Fingerprint Alignment Based on Local Feature Combined with Affine Geometric Invariant

Chuchart Pintavirooj
Department of Electronics
Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Thailand 10520
kpchucha@kmitl.ac.th

Fernand S. Cohen
Department of Electrical and Computer Engineering
Drexel University
Philadelphia, PA 19104

Woranut Iampa
Department of Electronics
Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang
Thailand 10520
woranut_nuch@hotmail.com

ABSTRACT

In this paper we introduce a novel method of fingerprint alignment that uses the intrinsic geometric properties of minutiae-based triangles combined with the geometric invariant. The minutiae points are extracted from the fingerprint image and a Delaunay (DL) triangulation is constructed from these minutiae points resulting in a series of triangles. Corresponding minutiae points are established using local affine invariants constructed from the local minutia-based triangles. Triangles that are distorted by noise or have no counter part on the query are discarded. We rely only on "strong" matches that are reliable and present, for example, where the error metric between the local absolute invariants is below a set threshold. The correspondences of such matches are then used to estimate transformation parameters. The performance of our method is represented by computing the distance map error between a template and a query fingerprint after undoing the transformation, computed from the ridge structures of the two fingerprints. In conclusion, the proposed method can be used to find the corresponding minutiae and align any fingerprints considered into affine transformation, in the presence of noise including the partial occlusion.

Keywords

Fingerprint Alignment, Geometric Invariant, Delaunay Triangulation

1. INTRODUCTION

Biometric recognition based on distinctive anatomical and behavioral characteristics is used to recognize an individual in terms of verification and identification purposes. The biometric systems are applied to building access systems, authenticating person to access facilities, electronic access control including forensic identification. Commonly used biometric identifiers are human's face, fingerprint, iris, signature, and voice. The fingerprint is one of the most widely used biometric identifiers because of its uniqueness and immutability. The most evident structural characteristic of a fingerprint is a pattern of interleaved ridges and valleys.

Fingerprint matching can be categorized into 3 main approaches [Mal09] which are (i) correlation-based matching; (ii) minutiae-based matching; and (iii) non-minutiae feature-based matching. Correlation-based fingerprint matching is the simplest and earliest method. In the matching scheme, two fingerprint images consisting of template and query are superimposed in order to estimate the correlation between the corresponding pixels of the two images. For example, the differential matching rate based on the cyclic structure in the local area of fingerprint pattern was used to calculate the correlation value in the fingerprint verification algorithm [Hat02a]. Additionally, the correlation-based technique was applied based on coherence of the orientation field to match the fingerprints scanned from high resolution and touchless sensors [Lin09a]. Consequently, this technique was developed to the correlation filters tolerated to distorted fingerprints [Ven03a]. The performance of the correlation-based technique significantly relies on the alignment accuracy, which can be quite sensitive to transformation changes.

Minutiae-based matching is the technique for fingerprint matching to find the alignment of minutiae feature sets between the template and the query fingerprint images. These minutiae, ridge endings and bifurcation, are characterized by their attributes such as location, orientation, and minutiae types. The local minutiae matching [Mal09] can be classified according to the local structures which are nearest neighbor-based structures [Jea05a], [Chi06a], fixed radius-based structures [Che06a], [Fen08a], minutiae triangles [Tan03a], [Che06b] and texture-based local structures [Tic03a], [Ben07a]. For the non-minutiae feature-based matching, due to the complexity of minutiae extraction in quite low-quality fingerprint images, other features of the fingerprints are extracted from the ridge pattern, for instance, local ridge orientation [Yag05a], [Liu06a] and frequency, shape, texture information [Jai00a], and sweat pores.

From these three approaches of fingerprint matching, the local minutiae-based matching is the most widely used technique. Moreover, many of minutiae-based matching construct Delaunay triangles from the minutia set and extract various features from these triangles. In [Beb99a], the ratio of side of triangle and cosine of the angle between the smallest two sides were used as the invariant features for the fingerprint indexing. The relative position and orientation of each minutia with respect to its neighbor of triangle structure were utilized in the fingerprint minutiae-matching algorithm [Par04a]. The invariant feature vectors consisting of the distance between the two minutiae and the relative radial angle between directions of each two minutiae were obtained from the minutia triangle and were then used together with the growing and fusing region of minutiae structures to match the fingerprints [Xu07a]. In addition, the minutiae type, the minimum and median angles, the length of the longest edge of the triangle including the difference between angles of two edges and orientation field at any minutiae were determined from the low-order Delaunay triangles to find the corresponding triangles for the fingerprint identification [Lia07a].

In this paper we introduce a novel method of fingerprint alignment that uses the intrinsic geometric properties of triangles constructed from minutia triplet to align minutiae points on the query and the template. Finding correspondences using invariants allows a fast non-iterative procedure for alignment, additionally, it is robust to noisy or missing data since these invariants are based on the local triangles constructed from the minutiae points. Triangles that are distorted by noise or have no counter part on the query are discarded. We rely only on "strong" matches that are reliable and present, for example, where the error metric between the local absolute invariants is below a set threshold. The correspondences of such matches are then used to estimate transformation parameters.

This paper is organized as follows. Section 2 is related to Delaunay triangulation. Section 3 describes minutiae-based matching in the presence of affine transformation including estimation of linear transformation. Section 4 shows experimental results on the proposed algorithm. Discussion and conclusion are given in Section 5.

2. DELAUNAY TRIANGULATION OF MINUTIAE SET

Given a set $\Re$ of minutiae points $m_1, m_2, ..., m_N$, a Voronoi diagram divides the region into sub-region about each point m_i such that all points around m_i are closer to m_i than any other minutiae point. By connecting an edge between each pair of centers in the Voronoi diagram, a Delaunay triangulation is formed. A Delaunay Triangulation possesses attractive properties that make them very suitable for fingerprint matching [Beb99a]. The following properties in particular are extremely relevant to fingerprint matching:

(i) Affine invariance: A Delaunay Triangulation constructed from minutiae subjected to an affine transformation is still a Delaunay Triangulation whose minutiae points are obtained by subjecting the original minutiae points to that affine transformation.
(ii) Local shape controllability: Any local deformation of minutiae is locally confined. This is very important when trying to deal with fingerprint identification in the presence of missing parts or noise.

(iii) Uniqueness: A Delaunay Triangulation is unique. The same set of minutiae always generates the same Delaunay Triangulation.

(iv) Robustness: A Delaunay Triangulation is immune to noise. Any disturbance to the vertex does not significantly affect the triangulation pattern.

(v) Linear computational time complexity: This makes the algorithm suitable for on-line fingerprint matching system.

3. MINUTIAE-BASED MATCHING

An overview of fingerprint alignment using minutiae-based matching is shown in Figure 1. A Delaunay triangulation is constructed from the minutiae sets resulting in series of triangles. Then, the corresponding minutiae are established prior to determine transformation parameters and align the two fingerprint images.

In this paper, we present the fingerprint matching in the case of the fingerprint derived from a different scanner and with a different shear on the query sample. It is considered into an affine transformation rather than a rigid transformation. Therefore, finding the matched triangle will be done based on absolute affine invariant.

From a relative invariant, the areas of the two corresponding triangles are related to each other through the determinant of linear transformation matrix as shown in Equation 1. From the equation, *A(k)* are the area patches of sequence of triangles on the template and $A_a(k)$ are those of triangles on the query.

$$A_a(k) = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} A(k), \quad k = 1,2,...,n \qquad (1)$$

By taking the ratio of the consecutive area of the sequence, absolute invariants are obtained. These absolute invariants are applied to find the matched triangles between the two fingerprints according to following algorithm:

(i) Obtain the set of triangles for the template and the query fingerprint using the Delaunay triangulation process.

(ii) Find the list of triangles having the minutiae as a vertex and order their sequence in a counter-clockwise direction.

(iii) Compute the absolute invariant by taking the ratio of the consecutive area of ordering triangles.

(iv) Search for the longest string of absolute invariant that matched between the template and the query. Given one minutia in the unknown, searching the matched criterion between each pair of absolute invariant, says invariant i^{th} and j^{th}, is defined by Equation 2.

$$\%\varepsilon = \frac{|I(i) - I_a(j)|}{I(i)} x100 \quad < \quad \xi \qquad (2)$$

(v) Circular shift of the absolute invariant is performed both in each sequence of triangles corresponding to a vertex and the list of triangles having the minutiae as a vertex.

(vi) Declare the match on the longest string (N) of triangles that yields minimum averaged error of $\frac{\sum_i \%\varepsilon_i}{N}$

Eventually, the matched triangles are obtained from the algorithm described above. The vertices of the matched triangles are considered as the corresponding minutiae. The corresponding minutiae between template and query fingerprint are used to compute the transformation matrix. The matrix is estimated in a least square sense, from normal equation as shown in Equation 3.

$$T = (G^T G)^{-1}(G^T F) \qquad (3)$$

Where

$$F = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ . & . & . \\ . & . & . \\ . & . & . \\ x_n & y_n & 1 \end{bmatrix} \quad G = \begin{bmatrix} x'_1 & y'_1 & 1 \\ x'_2 & y'_2 & 1 \\ . & . & . \\ . & . & . \\ . & . & . \\ x'_n & y'_n & 1 \end{bmatrix}$$

and where F and G are the sets of corresponding minutiae between template and inquiry fingerprint.

4. EXPERIMENT AND RESULTS

Two fingerprints of thumb of the same individual shown in Figure 2 were scanned with a fingerprint scanner of L SCAN 100R. The resolution of the scanner is 500 pixels per inch (ppi). Prior to the computation of DL triangulation, the pre-process was performed including Gaussian blurring, Gabor filtering, thinning and minutia detection. Only two types of minutia were interested including ridge ending and bifurcation as represented in Figure 3. The DL triangulation of minutiae of the two fingerprints is shown in Figure 4.

As a result, according to the algorithm described in Section 3, the matched triangles of the two fingerprint images were found as shown in Figure 5. The vertices of the corresponding triangles were used as to estimate transformation parameters. The two fingerprint images before and after the alignment are shown in Figure 6a and 6b, respectively. Since the true correspondences of the scanned ridge points are not known, we elect to use the distance map that displays the distance between any point of one ridge coordinate and the closest point on the other image after undoing the transformation to the second image. The average distance map before and after the alignment are 39.8519 and 23.1273 pixels, respectively. The alignment errors on average before and after the alignment are 10.71% and 6.22% of the size of the finger, respectively.

Moreover, the results of fingerprint matching in the presence of noise are shown in Figure 7. The two fingerprint images before and after alignment are shown in Figure 8. The average distance map before and after the alignment are 2.0424 and 1.2852 pixels, respectively. The alignment errors on average before and after the alignment are 0.55 % and 0.35% of the size of the finger, respectively.

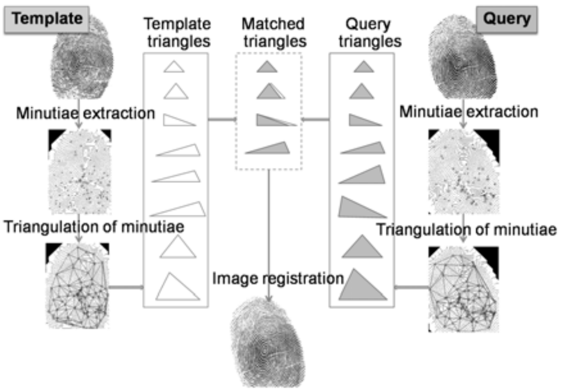
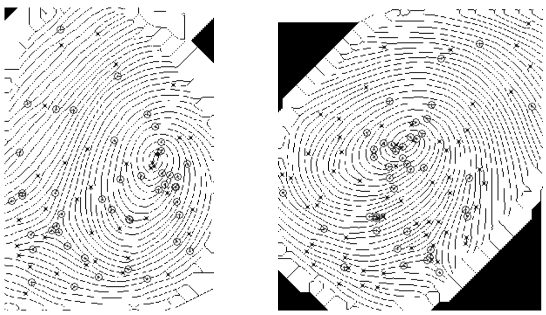


Figure 1. An overview of fingerprint alignment using minutiae-based matching.

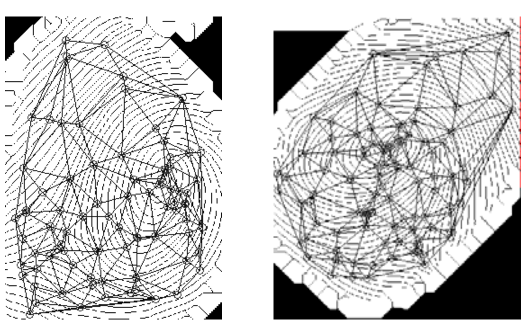
a) b)

Figure 2. Template (a) and query (b) fingerprints



a) b)

Figure 3. Minutiae position of template (a) and query (b) fingerprints. Cross signs indicate ridge endings and circle signs indicate ridge bifurcations.



a) b)

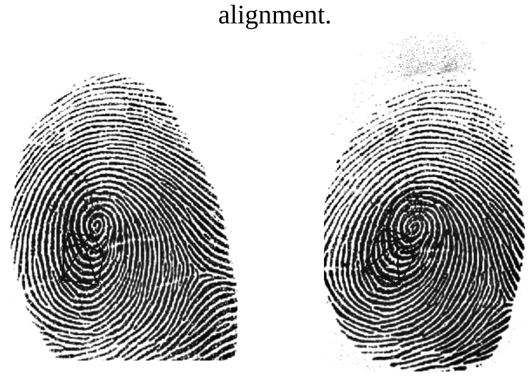
Figure 4. DL triangulation constructed from the minutiae of the template (a) and the query (b).

a) b)

Figure 5. Matched triangles of the template (a) and the query (b) derived from the minutia-based matching

a) b)

Figure 6. Two fingerprints before (a) and after (b) alignment.



a) b)

Figure 7. Matched triangles of the template (a) and the query (b) fingerprints in the presence of noise

a) b)

Figure 8. Two fingerprints in the presence of noise before (a) and after (b) alignment

5. DISCUSSION AND CONCLUSION

In this paper, we introduced a geometric-based method to perform shape matching by aligning fingerprint image. For the 2D-to-2D alignment, a set of minutia points are extracted. The fiducial points were local and hence are well suited to deal with the partial alignment problem (occlusion). This is sharp contrast to other geometric invariant methods like moments and Fourier descriptors that are global in nature. To find correspondences between the minutia points on the two fingerprint images, a set of geometric invariants were determined based on the triangles constructed from sets of the minutia point triplets. After the correspondences were established, the parameters of a relevant transformation were estimated and the two images were aligned. The performance of our method is demonstrated by the ability to register the fingerprint image scanned under a host of shape transformations. In conclusion, the proposed method can be used to find the corresponding minutiae and align any fingerprints in case considered as the affine transformation, the presence of noise including the partial occlusion.

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