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Letters

A hierarchical *k*-means clustering based fingerprint quality classification

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ABSTRACT

This paper presents a novel technique that employs a hierarchical *k*-means clustering for quality based classification of fingerprints for subsequent improvement in fingerprint matching results. A set of statistical and frequency features have been calculated from a fingerprint image. A hierarchical *k*-means clustering algorithm has been utilized to classify the fingerprint image into one of four quality classes, i.e. good, dry, normal or wet. An objective method has also been proposed to evaluate the performance of fingerprint quality classification. It has been shown through experimental results that the performance of minutiae based matcher improves when the quality of fingerprint image is incorporated in the matching stage. The false accept rate and false reject rate of minutiae based fingerprint matcher are 1.8 on FVC 2002 db1 database without utilizing fingerprint quality information. False accept rate has been reduced from 1.8 to 0.79 whereas the false reject rate is at 1.8 when fingerprint quality based threshold value is utilized. This significant improvement in the performance of the fingerprint matching system shows the effectiveness of hierarchical *k*-means clustering technique in quality based classification of fingerprints.

1. Introduction

Fingerprint identification is one of the leading biometrics used in criminal investigation, border access control systems, national identification cards, ATMs, airports and other security installations. Fingerprints are believed to be unique across individuals and across fingers of same individual. Even identical twins having similar DNA, are believed to have different fingerprints [1]. These observations have led to the increased use of automatic fingerprint-based identification in both civilian and law-enforcement applications.

The performance of fingerprint identification system depends heavily on the quality of the fingerprint image [2,3]. If the fingerprint image quality is poor then there will be a more probability of error in fingerprint matching. Poor quality fingerprint image contains many spurious minutiae which degrades accuracy of the fingerprint matching system.

2. Fingerprint quality

The quality of fingerprint image effects the accurate extraction of minutiae. The low quality image contains large number of false minutiae as compare to good quality image. Fig. 1(a–d) shows the dry, good, wet and normal quality of fingerprint images. Fingerprint quality [3,4] is usually defined as a measure of the clarity of ridges and valleys. Good images have very clear ridges and valleys. Wet images have thicker dark ridges and thin valleys while the dry images have very thin light ridges. Normal images are those which have 60–70% clear ridges and 30–40% light ridges. Many factors affect the quality of the fingerprint image. The fingerprint scanner surface is dirty which degrades the quality of the acquired image. The surface of the fingerprint may also be dry. Person applies less pressure of the fingerprint on the scanner surface which also degrades the acquisition quality. So there are many factors which are related to the environment or user body which affects the quality of the fingerprint image. A fingerprint consists of ridges and valleys which run in parallel. In good quality fingerprint images, the ridges and valleys are clearly defined. But in low quality images, the ridge and valley structure is not clearly defined. Fingerprint quality is utilized to improve the quality of database and acceptability of fingerprint image during enrollment. The performance of fingerprint identification systems depends heavily on the quality of the fingerprint image. The performance degrades significantly when the input image is of low quality. The different conditions of the skin of the finger and limitations of the fingerprint scanners affect the quality of the acquired images.

Various techniques have been proposed in the literature for estimation of fingerprint quality. Hong et. al. [5] computed the frequency of the each block of fingerprint image and marked each block into recoverable and non-recoverable regions. Shen et. al. [6] used a bank of gabor filters on blocks of fingerprint image to

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Fig. 1. (a) Dry fingerprint image, (b) good fingerprint image, (c) wet fingerprint image and (d) normal fingerprint image.

determine the quality of that image. Chen et. al. [4] used the fingerprint quality factor and quality index in frequency domain and spatial domain to predict the quality of a fingerprint image. Chen et. al. calculated the energy rings in frequency domain and block-wise coherence in spatial domain to estimate the quality of the fingerprint image.

This paper presents a novel hierarchical *k*-means clustering method for quality based fingerprint classification. A set of features have been extracted in frequency domain and spatial domain. Then these features are utilized by fingerprint quality classifier to estimate the quality of fingerprint image as dry, wet, good or normal. An objective method has also been proposed for performance evaluation of the fingerprint quality classification. In the following sections, this technique has been described in detail. Section 3 describes the extraction of quality features in frequency domain. Section 4 explains the extraction of statistical features in spatial domain. Section 5 describes the hierarchical *k*-means clustering based fingerprint quality classification. Section 6 describes the experiments conducted to evaluate the performance of fingerprint quality classification method and Section 7 summarizes the paper.

3. Quality features in frequency domain

Chen et. al. [4] proposed a fingerprint quality estimation framework based on Fourier and spatial features. Fourier features have been calculated by the approach proposed by Chen. Enhancements have been proposed in our technique which improves the performance of the quality estimation technique. The quality features in frequency domain are used to classify the fingerprint image as good or poor (dry) quality image. The main steps of quality feature extraction algorithm in frequency domain are the following:

i. The fingerprint image is transformed into frequency domain using the Discrete Fourier Transform (DFT) [7].
ii. The power spectrum [8] is obtained which is square of the absolute of DFT of the image.
iii. Fifteen Butterworth band-pass filters [4] are used to extract the energies in the annular bands from the power spectrum of the DFT.
iv. The energies in the tth annular bands are extracted after convolution with fifteen band-pass Butterworth filters and these energies are denoted by E_t where t varies from 1 to 15 ($T=15$).
v. The normalized energy for the tth band-pass filter is defined in the following equation:

$$P_t = \frac{E_t}{\sum_{t=0}^{T-1} E_t} \tag{1}$$

vi. The extent of energy concentration is given by the following equation:

$$E = -\sum_{t=0}^{T-1} P_t \log P_t \tag{2}$$

vii. Quality feature Q_f is calculated by Eq. (3) in which all the 15 band-pass filters are used for extraction of ring energies:

$$Q_f = \log T - E \tag{3}$$

viii. Quality feature $Q_{f\_limited}$ is also calculated for different number of filters. This calculation is done using the following equations:

$$P_{t\_limit} = \frac{E_t}{\sum_{t=start\_ring}^{end\_ring} E_t} \tag{4}$$

$$E_{limit} = -\sum_{t=start\_ring}^{end\_ring} P_{t\_limit} \log P_{t\_limit} \tag{5}$$

$$Q_{f\_limited} = \log T - E_{limit} \tag{6}$$

The value of *start_ring* is set to 1 whereas *end_ring* varies from 4 to 8 and also T varies from 4 to 8. This corresponds to band-pass filters from 1 to 4, 1 to 5, 1 to 6, 1 to 7 and 1 to 8 which were used to extract energy from annular bands of power spectrum of DFT. Extracted ring energies of 15 filters are shown in Fig. 2. This figure shows the ring energies in good and dry fingerprint images. Maximum amount of energy is concentrated in first 5 filters. Different ranges of filters have been tested and it is found out that quality feature calculated for filter 1–5 provides the best accuracy and minimum error in classification of fingerprint images as good or poor (dry) quality image. Therefore two quality features have been calculated Q_f and $Q_{f\_limited}$. All the extracted ring energies of 15 band-pass filters are used to calculate quality feature Q_f whereas $Q_{f\_limited}$ is calculated using the extracted ring energies of first 5 band-pass filters.

4. Quality features in spatial domain

In spatial domain, the foreground of fingerprint image was segmented from the background. The segmented fingerprint image consists of ridge and valley area of fingerprint. The segmented fingerprint image is divided into non-overlapping blocks of size 13×13. The 13×13 block size is chosen after