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Research Article

Fuzzy Fingerprint Recognition

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Abstract: In order to effectively carry out the fingerprint image recognition, this study proposes a fingerprint preprocessing algorithm and feature extraction technology. In the fingerprint image preprocessing, this study gives the location method of region of interest. In terms of feature extraction, this study extracts the decomposition energy features of fingerprint. In terms of matching recognition, this study presents a new recognition method for fingerprint and uses the method to carry out the matching and recognition of fingerprint. In the simulation, the presented fingerprint recognition method is compared with several existing major fingerprinting methods. The comparison results show that the proposed recognition method is more accurate and faster than some existing better recognition methods. Its recognition precision is higher, the recognition speed is faster and the anti-noise ability is stronger. These researches in this study on fingerprinting promote an improving of the accuracy and speed of recognition and provide a new way of thinking for target recognition, which has an important theoretical references and practical significance.

Keywords: Feature extraction, fingerprint recognition, image preprocessing, wavelet packet transforms

INTRODUCTION

At present, the fingerprint recognition technique had been applied to a lot of aspects in information society. Since the fingerprint has a fine uniqueness and stability, as well as a wealth of texture information, the fingerprint recognition technique had got a rapid development and been widely used in the field of information security by Nikou (2007), Fan *et al.* (2012) and Caldwell (2013). In recent years, the fingerprint recognition technique had been gradually used from police to civilian use, from special use to public use and becoming one of the frontier high-tech that the people concern about. Lin *et al*. (2011), Fan *et al*. (2012) and Zhang *et al*. (2013) usually used the biological anti-pseudo technology, currently, there are the fingerprint identity anti-pseudo recognition technique, iris identity anti-pseudo recognition technology and DNA goods anti-pseudo technique and so on. The fingerprint identity recognition was one of the oldest anti-pseudo techniques and it now combines with computer fingerprint identification to become an important means of identification and has been acquired a wide range of applications in many respects. For example, the security inspection of international travellers, supermarket shopping payment and so on, in various aspects of life and work, its industrialization is higher. In China, the fingerprint technology began entering a period of rapid growth since 2000.

Nanni and Lumini (2006), Lumini and Nanni (2008), Kızrak Ayyüce and Özen (2011), Fan *et al*. (2012), Jiang *et al*. (2012) and Zhang *et al*. (2013) gave some fingerprint recognition methods, however, without deeper research to some tiny fingerprints. Aditya and Stephanie (2009), Vatsa *et al*. (2011), Lin *et al*. (2011), Wang *et al*. (2012) Caldwell (2013) and Moros *et al*. (2013) introduced the application of identity recognition based on the comprehensive features of fingerprint and gave the experimental results. They proposed a recognition method in combination with the fingerprint shape and the texture feature of fingerprint. Lin *et al*. (2011), Wang *et al*. (2012) and Caldwell (2013) described systematically and comprehensively an idea of automatic recognition by using fingerprint, summarized comprehensively the characteristics of fingerprint veins and its direction of rotation and further studied fingerprint recognition technology. Based on high resolution fingerprint images, the identification could be carried out by using the point of interest of the fingerprint. Moros *et al*. (2013) utilized the machine learning method and laser-induced oscillation damaged spectroscopy method to extract some characteristic points from a fingerprint image of express service personnel and implemented the fingerprint recognition based on the location and direction of these points. Lin *et al*. (2011) proposed a pattern classification for fingerprint recognition by using the optical sensor measurement method and the

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fractal method based on measuring biology. Zhang *et al*. (2013) implemented the fingerprint identification by using feature fusion and pattern entropy method for fingerprint with incomplete information and formed a new fingerprint signature. However, these signatures did not contain the direction information of every point on fingerprint, which reduces their distinguishing performance. Additionally, some fruitful researches had been implemented by many universities and institutes in the world.

Among image segmentation algorithms presented by Xie *et al*. (2013), Zhou *et al*. (2013), Yu (2011), Edward *et al*. (2011) and Inyang and Akinyokun (2014), the Fuzzy C-Means clustering presented by Yu (2011) that was one of algorithms has some better features which can meet the human cognition pattern, be described concisely and clearly, be easy to implement and so on. However, this algorithm had some disadvantages such as its performance depends on the initial clustering center, poor antinoise capability and slow convergence and so on.

The fingerprint recognition method studied in this study is mainly composed of three parts, i.e., fingerprint image preprocessing, feature extraction, matching and recognition. The fingerprint image preprocessing is to carry out firstly a preprocessing for the acquired fingerprint image samples, which includes the image enhancement. In the stage of feature extraction, this study extracts the features of texture principal lines, papilla ridges and bifurcation points to fingerprint by using the given segmentation algorithm. At the same time, this study carries out the fingerprint decomposition to the preprocessed image based on the wavelet packet transform, extracts the energy features of fingerprint and constructs the characteristic vectors. In the stage of matching and recognition, this study calculates the distance between the characteristic vector of identified fingerprint and that of known fingerprint and estimates the similar degree between the two vectors by the distance. Finally, the comparison of the obtained similar degree and an experimental threshold value is given. According to the minimum distance, the recognition result can be obtained.

MATERIALS AND METHODS

In a gathered fingerprint image, besides the noise in the data of fingerprint and background, the translation and rotation of fingerprint when is gathered can influence the quality of image. All these factors do not make against the extraction and matching of fingerprint features. Therefore, some preprocessing such as segmentation, calibration and normalization must be implemented before the features extraction of fingerprint is carried out.

Feature preprocessing based on fingerprint pattern: This section gives two methods for extraction of Region Of Interest (ROI). The one method is:

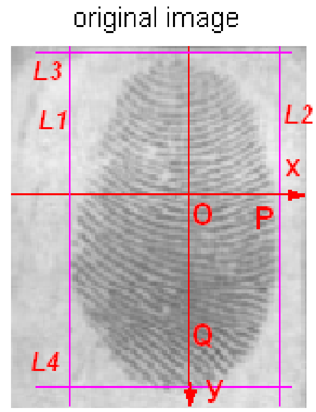

Fig. 1: Construction of a coordinate system

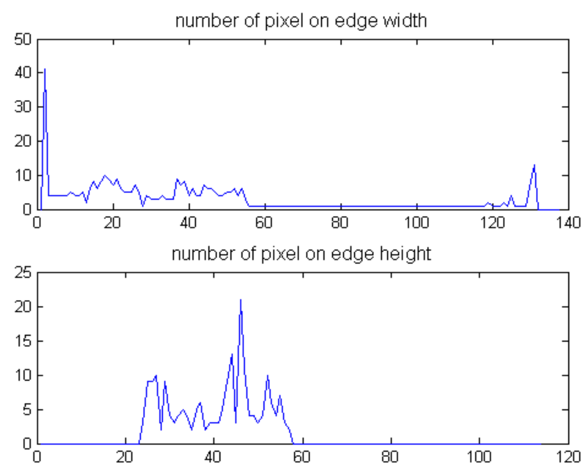

Fig. 2: Numbers of pixel on edge width and height

In the coordinate system shown in Fig. 1, how to divide up a fingerprint image and get the Region Of Interest (ROI) that contains the abundant information and simplicity of operation, this study gives a fast and convenient approach. That is to say, firstly, in the OP direction along x axis, searches a sharp growth value h_1 and a sharp reduction value h_2 in the gray-level mutation, then the left boundary l_1 and right boundary l_2 of ROI can be obtained. Secondly, in the OQ direction along y axis, searches a sharp growth value w_1 and a sharp reduction value w_2 in the gray-level mutation, then the upper boundary l_3 and lower boundary l_4 of ROI are obtained. Where, the sharp growth and sharp reduction in the gray-level have something to do with the amount of pixel of edge width and edge height of fingerprint, as well as the position of edge of fingerprint, i.e., the mutation case of gray-level is decided by the two factors. The numbers of pixel on edge width and edge height are shown in Fig. 2.

The other method is: search the change of gray value along the pixel width direction or the pixel height direction. When a gray value turns into a sharp growth value and a sharp reduction value, at the time, record

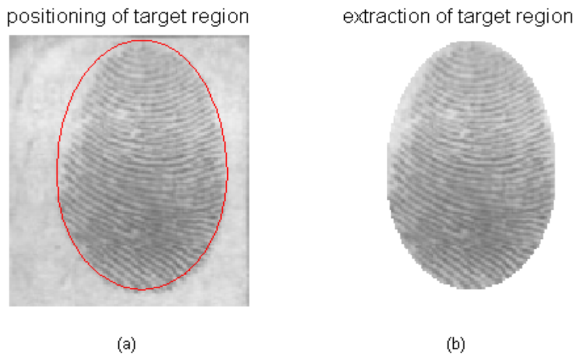

Fig. 3: Positioning and extraction of target region

the positions $P_1, P_2, \cdots, P_n$ where the pixels locate in. Connect these points $P_1P_2 \cdots P_n$. A target region with rich information is formed by these points $P_1P_2 \cdots P_n$ (Fig. 3a). The area of image falling within this region is extracted as the ROI (Fig. 3b). The ROI obtained in this way has eliminated the influence of noise, rotation, translation and so on. Experiment proved that the ROI extracted in this way is more beneficial to the subsequent feature extraction of fingerprint.

The area of ROI obtained by using this segmentation algorithm is bigger, which almost completely contains the grain ridges line of a fingerprint, its pattern, bifurcation point end point, etc., as well as has a clearer papillary ridge. Therefore, the accuracy of the subsequent feature extraction and feature matching is improved. The difficulty of this algorithm is that it requires a high level acquisition device to obtain the high quality fingerprint images and needs to build an image database that contains a large number of high quality fingerprints, so as to carry out some experiments.

In addition, the proposed extraction algorithm based on the gray-level mutation is compared with existing extraction algorithms for fingerprint (Fig. 4). It can be seen from Fig. 4, the extraction effect of the proposed extraction algorithm for fingerprints is better than that of other existing extraction algorithms, because it almost eliminates the background, reduces the noise and almost completely contains all the information on the fingerprint.

From experimental results and Fig. 4, if the proposed extraction algorithm is combined with an existing classical extraction algorithm, the extraction effect to fingerprint is better. The combinative result between the old and new algorithms is shown in Fig. 5.

The algorithm in Fig. 5a is easy to lose some information of target and especially at a breakpoint in

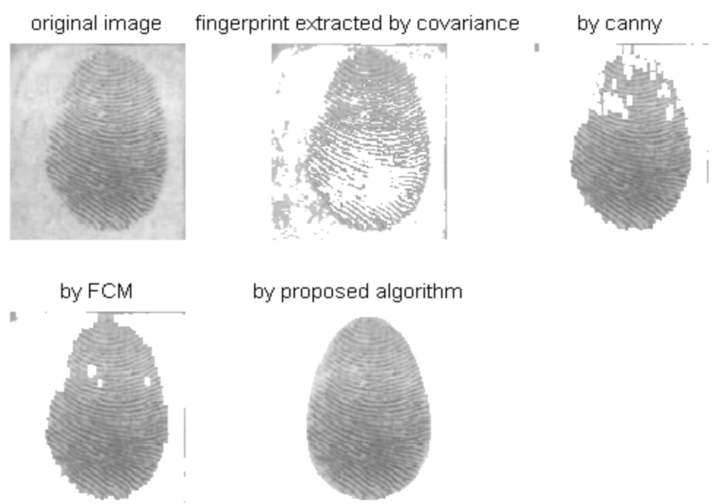

Fig. 4: Comparison of fingerprint extraction

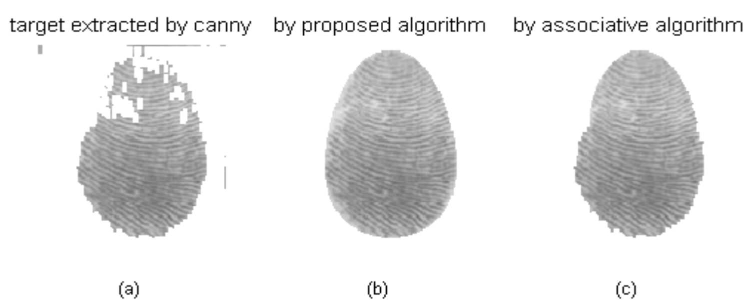

Fig. 5: Target extracted by combination of the proposed algorithm with canny algorithm

texture. The algorithm in Fig. 5b is easy to contain some redundant information of target and this unnecessary information divided into ROI is easy to disorder the extraction of valid information. Figure 5c is the combination of two previous algorithms, avoids the shortcomings of the two former, makes the extracted target be closest to the original image information, so it is an ideal algorithm, which provides a good basis for the subsequent target feature extraction.

Extraction of characteristic points of fingerprint: The processing algorithms discussed in the previous section mainly process the general fingerprint images acquired by ordinary camera. The resolution of these images is mostly low, so it can be not well adapt to the high-speed development requirements of science and technology. With the development of fingerprint recognition technology, the fingerprint capturing device will be designed to be able to obtain a high resolution, high quality fingerprint image with clear details. In response to this trend, an extraction algorithm of fingerprint in Region Of Interest (ROI) will be proposed to be suitable for high resolution images and make full use of the geometrical characteristics of the papillary lines on fingerprint, which will be discussed in detail as follows.

There are also widespread papillary ridges on a finger. Through a large number of observations, the papillary ridges on the fingers have certain regularity in some specific regions. To take the endpoint and the intersection point as an example, the feature point detection and extraction are discussed. From their geometrical features attribute, they are the points that have high curvature, so Susan operator can perform well to detect and extract them, but Susan operator can't distinguish one point is an end-point or an intersection on earth. We perform further work on the basis of Susan corner operator, i.e., give an improved Susan corner operator as follows:

Based on the Susan algorithm has detected out the corner points but is unable to distinguish the edge points, we take these points as the center of a circle O to do a group of concentric circle rings. We inspect a circle along clockwise direction on the circle rings in order to know the times of change of gray level. If the times of change of gray level are more than twice, then the above corner points or edge points are called the intersection. We carry out the algorithm in detail as follows:

If the gray value of the pixels is the same or similar as that of the center of a circle O in neighborhood of the point O, then we label the pixels as '1' and mark the other pixels as '0'. We inspect the pixel distribution things for any circle along the clockwise direction or anti-clockwise direction from the beginning of a certain point on the circle ring. We count the change times of gray value of pixels from '1' to '0' or from '0' to '1'. If the times of change of gray value are just right twice, the point O is called an end-point. However, the times of change of gray value are more than twice, the point O is called an intersection point.

Detection of characteristic points: The texture of fingerprint image is clear through processing by the above step, so it is easy to better implement the detection of characteristic points and tracking to them. According to the gray level jump algorithm given in the above, it can not only achieve the image edge detection, but also can detect a corner point, endpoint, bifurcation points, etc. The detection to corner points based on the gray level jump algorithm is shown in Fig. 6.

The characteristic points are the endpoints, corner points, bifurcation points, etc., which the papillary ridges form on the fingerprint. The type of corner points detected by the gray level jump algorithm is various, so it requires filtering the detected corner points. Select a enough small radius r and then take the corner points as the center of circle to draw a circle. We detect the times of change of gray level along this circle. If there are three sharp growth values or sharp reduction values of gray level jump at a certain point, the point is a characteristic point.

Feature extraction of fingerprint: The feature extraction of fingerprint is carried out by wavelet transform in here. Choose a function $\psi(\overset{\mathbf{1}}{t})$ to construct $\psi_{\vec{j},\vec{k}}(\vec{t}) = 2^{\vec{j}/2}\psi(2^{\vec{j}}\vec{t} - \vec{k})$ and make it do inner product with image $p(x,y)$, i.e., $\left\langle \psi_{\vec{j},\vec{k}}(\vec{t}), p(x,y) \right\rangle$, which can carry out some processing for a fingerprint image such as smoothing, denoising, enhancing, compressing and so on. Where, $\vec{t} = (x,y)$, $\vec{j} = (j_1, j_2)$, $\vec{k} = (k_1, k_2)$.

Make it process the image p(x, y), then the concrete algorithm is $W_{\vec{j},\vec{k}} = \left\langle \psi_{\vec{j},\vec{k}}(\vec{t}), p(x,y) \right\rangle$, which can carry out a decomposition and extraction of energy coefficient features of image $p(x,y)$. For a region of texture with rich features, it shows that the energy is denser, the difference in amplitude is little and the distribution of energy is regular as the decomposition levels increase. For a region with sparse texture, the energy takes on the form of jumping, sparse rendering as the decomposition levels increase.

From the decomposition calculation of wavelet known, the *i*th level energy feature of ripple is calculated by the *i*th level decomposition coefficient of wavelet, which shows the texture feature of a fingerprint image in the 2^{-i} scale, in different directions and different positions.

In order to further carry out the subdivision to the decomposed frequency band, that is, to further carry out the localization of time-frequency, the definition of wavelet packet is introduced.

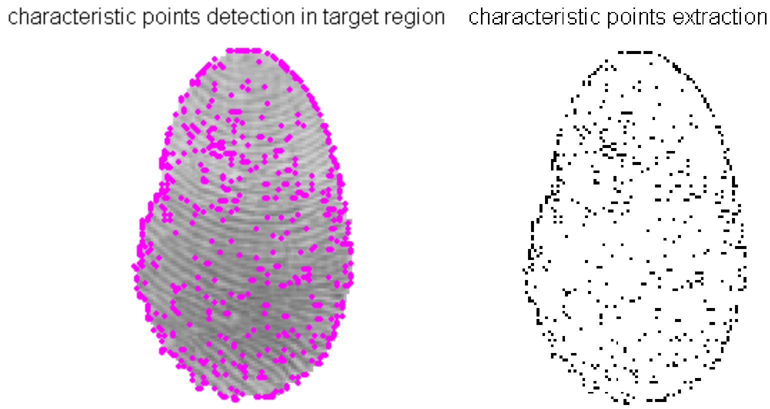

Fig. 6: Detection and extraction to corner points based on the algorithm of gray level jump

The energy feature can be calculated by using the decomposition results of wavelet packet to image. According to the algorithm described in this study, the energy of image decomposed by wavelet packet is defined as follows:

$$E_{(i,j)} = \sum_{x=1}^{n\times 2^{-i}} \sum_{y=1}^{m\times 2^{-i}} [H_{(i,j)}(x,y)]^2 \quad (1)$$

where, $E_{(i,j)}$ is the energy of image at each node and (i, j) denotes different nodes in a quad-tree of wavelet packet decomposition. Under the 2-level wavelet packet decomposition, there are $i \in \{0,1,2\}$ and $j \in \{0,1,2,\cdots,15\}$. $H_{(i,j)}(x,y)$ is the energy of detailed image on each node. m and n are the height and width of the image, respectively. To extract the energy of detailed image on each layer, the energy feature of the image decomposed by the wavelet packet can be established as follows:

$$E_i = \left(E_{(i,0)}, E_{(i,1)}, E_{(i,2)}, \cdots, E_{\left(i,2^{2i}-1\right)} \right) \quad (2)$$

Therefore, the E_i is called the energy feature of image decomposition at the i th layer. It is normalized as follows:

$$E_j = \frac{E_{(i,j)}}{\sum_{x=1}^{n} \sum_{y=1}^{m} \left[H_{(0,0)}(x,y) \right]^2} \quad (3)$$

where, $j \in \{0,1,2,\cdots,2^{2i}-1\}$. The further simplification can be obtained:

$$E_i = \left(E_0, E_1, E_2, \cdots, E_{2^{2i}-1} \right) \quad (4)$$

Matching and recognition method: Based on the above method to feature extraction, different samples of fingerprint are trained and learnt and the energy characteristic vectors in different level can be acquired. Use these characteristic vectors as a standard template is stored in the system. We compare the characteristic vectors of unknown fingerprint image with the characteristic vectors of known classificatory fingerprint image that has been trained and stored in the retrieval system. Based on the minimum difference principle, if and only if the difference value between the characteristic vector of unknown fingerprint image and that of given i_0 th fingerprint image is minimal, we judge that the unknown fingerprint belongs to the i_0 th category. The feature matching of fingerprint is to judge whether two fingerprint images are from the same one fingerprint. If the matched result is positive, the system will output the information of the fingerprint. If the matched result is negative, the system continues to match with other standard templates. Therefore, the identification can be achieved. The matching algorithm is given as follows:

If W_l is the known characteristic vector in the retrieval system, V is the characteristic vector to be identified. Where l = 1, 2, …, Q and Q is the number of known characteristic vectors. The following distance is defined to estimate the difference between the energy characteristic vectors V and W_l of two wrinkles:

$$d_l = \|V - W_l\| = \sum_{i=1}^{n} |V_i - W_{li}| \quad (5)$$

where, $|V_i - W_{li}| = \frac{1}{2^{2i}} \sum_{j=0}^{2^{2i}-1} \left| c_{ij}^{V_i} - c_{ij}^{W_{li}} \right|$ represents the difference between the characteristic vectors of coefficient for image, or $|V_i - W_{li}| = \frac{1}{2^{2i}} \sum_{j=0}^{2^{2i}-1} \left| E_{ij}^{V_i} - E_{ij}^{W_{li}} \right|$ is the difference between the characteristic vectors of energy of the image decomposed by wavelet packet. $c_{ij}^{V_i} \in V_i$, $c_{ij}^{W_{li}} \in W_{li}$, $E_{ij}^{V_i} \in E_i^{V_i}$, $E_{ij}^{W_{li}} \in E_i^{W_{li}}$, i is the number of layers of the wavelet packet to the image decomposition. The recognition principle is described as follows:

Here we use the minimum distance principle to judge the category of the target to be identified. This recognition approach is as follows:

If $\exists l_0 \in \{1, 2, \cdots, Q\}$, satisfy:

$$l_0 = \arg \min_{l \in \{1,2,\cdots,Q\}} \{d_l\} \tag{6}$$

Then based on the minimum distance principle, we judge that the target to be identified belongs to the l_0 th category, that is, the fingerprint is judged which standard template categories it belongs to.

In the recognition process, it needs to search for all the samples in the database, so as to find the sample which it and the identified fingerprint image are from the same fingerprint and then the fingerprint recognition is achieved. In order to improve the accuracy and efficiency of recognition, the hierarchical recognition method is introduced for searching. After preprocessing and feature extraction to each fingerprint image, the fingerprint image is determined by two kinds of characteristics. Firstly, the database is searched by the feature of image decomposition coefficient for the first time and then the candidate set that consists of the fingerprint images of similar features of coefficient is obtained. Then, in the candidate set, the second search is carried out by using the energy feature of image decomposition achieved by wavelet packet and then the final recognition results are obtained. In the recognition process, we use the feature of image decomposition coefficient to search for the first time is because of its computational complexity is relatively small, which increases the speed of recognition. To implement the search for the second time to the candidate set, because the number of samples in candidate set is less than that of in the database, similarly, the overall recognition efficiency is also improved.

RESULTS AND DISCUSSION

The main fingerprint used here is from the fingerprint database of a biometric identification research center, which is constructed by a certain image institute. The experimental basic steps are given as follows:

P1: 100 different fingers are chosen from fingerprint Database and each fingerprint is chosen from 6 fingerprint images sampled in different time.

P2: The first group images are carried out a preprocessing and feature extraction by 3-level Haar wavelet packet decomposition. The 100 energy characteristic vectors E_i of 3-level wavelet packet decomposition to image are acquired, respectively, which are archived as training samples.

P3: The second group images are used as the test samples to be identified. The random selections and matching recognitions in 500 times are implemented based on the recognition principle. The final recognition results are obtained.

P4: For each image in the test sample database, after 500 times recognition are done according to the step P3, the times of the correct recognition and error recognition are recorded respectively and the correct recognition rates are obtained by calculating.

For each fingerprint image, 10 times repeating experiments are carried out from the step P1 to step P4 based on Haar wavelet basis function in simulation. The number of samples is different in each experiment. The proposed hierarchical recognition method compares with those currently better fingerprint recognition methods such as feature fusion and pattern entropy proposed by Zhang *et al*. (2013), LDSSs proposed by Jiang *et al*. (2012) and system method with eight-neighbours deviation proposed by Nanni and Lumini (2006). Based on the tests, as the number of samples increases, the correct recognition rate of a certain number of samples is obtained by statistics for each certain quantitative sample in the same time step and further the average correct recognition rate of different quantitative samples is calculated within the sampling period. The average correct recognition rates of these methods are 97.95, 96.94, 95.97, 95.00%, respectively in simulation of 500 times, respectively. The simulation results are shown in Fig. 7.

From Fig. 7 concluded, the average correct recognition rate of the proposed recognition method based on the image preprocessing and feature extraction is the highest among all referred methods. In experiment, the average correct recognition rate increases constantly with the increasing recognition samples and the curve of average correct recognition rate gradually levels off as the samples increase when the number of samples reaches a certain value. On the basis of the simulation results, the recognition method based on image preprocessing and feature extraction not only has the faster processing speed, the lower memory capacity and communications traffic, but also has better recognition effect.

CONCLUSION

Firstly, this study analyzes the features of a fingerprint image such as wrinkles, pattern, papillary ridges of tiny lines, endpoint, intersection points, bifurcation points and so on. Then, this study presents a fingerprint preprocessing algorithm and a segmentation algorithm of ROI based on the edge contour of fingerprint, gives the feature extraction algorithm of ROI, as well as feature extraction of coefficient and energy based on wavelet packet decomposition to

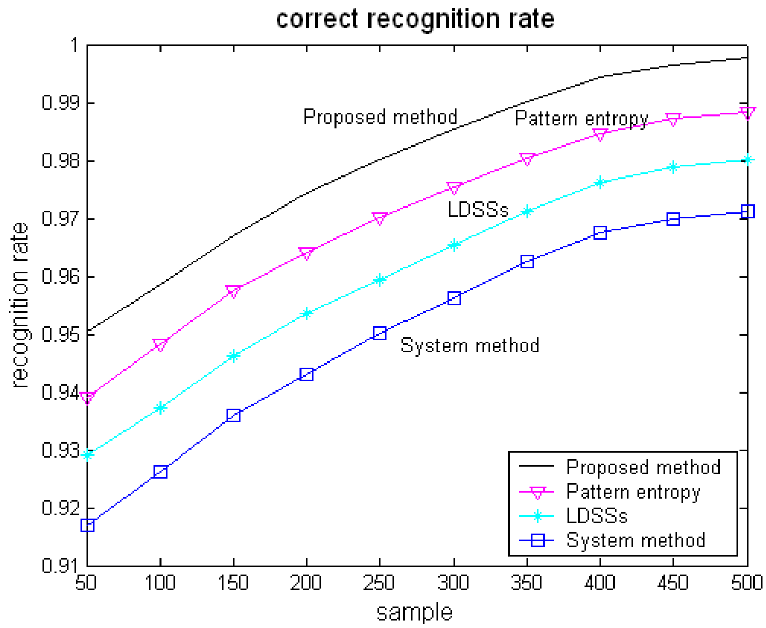

Fig. 7: Comparison of correct recognition rate for the proposed and other methods

image. Moreover, this study gives the matching and recognition method of fingerprint image and carries out the simulation test. Finally, the simulation results prove the feasibility and effectiveness of all proposed algorithms or methods in each stage.

How to choose or construct a proper wavelet packet basis function, how many levels of decomposition can be carried out to obtain the best recognition effect and how to combine fingerprint and its feature to achieve a better and faster distinguishing effect, are some questions which need further study in the future.

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