier transform, respectively.

A Fingerprint can be considered as a pattern of the ridges and valleys on the fingertip. A good quality fingerprint image has its peculiar attribute in spectrum. Fig. 1 shows two fingerprint images with different quality levels and corresponding frequency spectrums. Fig. 1(c) shows the Fourier spectrum of a good quality fingerprint. A ring of relatively large magnitudes clearly appears around the origin in it. In contrast, as showed in Fig. 1(d), there is not a clear ring in the Fourier spectrum of poor quality fingerprint.

3. Proposed Method

In order to calculate the relative magnitude of the band frequency components, the ring must be located at first. For a fingerprint of size \( N \times N \), the geometry of the ring in spectrum is similar to circularity. In addition, because the centre of the ring is always at origin, we just need estimate the radius of the ring. This task can be performed by an effective operator as

\[ \max(R) \left\{ G_\sigma(R) * \left[ \int_{0}^{2\pi} \frac{p(u, v)}{2\pi R} \, ds \right] \right\} \]  

(4)

where \( p(u, v) \) is a power spectrum image of fingerprint, * denote convolution and \( G_\sigma(R) \) is a smoothing function such as a Gaussian of scale \( \sigma \). The complete operator behaves in effect as a circular detector, blurred at a scale set by \( \sigma \).

For a fingerprint image scanned at a fixed resolution, the intervals of ridge-valley lies in a certain range. Therefore, we can search the radius of ring in a limited range in practice. For example, for 500dpi fingerprint image of size \( M \times M \), the intervals of ridge-valley is between 5 and 23 pixels, in spectrum the range of radius of ring is between \( M/23 \) and \( M/5 \) pixels.

For a fingerprint image of size \( M \times N \), instead of a circular ring, there is an elliptical ring of relative higher magnitude in the spectrum. We can locate it by following operator

\[ \max(R) \left\{ G_\sigma(R) * \int_{0}^{2\pi} p(u, v) \, d\theta \right\} \]  

(5)
where \( r \) is half of the distance between ellipse climax on vertical axis. Fig. 2 shows an example of ring localization.

Since the radius of the ring is in direct proportion to ridge frequency and in inverse proportion to ridge period, global average ridge period can be estimated as \( P=N/r \). However, since local ridge distance is not constant in a fingerprint image, the frequency components corresponding to the ridge structure distribute in a band of frequencies in practice. In our study, we find local ridge period is between \([P-P/5,P+P/5]\). Thus, the band of frequencies is between \([R-R/6,R+R/5]\). In addition, in order to eliminate the effect of the low frequency components, we computed quality score (QS) as

\[
QS = C \left( \int_{R-R/6}^{R+R/5} P(u,v) \frac{ds}{2\pi r} \right) - \left( \int_{R-R/6}^{R+R/5} P(u,v) \frac{ds}{2\pi r} \right)
\]

where \( R \) is the radius of the ring, \( C \) is a normalize factor which normalizes the QS in the rang from 0 to 1.

### 4. Experimental Results

In order to verify out method, the public fingerprint database, DB1 set A in FVC2004 which consists of 800 fingerprint images from 100 different fingers with 8 impressions per finger is used. The size of each fingerprint image is 640×480 pixels with the resolution 500 dpi and 256 gray levels. The images is divided into three categories by human visual estimation, giving rise to 96 fingerprints of poor quality, 522 fingerprints of normal quality, 182 fingerprints of good quality. Fig. 3 shows the QS histogram.

It can be observed that the QS of poor quality fingerprints is obviously inferior to that of good quality fingerprints. But the QS of some of good quality images are inferior to that of some of normal quality images.

![QS histogram of DB1 set A in FVC2004.](image)

Fig. 3. QS histogram of DB1 set A in FVC2004.

Equations (7)-(10) describe the method of benchmarking the proposed quality measurement:

\[
e_i(i,j) = \begin{cases} 
1, & \text{if } QS_i < QS_j \\
0, & \text{Otherwise}
\end{cases} 
\]

(7)

\[
e_j(j,k) = \begin{cases} 
1, & \text{if } QS_j < QS_k \\
0, & \text{Otherwise}
\end{cases} 
\]

(8)

\[
e_k(i,k) = \begin{cases} 
1, & \text{if } QS_i < QS_k \\
0, & \text{Otherwise}
\end{cases} 
\]

(9)

\[
E = \frac{\sum_{i=1}^{L} \sum_{j=1}^{M} e_i(i,j) + \sum_{j=1}^{M} \sum_{k=1}^{N} e_j(j,k) + \sum_{i=1}^{L} \sum_{k=1}^{N} e_k(i,k)}{LM + MN + LN}
\]

(10)

where \( i \) is a image with good quality by human vision, \( j \) is a image with normal quality, \( k \) is a image with poor quality. \( QS_i \), \( QS_j \) and \( QS_k \) are machine computed quality score of them, respectively. \( L \), \( M \) and \( N \) are the number of images of three categories, respectively.

By using equations (7)-(10), the error rate \( E \) of 0.051 is found. That means the QS distribution is coincides with the human visual estimation.
5. Conclusions

In this paper, we have proposed a method for measuring fingerprint image quality using Fourier spectrum. This method measures fingerprint image quality based on the global characteristics of the image and do not rely on local ridge orientation estimation. Experimental results show our algorithm can assign invalid and low quality images lower quality scores while higher quality ones with higher scores. Currently, we are developing the fingerprint matching algorithm taking advantage of the QS given by our quality measurement method.

References


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