Fast Fingerprint Matching Based on the Novel Structure Combining the Singular Point with Its Neighborhood Minutiae*

Peng Shi[1,2,3], Jie Tian[1,2,3,**], Weihua Xie[1,2,3], and Xin Yang[1,2]

[1] Center for Biometrics and Security Research
[2] Key Laboratory of Complex Systems and Intelligence Science, Institute of Automation, Chinese Academy of Sciences
[3] Graduate School of Chinese Academy of Sciences, P.O. Box2728, Beijing 100080, China
tian@doctor.com, jie.tian@ia.ac.cn
http://www.fingerpass.net

Abstract. It is a very demanding task to design a reliable fingerprint matching approach with high accuracy and speed. An algorithm based on the novel structure combining the singular point with its neighborhood minutiae proposed in this paper can solve this problem efficiently. The structure introduced in this paper has two novel ideas as follows: First, we give an efficient singular points detection method by the inter-relationship between the singular points and the minutiae around them. It can reject the spurious singular points detected by the Poincare index. Second, an improvement of minutiae pairing strategy is introduced, which can sharply decrease the number of candidate minutiae pairs. Experiment results show that these improvements can highly speed up the matching with a preferable accuracy. This algorithm can be used in the one-to-many matching of the on-line fingerprint identification system.

Keywords: Fingerprint; Matching; Singular Point; Minutiae Pairing.

1 Introduction

Fingerprint is one of the most widely used features in biometric identification. The most crucial technology in the Automated Fingerprint Identification System (AFIS) is the matching method. A big challenge to the matching method is to reduce the matching error and to improve the matching speed. The features used in the matching process can be basically divided into two types: the global features and the local features. The most widely used global features in fingerprint recognition are the

* This paper is supported by the Project of National Science Fund for Distinguished Young Scholars of China under Grant No. 60225008, the Key Project of National Natural Science Foundation of China under Grant No. 60332010 and 60575007, the Project for Young Scientists' Fund of National Natural Science Foundation of China under Grant No.60303022, and the Project of Natural Science Foundation of Beijing under Grant No.4052026.
** Corresponding author. Tel.: 8610-82618465; Fax: 8610-62527995.

J.F. Martínez-Trinidad et al. (Eds.): CIARP 2006, LNCS 4225, pp. 804 – 813, 2006.

orientation field and the singular points, including cores and deltas, while the local features are mostly minutiae, such as the ridge endings and bifurcations.

For seeking a high accuracy, many matching algorithms use minutiae as the main features because that the local structure is more stable. Nandakumar and Jain used local correlation of minutiae to ascertain the quality of fingerprint image [1]. Jiang and Yau used the minutiae matching based on the local structure and global structure respectively [2]. And a fingerprint matching using the minutiae triangulation is provided by Parziale and Niel in [3]. The stability of triangle structure is efficient in avoiding the non-linear deformations of the fingerprint image. But at the same time, the traditional minutiae-based method encounters some difficulties in the matching process.

1. The minutiae extraction process could be difficult if the input image has a very low quality. The lost of true minutiae and the extraction of spurious minutiae caused by the low quality image would heavily affect on the following matching process. It will directly cause the matching failure.

2. The arrangement of all minutiae in a fingerprint is a time consuming process. Usually there are 30-60 minutiae in a fingerprint, if we construct local structures for all minutiae, the template size will be very large, and the large template will decrease the system's efficiency.

As a result, the matching method only using the minutiae cannot perform the one-to-many matching efficiently. Though many state-of-art AFIS have good performance on small databases, it is not satisfactory for large-scale applications. A fast and reliable matching strategy is necessary for the fingerprint identification system.

As global features, singular points are used as important features in fingerprint recognition, mostly in the classification. By the relative position of the singular points, a fingerprint database can be primarily classified under the Henry classification scheme as NIST4 fingerprint database [4]. Jain et al. used a multi-channel approach to fingerprint classification including the singular points [5]. The correlation between singular points was also used in indexing the fingerprint in Liu et al.'s paper [6]. But the singular points were seldom used in the matching process. The main reason is that is difficult to detect all the genuine singular points and reject the spurious ones. In order to do matching efficiently, one of the singular points can be chosen as the reference point to accelerate the matching speed as part of the matching structure.

In this paper, we provide a matching algorithm based on the novel structure combining the singular point with its neighborhood minutiae, which gives attention to both efficiency and accuracy. The paper is organized as follows: In Section 2, a new method based on the relationship between singular points and their neighborhood minutiae is used in the singular point detection. The matching process using the novel structure is illuminated in Section 3. Experimental results are presented in Section 4. Finally, we finish with conclusions and future directions in Section 5.

2 Singular Point Detection

After pre-processing of the input image, the orientation field is calculated by the method described in [7]. There have been several approaches for the detection of singular points on the orientation field map. The most popular method is the one proposed by Kawagoe and Tojo [8] and is based on the Poincare index. For these algorithms, a point in the orientation field is classified as a singular point if along a closed curve around that point the orientation changes $\pm 180^{o}$, but it heavily depends on the quality of the input image. The noise of the input image always causes spurious singular points detection by Poincare index. And the impact of singular points detection on matching is discussed by Chikkerur and Ratha in [9]. It is proved that the singular point detection will be not reliable if only based on the traditional Poincare index. In this paper, we define the novel structure including the singular points and their neighborhood minutiae. By computing the inter-relationship of them, we can detect the spurious singular points efficiently and give a reliable reference point to the following matching process.

2.1 Defining the Singular Point Area

In a fingerprint image, the singular points detection algorithm is described below.

1. Estimate and smooth the directional fields of the input fingerprint image;
2. In each block (8×8), we compute the Poincare index. The Poincare index is defined and computed as follows:

$$Poincare(i, j) = \frac{1}{2\pi} \sum_{k=0}^{N-1} \Delta(k) \tag{1}$$

$$\Delta(k) = \begin{cases} \delta(k), if \; |\delta(k)| < \pi / 2 \\ \pi + \delta(k), if \; \delta(k) < -\pi / 2 \\ \pi - \delta(k), otherwise \end{cases} \tag{2}$$

$$\begin{aligned} &\delta(k) = \theta(X(k^{'}), Y(k^{'})) - \theta(X(k), Y(k)) \\ &k^{'} = (k+1) \bmod N \end{aligned} \tag{3}$$

where θ is the orientation field, $X(k^{'})$ and $Y(k^{'})$ denote coordinates of the k^{th} point on the arc length parameterized closed cure. We consider as singular point candidates those pixels whose Poincare index calculated from Eq. (1) exactly equals to $\pm 1/2$.

2.2 Spurious Singular Points Detection and Reference Point Selection

After computing the Poincare index of the orientation field of the input image, several singular points may be detected as candidate points, including the genuine and some spurious singular points. Certainly, if the input fingerprint belongs to the arch class, or its singular point was missed in the fingerprint collection, there is no singular point can be detected. So we will still use all minutiae to form local structures for matching. In fact, the arch class contains a very small portion of 3.7% in nature [10], it will affect very little on the matching performance of the whole database. With little affect of no singular point in the image, we continue matching with our novel algorithm.

(a) (b) (c)

Fig. 1. The spurious singular points detection using their neighborhood minutiae. (a) illustrates the singular points detected by Poincare Index. The minutiae are marked in (b), and (c) is the sketch map of structure in the detection of spurious singular point, which takes the singular point S_i as the centre. The red points P are minutiae around the singular point.

Wu and Zhou presented a model-based spurious singular points detection method in [11]. But these model-based approaches need much orientation field calculation and are time consuming. As illustrated in Fig. 1, we can see that the spurious singular points always occurs in the borders of the foreground region, where there are little other local features can be detected. We use the inter-relationship of singular points and there neighborhood minutiae to detect the spurious singular points as follows:

1. As shown in Fig. 2, at the same time of singular point detection, we get all the minutiae of the fingerprint image by the minutiae extraction process.

2. Defining each of the singular point S_i ($i \geq 1$) as the centre, several circles can be drawn with the equal radius of r pixels, which is shown in Fig. 1. In this process, r is defined by an experimental value as 14.

$$\left| P_i - S_i \right| \leq r \tag{4}$$

3. Computing the number of minutiae M_i and the average distance d_i between each minutia with the centered singular point of each circle. As the Eq. (6), the singular point which has the smallest d_i and a reasonable number M_i ($M_i \geq 2$) can be defined as the reference point.

$$d_i = \frac{1}{M_i} \sum_{j=1}^{M_i} d_j \tag{5}$$

$$R = \min(d_i) \tag{6}$$

After these processes, we acquire the most reliable singular point of the fingerprint. According to the experiment results, this reference point is often the core point and the centre area of the image, where most minutiae occur. Therefore, it is a perfect feature for the fast matching.

3 Fingerprint Matching

Matching is the key step of fingerprint recognition. Many approaches were taken to improve the speed and accuracy of matching process. In Wang and Rong's algorithm, they mainly abandoned the global features and controlled the number of evolutionary species [12]. Ratha et al. employed an elastic matching algorithm to keep the matching accuracy [13]. In this paper, we get the reference point after the singular points detection. In order to keep the matching accuracy with a smaller template and a higher speed, the novel structure combining the global feature and the local features is constructed for the matching step. The algorithm's process using the combined template of singular point with minutiae is illustrated in Fig. 2.

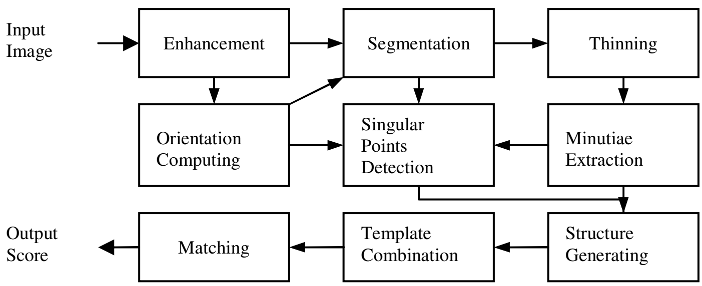

Fig. 2. The algorithm's process based on the novel structure combining the singular point with its neighborhood minutiae

In the matching process, we firstly give the definition of the novel structure, which contains the reference point and the minutiae around it. Then, many minutiae pairs are generated under defined rules in the structure. Finally, we complete the matching process by comparing the matching pair vectors and calculating the matching score.

3.1 Definition of Novel Structure

In the traditional core-based matching algorithms, the information of the singular points doesn't participate in the matching process for two reasons as follows: First, the singular points detected often vary in position and type. It is difficult to choose the most suitable singular point as the reference point. Second, the uncertainty of singular points can decrease the performance of the algorithm. In Section 2, the reference point choosing problem has been solved. Further, to improve the performance of matching, a novel structure is defined combining the reference point and the minutiae around it.

$$\overline{P_i} = \left[(x, y), \theta, ZOD \right] \tag{7}$$

The equation above is the traditional definition of minutiae, where (x, y) is the position, θ is the orientation and ZOD is the orientation field information of the minutiae. In our algorithm, the new definition of minutiae also contains the information of the reference point as follows, which can be seen in Eq. (8) as $\overline{P_i'}$.

$$\overline{P_i'} = \left[(x, y), \theta, \ell, ZOD \right] \tag{8}$$

$$\ell = \frac{|P_i - R|}{r} \tag{9}$$

where ℓ is the level which P_i belongs to. As illustrated in Fig. 3, defining the reference point R as the centre, we draw several circles around R with the radii kr ($1 \le k \le 15$), where r is the pre-defined radius 14 pixels, the same as r in the singular points detection process. Then, we can divide the neighborhood area around R into k levels. Minutiae belonging to the k^{th} level have the parameter ℓ equals to k . If there is no singular point in the input image, ℓ is defined as 0.

Each ℓ is wide enough to avoid excursion of the reference point in fingerprint image. On the other hand, since ℓ classifies different minutiae, it will speed up the searching process of the matching minutiae.

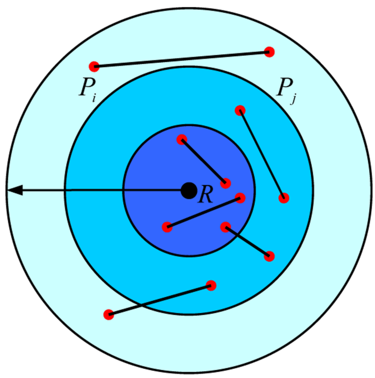

Fig. 3. Sample of the novel structure for matching. Every circle takes the reference point as the centre, and the radius is kr . Different color denotes different level ℓ around the reference points. The red points such as P_i and P_j are minutiae and the thin lines denote minutiae pairs defined in our algorithm.

3.2 Minutiae Pairing

The traditional minutia-to-minutia matching algorithm is heavily affected by the low quality and the distortion of fingerprint image, so it is necessary to use a kind of minutiae combination to perform matching. It can both reduce the affect of noise and distortion to matching and increase the matching speed. But many minutiae pairing strategy such as [14] encounter a problem that too many minutiae pairs will cause a large template and a low speed. In this paper, we use the minutiae pair to do matching. It can cut down the size of the template and increase matching speed with little accuracy losing, and it is suitable to the one-to-many matching system.

In the fingerprint matching algorithm based on the minutiae pairs, the number of minutiae pairs will affect the performance heavily. The theoretical number of the matching pairs is calculated as:

$$Num = M(M-1) \times N(N-1)/4 \tag{10}$$

where M is the number of input minutiae and N is the number of matching minutiae. In this case, many false matching pairs waste a lot of searching time. In our fast matching algorithm, the level of minutiae is used in matching as the a rule of matching minutiae pairs' selection.

If P_i and P_j are the minutiae of input minutiae set, Q_i and Q_j are the minutiae of template minutiae set. The minutiae pair $\overline{p_i p_j}$ and $\overline{q_i q_j}$ will be selected as the possible matching pairs as:

$$\begin{cases} \overline{p_i p_j} \mid \ell^i_p - \ell^j_p \le 1 \\ \overline{q_i q_j} \mid \ell^i_q - \ell^j_q \le 1 \end{cases} \tag{11}$$

where ℓ^i_p, ℓ^j_p, ℓ^i_q and ℓ^j_q are the levels which the minutiae P_i, P_j, Q_i and Q_j belong to. Because the minutiae are pre-classified by the level ℓ, the number of possible minutiae pairs will be rapidly decreased. And the searching process for the matching minutiae pairs will be highly speeded up.

3.3 Matching by the Novel Structure

Since the candidate minutiae pairs are selected, the matching process can be done favourably. An improved method using alignment-based matching [2] is provided in our algorithm, where the fingerprint minutiae information is like the following structure. The fingerprint minutiae matching process includes 4 steps as follows:

1. Getting the minutiae vectors as $\overline{P_i}$. All minutiae vectors represent the unique fingerprint. Since these vector structures only contain the local information, so the set of these fingerprint minutiae possesses excellent differentiability.

2. In the first match, we use the fingerprint minutiae vector to get the matching pairs like the following structure.

$$Fl_k = (d_{ki}, d_{kj}, \theta_{ki}, \theta_{kj}, Z_{ki}, Z_{kj}, n_{ki}, n_{kj}, t_k, t_i, t_j)^T \tag{12}$$

The structure was generated as a kind of multi-dimensional vector, where d_{ki}, d_{kj} is the distance between the minutia k and minutia i, j; z_{ki}, z_{kj} is the minutiae orientation difference between k and i, j; θ_{ki}, θ_{kj} is the angle between $\overrightarrow{k_i}$, $\overrightarrow{k_j}$; and φ_k, n_{ki}, n_{kj} is the number of crossed ridge line respectively.

3. Using $Fl_k^{'}$ as the template to match the structure Fl_k with $Fl_k^{'}$. Through the process, two matching arrays can be obtained, one records the power of the position shift, another posts the power of angle deviation. The shifting parameter and rotation parameter are calculated by the two arrays.

4. After getting the shifting and rotation parameters, we translate the template minutiae set into the aligned minutiae set through the global shifting and rotation translation. Since the aligned minutiae set is very close to the inputting minutiae set, the second match only compares the position of corresponding minutiae and gets the matching score.

4 Experimental Results

The experiments reported in this paper have been conducted on the public domain collection of fingerprint images. Both DB1 in FVC2002 and FVC2004 [15] are selected to be computed the matching performance of our algorithm. Each database is 100 fingers wide and 8 impressions per finger deep (800 fingerprint in all). The image size of DB1 in FVC2002 is 388×374 pixels, and that of DB1 in FVC2004 is 640×480 pixels with much lower quality. They both have the resolution of 500 dpi.

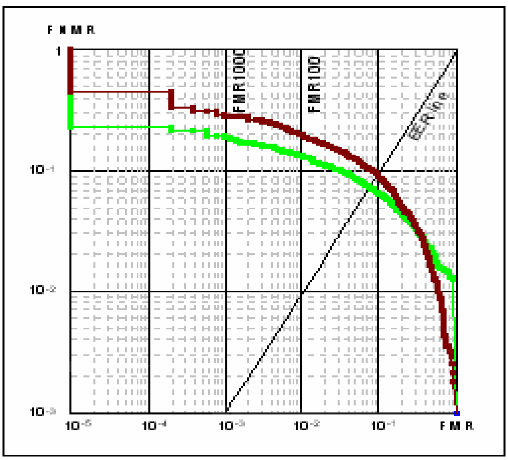

Fig. 4. ROC-curves of experiments on DB1 in FVC2004. The red line denotes the performance of our algorithm based on the novel structure, the green line denote that of the algorithm based on the traditional matching strategy of minutiae pairing.

We employed a set of experiments in order to validate our algorithm. Both the accuracy and speed were considered in the matching experiments. Firstly, we employed an experiment of our algorithm with novel structure on DB1 in FVC2002. There were 2800 genuine matches and 4950 imposter matches executed in the experiment under the test protocol of FVC. The Equal Error Rate (EER) was 1.64%. This proves that our algorithm can have a good performance on the public database. Secondly, under the same protocol on DB1 in FVC2004, we employed two experiments of algorithm with novel structure and without the novel structure to validate our algorithm. The Receiver Operating Characteristic (ROC) curves obtained by the two algorithms are illustrated in Fig. 4.

The average template size is 0.8 KB in experiment with the novel structure, and we employed the experiments on CPU of 2.8GHz, 512MB RAM. The average match time was 0.001 second in the experiments, and it was far less than the time consuming of most of the algorithms. Because the tests of FVC2004 were performed on CPU of 1.4GHz, the time consuming of P068 was divided by 2 as shown in Table 1. P068 is the algorithm in FVC2004 on DB1 which obtain the 10th place ranked by EER.

Table 1. Comparison of our algorithm with P068 in light category on DB1 in FVC2004. Each time consuming is supposed on CPU of 2.8GHz.

Algorithm	EER	Average enroll time	Average match time	Average model size
Our algorithm with novel structure	9.25%	0.031s	0.001s	0.8KB
Our algorithm without novel structure	7.31%	0.221s	0.034s	1.0KB
P068	9.92%	0.080s	0.090s	2.0KB

From Table 1. we can see that our algorithm has a considerable improvement on the time consuming of matching, and the rank of EER is also in the first 10 place in FVC2004. The least average match time of DB1 in FVC2004 is 0.035 second (supposed on CPU of 2.8GHz), far more than that of our algorithm. The template size is also reduced by using the novel structure as shown in Table 1. Because of the high speed, the preferable accuracy and the small template, our algorithm has a better performance in the large scale application.

5 Conclusions and Future Directions

With the increasing demand of on-line verification for large scale fingerprints database [16], the time and memory consuming of the matching algorithm is becoming more and more important in AFIS designing. In this paper we define a novel structure by choosing the most reliable singular point and reducing the number of candidate minutiae pairs in our algorithm. The experiment results show that these improvements can highly speed up the matching with only a little accuracy loss. Because the novel structure performed in this paper centralizes much useful information for the following matching process, the template size will be decreased and the time consuming in matching can be cut down remarkably. It can have a good performance in the real-time matching system for large scale fingerprint database.

Furthermore, if different thresholds can be defined in the detection of spurious singular points, all the genuine singular points can be correctly detected by the novel structure rather than only one reference point. By the relative positions of core(s) and delta(s), we may get useful classification information of the input fingerprints, and write it into the templates. This classification work can give a further considerable acceleration to the following matching process, which can reduce the size of scanning database. And the matching error can be further reduced by improvements in generating minutiae vectors in the novel structure. Future works on the integration of classification with fast matching can make the AFIS more efficient in performing the one-to-many matching task in public use.

References

1. Nandakumar, K., Jain, A.K.: Local Correlation-based Fingerprint Matching. The Indian Conference on Computer Vision, Graphics and Image Processing (ICVGIP), Kolkata (2004)
2. Jiang, X., Yau, W.Y.: Fingerprint Minutiae Matching Based on the Local and Global Structures, Proc. of the 15th Int'l Conf. on Pattern Recognition (ICPR), Barcelona: IEEE Computer Society (2000) 1038-1041
3. Parziale, G., Niel, A.: A Fingerprint Matching Using Minutiae Triangulation, Biometric Authentication: First International Conference (ICBA), Hong Kong (2004) 241-248
4. NIST Special Database 4. http://www.nist.gov/srd/nistsd4.htm
5. Jain, A.K., Prabhakar, S., Hong, L.: A Multichannel Approach to Fingerprint Classification, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Computer Society (1999), vol. 21, no. 1, 348-359
6. Liu, T., Zhu, G., Zhang, C., Hao, P.W.: Fingerprint Indexing Based on Singular Point Correlation, Int'l Conf. on Image Processing (ICIP), Genova (2005), vol. 3, 293-296
7. Hong, L., Wan, Y., Jain, A.K.: Fingerprint Image Enhancement: Algorithm and Performance Evaluation, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Computer Society (1998), vol. 20, no. 8, 777-789
8. Kawagoe, M., Tojo, A.: Fingerprint Pattern Classification, Pattern Recognition, Pergamon Press, Oxford, (1984) vol. 17, no. 3, 295-303
9. Chikkerur, S., Ratha, N.: Impact of Singular Point Detection on Fingerprint Matching Performance, Fourth IEEE Workshop on Automatic Identification Advanced Technologies (AutoID), (2005) 207-212
10. Maltoni, D., Maio, D., Jain, A.K., Prabhakar, S.: Handbook of Fingerprint Recognition, Springer Verlag, Berlin Heidelberg New York (2003) 176
11. Wu, N., Zhou, J.: Model Based Algorithm for Singular Point Detection from Fingerprint Images, Int'l Conf. on Image Processing (ICIP), Singapore (2004), vol. 2, 885-888
12. Wang, Q., Rong, L.: A Fast Fingerprint Matching Approach in Medicare Identity Verification Based on Gas, Advances in Natural Computation: First International Coference, (ICNC), Changsha, (2005) 151-160
13. Ratha, N.K., Karu, K., Chen, S., Jain, A.K.: A Real-time Matching System for Large Fingerprint Database, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Computer Society (1996), vol. 18, no. 8, 799-813
14. Lee, D., Choi, K., Kim, J.: A Robust Fingerprint Matching Algorithm Using Local Alignment, Proc. of the 16th Int'l Conf. on Pattern Recognition (ICPR), Quebec: IEEE Computer Society (2002), vol 3, 803-806
15. Fingerprint Verification Competition. http://bias.csr.unibo.it/fvc2002/, http://bias.csr.unibo.it/fvc2004/
16. Jain, A.K., Hong, L., Bolle, R.: On-line Fingerprint Verification, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Computer Society (1997), vol. 19, no. 4, 302-314