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A Fingerprint Matching Method Based on Minutiae and Ridges

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Abstract

Attributions including the type of minutiae, the curvature of ridge, the length ratio of 2 line segments of ridge and the relative topological relationship among minutiae and ridges were used in partial and/or nonlinear distorted fingerprint matching. Three kinds of criterions were defined to describe the pattern of fingerprint. Fingerprint was matched in steps according to the criterions consist of attributions of and topological relationship among minutiae and their adjacent ridges. The final matching result was synthetically judged by the matching results in step-matching. Experiments show that the algorithm presented can achieve excellent matching result in partial and/or distorted fingerprint matching.

1. Introduction

Fingerprint recognition is one of most mature technique in biometrics and has been used in authentication system widely. Fingerprint matching algorithms are usually based on structural features statistics, neural network and syntactic analysis, the first of which is the main method used in computer auto fingerprint identification system. Even the type, position, orientation of minutiae, number of ridges between minutiae and adaptive parameters are used, the results are still not satisfied in fingerprint especially in partial and/or nonlinear distorted fingerprint matching[1].

Recently, attributions of ridge and relationship among ridges were use in partial and/or distorted fingerprint identification and excellent results were achieved because the pattern constructed by minutiae and ridges is the most stable pattern in fingerprint. But attributions and local relationship among ridges near a minutia have little information of global features, the direction field of ridges in fingerprint which express the global features of fingerprint changes greatly in partial and/or distorted fingerprint[2].

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There are many creative algorithms in partial and/or nonlinear distorted fingerprint matching, but the attributions of minutia and ridge, the topological relationship among minutiae and ridges are not used effectively. The complex direction feature which consists of rotation direction of the ridge and its 4 local relative direction was used to recognize the minutia and a satisfied result in slightly distorted fingerprint matching was achieved, but in which the topological relationship among minutiae and ridges was not used[3]. Local structure comprised of attributions of minutiae, relationship among ridges and minutiae were used, which make the algorithm insensitive to the nonlinear distortions of fingerprint. But the global attribution of ridge was not used and the relationship among ridges was expressed by sampling dots on the ridge, which make the performance of this algorithm decrease for larger sampling interval and time consuming for smaller sampling interval[4]. The relationship among a ridge and its neighbor was indicated by associate table, which can describe the local relationship among ridges accurately, but the relationship among the minutiae and ridges in whole was not used in fingerprint matching[5].

A fingerprint matching method based on type of minutiae, attributions of ridge and topological relationship among minutiae and ridges are proposed in this paper, which can achieve excellent results in fingerprint matching, especially in partial and/or nonlinear distorted fingerprint matching. The fingerprint was preprocessed including enhancing, thinning, binarying, ridge closing and pseudo minutiae removing, then the attributions of ridge, the topological relationship were obtained from the minutiae set and the processed fingerprint and at last the matching was performed based on the criterions constructed.

2. Criterion definition

The ridge is the section of line between two minutiae. Type of minutia, the curvature of the ridge, the distance ratio of the lines between the point which has the maximum curvature and the two terminal vertexes of the ridge, the topological relationship among ridges described by included angles of them are used in fingerprint matching. It can be proved that the attributions of minutiae, ridge and the topological relationship among them not only can keep invariant when the fingerprint was rotated and distorted slightly but also can keep good completeness in partial fingerprint.

There are a bifurcation and 3 ridges in figure 1. For ridge ab, point c is the point which has the maximum curvature or the mid-point when the ridge ab is line or arc. The curvature of the ridge which indicated by $\angle acb$ and the distance ratio of the line segment ac and cb are used as ridge attributions. The include angles of the lines between the minutia a and the crossing points of the ridges and the circle with center is a and the radius is r, which is used to express the topological relationship among ridges.

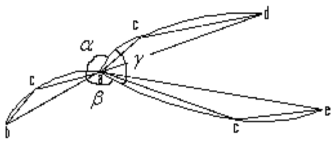

Figure 1. Sketch of topological relationship

The criterion defined above can be expressed as:

$$RCR = \{Id,\ TypeID,\ NrJ,\ (\alpha, Cr,\ Mtne,\ Rol)_i \mid i = 1,2,\cdots,NrJ\}$$

where Id is the ID of the criterion, $TypeID$ is the type of the criterion, $TypeID = 0$ when the criterion describes a pattern consists of ridges with central bifurcation and $TypeID = 1$ when the criterion describes a pattern consists of only 1 ridge with 2 terminations, NrJ is the total number of ridges included, α_i is the included angle of ridges, the order of the included angles is counter clockwise beginning from a optional one when $TypeID = 0$, which make the ring keep changeless in slightly distorted and $\alpha = 0$ when $TypeID = 1$, Cr is the curvature of ridge, $Mtne$ is the type of the minutia at the other end of the ridge, which is termination or bifurcation when $TypeID = 0$ and termination when $TypeID = 1$, Rol is the distance ratio of the lines between the point which has the maximum curvature and the two terminal vertexes of the ridge.

Before criterion constructing, the fingerprint was enhanced using Gabor filter given in [6], binaried using adaptive threshold, thinned and ridge closed using the algorithm presented by [7], and the minutiae were filtered and merged to meet the rule that the distance between two minutiae must larger than twice of the distance between two ridges.

The first step of criterion forming is searching from a unmarked bifurcation to another minutia along the ridge and marked the minutiae using the method presented in [8,9] until all the bifurcation were marked, searching from a unmarked termination along the ridge to another minutia and marked the minutiae until all the termination were marked.

Point with the maximum curvature on the ridge extraction is very important for ridge attributions computing. In this paper, the curvature is computed by the following expression given in [10]:

$$k = sign[(x_i - x_{i-5})(y_{i+5} - y_i) - (y_i - y_{i-5})(x_{i+5} - x_i)]\frac{R_{i1}R_{i2}}{\|R_{i1}\|\|R_{i2}\|}$$

where $R_{i1} = P_i - P_{i-5}$, $R_{i2} = P_{i+5} - P_i$ and (x_i, y_i) is the coordination of P_i. Although k is not the curvature defined in mathematics, it can express the curvature of the ridge exactly and is robust to noise.

The topological relationship among ridges connected by bifurcation is described by their included angles. In include angles computing, usually $r = 6$ and $\alpha = 0$ in the RCR with $TypeID = 1$.

The ridge with two bifurcations must appear in 2 RCRs with $TypeID = 0$. In order to improve the accuracy in fingerprint matching, RCRG is constructed by RCRs with the same ridge and described as:

$$RCRG = \{Id, NoR, IdoRCR_i \mid i = 1,2,\cdots, NoR\}$$

where Id is the ID of RCRG, NoR is the number of RCR included, $IdoRCR$ is the ID of the RCR included.

The procedure of RCRG constructing is as following: the ridge with 2 bifurcations in different RCRs were matching with each other, if two ridges with almost the same curvature and the product of their $Rols$ is almost 1, the 2 ridges were deem to be the same and the 2 RCRs were merged in one RCRG.

3. Matching strategy

Fingerprint is matched in steps and the final matching result is synthetically judged by the matching results in the step-matching.

For RCRs with $TypeID = 1$, if the Cr and Rol of 2 ridges are equal within a presetting error range, the 2 RCRs are considered to be matched. The ID of RCRs are marked down and the number of RCRs matched are added up for the synthetically judgment.

For RCRs with $TypeID = 0$, only if the numbers of the ridges in them are equal, the 2 included angle rings are to be matched. And if the 2 included angle rings are matched, the 2 attributions rings *(Cr, Mtne, Rol)*$_i$ are to be matched according to the order of the included angle in the ring. In *(Cr, Mtne, Rol)*$_i$ matching, if both Cr and Rol of 2 ridges are equal within a presetting error range and the 2 $Mtne$ are the same, the 2 RCRs are considered to be matched. The ID of RCRs are marked down and the number of RCRs matched are added up for the synthetically judgment.

Two RCRGs are deemed to be matched if the numbers of RCRs with $TypeID = 0$ included are equal and the IDs of RCRs with $TypeID = 0$ included are matched respectively. The ID of RCRGs are marked down and the number of RCRGs matched are added up for the synthetically judgment.

Two fingerprints can be deemed to be matched if the number of matched RCRGs $A \geq 70\% \times \min\{m, n\}$ in which m and n are the number of RCRG in the 2 fingerprints. And if $A \leq 20\% \times \min\{m, n\}$, the 2 fingerprints can be deemed not matched, otherwise the matching results depend on the matching of RCR with $TypeID = 0$. The 2 fingerprints can be deemed to be matched if the number of matched RCRs with $TypeID = 0$ $B \geq 70\% \times \min\{\alpha, \beta\}$ in which α and β are the number of the RCR with $TypeID = 0$. And if $B \leq 20\% \times \min\{\alpha, \beta\}$, the 2 fingerprints can be deemed not matched, otherwise the matching results depend on the matching of RCR with $TypeID = 1$. The 2 fingerprints can be deemed to be matched if the number of matched RCRs with $TypeID = 1$ $C \geq 70\% \times \min\{\phi, \gamma\}$ in which α and β are the number of the RCR with $TypeID = 1$. And if $C \leq 20\% \times \min\{\phi, \gamma\}$, the 2 fingerprints can be deemed not matched, otherwise the 2 fingerprints can not be determined matched or not.

4. Summary of the matching algorithm

In order to evaluate this algorithm in fingerprint matching, especially in partial and/or distorted fingerprint matching, two experiments were made as followings:

Experiment 1: Fingerprint matching was executed among a fingerprint (Figure 2a), its distorted and partial images (Figure 2b-g). The criterions of each fingerprint were formed firstly according the algorithms proposed and the number of criterions of each fingerprint is given in Table 1:

Table 1. Number of criterions of fingerprint

	RCRG	RCR with $TypeID = 0$	RCR with $TypeID = 1$
Original	2	12	6
Left rotation	2	12	5
Pin	2	12	6
Barrel	2	12	5
Polynomial	2	12	6
Part 1	2	11	4
Part 2	0	5	3

Figure 2a. Figure 2b. Figure 2c. Figure 2d. Figure 2e. Figure 2f. Figure 2g.

Figure 2a~g. Original image and its left rotation, pin , barrel, polynomial distortion and 2 partials

For 2 RCRs with $TypeID = 1$, if $|Cr_1 - Cr_2| \leq 15\% \times \min\{Cr_1, Cr_2\}$ and $|Rol_1 - Rol_2| \leq 15\% \times \min\{Rol_1, Rol_2\}$, the 2 RCRs are deemed to be matched. Two included angles α_1 and α_2 can be regarded equal if $|\alpha_1 - \alpha_2| \leq 10\% \times \min\{\alpha_1, \alpha_2\}$ and if included angles in 2 included angle rings are equal in turn, the 2 included angle rings are deemed to be matched. Two ridges are deemed to be matched only if $|Cr_1 - Cr_2| \leq 15\% \times \min\{Cr_1, Cr_2\}$, $|Rol_1 - Rol_2| \leq 15\% \times \min\{Rol_1, Rol_2\}$ and the type of another terminal is the same. For RCRs with $TypeID = 0$, only when both the included angles rings and attributions rings of ridges are matched, the 2 RCRs are deemed to be matched. The matching results of the above 7 fingerprints is given in Table 2 in which x/y/z means the number of RCRG matched is x, the number of RCR with $TypeID = 0$ matched is y, the number of RCR with $TypeID = 1$ matched is z.

Table 2. The matching results

Result of matched	Original	Left rotation	Pin	Barrel	Polynomial	Part 1	Part 2
Original	2/12/6	2/12/5	2/8/3	2/8/3	2/9/4	1/10/4	0/4/2
Left rotation	2/12/5	2/12/5	2/8/4	2/8/3	2/9/4	1/10/4	0/4/1
Pin	2/8/3	2/8/4	2/10/6	1/8/2	1/8/3	1/8/2	0/3/1
Barrel	2/8/3	2/8/3	1/8/2	2/10/4	1/8/4	1/9/3	0/3/1
Polynomial	2/9/4	2/9/4	1/8/3	1/8/4	2/11/5	1/8/2	0/3/1
Part 1	1/10/4	1/10/4	1/8/2	1/9/3	1/8/2	2/11/4	0/3/1
Part 2	0/4/2	0/4/1	0/3/1	0/3/1	0/3/1	0/3/1	0/5/3

Experiment 2: Twenty fingerprints from DB1-A of FVC2004 and 80 fingerprins picked up by scaner in our lab were used to test the presented algorithm. There are 700 fingerprints including rotation, barrel distortion, pin distortion, polynomial distortion and 2 partial fingerprints of them. Partial 1 is about 2/3 and partial 2 is about 1/2 of the fingerprint. Each fingerprint was matched with others using the algorithm given. The results of matching are FRR=0.8%, FAR=2.6% and there are about 6％ fingerprints can not be determined, which are almost caused by partial fingerprint for little ridges and minutiae included.

From the above two experiments we can see that the matching algorithm presented in this paper is efficient and has a better performance in partial and/or distorted fingerprint matching. But in distorted fingerprint matching, the matching result is not good as that of the algorithm develped by our lab[11], and partial fingerprint matching results depended on the minutiae and ridge included.

There are two problems in the algorithm, one is the correctness and the completeness of the minutiae extracted from the fingerprint, which are vital to the approach, the other is the algorithm of ridge tracing and attribution computing. Some approved methods must be used to ensure the correctness and the completeness of the minutiae and ridges to make a good basis for our approach.

5. References

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