A Fingerprint Matching Algorithm of Minutia Based on Local Characteristic

Jiong Zang, Jie Yuan, Fei Shi, Si-dan Du

(Department of Electronic Science and Engineering, Nanjing University, Nanjing 210093, China)
(zangjiong2001@hotmail.com, nju.yuanjie@163.com, b041161021@nju.edu.cn,
dsd@ese.nju.edu.cn)

Abstract

To overcome the adverse effect caused by shift and rotation in fingerprint matching, a new method for fingerprint minutia extraction is presented. Since the orientation field around the fingerprint core has a certain specific regularity, we extract the fingerprint reference point and reference direction based on the orientation field of the image. Then we take the reference point as the origin, and the reference direction as the polar axis to establish a polar coordinate system. The fingerprint minutia information which is constituted by minutia point type, polar coordinate and the direction of minutia point is independent of the shift and rotation of the fingerprint. Overall matching is employed here to match two fingerprint images with shift and rotation. Experiments show that this method can effectively eliminate the effects caused by shift and rotation in fingerprint matching, and can be widely used on DSP chips in real-time applications.

1. Introduction

The fingerprint - a biological feature of humankind - has many particular properties such as uniqueness, stableness, and inseparability from the host. It has been used for personal verification for more than one hundred years, and is the most widely used biological recognition technique today. The developments of image processing and pattern recognition technologies have enabled automatic fingerprint recognition, which has a promising prospect of wide application. Here is a simple flow chart of an Automatic Fingerprint Identification System (AFIS)
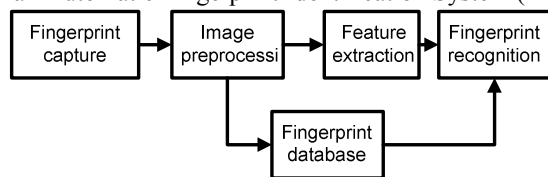
Figure 1. Flow chart of fingerprint identification system

The feature matching is a critical link to the identification system, and the qualities of relevant algorithms directly affect its performances. In this area, there are many algorithms proposed, some of which are based on graphs and images, or ridge structures. Among them, yet, the feature point (minutia) based feature matching algorithms demonstrate many advantages such as simplicity, efficiency, and robustness when compared with other algorithms used. At present, the most popular method for minutia matching is the minutiae coordinate model, which was proposed by FBI. Two kinds of minutiae – bifurcation and ending - are used in this model to identify a fingerprint.

To resolve minutia pattern matching problem, many algorithms were already put forward. For example, Sanjay Ranande and Azriel Rosenfeld used relaxation pattern recognition [1], Chang et al [2] utilized Two-dimensional clustering, and Zsolt et al [3] Triangular matching. It is inevitable that distortions due to shift or rotation happen when fingerprint images are captured. To lessen the adverse effect caused by shift or rotation, we present in this paper a novel point pattern matching algorithm. Through analysis of the orientation field in a local neighborhood at the reference point, we extract reference direction of the fingerprint. Then based on reference point and reference direction, we establish a polar coordinate system to reflect fingerprint feature information. Finally, we employ global matching techniques to obtain the ultimate results. Experiments show that our method gives an efficient solution to eliminate the adverse effects due to image shift and rotation and consequently improve the performance of feature matching process.

2. The reference direction of fingerprints

Before introducing the characteristics of the orientation field, a new concept - the reference direction of fingerprints - should be presented first:

For the fingerprint with two cores, its reference direction is defined as along the link between the two cores; for those with only one core, its reference direction is defined as along the link from the core toward the fingertip.

The orientation field of fingerprint image is depicted in fig 2.a. It describes the tangent direction of each pixel's ridge and valley. The measurement of tangent direction, which could be directly obtained from information in gray scale images, has always been an indispensable step in the area of fingerprint recognition. Inspired by [4] [5], we found that, for those single-core fingerprints, the orientation fields around the core could distinctively indicate regular structural properties:

The core of the fingerprint is defined as the origin and reference direction as the polar axis of the polar coordinates. As observed in fig 2.b, the orientation field in the semicircular region with polar angle ranging from $-\pi$ to $+\pi$, is perpendicular to the polar radial at each pixel.
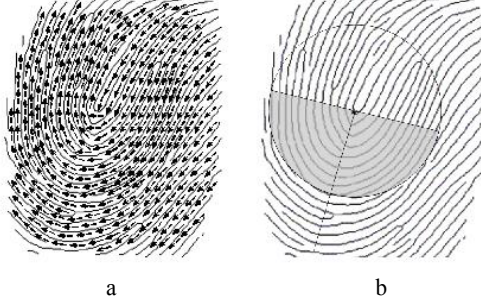

a   b

Figure 2. The orientation field of fingerprint

3. The feature information of the minutia of fingerprint

Generally, the feature information of the fingerprint minutia include: the coordinates and the direction of the minutia.
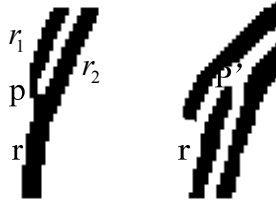

Figure 3. The minutia of fingerprint

(See from Fig 3) We unify the definition of minutia's orientation. Let p be a bifurcation minutia with three ridges incident upon it, namely r, r_1 and r_2, where r is the ridge before bifurcation, r_1 and r_2 are the two ridges after bifurcation. We take the direction toward r as the bifurcation's orientation. And let p' termination minutia. As there is only one ridge r incident upon it, we take the direction against r as the termination's orientation. In this way, even if the quality of fingerprint image is low and the confusion between bifurcation and ending occurs, the direction of the minutia will still maintain the same on the whole. In order to denote the coordinates of the minutia, we should firstly specify the reference point. For the fingerprint with a single core, its reference point is defined as itself; for those with two cores, its reference point is defined as the midpoint of the line connecting the two cores. For the sake of avoiding changes to the mathematical expression of feature information which occur due to image distortions caused by shift and rotation, in this paper, we makes use of minutia coordinate (r,e) and the angle φ between the direction of the minutia and the polar radial in the polar coordinate system, instead of using (x,y) and reference point direction φ' in the Cartesian coordinates.
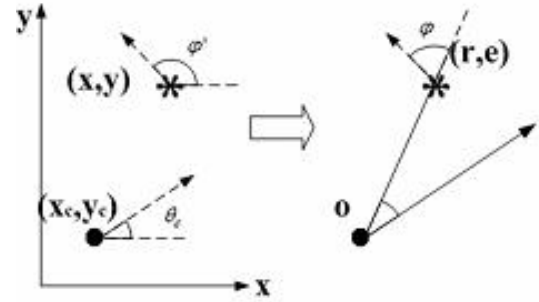

Figure 4. Coordinate transformation of the minutia

Let the reference direction of the fingerprint is θ_c, and the coordinate of the reference point (x_c, y_c), then the feature information $(r, e), \varphi$ are:

$$r = \sqrt{(x - x_c)^2 + (y - y_c)^2} \qquad (1)$$

$$e = arc\tan 2(\frac{y - y_c}{x - x_c}) - \theta_c$$

$$\varphi = \varphi' - e - \theta_c$$

From fig 4, we can find $(r, e), \varphi$ are independent of shift and rotation of the fingerprint image, and therefore could be treated as an effective way to avoid the effects caused by fingerprint shift and rotation.

4. Matching algorithm of fingerprints

We use the methods described in [8] [9] to pre-process the fingerprint image and then employ feature extracting techniques to obtain the orientation field, fingerprint core, and minutia coordinates in the Cartesian coordinate system.

Next, we extract the reference direction of fingerprint. When a fingerprint has two cores, the definition mentioned above should be referred to. Yet here we provide a specific description of an orientation field based reference direction extracting method in the case of single-core fingerprint sample:

1、 First we divide the circular region, where the fingerprint core is located, into small sectors (see fig

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5). The circular area is divided into n*m sectors with each one denoted by a coordinate (i,j).
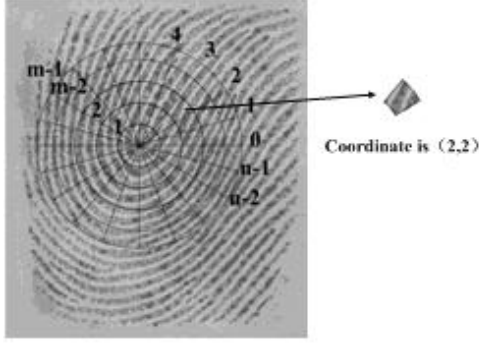
Figure 5. The region of interest sector

2、 Calculate Q_2 - the mean value of the directions of all pixels one the sector, as well as Q' - the direction of polar radial at the center point in the sector. Calculate Q - the angle between Q_2 and Q'

$$q(i, j) = \min(| q'(i, j) - q_2(i, j) | \\ , \pi - | q'(i, j) - q_2(i, j) |) \quad (2)$$

At the same time, we use $A = \sin(Q)$ to quantify the vertical extent between Q_2 and Q', and take it as the eigenvalue of each small sector.

3、 Respectively calculate B - the sum of eigenvalues of the sectors within the semicircular which centers about the polar radial i when we are dividing sectors according to step 1.

$$b(i) = \sum_{j=0}^{m-1} \sum_{k=(i-5)}^{i+4} a((k)_{\mod(n)}, j) \quad (3)$$

Then we get b(t) - the maximum of B. And next, we set the direction of polar radial t as the reference direction of the fingerprint. Fig 6 gives an example of using above method to deal with two sample fingerprints, between which there is a rotation relationship.

When the reference point and reference direction are obtained, we modify the feature information in accordance with equation (1), and yield feature information in the polar coordinate system. Then we sort the template in the polar coordinates and the minutiae of input images in ascending order according to the polar angle. Upon that, denotations are derived as below:
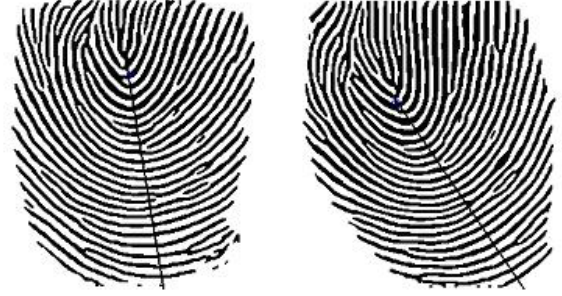

Figure 6. The fingerprint reference direction extraction

$$P_i = \{(r_{i0}, e_{i0}, s_{i0}, \varphi_{i0})^T, ..., \\ (r_{i(n-1)}, e_{i(n-1)}, s_{i(n-1)}, \varphi_{i(n-1)})^T\} \quad (4)$$

$$W_j = \{(r_{j0}, e_{j0}, s_{j0}, \varphi_{j0})^T, ..., \\ (r_{j(m-1)}, e_{j(m-1)}, s_{j(m-1)}, \varphi_{j(m-1)})^T\} \quad (5)$$

Where $(r_{i*}, e_{i*}, s_{i*}, \varphi_{i*})$ and $(r_{j*}, e_{j*}, s_{j*}, \varphi_{j*})$ denote respectively the polar radial, polar angle, type of the point, and direction of the minutia relative to the direction of polar radial. Then, we match every pixel in P_i with every pixel in W_j by utilizing the method of variable bounding box introduced in [6].
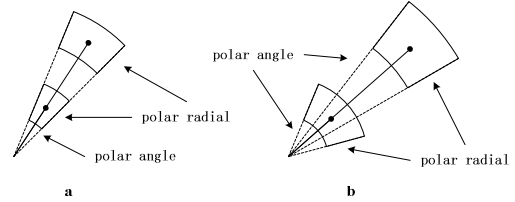
Figure 7. The bounding box
a. Fix bounding box; b. Variable bounding box

As shown in Fig 7, a bounding box is a box which stands at the template minutia, and its size is represented by polar angle and polar radial. Whereas [6] introduced the variable bounding box, whose polar angle and polar radial vary in accordance with the size of the polar radial of the minutia. If a template minutia has a longer polar radial, its bounding box will have a smaller polar angle and a longer polar radial correspondingly. If two minutia P_i and W_j locate in the same bounding box, we consider it as one successful matching.

Finally, suppose that the number of minutiae in two point sets is N_0 and M_0 respectively, and among them M_N pairs are successfully matched. When $M_N / \sqrt{N_0 M_0}$ is larger than a threshold β, we regard the two corresponding fingerprints as exactly the same. Here β represents the geometric mean of the proportions that the numbers of matched minutiae make up in the two point sets. We set $\beta = 0.6$ in our paper.

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5. Experimental results

We use C language to implement our algorithm to an embedded system, which is constructed mainly by a TI-manufactured 16 bit fix-point DSP chip, whose frequency is 300M.

Using this system, we test four databases – DB1, DB2, DB3, and DB4 – which are provided by FVC2000. Specifically, we choose 10 fingerprints from each database, and 8 samples for each fingerprint. After processing these samples by randomly choosing two of them to match, we calculate the Fake Acceptance Rate (FAR) and the False Rejection Rate (FRR) of our method, which are then compared with the method published in [10].

$$FAR = \frac{error\_num}{snum} \qquad (6)$$

$$FRR = \frac{reject\_num}{snum} \qquad (7)$$

Where error_num denotes the number of error matching process, reject_num denotes the number of rejected matching, and snum represent the total number of matching.

Table 1. The result of fingerprint matching of [10]

Database	FRR	FAR
BD1	2.15%	0.16%
BD2	1.91%	0.15%
BD3	2.22%	0.15%
BD4	2.78%	0.12%

Table 2. The result of fingerprint matching of our approach

Database	FRR	FAR
BD1	1.25%	0.05%
BD2	1.21%	0.04%
BD3	1.31%	0.04%
BD4	1.34%	0.05%

Results above confirm that our method could effectively avoid adverse effects caused by linear deformation such as rotation and translation and some degree of nonlinear deformation in process of fingerprint matching. In addition, since mean value of regional directions possesses strong anti-noise capability, even if the image qualities are low, our method is still able to extract accurate reference direction and hence yield preferable matching results.

6. Conclusion

The paper proposes a novel point matching algorithm, which uses fingerprint reference point and reference direction to establish a polar coordinate system for representing feature information of fingerprints. Since the reference point and reference direction defined in this paper are uniquely specified by the image orientation field, and are also independent of fingerprint shift and rotation, method presented here offers a good solution in overcoming the effects caused by fingerprint shift and rotation, yet maintains a comparatively low algorithmic complexity at the same time. Furthermore, experimental results also confirm the strong suitability and high correctness of the proposed method. However, when processing elder people's fingerprints which are usually dry and coarse, we cannot get the orientation field effectively because that serious rupture in the grain of the fingerprint as well as extreme blurring of the image will bring a large number of false minutiae and prevent us from extracting reference direction accurately. Our next attention will be paid to improving our algorithm for dealing with such kind of fingerprints, and great efforts need to be made in the future.
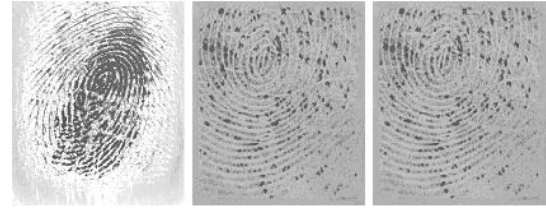
Figure 8. The fingerprints of elder people.

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