Latent-to-full palmprint comparison based on radial triangulation under forensic conditions

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Abstract

In forensic applications the evidential value of palmprints is obvious according to surveys of law enforcement agencies which indicate that 30 percent of the latents recovered from crime scenes are from palms. Consequently, developing forensic automatic palmprint identification technology is an urgent and challenging task which deals with latent (i.e., partial) and full palmprints captured or recovered at 500 ppi at least (the current standard in forensic applications) for minutiae-based offline recognition. Moreover, a rigorous quantification of the evidential value of biometrics, such as fingerprints and palmprints, is essential in modern forensic science. Recently, radial triangulation has been proposed as a step towards this objective in fingerprints, using minutiae manually extracted by experts. In this work we help in automatizing such comparison strategy, and generalize it to palmprints. Firstly, palmprint segmentation and enhancement are implemented for full prints feature extraction by a commercial biometric SDK in an automatic way, while features of latent prints are manually extracted by forensic experts. Then a latent-to-full palmprint comparison algorithm based on radial triangulation is proposed, in which radial triangulation is utilized for minutiae modeling. Finally, 22 latent palmprints from real forensic cases and 8680 full palmprints from criminal investigation field are used for performance evaluation. Experimental results proof the usability and efficiency of the proposed system, i.e, rank-1 identification rate of 62% is achieved despite the inherent difficulty of latent-to-full palmprint comparison.

1. Introduction

In recent years, the universal consciousness of the evidential value of palmprints in forensic applications has highlighted the need for developing forensic automatic palmprint identification technology, according to surveys of law enforcement agencies which indicate that 30 percent of the latents recovered from crime scenes are from palms [1]. Forensic automatic palmprint identification technology deals with latent (i.e., partial) and full palmprints captured or recovered at 500 ppi at least (the current standard in forensic applications [2]), which is applied to minutiae-based offline recognition, mainly the type of latent-to-full palmprint comparison [6-8]. Some fundamental technologies on offline palmprint recognition have been developed, i.e., high resolution full palmprint segmentation, enhancement, feature extraction and minutiae-based comparison [3-6]. Pioneering works such as [7, 8] made relevant contribution to the objective of real forensic latent-to-full palmprint comparison. However, more research is needed in this field in order to achieve a robust and meaningful technology.

Moreover, a rigorous quantification of the evidential value of biometrics, such as fingerprints and palmprints, is essential in forensics in order to converge to scientific methodologies, which is a requirement of modern forensic science. Recently, radial triangulation has been proposed as a step towards this objective in fingerprints [9], and used for modeling minutiae manually extracted by experts. Based on this approach, distances among minutiae models are used as a basis for the computation of likelihood ratios, which represent the value of the evidence in a given case. The whole strategy based on radial triangulation is in accordance with the interpretation needs of modern forensic science [10].

In this paper, with the two objectives above, we develop latent-to-full palmprint identification technology based on radial triangulation as a first step towards a quantification of the value of evidence in palmprints using likelihood ratios. Firstly, palmprint segmentation and enhancement are implemented for full prints feature extraction by a commercial biometric SDK [11] in an automatic way, while features of latent prints are manually extracted by forensic experts. Then a latent-to-full palmprint comparison algorithm based on radial triangulation is proposed, in which radial triangulation is utilized for minutiae modeling. Finally, 22 latent palmprints from real forensic cases and 8680 full palmprints from criminal

978-1-4577-1359-0/11/$26.00 ©2011 IEEE

investigation field captured by Beijing Institute of Criminal Technology in China are used for performance evaluation. Experimental results proof the usability and efficiency of the proposed system, i.e., rank-1 identification rate of 62% is achieved despite the inherent difficulty of latent-to-full palmprint comparison. This shows the adequacy of radial triangulation as a useful way of extracting information on identity from palmprints, and therefore supports [9].

The rest of this paper is organized as follows: Section 2 describes the methods implemented for full palmprint preprocessing and feature extraction with post-processing. Section 3 describes radial triangulation modeling for minutiae in palmprints. Section 4 proposes a latent-to-full palmprint comparison algorithm based on radial triangulation. Experimental results are provided in Section 5, with conclusions presented in Section 6.

2. Preprocessing and post-processing

In forensic applications, minutiae of latent palmprints are usually marked manually by forensic experts due to the complex background and multiple overlapping prints in a single latent image. On the other hand, full palmprints in forensic background database are mainly inked on the paper and then transmitted into a computer through a digital scanner with high resolution, or even directly acquired with live-scan devices. Therefore, minutiae of full prints can be extracted in an automatic way properly. However, original full prints usually contain blank regions, knuckle-finger print regions, unrecoverable low quality regions and creases as shown in Figure 1, which result in many spurious minutiae. Therefore, image preprocessing, i.e., segmentation and enhancement, and post-processing for full palmprints are essential for feature extraction to improve identification rate and computation efficiency.

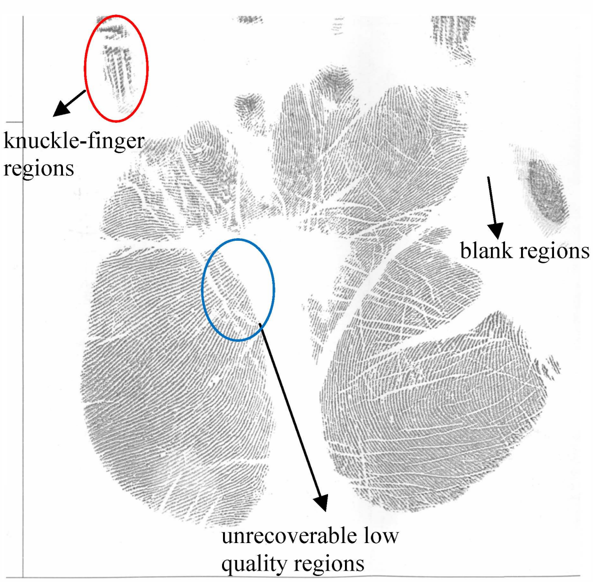

Figure 1: Different regions of an original full palmprint.

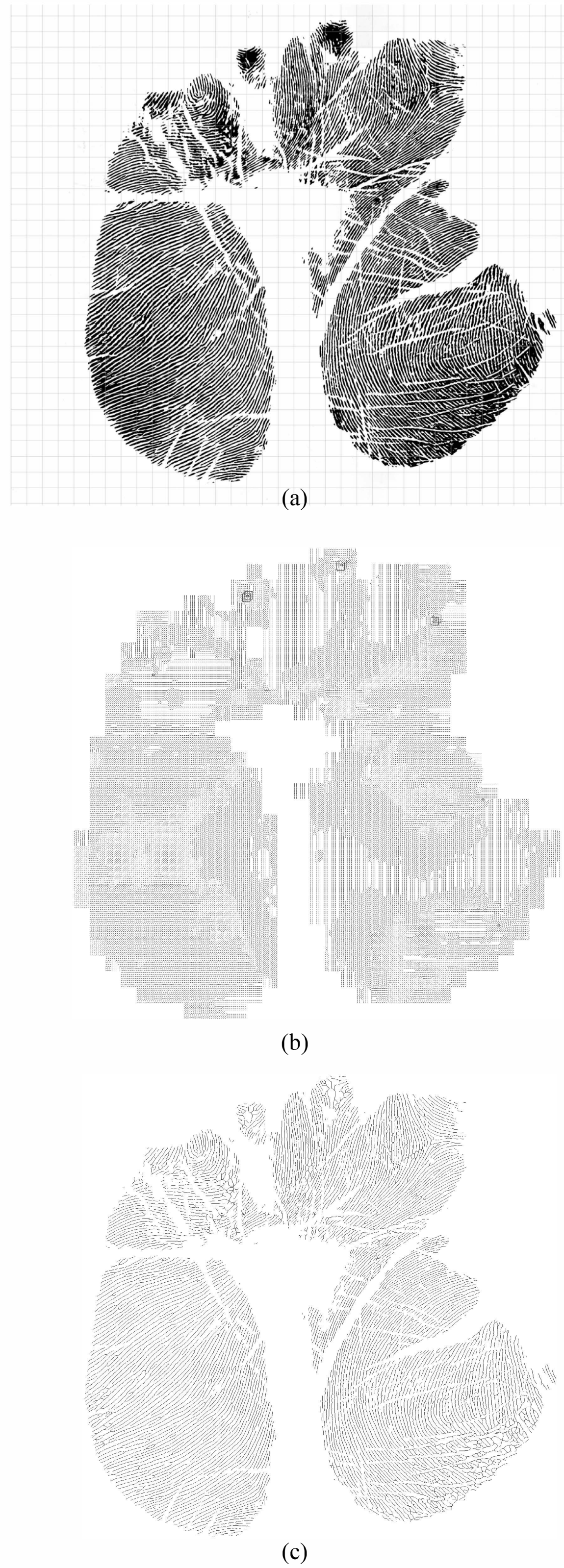

Figure 2: Full palmprint preprocessing for the original image in Figure 1. (a) Segmentation. (b) Orientation field. (c) Thinned image.

2.1. Segmentation and enhancement

For full palmprint segmentation, block-based method [3] is used. An original palmprint image is divided into four types of distinctive areas: blank regions, knuckle-finger regions, unrecoverable low quality palm regions and high quality palm regions. The first three kinds of areas are identified respectively: 1) Blank regions are separated according to the block white pixel proportion and the block variance. 2) Knuckle-finger regions are separated from palm regions marked as Main Connected Components (MCC). 3) Unrecoverable low quality palm regions are separated from high quality palm regions by a feed-forward neural network classifier using orientation and ridge information. Segmentation result of the original image is shown in Figure 2 (a).

In order to obtain high-quality minutiae, palmprint enhancement is implemented using the method in [4]. There are four steps: 1) Estimate and modify the orientation field as shown in Figure 2(b). 2) Remove noises in a grey-scale image. 3) Convert a grey-scale image into a binary image. 4) Remove noises in a binary image. The final thinned image is shown in Figure 2(c).

2.2. Feature extraction with post-processing

In this work, we use one commercial SDK named MegaMatcher 4.0 SDK [11], distributed by Neuro-technology, to extract minutiae information (i.e., minutia position and direction) from the thinned images of full palmprints. However, there are still some spurious minutiae around creases of palmprints. In order to improve the accuracy and reliability of latent-to-full palmprint identification system, minutiae filter based on line feature extraction [5] is served as post-processing to remove spurious minutiae. Minutiae extraction result with post-processing for the original image is shown in Figure 3.

3. Radial triangulation modeling

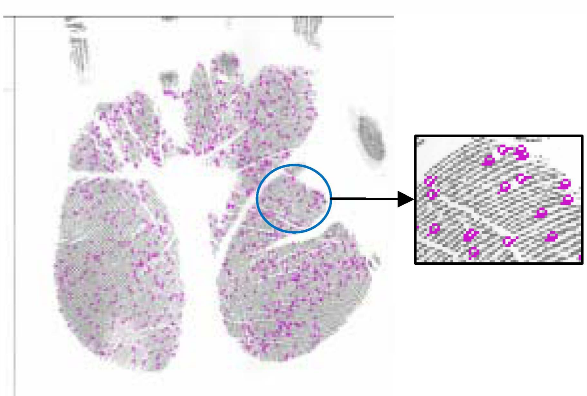

Figure 3: Minutiae extraction result with post-processing for the original image in Figure 1.

In order to execute minutiae-based comparison between latent and full palmprints, the spatial arrangement of minutiae, i.e., local minutiae structures, is essential not only for local minutiae comparison but also for global minutiae comparison, as latent prints are usually partial images. For instance, MinutiaCode, a fixed-length minutiae descriptor was proposed in [8] aimed to latent-to-full palmprint comparison.

The theory that the spatial arrangement of minutiae can be modeled through a triangulation of a polygon whose vertices are minutia locations, such as Delaunay triangulation [12], is not new in fingerprint research area. Recently, radial triangulation has been proposed and applied to minutiae modeling for fingerprints [9]. The radial triangulation modeling is proved to be more robust and efficient than other kinds of triangulation, since there is a unique centroid defined by the arithmetic mean of the coordinates when given a set of minutiae locations. The centroid is then used for ordering the minutia locations in a ''radar'' manner, which is used to define a unique polygon. Given the polygon the centroid is also used for triangulating it: radii are added from the vertices of the polygon to the centroid.

In this work, we generalize radial triangulation to palmprint minutiae modeling. Then radial triangulation is served as local minutiae structure as shown in Figure 4. Given a set of N minutiae, i.e., $M = \{m_k\}_{k=1}^{N}$ where $m_k = (x_k, y_k, \theta_k)$, the general vector form of the local minutiae structure based on radial triangulation is,

$$LS = [P_C, \{V_k, R_k, L_{k,k+1}, ST_k\}_{k=1}^{N}] \quad (1)$$

where $P_C = (x_C, y_C, \theta_C)$ is the centroid of the polygon, V_k is a vertex where a minutia locates, R_k is the radius of minutia k to the centroid, $L_{k,k+1}$ is the length of the polygon side between minutia k and minutia $k+1$, ST_k is the area of the triangle defined by minutiae k, $k+1$, and the centroid. In order to be used in local structure comparison, each vertex V_k in a polygon has been transformed into the polar coordinate system of the centroid from its corresponding minutiae m_k as following:

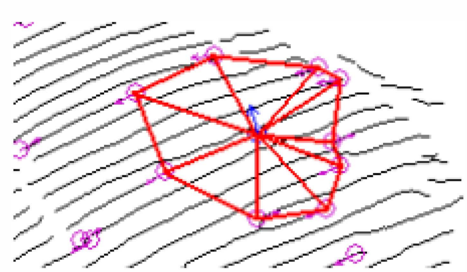

Figure 4: Radial triangulation of a set of nine minutiae from a palmprint.

$$V_k = \begin{pmatrix} r_k \\ \alpha_k \\ \varphi_k \end{pmatrix} = \begin{pmatrix} \sqrt{(x_k - x_C)^2 + (y_k - y_C)^2} \\ (\arctan(\frac{y_k - y_C}{x_k - x_C}) \times \frac{180}{\pi} + 360)\%360 \\ ((\theta_k - \theta_C) + 360)\%360 \end{pmatrix} \quad (2)$$

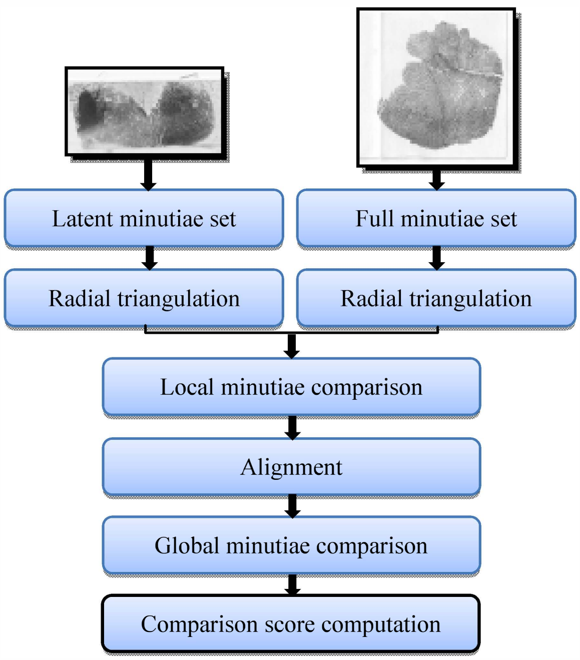

Figure 5: Latent-to-full palmprint comparison.

where the centroid $P_C = (x_C, y_C, \theta_C)$ is the pole, r_k denotes the polar radius of V_k relative to P_C, α_k denotes the polar angle of V_k relative to P_C, and φ_k denotes the angle of V_k relative to P_C according to their directions.

In the minutiae structure vector LS, radial triangulation vector $RT = \{V_k, R_k, L_{k,k+1}, ST_k\}_{k=1}^{N}$ is used for local minutiae comparison and the centroid P_C can be used for global minutiae comparison.

4. Latent-to-full palmprint comparison

The procedures of latent-to-full palmprint comparison based on radial triangulation are shown in Figure 5.

4.1. Radial triangulation structure comparison

As latent palmprints are partial prints and much smaller than full prints, position and direction information of a minutia cannot be used for latent-to-full palmprint comparison directly. Instead, local minutiae comparison based on radial triangulation are implemented as following steps.

Step 1: Selection of local N-minutiae sets. Given the minutiae set of a palmprint, selection of local N-minutiae sets is detailed as below.

- Minutiae are sorted in ascending order of the distances between minutiae and the origin of the coordinate system.
- The minutia nearest to the origin in the sorted minutiae set is selected as the starting point. And N-1 minutiae nearest to the starting minutia are selected to form a local N-minutiae set. Then the total N minutiae are deleted from the sorted minutiae set.
- The same procedure as the above step is implemented on the reduced minutiae set until the number of remaining minutiae is less than N.

Step 2: Radial triangulation structure extraction. Local minutiae structure sets $LSS_{Latent} = \{LS_i\}_{i=1}^{L}$ and $LSS_{Full} = \{LS_j\}_{j=1}^{F}$ based on radial triangulation are extracted for each latent and full palmprint based on their local N-minutiae sets. $L = \lfloor n_{LM} / N \rfloor$ and $F = \lfloor n_{FM} / N \rfloor$ denote radial triangulation structure numbers in a latent print and a full print respectively, where n_{LM} and n_{FM} denote numbers of minutiae in a latent palmprint and a full palmprint respectively.

Step 3: Comparison between two local radial triangulation structure sets $RTS_{Latent} = \{RT_i\}_{i=1}^{L}$ from a latent palmprint and $RTS_{Full} = \{RT_j\}_{j=1}^{F}$ from a full palmprint is executed. Firstly, for each pair of radial triangualtion structure RT_i and RT_j, their distance vector D_{ij} is calculated by (3), while the pair of the structure is considered as a matched pair when the distance vector is within the threshold of the average distance $D_0 = \{DV_0, DR_0, DL_0, DST_0\}$. Then the similarity $s_m(k_i, l_j)$ of minutiae k_i from the latent print and l_j from the full print in the paired structure is calculated using (4), while the minutia l_j is considered as the one paired with the minutia k_i only when the similarity $s_m(k_i, l_j)$ is the maximum value in the similarity set of minutia k_i, i.e., $s_{k_i} = \{s_m(k_i, l_j)\}_{l=1}^{N}$. Finally, all paired minutiae are marked as candidates.

$$D_{ij} = \{\frac{1}{N^2}\sum_{l=1}^{N}\sum_{k=1}^{N} DV_{k_i,l_j}, \frac{1}{N^2}\sum_{l=1}^{N}\sum_{k=1}^{N} DR_{k_i,l_j}, \frac{1}{N^2}\sum_{l=1}^{N}\sum_{k=1}^{N} DL_{k_i,l_j}, \frac{1}{N^2}\sum_{l=1}^{N}\sum_{k=1}^{N} DST_{k_i,l_j}\} \quad (3)$$

where

$$DV_{k_i,l_j} = \sqrt{(r_{k_i}\cos\alpha_{k_i} - r_{l_j}\cos\alpha_{l_j})^2 + (r_{k_i}\sin\alpha_{k_i} - r_{l_j}\sin\alpha_{l_j})^2},$$

$$DR_{k_i,l_j} = \left|r_{k_i} - r_{l_j}\right|, \; DL_{k_i,l_j} = \left|L_{k_i} - L_{l_j}\right|, \; DST_{k_i,l_j} = \left|ST_{k_i} - ST_{l_j}\right|.$$

$$s_m(k_i, l_j) = \frac{\frac{1}{N^2}\sum_{l=1}^{N}\sum_{k=1}^{N} DV_{k_i,l_j}}{DV_{k_i,l_j}} \quad (4)$$

4.2. Global minutiae comparison

Given the similarity of all candidate minutia pairs, the one-to-one correspondence between minutiae is established in this stage. All minutia pairs are sorted in the decreasing order of similarity defined in Section 4.1 and each of the top-ten minutia pairs is used to align the two sets of minutiae. Minutiae are examined in turn, while a minutiae pair that is the closest with each other according to both location and direction, is deemed as a matched minutiae pair. After all the minutiae pairs have been examined, a set of matched minutiae is obtained.

4.3. Comparison score computation

The minutiae-based comparison score S between two palmprints in this paper is set as the product of a quantitative score S_n and a qualitative score S_q as described in [8]. The quantitative score measures the quantity of evidence while the qualitative score measures the consistency in the common region between two palmprints. The quantitative score is computed as

$$S_n = \frac{N_M}{N_M + 20} \tag{5}$$

where N_M denotes the number of matched minutiae and the value 20 is an experience value of the minimum number of matched minutiae for genuine comparison referred to [8]. The qualitative score is computed as

$$S_q = S_D \times \frac{N_M}{N_M + N_L} \times \frac{N_M}{N_M + N_F} \tag{6}$$

where S_D is the average similarity of radial triangulation structures for all the matched minutiae, N_L and N_F denote the number of unmatched minutiae in latent and full palmprints.

5. Experiments

There is no public latent and mated full palmprint database available. In our experiments, 22 latent palmprints from real forensic cases and 8680 full palmprints from criminal investigation field captured by Beijing Institute of Criminal Technology in China are used to evaluate the performance of the proposed forensic automatic palmprint identification system. 8680 full prints are from 4340 subjects while each subject leaves two palmprints from left hand and right hand respectively, including mated images to the 22 latent prints. Image size of full palmprints is 2304 ×2304, while the size of latent palmprints varies and generally is smaller than that of full prints. All the palmprints are recovered (i.e., latent prints) or captured (i.e., full prints) with the resolution of 500 ppi.

Under forensic conditions, minutiae of 22 latent palmprints are manually extracted by forensic experts, while minutiae extraction of 8680 full palmprints is

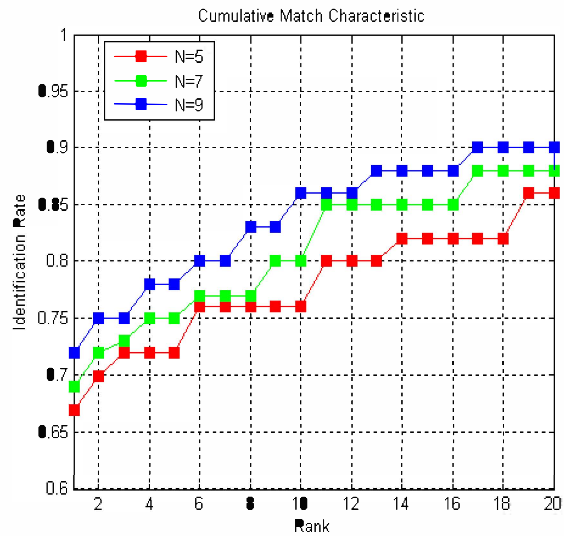

Figure 6: CMC curves for different values of N on subset of the full databases.

executed by MegaMatcher 4.0 SDK in an automatic way. In order to evaluate the influence of spurious minutiae in comparison performance, we extract minutiae of three kinds of full palmprints, i.e., original palmprint, palmprint with preprocessing and palmprint with pre- and post-processing. Statistical results of average minutiae number on latent palmprint database and full palmprint database are shown in Table 1. For full palmprints, it is obvious that the average minutiae number in an original palmprint is about two times of that in a palmprint with pre- and post-processing. The existence of a large number of spurious minutiae will significantly deteriorate the performance of latent-to-full palmprint comparison as shown in Table 2, where RT1, RT2 and RT3 denote radial triangulation-based comparison method implemented on original full palmrpints, full palmprints with preprocessing, full palmprints with pre- and post-processing respectively.

Table 1: Statistical results of average minutiae number.

		Average minutiae number	Image number
Latent palmprints		43	22
Full palmprints	Original	2191	8680
	With preprocessing	1268	
	With pre- and post-processing	1023	

As mated pairs of full prints and latent prints are known a priori, we should use CMC (i.e., Cumulative Match Characteristic) curve to plot the performance of latent-to-full palmprint comparison which is set as a closed-set identification task. Latent-to-full comparison experiments are firstly executed between the 22 latent palmprints and a subset of 100 full palmprints including mated images to the latent prints, in order to choose a proper value of minutiae number N in the local structure based on radial triangulation. Comparison results for different values of N are shown in Figure 6. According to the results, we choose N=9 in the experiment of comparison between 22 latent palmprints and the total 8680 full palmprints. Comparison results with MinutiaCode-based method [8] are shown in Table 2. Despite the inherent difficulty of latent-to-full palmprint comparison, rank-1 identification rate of 62% is achieved, while the average comparison time is 100ms. Due to the lack of public latent and mated full palmprint database, we do comparison between different methods on different databases. It is obvious that the proposed method in our work costs less computation time, which is significant for forensic automatic palmprint identification system.

Table 2: Comparison results with the method in [8].

	Database		Comparison results		
	Latent	Full	Rank-1	Rank-20	Average time(ms)
RT1	22	8680	41%	61%	230
RT2	22	8680	55%	68%	140
RT3	22	8680	62%	70%	100
MinutiaCode [8]	100	10200	69%	76%	340

6. Conclusions

In this paper, we developed latent-to-full palmprint identification technology under forensic conditions. The aim of this work was to show the adequacy of radial triangulation as a method of local minutiae structure modeling used for minutiae-based palmprint comparison. Firstly, we implemented image preprocessing of full palmprints based on novel palmprint segmentation and enhancement methods, and post-processing for full palmprint minutiae extraction. Then latent-to-full palmprint comparison algorithm based on radial triangulation was proposed, which includes local minutiae comparison and global minutiae comparison using local minutiae structure based on radial triangulation. Finally, the proposed latent-to-full palmprint comparison system was evaluated as a close-set identification task on the database containing 22 latent palmprints and 8680 full palmprints from criminal investigation field. Experimental results have shown the usability and efficiency of the proposed system despite the inherent difficulty of latent-to-full palmprint comparison.

As it is obvious that the centroid of the polygon generated by radial triangulation can be used to select calibration center for the alignment of latent and full palmprint minutiae sets, one focus of our future work is to improve the performance of global comparison utilizing the centroid. Moreover, developing a model for the computation of likelihood ratios using the evidence in palmprints following the work for fingerprints [9] is also our future research focus.

Acknowledgements

The authors would like to thank Prof. Guangshun Shi in Nankai University who provided latent and full palmprint databases used in our experiments. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 238803.

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