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Enhancement of Robustness and Accuracy of Fingerprint Recognition

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ABSTRACT

Identification systems using fingerprints are highly reliable and secure. A new and effective combined approach for fingerprint recognition is introduced in this paper. In the proposed method, fingerprint images are normalized in order to enhance the quality. Then, the orientation of ridges is estimated using gradient method. Afterwards, using Gabor filter, lost ridges are reconstructed. Due to the selective nature of the frequency and orientation of Gabor filter, and due to the fact that it has a favorable resolution in both spatial and frequency domain, it is used for reconstructing corrupted fingerprint images. Then, discrete wavelet transform and Gabor filter are jointly used for feature extraction. Being insensitive to rotation, Gabor filter is used for feature extraction. It is used in 6 different orientations in this study. Because discrete wavelet transform extract features in 5 levels, this method is also exploited for feature extraction. Finally, neural network is used for classification. The database used in the experiment is DB3 FVC2004 sub-database. The accuracy in the introduced combined approach is 99% while FRR, FAR, and EER are all calculated to be 1% which is better than those calculated for all investigated approaches in this paper.

1. Introduction

Identification systems that use human behavioral or physiological features, including fingerprint, face, and iris are of the most secure and reliable identification systems. Fingerprint lines have bumps and dents. The bumps are called ridges, and the empty spaces between two ridges are called valleys. Ridges and valleys are characterized by regular structures and specific shapes that make them unique. The process of fingerprint recognition is comprised of three levels: preprocessing, processing, and post-processing. In an image with an ideal quality, ridges and valleys are placed one after another. In such cases, it would be very easy to extract the features. Practically, however, depending on factors, including the pressure exerted on the finger, the structure of the bumps and dents on one's skin, and the scanner. non-ideal images are obtained. This makes feature extraction difficult. After preprocessing, features are extracted, and then images are classified [10]. A new and effective combined approach for fingerprint recognition is proposed in this study. In the rest of the paper, Section 2 reviews the literature. Section 3 describes the proposed method. Section 4 evaluates the results. Finally, Section 5 summarizes the results to form a conclusion.

2. Literature review

The two-level method of enhancing fingerprint image quality through learning from images was first introduced by Jucheng Yang [7] in 2012. According to this method, in the first level images are enhanced by a ridge reconstruction filter in the spatial domain. A band-pass filter is used in the second level. Although the first spatial domain filter increases the ridge contrast perpendicular to the ridges, this process can blur the image. Hence, it is proposed that the second level be enhanced by consecutively using a band-pass filter adjusted for enhancing fingerprint images quality. Having enhanced the quality of fingerprint images, features are extracted using minutiae method [7].

A method is proposed by HuongThuy, et al. in 2013, which uses a fingerprint matching method based on local point model [9]. For smoothing non-linear distorted *fingerprints, a fingerprint matching algorithm was used in this method which is based on thin-plate spline (TPS). It needs to be noted that TPS is a warping technique.*

Curved-region-based ridge frequency estimation and curved Gabor filters which are used for enhancing fingerprint images are introduced by Carsten Gottschilch in 2013 [8]. First, two orientation field estimation methods are combined for a more accurate estimation of noisy images. Then, curved Gabor filter is used for image enhancement. Having enhanced the quality of images, VeriFinger Grayscale 5.0 is used for matching fingerprint images [8].

Orientation field estimation method is proposed by Yoon in 2012 [3]. In this method, the orientation of ridges is estimated using orientation field estimation and directional derivative methods. After extracting features, classification is carried out by support vector machine (SVM) [3].

In the classic extraction method, specific points and minutiae points (ridge bifurcations, and ridge endings) are extracted [5]. Having completed preprocessing, the skeleton image of the fingerprint is extracted from the binary image. Then, features are extracted in the next level. Finally, faulty specific points are eliminated in the post-processing level [5].

3. Proposed method

An important factor in fingerprint recognition is to use uncorrupted fingerprints. In our proposed method, all images are normalized at first in order that all images had the same intensity. In order to identify ridges, directional derivative and region-based frequencies are used. Then, Gabor filter is used to reconstruct disconnected ridges. In feature extraction level, Gabor filter and discrete wavelet transform is used. Finally, classification is carried out using MLP neural network.

The reason that why Gabor filter is used for reconstructing disconnected ridges is that it extracts all minutiae of a ridge or valley from various angles. Moreover, the orientation and frequency of this filter is selective and has a favorable resolution in both spatial and frequency domains. Since Gabor filter is not sensitive to rotation and extracts features in 8 different orientations, it is used in feature extraction. Curvelet transform is not used for feature extraction, is due to its lower accuracy than those of Gabor filter and discrete wavelet transform. Discrete wavelet transform is used in the proposed method. First, because it extracts minutiae by transforming images from spatial domain into frequency domain, and eliminating the frequencies altogether. Moreover, it extracts features in multiple levels. Neural networks are high speed due to their parallel processing. As with human brain, they consistently learn and adapt to their environment. If some neurons do not function properly, the brain will not fail altogether, and making a correct decision will still be possible. This method can provide logical answers for uncertain data and situations- whether they are fuzzy, defective, or noisy. Hence, neural networks are exploited for classification.

3.2. Preprocessing

3.2.1. Normalization

Having obtained fingerprint images, they must be normalized in order that all images lie in an acceptable range, and have the same intensity. Various methods have been proposed for normalization, the most famous of which is shown in Eq. (1).

$$N_i(x,y) = \begin{cases} M_0 + \sqrt{\dfrac{V_0 \times (I(x,y) - M_i)^2}{V_i}} & if \quad I(x,y) > M_i \\ M_0 - \sqrt{\dfrac{V_0 \times (I(x,y) - M_i)^2}{V_i}} & Otherwise \end{cases} \quad (1)$$

Statistically, data with an average of zero, and a variance of one are considered to be normal. In Eq. (1), N is the normalized image, and I is the input image. M_0 and V_0 are desired variance and mean value, respectively In which the image is supposed to lie and V and M are the variance and average of the image, respectively [6].

3.2.2. Directional derivative (gradient)

The orientation of each block must be determined in this level which is done by gradient. There are other methods to achieve this, but this method that is based on gradient is the most accurate. Prewitt or Sobel operators can be used for computing the directional derivative of an image [6]. Both filters are two-part where each part defines a 3×3 matrix. One of them is used for computing the derivative along X axis, and the other one is used for computing the derivative along Y axis. Sobel operator is used in this study which is shown in Fig. 1.

$$\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

Fig. (1) Sobel gradient matrix along the vertical and horizontal axes

3.2.3. Using Gabor filter for reconstructing fingerprint ridges

A one-level filter was introduced by Dennis Gabor in 1946. Applying this filter on features has brought about some success. It has been due to the features of Gabor filter, particularly the representation of the orientation and frequency that was similar to those of human visual systems. Along with similar lines method, Gabor function is known as a useful tool in machine vision, image processing, and it has been found particularly useful in texture analysis due to their regional features in both spatial and frequency domains. Gabor filter extracts all ridges and valleys minutiae in various angles. Gabor filter relations are introduced in section 3.3.1 [4].

3.3. Feature extraction

3.3.1. Feature extraction using Gabor filter

As shown in Eq. (2), Gabor filter is a two-dimensional filter which is a combination of cosine and a 2D Gaussian function. Gabor filter is then

$$g(x',y',\theta,f)=\exp(-\frac{x'^2}{2\sigma_x^2}-\frac{y'^2}{2\sigma_y^2})\cos(2\pi fx')$$
$$x'=x\cos\theta+y\sin\theta \quad (2)$$
$$y'=-x\sin\theta+y\cos\theta$$

Where GF lies in the center of the area, θ represents filter rotation along X axis, and f is the regional frequency. Also, σ_x and σ_y are the standard deviations of the Gaussian function along X and Y axes, respectively. [8]

As shown in Fig. (2), firstly the image center is identified. Since in the proposed method, applying Gabor filter in 6 directions is shown to have better results in comparison with when it was applied in 8 directions, Gabor filter is used in 6 different angles as orthogonal circles. If the center of the image had not been in the middle of the plane, it will be shifted to the middle before applying orthogonal circles [11]. Finally, six features are extracted using Gabor filter.

3.3.2. The features of discrete wavelet transform

Because discrete wavelet transform extracts feature in multiple levels, selecting an optimal number of levels is highly effective in extracting the most valuable features from images. Having evaluated the performances of 2D discrete wavelet transform with 2 levels up to 5 levels, 5-level wavelet transform is selected for the proposed approach. This function extracts5 features from the pyramid-structured wavelet transform. An image is then divided into 4 sub-images in four bands: low-low, low-high, high-low, and high-high. As shown in Fig. (3), this was continued up to the fifth level [2].

Finally, the energy of each level is calculated by Eq. (3), and 5 highest energies are selected as the image features

$$E=\frac{1}{MN}\sum_{i=1}^{m}\sum_{j=1}^{n}|X(i,j)| \quad (3)$$

In Eq. (3), M and N are image dimensions, and X is the intensity of pixels. Finally, in feature extraction level, 11 features are extracted in total.

4.3. Classification

A three-layer perceptron, which is a feed-forward neural network, is used for classification. The function used in the hidden layer is a sigmoid function of stimulus, and the function used in the output layer is a linear function. The perceptron is trained using backpropagation. [1] The linear function is defined as

$$a=n \quad (4)$$

While the sigmoid function of stimulus is defined as

$$a=\frac{1}{1+e^{-n}} \quad (5)$$

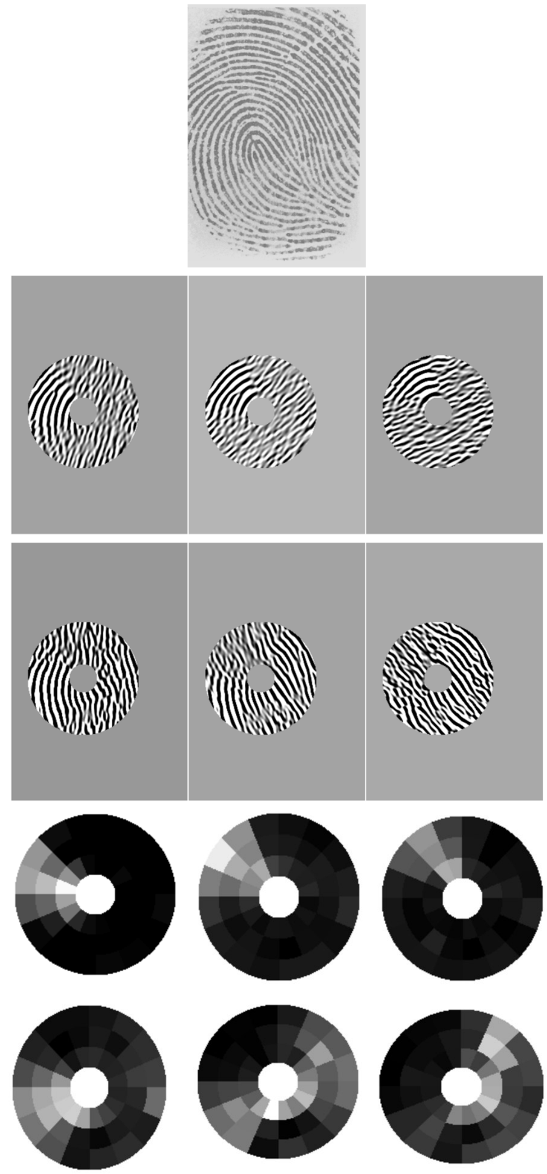

Fig. (2) Applying Gabor filters, and extracting features from filter outputs from the sectors around the center point [11]

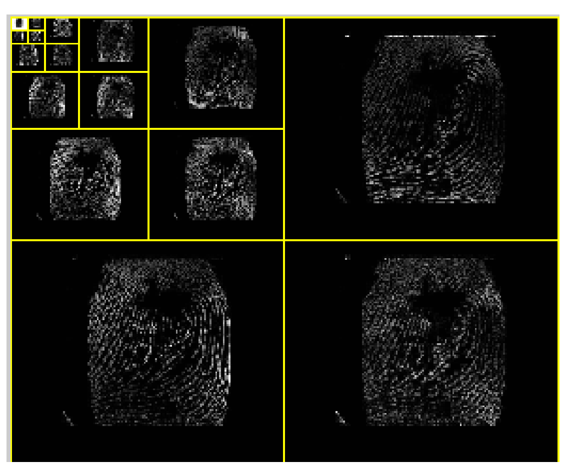

Fig. (3) Applying wavelet transform on a fingerprint image [2]

3.5. Assessment conditions

Performance metrics, including false acceptance rate (FAR), false rejection rate (FRR), and equal error rate (EER) are calculated in order to evaluate the performance of the proposed method.

$$FRR = \frac{\begin{array}{c} Number\ of\ rejected \\ genuine\ claims \end{array}}{\begin{array}{c} Total\ number\ of \\ genuine\ accesses \end{array}} \times 100 \quad (6)$$

$$FAR = \frac{\begin{array}{c} Number\ of\ accepted \\ imposter\ claims \end{array}}{\begin{array}{c} Total\ number\ of \\ imposter\ accesses \end{array}} \times 100 \quad (7)$$

Compared with FVC2000, and FVC2002 databases, FVC2004 has weaker set of images by focusing on low-quality images. Furthermore, compared to FVC2006, accessing FVC2004 is easier. Hence, the sub-database used in this study is FVC2004 DB2 [12]. Resolution of the images is of 512 DPI. It contains 800 fingerprint images (8 fingerprints from each person in a group of 100 people) in 256-levels grayscale. The images in DB3 are collected using thermal vacuum sensor. Its image dimensions are 300×480. It is worthy to be noted that all implementations are carried out by MATLAB.

4. Results

Low-quality fingerprint images are used as input are illustrated in Fig 4.

Fig. (4) Samples of low-quality fingerprint images in FVC2004.

4.1. Preprocessing

Having obtained fingerprint images, they need to be normalized in order that all images lie in the same acceptable range, and have the same intensity.

4.2. The orientation of ridges

An accurate estimation of the orientation of lines is an important task in processing fingerprint images. It helps in identifying ridge orientations, and connecting interrupted ridges. As shown in Fig. (5), ridge orientations are estimated by directional derivative.

Fig. (5) Estimating ridge orientations of fingerprint images.

4.3. Detaching images from the background and reconstructing lost ridges

Because Gabor filter extracts all minutiae of ridges or valleys from various angles, it is exploited for detaching fingerprints from their backgrounds. Results of Gabor filter application are shown in Fig. (6).

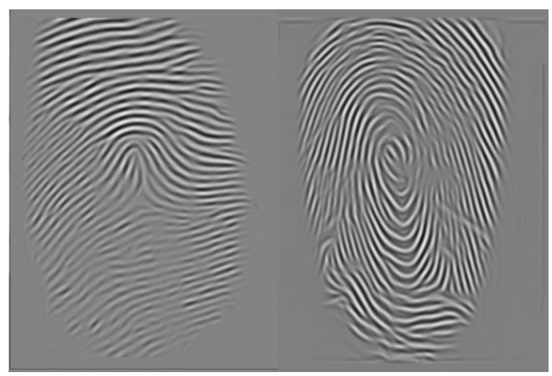

Fig. (6) Applying Gabor filter in order to prepare images for reconstruction

As shown in Fig. (6), the ridges are reconstructed efficiently. Thresholding method is exploited for creating binary images in order to prepare images for feature extraction using wavelet transform.

5. Results

Table 1 shows the results of finger print identificationon non-enhanced images, enhanced and when Gabor features are used, enhanced and when wavelet features are applied, and the proposed method.

Table (1) Results obtained from the proposed method on FVC2004 DB3 subdatabase.

Method	*Accuracy*	*FAR*	*FRR*	*EER*
Non-enhanced images	*89%*	*4%*	*20%*	*12%*
Enhanced, Gabor features	*91%*	*4%*	*12%*	*8%*
Enhanced, wavelet transform features	*73.5%*	*31%*	*22%*	*26.5%*
Enhanced, Gabor and wavelet features	*99%*	*1%*	*1%*	*1%*

Table (2) The comparison of the performance of the proposed method on FVC2004 DB3 with other methods

Method	Accuracy	EER
Two-level image enhancement [7]	97.6%	3.6%
Global TPS [9]	-	1.97%
Local TPS[9]	-	1.98%
Ridge frequency estimation and direct Gabor filter [8]	-	1.90%
Ridge frequency estimation and curved Gabor filter [8]	-	1.66%
The proposed method	99%	1%

As it is shown clearly, compared to other methods, the proposed method is more improved. Low-quality fingerprint images that have disconnected ridges are reconstructed using Gabor filter. Gabor filter is used for reconstruction since it extracts the minutiae of ridges and valleys from various angles. Moreover, its frequency and its selective orientation have favorable resolution in both spatial and frequency domains. Furthermore, if Gabor and wavelet features are used jointly they will produce better results than when they are used separately.

6. Conclusion and discussion

This paper proposed a new and effective hybrid approach for fingerprint recognition. Firstly, in order to enhance the accuracy of fingerprint recognition, the orientation of the ridges was determined using gradient. Since using an uncorrupted fingerprint image is crucial in identifying fingerprint features, disconnected ridges were reconstructed using Gabor filter. It reconstructed the fingerprint image effectively. Having enhanced the quality of the images, features were extracted using Gabor filter with the same frequency in 6 directions. Then, using pyramid-structured wavelet transform, 5 features were extracted. Finally, these 11 features were given to three-layer perceptron neural network for classification. FVC2004 DB3 was the sub database used in this experiment. The new approach was evaluated using performance metrics, including FAR, FRR, and EER. The accuracy, FAR, FRR, and EER were calculated as 99%, 1%, 1%, and 1%, respectively. Compared with some other studied approaches, the results from this proposed method were improved.

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