A Matching Algorithm Based on Local Topologic Structure*

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Abstract. How to cope with non-linear distortions in the matching algorithm is a real challenge. In this paper, we proposed a novel fingerprint matching algorithm based on the local topologic structure and a novel method to compute the similarity between two fingerprints. The algorithm firstly aligns the template fingerprint and the input fingerprint. Then local topologic structure matching was introduced to improve the robustness of global alignment. Finally a novel method was introduced to compute the similarity between the template fingerprint and the input fingerprint. The proposed algorithm has been participated in Fingerprint verification competition (FVC2004). The performance was ranked 3rd position in open category in FVC2004.

1 Introduction

Significant improvements in fingerprint recognition have been achieved on the algorithmic side, but a great number of challenging problems still exist. One of the challenging problems is matching of non-linear distorted fingerprints. The acquisition of a fingerprint is a 3D-2D warping process [1][2]. The fingerprint captured with a different contact center will result in a different warping mode. The other reason that will introduce distortion to fingerprint is the non-orthogonal pressure people exert on the sensor. In Fingerprint Verification Competition 2004 (FVC2004)[3], the organizers have insisted on: distortion, dry and wet fingerprints in particular. How to cope with these non-linear distortions in the matching algorithm is a real challenge.

Recently, some algorithms were presented that explicitly deal with the problem of the non-linear distortion in fingerprint images to improve their matching performance. Maio and Maltoni et al. [1] proposed a plastic distortion model to "describe how fin-

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gerprint images are deformed when the user improperly places his/her finger on the sensor plate". This model helps to understand this process. However, due to the insufficiency and uncertainty of information, it is very difficult to automatically and reliably estimate the parameter in that model. Bazen et al. [4] used a thin-plate spline model to describe the non-linear distortions between the two sets of possible matching minutiae pairs. By normalizing the input fingerprint with respect to the template, this method is able to perform a very tight minutiae matching and thus improve the performance. However, the TPS model focuses on smoothly interpolating images over scattered data. When applied this model to fingerprint recognition, it can make two fingerprints, no matter they come from the same finger or not, more similar to each other.

In this paper, we proposed a novel fingerprint matching algorithm based on the local topologic structure. The algorithm firstly aligns the template fingerprint and the input fingerprint using the registration method described in [6]. Then we introduce local topologic structure matching to improve the robustness of global alignment. Finally a novel method is introduced to compute the similarity between the template fingerprint and the input fingerprint.

This paper is organized as follows. Section 2 describes the details of matching using local topologic structure. Section 3 proposes a novel method which uses to compute the similarity between the template fingerprint and the input fingerprint. The performance of the proposed algorithm is shown by experiments in Section 4. Section 5 contains conclusion and discussion.

2 Match Using Local Topologic Structure

The task of the fingerprint registration is to align the two fingerprints and find the corresponding minutiae pairs between the two feature sets. We used the registration method described in [6]. For an input fingerprint image, we use the method described in [5],[7] to enhance the image and detect the minutiae set. The ridge points were sampled at the average inter-ridge distance along the ridge linked with the corresponding minutiae point. In this paper we introduce local topologic structure matching to improve the robustness of global alignment.

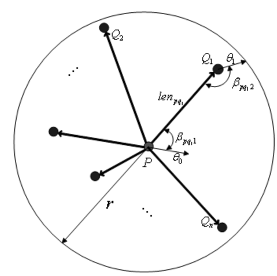

Fig. 1. The local topological structure of P

2.1 Defining of Local Topologic Structure

Let *P* denote a minutiae in the fingerprint image and *Q1,Q2,…,Qn* are the minutiaes circle around *P* within r radius. We use the len_{pq_1}, $\beta_{pq_1 1}$, $\beta_{pq_1 2}$ to descript the relationship between *P* and *Q1*. len_{pq_1} denotes the distance between *P* and *Q1*., $\beta_{pq_1 1}$ denote the angle between the orientation of minutiae *P*(θ_0) and the direction from P to $Q1$. $\beta_{pq_1}2$ denotes the angle between the orientation of minutiae $Q1(\theta_1)$ and the direction from $Q1$ to P, Fig. 1 show the meaning of these parameters. And we can find that len_{pq_1}, $\beta_{pq_1}1$, $\beta_{pq_1}2$, is no relevant to shift and rotation. Then we can define the local topologic structure of P as following:

$$LoTopo_P = \left((len_{pq_1}, \beta_{pq_1}1, \beta_{pq_1}2), (len_{pq_2}, \beta_{pq_2}1, \beta_{pq_2}2), \cdots, (len_{pq_n}, \beta_{pq_n}1, \beta_{pq_n}2)\right)$$

2.2 Local Topologic Structure Match

Suppose P is a minutiae in the template fingerprint, $Q1, Q2, \ldots, Qn$ are n minutiaes circle around P within r radius. Then we can get the local topologic structure of P:

$$LoTopo_P = \left((len_{pq_1}, \beta_{pq_1}1, \beta_{pq_1}2), (len_{pq_2}, \beta_{pq_2}1, \beta_{pq_2}2), \cdots, (len_{pq_n}, \beta_{pq_n}1, \beta_{pq_n}2)\right)$$

And suppose R is a minutiae in the input fingerprint. As the fingerprint is deformed, we search minutiaes circle around R within $r + r_s$ radius, r_s is the distance toleance. Suppose $S1, S2, \ldots, Sm$ are m minutiaes circle around R within $r + r_s$ radius. Then we can get the local topologic structure of R:

$$LoTopo_R = \left((len_{rs_1}, \beta_{rs_1}1, \beta_{rs_1}2), (len_{rs_2}, \beta_{rs_2}1, \beta_{rs_2}2), \cdots, (len_{rs_m}, \beta_{rs_m}1, \beta_{rs_m}2)\right).$$

We use the following algorithm to determine whether two minutiae P and R is matched:

Step 1: For i ($1 \le i \le n$) and j ($1 \le j \le m$), match PQ_i $(len_{pq_i}, \beta_{pq_i}1, \beta_{pq_i}2)$ and RS_j $(len_{rs_j}, \beta_{rs_j}1, \beta_{rs_j}2)$, get the matched number n_{match1}. Here one pair PQ_i matched one pair RS_j at most. If PQ_i matched several pairs, keep only one pair.

Firstly three parameters len_{diff}, β_{1diff}, β_{2diff} are calculated as following:

$$len_{diff} = \left| len_{pq_i} - len_{rs_j} \right| \tag{1}$$

$$\beta_{1diff} = \left| \beta_{pq_i}1 - \beta_{rs_j}1 \right| \tag{2}$$

$$\beta_{2diff} = \left| \beta_{pq_i}2 - \beta_{rs_j}2 \right| \tag{3}$$

Then we use adaptive matching bounding box $M_{box} = (len_{thr}, \beta_{thr})$ to determine whether PQ_i and RS_j is matched. The size of matching box changes according to the distance len_{pq_i} as follows:

$$len_{thr} = \begin{cases} len_L & \text{if } len_{pq_i} < Thr_L \\ len_H & \text{if } len_{pq_i} > Thr_L \\ len_L + \frac{len_H - len_L}{Thr_H - Thr_L} \bullet (len_{pq_i} - Thr_L) & \text{otherwise} \end{cases} \quad (4)$$

$$\theta_{thr} = \begin{cases} \theta_L & \text{if } len_{pq_i} < Thr_L \\ \theta_H & \text{if } len_{pq_i} > Thr_L \\ \theta_L + \frac{\theta_H - \theta_L}{Thr_H - Thr_L} \bullet (len_{pq_i} - Thr_L) & \text{otherwise} \end{cases} \quad (5)$$

Where $len_L < len_H, \theta_L > \theta_H$. The purpose for using a changeable sized bounding box is to deal with nonlinear deformation more robustly. When the distance of PQ_i is small, a small deformation will mean a large change of the radial angle while the change of radius remains small. Hence in this case the θ_{thr} of the bounding box should be larger and the len_{thr} of the bounding box should be smaller. On the other hand, when the distance of PQ_i is large, a small change in radial angle will cause a large change in the position of the minutia. While the radius can have larger deformation as it is the accumulation of deformation from all the regions between Q_i and P. Hence in this case the len_{thr} of the bounding box should be larger and the θ_{thr} of the bounding box should be smaller.

If Equations (1),(2),(3) satisfy the following conditions: (1) $len_{diff} < len_{thr}$, (2) $\beta_{1diff} < \theta_{thr}$ (3) $\beta_{2diff} < \theta_{thr}$ then we determine that PQ_i and RS_j is matched.

Step 2: If $n_{match1} / n > Thr_{topo}$ then goto Step 3, else we determine that P and R is not matched.

Step 3: Search minutiaes circle around R within $r - r_s$ radius, get the other local topologic structure of R:

$LoTopo_{R2} = \left((len_{rt_1}, \beta_{rt_1}1, \beta_{rt_1}2), (len_{rt_2}, \beta_{rt_2}1, \beta_{rt_2}2), \cdots, (len_{rt_l}, \beta_{rt_l}1, \beta_{rt_l}2)\right)$.

Using the same algorithm defined in step 1, match the local topological structure $LoTopo_P$ and $LoTopo_{R2}$, get the matched number n_{match2}

Step 4: If $n_{match2} / n > Thr_{topo}$, then we determine that P and R is matched, else P and R is not matched.

3 Similarity Computing

How to compute the similarity between template fingerprint and input fingerprint for deformed fingerprints is a difficult task. In some algorithms [2][4], they only use the number of matching minutiae to compute the similarity between template fingerprint and input fingerprint. In order to tolerate matching minutiae pairs that are further apart because of plastic distortions, and therefore to decrease the false rejection rate (FRR), most algorithms increase the size of the bounding boxes. However, as a side effect, this gives non-matching minutiae pairs a higher probability to get paired, resulting in a higher false acceptance rate (FAR). Different with above algorithm, we give out a novel method to compute the similarity between two fingerprint images. We considered not only the number of matching minutiae but also the distance difference of the corresponding minutiae pairs.

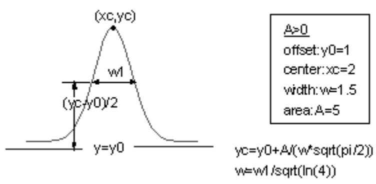

Fig. 2. The illustration of the expression (8).

Using the proposed algorithm, we can get the corresponding minutiae pairs between template fingerprint and input fingerprint. Suppose we get N1 corresponding minutiae pairs, and there are n_i sample points for every minutiae pair. Then we can compute the sum N2 of matched sample points as following.

$$N2 = \sum_{i=1}^{N1} n_i \tag{6}$$

Meanwhile we compute the mean of distance difference between every two minutiaes as following:

$$LenDif = \frac{1}{N1} \sum_{i=1}^{N1} len_{dif} \tag{7}$$

Where the meaning of len_{diff} can be seen expression (1).

After statistical analysis, we find that N2 and LenDif is approximately Guassian distributed. The experiments were done on FVC2002 DB1. It contains 800 fingerprint images captured by optical sensor "Identix TouchView II". Fig. 3,4 show the distribution of N2, LenDif in imposter match and genuine match. From Fig. 3, we can find that the value of N2 in genuine match is much bigger than in imposter match. And From Fig. 4, we can also find that the value of LenDif in genuine match is much smaller than in imposter match. It means that N2 and LenDif have excellent classification performance for match. We use the following Guassian functions to describe the character of N2 and LenDif.

$$y(x) = y0 + \frac{A}{W\sqrt{\pi/2}} e^{-2\frac{(x-x_c)^2}{w^2}} \tag{6}$$

Where x represents N2 or LenDif, the meaning of parameter y0, A, W, Xc can be seen in Fig. 2. Then the similarity between template fingerprint and input fingerprint is computed as following:

$$\text{similarity} = F_{N2} * F_E \tag{7}$$

$$F_{N2} = \begin{cases} \eta_1 \cdot y(N2) \cdot \dfrac{N2 - a1}{a2 - a1} & a1 < N2 < a2 \\ 1 & N2 > a2 \\ 0 & N2 < a1 \end{cases} \tag{8}$$

$$F_{LenDif} = \begin{cases} \eta_2 \cdot y(lenDif) \cdot \dfrac{e2 - lenDif}{e2 - e1} & \mathrm{e1} < lenDif < e2 \\ 0 & lenDif > e2 \\ 1 & lenDif < e1 \end{cases} \tag{9}$$

Where η_1, η_2 a2,a1,e2,e1 are coefficients and a2>a1, e2>e1.

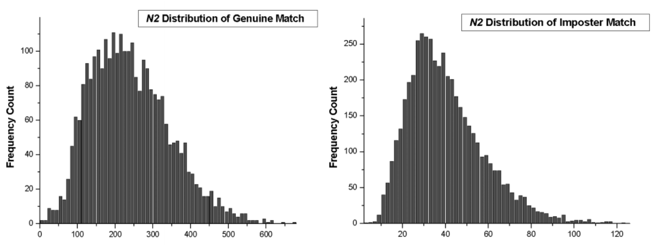

Fig. 3. The distribution of N2 In Genuine and Imposter Match on FVC2002 DB1.

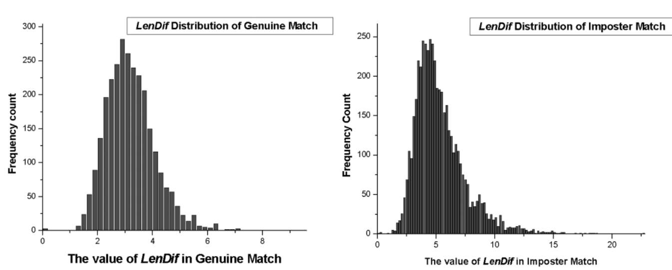

Fig. 4. The distribution of LenDif In Genuine and Imposter Match on FVC2002 DB1.

4 Experimental Results

The proposed algorithm has been participated in FVC2004. The Participant ID is P071 (open). The performance was ranked 3rd position in open category in FVC2004.

The detailed performance of the proposed algorithm can be seen from the website http://bias.csr.unibo.it/fvc2004/default.asp.

In FVC2004, databases are more difficult than FVC2000/FVC2002 ones. In particular in FVC2004, the organizer has insisted on: distortion, dry and wet fingerprints. In fingerprints database DB1 of Fvc2004, the distortion among the fingerprints from the same finger is obviously. The fingerprint images was acquired through CrossMatch V300 (Optical sensor). The size of the image is 640*480 pixels with the resolution about 500 dpi. The fingerprint database set A contains 800 fingerprint images captured from 100 different fingers, 8 images for each finger. Fig. 5 show two examples of big distortion captured from CrossMatch V300 sensor . Using the proposed algorithm, the similarity between these two fingerprints (102_3.tif and 102_5.tif) is 0.420082 (N2 =154, LenDif =8.511742). From Fig. 6, we can judge that these two fingerprints come from the same finger, it is a genuine match.

Fig. 5. The example of big distortion from FVC2004 DB1_B. (a) is 102_3.tif, (b) is 102_5.tif, (c) is the image which (a) (after rotation and translation) was added to (b). In region ◯ , the corresponding minutiae are approximately overlapped. But in region ◯ , the maximal vertical difference of corresponding minutiae is above 100 pixels.

The performance of the proposed algorithm on FVC2004 DB1 was shown in Fig. 6 . The equal error rate (EER) is about 4.37%. The experiments were done on PC AMD Athlon 1600+ (1.41 GHz).The average time for matching two minutiae sets is 0.77 seconds.

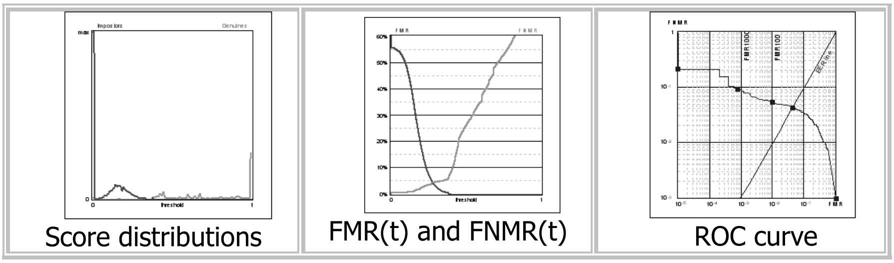

Fig. 6. Experimental results of the proposed algorithm on FVC2004 DB1_A.

5 Conclusion

How to cope with non-linear distortions in the matching algorithm is a real challenge. In this paper, we proposed a novel fingerprint matching algorithm based on the local topologic structure. The algorithm firstly aligns the template fingerprint and the input fingerprint using the registration method described in [6]. Then we introduce local topologic structure matching to improve the robustness of global alignment. Finally we proposed a novel method to compute the similarity between the template fingerprint and the input fingerprint. The proposed algorithm has been participated in FVC2004. The performance was ranked 3rd position in open category in FVC2004. Experimental results show that the proposed algorithm has good performance on accuracy and processing time.

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