# A Novel Measure of Fingerprint Image Quality Using Principal Component Analysis(PCA)

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## Abstract

*The performance of automatic fingerprint identification system relies heavily on the quality of the fingerprint images. Poor quality images result in missing or spurious features, thus degrading the performance of the identification system. Therefore, it is important for a fingerprint identification system to estimate the quality of the captured fingerprint images. In this paper, a new method based on Principal Component Analysis (PCA) is proposed for fingerprint quality measure. PCA is a common and useful statistical technique for finding patterns in data of high dimension. It can be found that fingerprint patches in a local neighborhood form a simple and regular circular manifold topology in a high-dimensional space. The characterization of manifold topology represents the local properties of the fingerprint. In our method, we first extract two novel features from the expected manifold topology. Then a local block measure of quality is generated according to these two features using multiplication rules. Finally, incorporating the normalized Harris-corner strength (HCS) as weighted value into local block quality measure, we obtain a global quality of a fingerprint image. The proposed method has been evaluated on the databases of fingerprint verification competition 2004DB1 (FVC2004) and our private database(AES2501). The experimental results confirm that the proposed algorithm is simple and effective for fingerprint image quality measure.*

## 1. Introduction

Fingerprint identification is one of the most popular and reliable biometric techniques and is widely used in many important applications such as electronic personal identification card, e-commerce due to its permanence and uniqueness [1]. However the performance of such a system is very sensitive to the quality of captured fingerprint image. The fingerprint sensor attached to the system is possibly subjected to improper use. This includes the applying one's finger that is dry or dirty on the sensor, problems of residue noise and partial fingerprint images. All of these cases could lead to "poor quality" or "invalid" captured images. Poor quality images result in spurious and missing features which degrade the performance of the fingerprint identification system. Therefore, it is vital for fingerprint identification system to consider the quality of the captured fingerprint images.

During the past decades, several methods have been proposed for the quality measure of fingerprint images, which can be broadly categorized as global level-based (i.e., a single quality value is derived for the whole fingerprint image), and local level-based (i.e., a distinct value is estimated for each block/pixel of the fingerprint image) [1][2].

Global level-based methods analyze the images in a holistic way and computer a global measure of quality. The most famous and popular approach to measure global fingerprint quality bas been proposed by [3] and is known as NFIQ (NIST Fingerprint Image Quality). The NFIQ algorithm is based on an artificial neural network that tries to predict the quality class from 11 features of the image. These features include the numbers of minutiae and image blocks with quality index exceeding several thresholds. The NFIQ measures quality by 5 classes, where class one refers to "excellent" and class five to "poor", and the "NFIQ value" output by NFIQ algorithm refers to the class number of the input fingerprint. Qi et al.[4] combine local and global features, but among the global features the authors suggest taking into account the size of the foreground area, the foreground centering with respect to image center and the present of detectable singularities. A good quality fingerprint image exhibits a ring around the origin of the frequency coordinate in the Fourier spectrum, because the ridge-valley patterns are quasi-periodic structures present a dominant frequency in most directions with an almost uni-



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form modulus. The implementation of ring detectors allows an measure of the overall fingerprint image quality [5][6].

Local level-based methods usually divide the image into nonoverlapped square blocks and extracted features from each block. Then a local measure of quality is generated and blocks are classified into groups of different quality. The local level-based methods is superior to global level-based methods since it is more descriptive and in any case, one could obtain the global quality from the statistic of the local estimations. A number of methods have been proposed to measure the block-wise quality. Most of them measure local quality according to the local orientation coherence [7][8] [9]. Although orientation coherence is a very powerful feature to measure quality, it fails near the singularities. In fact, singularities are characterized by high curvatures which results in low coherence. The method presented in [10] use linear parabolic symmetry operators to try to overcome this problem.

In this paper, a new method based on Principal Component Analysis (PCA) is proposed for fingerprint quality measure. Unlike the previous work where a pixel corresponds to a image, each image pixel can be embedded in a high-dimension space by forming a vector (or "patches") from its neighborhoods [17]. It can be found that fingerprint patches in a local neighborhood form a simple and regular circular manifold topology in a high-dimensional space. The higher the quality is, the more regular the circular manifold topology is. The characterization of manifold topology represents the local properties of the fingerprint. In our method, we first extract two novel features from the expected manifold topology. Then a local block measure of quality is generated according to these two features using multiplication rules. Finally, incorporating the normalized Harris-corner strength (HCS) [11] as weighted value into local block quality measure, we obtain a global quality of a fingerprint image. The HCS value in smooth areas is larger than in noise areas. And it also performs better than the fingerprint orientation coherence ($Coh$) [12], especially near the singular points.

The remainder of this paper is organized as follows: Section 2 indicates the details of the fingerprint image quality measure. Section 3 provides the experimental results of our method. We summarize our work in section 4.

## 2. Fingerprint Image Quality Measure

### 2.1. Manifold topology structure of fingerprint patches

Unlike the previous work where a pixel corresponds to a image, each pixel can be embedded in a high-dimensional space by considering the pixel and its neighborhood, i.e., by taking patches centered at the pixel location. In the feature space, pixels with similar neighborhoods will be close to each other and farther from dissimilar ones. Fingerprint patches in a local neighborhood form a simple and regular circular manifold topology in a high-dimensional space. The higher the quality is, the more regular the manifold topology is. The characterization of manifold topology represents the local properties of the fingerprint and reflects the local quality of the fingerprint.

For a fingerprint image $I$, we first divide it into blocks of size $W * W(W = 16$ in our paper). Then for each pixel of every image block, we obtain an $M * M(M = 7$ in our paper) vector (or "patch") centered at image pixel $(i, j)$ which is the order set of pixels $p = \{I(u, v) : |u - i| \leq (M - 1)/2 \wedge |v - j| \leq (M - 1)/2\}$. This embedding preserves local and context information, since it completely preserves the image joint distribution. Considering the patches extracted from a local region of a fingerprint and using principal component analysis (PCA) [13] for dimension reduction, we can easily observe the regular circular manifold topology formed by extracted fingerprint patches, as shown in Fig. 1. As asserted by the residual variance plot (Fig. 1(last column)), most of the data variance is contained in the first two dimensions, as expected since a circle is a 1-D topological structure in 2-D space. From the middle column of Fig. 1, we can observe that the foreground patch (Fig.1 (a)) which has the clearest ridge-valley structures form the best circle topological structure and the background (Fig. 1(b)) form the worst circle topological structure.

### 2.2. Features for block images quality measure

Structure of the manifold topology can be utilized for fingerprint quality evaluation since it characterizes the general distribution of the data embedded into the feature space. Here, we present two novel features that can measure image quality from the residual variances and the manifold topology structure.

The first novel feature is the two leading eigenvalues of the PCA projection which correspond to the variance along the first two principal components. The higher quality the block is, the higher the sum of the first two principal components residuals are (see the last column in Fig. 1). Hence the first feature can be defined as

$$f_1 = (D(1) + D(2))/(\sum_{i=1}^{M*M} D(i)) \quad (1)$$

where $f_1 \in [0, 1]$ denote the first feature. 1 means the highest quality and 0 the lowest quality. D(i) is the $ith$ $(i = 1...M * M)$ residual.

The second feature are proposed that can be utilize to measure differences between the observed manifold topology and a circle. We expected the samples distributed in circles uniformly. The feature is the average of samples from

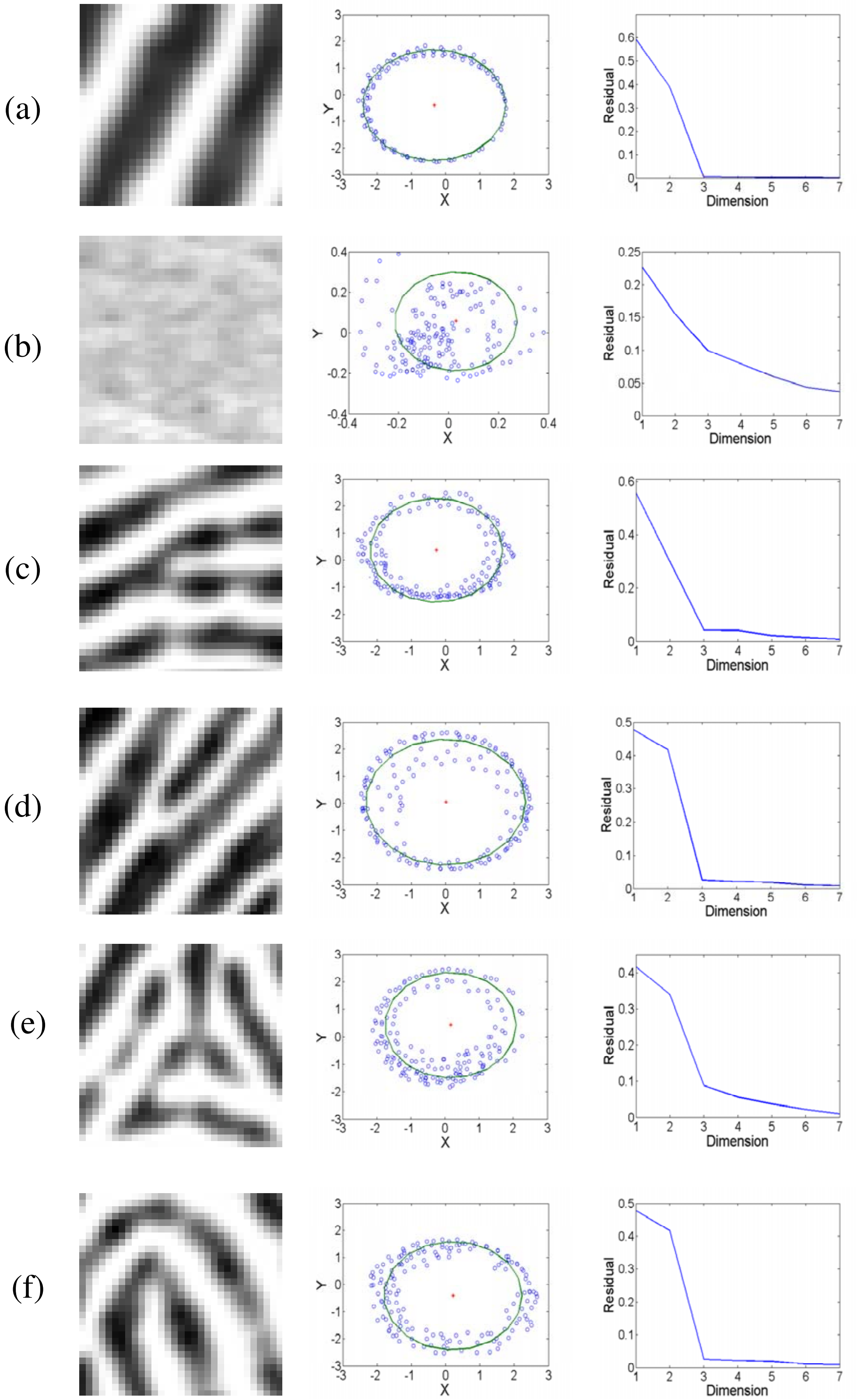


Figure 1. The first column shows the original block images which are from different parts of a fingerprint. The middle column shows PCA projection of 7∗7 fingerprint patches of the original block images and first 7 residual variance are shown in last column respectively. (a)foreground, (b)background, (c)bifurcation, (d)end, (e)delta, (f)core.

the original in the projection (see the middle column in Fig. 1). For a circle this value should be close to the circle radius. For a image block, this feature is

$$AveDis = \sum_{j=1}^{W*W} \sqrt{|Y_j - y_c|^2 + |X_j - x_c|^2}/Re - 1 \quad (2)$$

$$f_2 = exp(-AveDis) \quad (3)$$

where $Y_j$ and $X_j$ denote the 2D PCA projection coordinate respectively; $y_c$ and $x_c$ are the center coordinate of circle fitted by 2D PCA projection; $Re$ is the radius of circle fitted by 2D PCA projection. Here we subtract the circle radius, so the value $AveDis$ should be close to 0 and $f_2$ should be close to 1. 1 means the highest quality and 0 the lowest quality. Then a $kth$ block image quality $BQ$ can be measured

$$BQ(k) = f_1 * f_2 \; (k = 1...N) \quad (4)$$

where N is the number of blocks of a input image.

### 2.3. Global image quality measure

Incorporating the normalized Harris-corner strength (HCS) as weighted value into local block quality, we obtain a global quality $GB$ of a fingerprint image. A set of $HCS$ of a input image are calculated for each $W * W(W$=16) block using (5).

$$HCS = \frac{I_x^2 I_y^2 - I_{xy}^2}{I_x^2 + I_y^2} \quad (5)$$

$$I_x^2 = \sum_{i=1}^{W}\sum_{j=1}^{W} G_x^2(i,j) \quad (6)$$

$$I_y^2 = \sum_{i=1}^{W}\sum_{j=1}^{W} G_y^2(i,j) \quad (7)$$

$$I_{xy}^2 = \sum_{i=1}^{W}\sum_{j=1}^{W} G_x^2(i,j) G_y^2(i,j) \quad (8)$$

where $G_x(i,j)$ and $G_y(i,j)$ are the gradients at pixel $(i,j)$ and can be calculated using $Sobel$ operator or the more complex $Marr-Hildreth$ operator. The resulting corner strength image is shown in Fig. 2. We normalize $HCS$ to $N_{HCS} \in [0,1]$. Then the global quality $GB$ of a fingerprint image can be estimated as:

$$GB = \sum_{k=1}^{N} BQ(k) * N_{HCS}(k) \quad (9)$$

where N is the total number of blocks of a input image; $BQ(k)$ and $N_{HCS}(k)$ are the local quality and normalized Harris-corner strength of $kth$ block respectively.

Figure 2. (a) Original fingerprint image from 2004DB1(99_8.tif), (b) Harris-corner strength image of (a).

## 3. Experiment Results

It is difficult to obtain the fingerprint image quality criterion to test the performance of a quality analysis method. The most used method to test image quality measure are based on visual assessments of images. But it is not exactly precise. Hence we adopt a match algorithm VeriFinger 6.1 SDK [16] to evaluate our quality measure method on fingerprint image. The experiments are carried to evaluate the performance of our method on 2004DB1 (FVC2004)[14] which contains 800 fingerprints from 100 different fingers and our private database which use AES2501 [15] and contains 8640 fingerprints from 720 different fingers. Experiment 3.1 aims to directly test the performance of our method in visual way; Experiment 3.2 is designed to evaluate the influence of our method on matching performance. All the experiments are conducted on PC Intel Core2 E6550 @ 2.33 GHZ.

### 3.1. Visual assessment

For comparing the proposed method qualitatively, we give out some different quality images. In the following, we will display the measure results to demonstrate that the performance of our method is convincing.

Referring to fingerprint images in Fig. 3 by naked eye we would conclude that Fig. 3(a), (b), (e), (f) have the low quality, while Fig. 3(c), (d), (g), (h) have the high quality. These observation results are in accordance with the quality measure given by our proposed method.

From the matching score results, we find that Fig. 3(a), (b) have the worse match scores (all match scores are zeros) in genuine matching. At the same time, they give a very low global quality. We find that 3(c) and (d) give the higher match scores in genuine matching and they give a high global quality. Fig. 3(e), (f), (g) and (h) are also the same. The experimental results indicate that good quality images can get better match results. So we can conclude

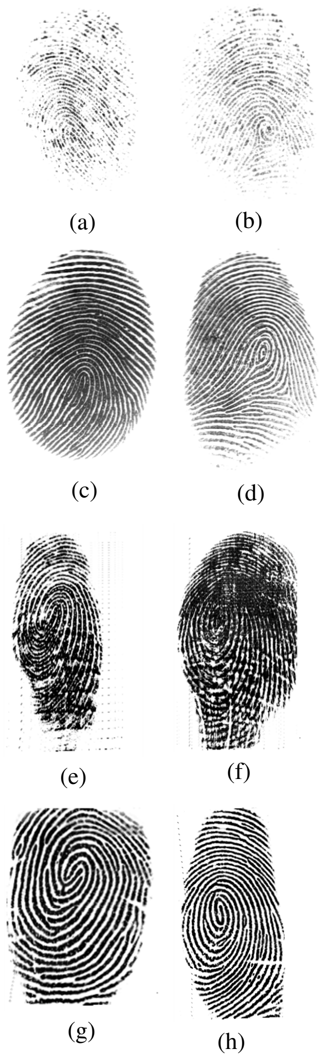


Figure 3. (a), (b), (c) and (d) are the images from FVC2004DB1 database; (e), (f), (g), (h) are the images from our database. The global quality of (a), (b), (c), (d), (e), (f), (g), (h) are 0.4256, 0.4148, 0.7178, 0.7444, 0.3541, 0.3908, 0.7471 and 0.7233 respectively.

that our proposed method can give the correct image quality.

## 3.2. Matching performance

In this experiment, we are going to evaluate the influence of our method on matching performance. The matching system VeriFinger 6.1 SDK [16] is implemented according to a matching algorithm based on minutiae. Since minutiae extraction depends heavily on the image quality, the matching results can reflect the accuracy of our proposed method. If the method is efficient, the matching performance should raise as the image quality improve.

We divide every database into three different quality subdatabases: good quality database, normal quality database and poor quality database. For example, 2004DB1 contains 100 different fingers and every finger contains 8 images. We sort the 8 images of every finger by ascending order according to the values of images quality. The first 4 images of every finger compose the poor quality database. The middle 4 images of every finger compose the normal quality database. The last 4 images of every finger compose the good quality database. Tab. 1 shows the matching results. It can be found that the matching performance is improving with the better quality images. The experimental results confirm that our proposed method is effective for fingerprint image quality measure.

Table 1. Improving the matching performance for different image quality.

| Database | | EER (%) |
|---|---|---|
| FVC2004DB1 | Good | 5.1667 |
| | Normal | 5.7286 |
| | Poor | 6.1139 |
| AES2501 | Good | 0.00005 |
| | Normal | 0.00141 |
| | Poor | 0.00197 |

## 4. Conclusions and Discussions

In this paper, we proposed a new method for fingerprint image quality measure based on Principal Component Analysis (PCA). PCA is a common and useful statistical technique for finding patterns in data of high dimension. Fingerprint patches in a local neighborhood are found to form a simple and regular circular manifold topology in a high-dimensional space. The characterization of manifold topology represents the local properties of the fingerprint. We first extract two novel features from the expected topology. Then a local block measure of quality is generated according to these two features. Finally, incorporating the normalized Harris-corner strength (HCS) as weighted value into local block measure, we obtain a global quality of a fingerprint image. The experimental results on FVC2004DB1 and AES2501 databases confirm that our proposed method is effective for fingerprint image quality measure.

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