FINGERPRINT QUALITY AND VALIDITY ANALYSIS

Eyung Lim,

Centre for Signal Processing
eelim@ntu.edu.sg

Xudong Jiang and Weiyun Yau

Laboratories for Information Technology
{xdjiang,wyyau}@lit.org.sg

ABSTRACT

This paper discusses methods to estimate the quality as well as validity of a fingerprint image. Orientation certainty is used to certify the localized texture pattern of the fingerprint images while ridge to valley structure is analyzed to detect invalid images. Global uniformity and continuity ensures that the image is valid as a whole. 150 images with various qualities are evaluated using the proposed algorithm and quality benchmark we defined. A monotonic relationship is found indicating that the proposed algorithm is feasible in detecting low quality as well as invalid fingerprint images.

1. INTRODUCTION

Fingerprint is one of the most commonly used biometric features for personal authentication. An automatic fingerprint identification system (AFIS) is set up for personal identification in criminal investigation, attendance system, access control and so on. The identification performance of such system is very sensitive to the quality of the captured fingerprint image. Since the AFIS system is expected to work independently, exposed to potentially large number of users, the fingerprint sensor that is attached to the system is possibly subjected to impropriate use. This includes the applying of one's finger that is dry, wet or dirty on the sensor. In addition, some CMOS type of sensors has problems of residue and background noise. Although optical sensors have generally better image quality, longer capture time makes it likely to capture a partial fingerprint image when a user removes his finger from the system before a complete capture. All of these cases lead to "poor quality" or "invalid" images being captured. While a poor quality fingerprint image is a result of genuine finger that is captured with noise (polluted fingerprint image) or with insufficient of information (partial fingerprint image), an invalid fingerprint image is a captured image residue, stain or watermark on the sensor. While residual images generate false features that might be able to gain access from the system, partially detected or heavily noised true fingerprint can cause the false rejection of an authorized user. As a result, the system's performance is degraded. Therefore, it is vital for the AFIS system to gain information on the quality and validity of the captured fingerprint images so that it can work independently in a reliable manner.

There are some on-going and past efforts in the investigation of fingerprint image quality. Bolle, et al [1] used the ratio of directional area to other non-directional area as a quality measure. Shen et al [2] applied Gabor filter to image sub-blocks, and concluded that a good quality block with clear repetition of ridge and valley pattern can be identified by the outputs of a Gabor filter bank. Both of these methods only use the local orientation information of the fingerprint image. However, as the gray level ridge and valley structure of the fingerprint image contains much more information than the orientation alone and a fingerprint image exhibits a global smooth ridge flow, the local directional strength alone might not be sufficient to measure the quality of fingerprint image. Ratha and Bolle [3] proposed a method for image quality estimation from a wavelet compressed fingerprint image. This is beneficial if the image to be processed is in WSQ compressed format. However, it is not the case for an automatic fingerprint identification system. Hong et al [4] modeled the ridge and valley pattern as a sin wave, and compute the amplitude, frequency as well as the variance of the sin wave to decide the quality of the fingerprint image. However, these measurements cannot distinguish some invalid images from the valid ones. This work proposes several quality analysis techniques to estimate the quality and validity of fingerprint images. Both local and global quality measures are developed, which ranges from block level orientation certainty level, block level ridge structure to image level orientation connectivity and image level ridge to valley ratio.

2. QUALITY AND VALIDITY ANALYSIS

A complete fingerprint image quality analysis should examine both the local and global structures of the fingerprint image. Fingerprint local structure constitutes the main texture-like pattern of ridges and valleys while valid global structure puts the ridges and valleys into a smooth flow. The quality and validity of a fingerprint image is justified by its local and global structures. For local structure we look into the local orientation certainty and compare the ridges and valleys. The continuity of ridge orientation as well as the variation in ridge to valley ratio are examined throughout the whole image for the global justification.

2.1. Local analysis

Local structure of an image is studied in block basis by partitioning the fingerprint image into blocks of size 32×32 pixels. Local quality analyses, which involve certainty level estimation and the study of ridge-valley structure, are performed on these blocks with each of the blocks analyzed to be "good ", "bad", "blank" or "undetermined".

The fingerprint image within a small block (as shown as in Fig.1) generally consists of dark ridge lines separated by white valley lines along a same orientation. The consistent ridge orientation and the appropriate ridge and valley structure are therefore the two distinguishable local characteristics of the fingerprint image.

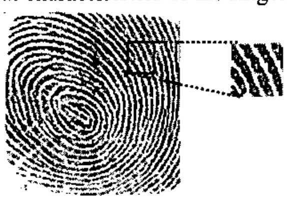

Fig. 1. A typical texture-like ridge block.

Fig. 2. A fingerprint's residual image.

The grey level gradient (dx, dy) at a pixel exhibits the orientation and the orientation strength of the image at this pixel. By performing Principal Component Analysis on the image gradients in an image block, an orthogonal basis for an image block can be formed by finding its eigenvalues and eigenvectors. The ratio between the two eigenvalues gives an indication of how strong the energy is concentrated along the dominant direction with two vectors pointing to the normal and tangential direction of the average ridge flow respectively.

The covariance matrix C of the gradient vector for a N points image block is given by

$$C = E\left\{\begin{bmatrix} dx \\ dy \end{bmatrix}\begin{bmatrix} dx & dy \end{bmatrix}\right\} = \begin{bmatrix} a & c \\ c & b \end{bmatrix} \quad (1)$$

where $E\{\bullet\} \equiv \frac{1}{N}\sum_{N} \bullet$

For the covariance matrix in (1), eigenvalues λ are found to be:

$$\lambda_{max} = \frac{(a+b)+\sqrt{(a-b)^2+4c^2}}{2} \quad (2)$$

$$\lambda_{min} = \frac{(a+b)-\sqrt{(a-b)^2+4c^2}}{2} \quad (3)$$

For a fingerprint image block, the ratio between λ_{min} and λ_{max} is then:

$$ocl = \frac{\lambda_{min}}{\lambda_{max}} = \frac{(a+b)-\sqrt{(a-b)^2+4c^2}}{(a+b)+\sqrt{(a-b)^2+4c^2}} \quad (4)$$

gives an indication of how strong the energy is concentrated along the ridge-valley orientation. The lower the value the stronger it is.It is obvious that *ocl* is between 0 and 1 as $a,b>0$.

Similar work has been done in [5] to determine image field direction by considering the cross correlations for the gradients in x and y direction, in [6] to determine tangential vector of an image pattern by finding extreme values for the minimization function. Here, we extend the work into determining fingerprint image block orientation as well as directly applying the ratio between the eigenvectors as an indicator of the certainty level.

The orientation certainty level defined above shows the orientation strength of a certain block and therefore is a good measure for fingerprint image quality. However, many residue images have also strong orientation strength inherited from the fingerprint image of the previous user (see Fig. 2). Therefore, we need to further examine the image ridge-valley structure. This is a crucial analysis for invalidity check. Fig. 3 shows a grey level plot for one image block in the direction normal to ridge flow. Each point in Fig. 3 is the average grey level of several pixels along the ridge orientation.

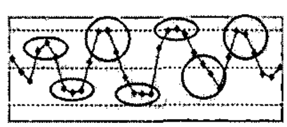

Fig. 3. Grey level plot

Fig. 4. ridge-valley direction

From Fig. 3, three successive local maximal and minimal grey level values are identified, an average of these values gives us a threshold value separating ridges and valleys which is independent of the ridge or valley width. From the 1D signal in Fig. 3, we can compute several useful parameters for our analysis. This includes ridge frequency value, ridge-to-valley thickness ratio and ridge thickness. While human fingerprint images cannot have abnormal ridges that fall too close or fall too far apart, one can use the nominal ridge frequency as a measure of whether a valid and good quality fingerprint image is captured. Similarly, ridges that are unreasonably thick or thin indicate that the fingerprint image is not captured properly or is a residual image.

Threshold values are determined for valid orientation certainty level, ridge frequency, ridge-to-valley thickness ratio and ridge thickness. It maps orientation certainty and ridge-valley structure of the block to "good", "bad" or "undetermined" identity respectively. In addition, an adaptive thresholding can identify the block as having a "blank" identity. The resultant non-blank quality identity assigned to each block can be summarized by Table 1 below.

Table 1 Resultant Local Block Quality Identity

Ridge-valley structure / Orientation Certainty	Good	Undet.	Bad
Good	Good	Good	Undet.
Undet.	Good	Undet.	Bad
Bad	Undet	Bad	Bad

Total quality score for local analysis is given by

$$S_L = \frac{T_G + 0.5 \times T_U}{T_G + T_U + T_B} \qquad (5)$$

Where T_G, T_U and T_B refer to the total number of good, undetermined and bad quality image blocks respectively.

2.2. Global analysis

Fingerprint images possess continuity and uniformity as the general characteristic. Continuity is found along the orientation change while uniformity is observed all over the image for its ridge and valley structure. Each of these characteristics contributes to a standalone global score that will be combined with the local analysis score under a weighted coefficient.

By examining the orientation change along each horizontal row and each vertical column of the image blocks (see Fig. 5), it is observed that there are smooth changes in the orientation for the valid fingerprint and abrupt changes in the region for noisy fingerprint image. The amount of orientation change that disobeys the smooth trend is accumulated. It is mapped into global orientation score (S_{GO}). S_{GO} has a highest quality score of 1 and a lowest quality score of 0. This provides an efficient way of investigating whether a fingerprint image posses a valid global orientation structure or not.

Fig. 5. ridge-valley direction in smooth trend

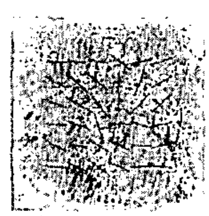

Fig. 6. disorder orientation pattern

Fig. 6 shows an image captured when a dry fingerprint image applied on a CMOS sensor that is full of residue. The disorder orientation pattern is easily noticed based on the previous rule of thumb.

Referring to fingerprint images in Fig. 7 (a), (b) and (c), by naked eye we would conclude that Fig. 7 (a) has the poorest quality among them, while Fig. 7 (c) has the best. Our judgment relies on the clearly separated ridges by valleys and the uniformity of the separation. This is where ratio for ridge thickness to valley thickness comes into play. We compute the ratio for ridge thickness to valley thickness for each image block. The standard deviation gives an indication of the quality the image carries. Although for a normal fingerprint image, ridge thickness to valley thickness ratio is not constant throughout the whole image, large deviation from the mean ratio value can nevertheless be a useful parameter to identify a bad quality from a good quality image. Again, it is mapped into a global score (S_{GR}) ranged within 0 and 1.

(a) (b) (c)

Fig. 7. Three sample fingerprint images.

2.3. Scoring

The total image quality is then measured by a quality score QS calculated by:

$$QS = (\alpha_1 S_L + \alpha_2 S_{GO} + \alpha_3 S_{GR}) \times \frac{\min(T - T_{BL}, A_{\min})}{A_{\min}}$$

$$\text{and} \quad \alpha_1 + \alpha_2 + \alpha_3 = 1 \qquad (6)$$

α_1, α_2, α_3 are the coefficients of quality analysis scores that contributes to the final image quality score. T_{BL} is the number of blank blocks obtained from adaptive thresholding. T is the total number of blocks or the sum of T_G ,T_U ,T_B, *and* T_{BL}. A_{min} is the required minimum number of blocks that identified as foreground images to avoid insufficient of information.

3. RESULTS

It is difficult to obtain the fingerprint image quality benchmark to test the performance of the proposed quality analysis algorithm. The fingerprint image quality and validity analysis is not aimed at selecting images of good visual appearance, but aimed at identifying poor quality or invalid fingerprint for the automatic fingerprint identification system. However, the authentication results of the AFIS depend not only on the input image quality, but also the template quality and the common area of the input and template. Therefore, we choose the quality of the features extracted from the fingerprint image by the automatic fingerprint identification system as the benchmark to test the performance of the proposed image quality analysis procedure. Concretely, from the feature extraction program [7] of an AFIS we can obtain the number of correctly detected minutiae c, the number of falsely detected minutiae f, and the number of undetected minutiae d.

The quality benchmark qb of a fingerprint image is defined as:

$$qb = \frac{c}{c+d+f} \times \frac{\min(Rf, Rm)}{Rm} \qquad (7)$$

where Rm is the minimal area of the fingerprint image required by the AFIS system for a robust authentication and Rf the area of the segmented fingerprint region. It is easy to see that $0 \le qb \le 1$ and $qb=0$ only if the segmented fingerprint area is zero or no correct minutia is extracted and $qb=1$ only if the segmented fingerprint area equals to or larger than Rm and all minutiae are correctly extracted.

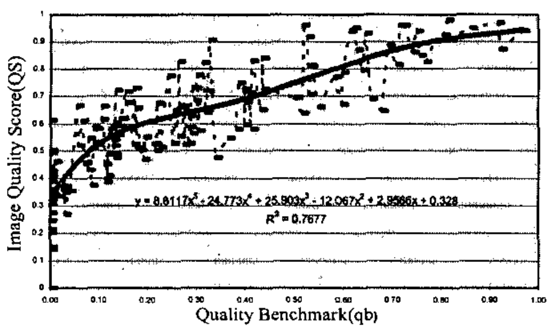

Fig. 8. Image quality score versus quality benchmark.

We plot the returned value from our quality analysis algorithm versus defined Quality benchmark for 150 images. Among them, 26 images or 17.3% are invalid images. Regression analysis is performed by fitting the curve with a 5th order line. It was found that R^2 value is 0.7677, while a perfect fit will give 1.

The ideal case for Fig. 8 is a one to one increasing trend, or the plot should monotonically increase. Regression analysis shows that the plot fits into a monotonically increased curve with 76.8% accuracy. Invalid images that located at x=0 have lower y values (image quality score). This shows that the quality and validity analysis is able to identify invalidity images. At the same time, a monotonically increased curve from regression analysis shows that the algorithm is able to differentiate good and poor quality images.

4. CONCLUSION

We have proposed algorithms for the estimation of fingerprint image's quality and validity in spatial domain. The repetition of ridges and valleys pattern is verified by the ratio of the eigenvalues obtained from covariance matrix for the image block's grey-level gradient. Ridge structures are examined as another element for local analysis. Global uniformity and continuity ensures that the image is valid as a whole. Final quality score returned from the analysis is plotted versus our defined benchmark to evaluate the performance of our algorithm. The algorithm is found to be able to assign invalid and low quality images lower quality scores while higher quality ones with higher scores.

5. REFERENCES

[1] Bolle et al, "System and method for determining the quality of fingerprint images", United State Patent number, US596356,1999.

[2] L.L.Shen, A. Kot and W.M Koo, "Quality Measures of Fingerprint Images", 3rd International Conference AVBPA 2001, p182-271, June 2001.

[3] Nalini K. Ratha and Ruud M. Bolle, "Fingerprint Image Quality Estimation", IBM Computer Science Research Report RC 21622, 1999.

[4] L.Hong, Y.Wan and A.K.Jain, "Fingerprint Image Enhancement:Algorithm and Performance Evaluation", IEEE Transaction on Pattern Analysis and Machine Intelligence, vol.20,no.8,Aug 1998.

[5] Shigeru Ando, "Image Field Categorization and Edge/Corner Detection from Gradient Covariance" IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 22, no. 2, pp. 179--190, 2000.

[6] M.J.Donahue and S.I.Rokhlin, "On the Use of Level Curves in Image Analysis", Image Understanding, vol 57, no. 2, pp.185-203, 1993.

[7] XD Jiang, WY Yau and Wee Ser, "Detecting the Fingerprint Minutiae by Adaptive Tracing the Gray Level Ridge", Pattern Recognition(34), No. 5, May 2001, pp. 999-1013.