

AUTOMATIC PALMPRINT VERIFICATION

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Automatic palmprint verification is an important complement of biometric authentication. As the first attempt of personal identification by palmprint, this paper explores different methods for three main processing stages in palmprint verification including datum point registration, line feature extraction and palmprint classification. The datum points of palmprint which have the remarkable advantage of invariable location are defined and their determination method using the directional projection algorithm is improved. Then, line feature extraction and line matching method is described to detect whether a couple of palmprints are from the same palm. In addition, palmprint classification method based on the orientation property of the ridges is discussed to distinguish six typical cases. Various palmprint images have been tested to illustrate the effectiveness of the proposed methods.

Keywords: Biometric Authentication; Palmprint Verification; Datum Point Registration; Line Feature Extraction; Palmprint Classification.

1. Introduction

Currently, there have been two main approaches, fingerprint and hand geometry, in personal identification which are based upon the measurement and comparison of the features extracted from the person's hand.^{1–3} Fingerprint identification is the most widespread application of biometrics technology where some small unique features (known as minutiae) are used to build the corresponding eigenspace. However, it is still a difficult task to detect the minutiae from the fingers of elderly people as well as manual labourers.⁴ For hand identification with the three-dimensional shape, one could fool it by capturing a person's hand geometry and creating a fake hand.²

Palmprint can be considered as one of the reliable means distinguishing a man from his fellows because of its stability and uniqueness.⁵ It shows that many useful characteristics, besides those extracted from both fingerprint and hand shape, can be simultaneously obtained in palmprint.^{6–7} The case of automatic palmprint

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verification as biometric system, however, is little explored. In this paper, we will introduce some main methods applied to different processing stages in palmprint verification to comprehensively develop personal identification by palmprint.

First of all, definition and notation of palmprint are given as follows. In fact, palm is the inner surface of the hand between the wrist and the fingers. Palmprint is composed of principal lines, wrinkles and ridges. There are usually three principal lines made by flexing the hand and wrist in the palm which are named as heart line, head line, and life line respectively (see Fig. 1). Both location and form of principal lines in a palmprint are very important physical features to identify individual because they vary slowly from time to time. Two endpoints, a and b , are obtained by the principal lines (i.e., life line and heart line) which intersect the both sides of palm. Owing to the stability of the principal lines, the endpoints and their midpoint o remain unchanged day in and day out. Some significant properties can be defined in the following: (1) the locations of the endpoints, a and b , and their midpoint o are rotational invariant in a palmprint; (2) a sole two-dimensional right angle coordinate system can be established, of which the origin is the midpoint o and the main axis passes through the endpoints; (3) a palm can be divided into three regions including finger-root region I, inside region II, and outside region III, by some connections between the endpoints and their perpendicular bisector; (4) the size of a palm can be uniquely estimated by both the Euclidean distance between two endpoints and the length of their perpendicular bisector in the palm. In this way, the pair of endpoints and their midpoint will act as the important datum points in our palmprint verification because of their invariable locations.

In addition to the datum points, there still exists rich and useful information in a palmprint. According to the width of wrinkles, we can classify them into coarse wrinkles and fine wrinkles so that more features in detail can be acquired. In a palmprint, these wrinkles are different from the principal lines in that they are thinner and more irregular. Both principal lines and coarse wrinkles are defined

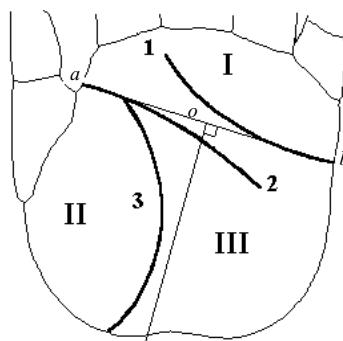


Fig. 1. Definitions of a palmprint: principal lines (1 — heart line, 2 — head line and 3 — life line), regions (I — finger-root region, II — inside region and III — outside region) and datum points (a , b — endpoint and o — midpoint between them).

as line features which are applied in our palmprint verification. Compared with fingerprint identification which is a point matching process, this palmprint verification by using line feature matching is effective in the following respects: (1) it could be used on the image with low spatial resolution so that the size of a palmprint image can be reduced even it is comparable to that of a fingerprint image; (2) significant features can be determined in case of the presence of noise because of feature extraction relied on low spatial resolution; (3) palmprint verification is a line matching process which has several advantages over point matching since a line has more information than a point.

Furthermore, it is well known that the flow characteristics of ridges are regular. There are some classes of ridges in palmprint, such as loop, whorl and arch formed by ridges (see Fig. 2). As a result, singular points including core and delta points defined in Ref. 8 can appear in the palmprint. This makes it possible to obtain these features and well establish the stability and uniqueness in palmprint classification. Of course, some other kinds of features such as geometry feature and minutiae feature can also be extracted from a palmprint. However, we do not use them in

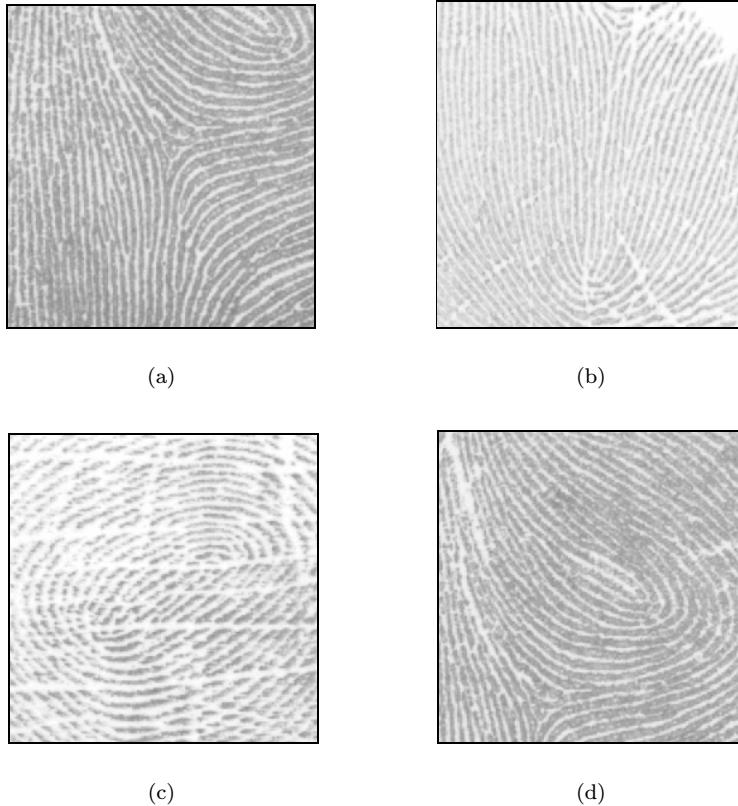


Fig. 2. Classes of ridges in palmprint. (a) Delta point, (b) arch, (c) whorl, (d) loop.

our methods because geometry feature is easily captured so that a fake palm could be created and minutiae features can only be obtained from a high quality image.

Palmprint verification which is to determine whether two palmprints are from the same palm can apply some useful features mentioned above to verify the identity of a live person in principle. How to determine the datum points which act as the registrations in palmprint verification will be demonstrated in Sec. 2. Section 3 presents palmprint feature extraction and matching method based on line features. Palmprint classification using the orientation property of the ridges is described in Sec. 4. Experimental results of the proposed methods are discussed in Sec. 5.

2. Datum Point Registration

The goal of determining datum point is to achieve the registrations in palmprint feature representation and matching. As a prime but important process in the palmprint verification, datum point determination is demanded as simple and effective as possible. Its basic idea is to locate the endpoints, a and b , of the principal lines related. According to the given regularity, the principal lines and their endpoints can be accurately detected by using the directional projection algorithm.⁷ However, it is still difficult to trace the principal line in the case of the life line crossed by many wrinkles. As a result, the directional projection algorithm to determine the datum points should be improved by this section.

2.1. Determining datum point b

Projection is a simple yet effective method of line segment detection along some orientation. Let F be a $(2m+1) \times (2n+1)$ gray scale sub-image and $f(x, y)$ be the gray level of pixel, (x, y) ($x = -m, -m+1, \dots, m-1, m; y = -n, -n+1, \dots, n-1, n$). Obviously, the horizontal projection of this sub-image is:

$$p(y) = \sum_{i=-m}^m f(x, y). \quad (2.1)$$

The smoothed set $q(y)$ is calculated as:

$$q(y) = \frac{1}{2w+1} \sum_{k=-w}^w p(y+k). \quad (2.2)$$

Then, the pixel $(0, y_0)$ where,

$$y_0 = \{k | q(k) = \max_y q(y)\}, \quad (2.3)$$

is detected and the corresponding pixel in F is defined as pixel (i_0, j_0) where,

$$\begin{aligned} i_0 &= i' + y_0 \cos\left(\alpha + \frac{\pi}{2}\right), \\ j_0 &= j' + y_0 \sin\left(\alpha + \frac{\pi}{2}\right). \end{aligned} \quad (2.4)$$

Here, this basic algorithm is classified as four forms by the different projective orientations: horizontal projection ($\alpha = 0^\circ$), projection with 45 degrees ($\alpha = 45^\circ$), vertical projection ($\alpha = 90^\circ$) and projection with 135 degrees ($\alpha = 135^\circ$).

From the study of the principal lines, their properties can be obtained as follows: (1) each principal line meets the side of palm at approximate right angle when it flows out the palm; (2) the life line is located at the inside part of palm which gradually inclines to the inside of palm in parallel at the beginning; (3) most of the life line and head line flow out the palm at the same point; (4) the endpoints are closer to fingers than wrist. Based on the projective correspondence (see Fig. 3), it is clear that the pixel (x, y) calculated by the basic algorithm belongs to the horizontal principal line if the parameter w , in Eq. (2.2) is equal to the half width of a principal line. However, the pixel on the other different kinds of lines cannot be determined by means of the conditions given above. This is because the projection of line which is not in parallel with the projective orientation or is shorter than the principal line would be less than that of principal line. In addition, a thin line

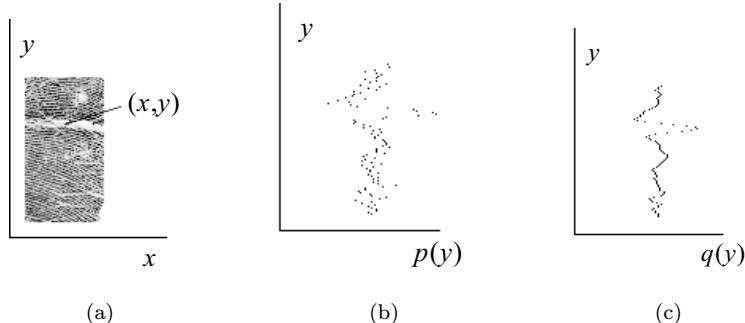


Fig. 3. Sketch map of the horizontal projection. (a) Original image, (b) horizontal projection, (c) after filtering.

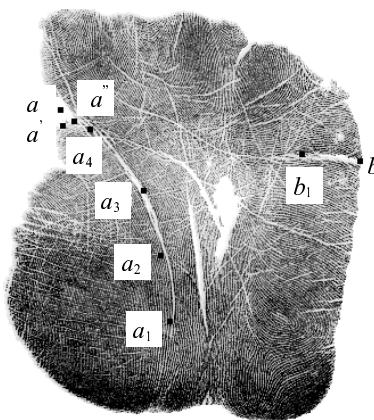


Fig. 4. Track of datum point determination by using the improved directional projection algorithm.

might map to the maximum value in the directional projection $p(y)$ s, but, it could be reduced after smoothing. So, the basic algorithm can be used to locate the pixel only on the principal line while the directional projection along the principal line is maximized in a palmprint sub-image.

The heart line is easily detected by using the algorithm mentioned above because there is only one principal line in the outside part of palm. The basic idea is to estimate the datum point by tracing the heart line as a point is detected on it (see Fig. 4). After the edges of both outside and topside are obtained, a pixel that has suitable offsets to two edges is adopted in palmprint. The horizontal projection algorithm can locate point b_1 which belongs to heart line. According to the peculiarities of heart line, the algorithm is also not difficult in locating endpoint b to a sub-image where there is a pixel situated at the outside edge with the same level as pixel b_1 .

2.2. Determining datum point a

The detection of life line cannot use the horizontal projection in the inside part of palm since the head line is determined sometimes instead of the life line while their flowing out palm at the different points. Therefore, the vertical projection algorithm processes another sub-image close to wrist and point a_1 on the life line is calculated. Since the detection of endpoint a is difficult from that of endpoint b because the life line is a curve from pixel a_1 to point a , we can improve the projection algorithm to locate point a correctly. The details of the improved algorithm are shown below,

Step 2.1. Point a' , (i_{00}, j_0) , is defined by the straight line which is a connection between endpoint, b and b_1 , intersecting the inside edge of palm.

Step 2.2. A sequence $\{(i_{y0}, j_y), y \in [-n, n]\}$ is given by:

$$j_{y+1} = j_y + 1, B(i_{y0}, j_y) = 0 \text{ and } B(i_{y0} - 1, j_y) = 1, \quad (2.5)$$

where $B(i, j)$ is the value of pixel (i, j) in the binary image; 0 and 1 represents background and palm respectively.

Step 2.3. Both the maximum value and the mean of the sequence i_{\max} and E_i are calculated. Then, a function is defined as:

$$w(i_{y0}) = (i_{\max} - E_i) \exp\{-\alpha(i_{y0} - i_{\max})\}, -n \leq y \leq n, \quad (2.6)$$

where α is a constant.

Step 2.4. The improved horizontal projection is denoted as:

$$p(y) = w(i_{y0}) \times \sum_{k=-m}^m f(i_{yk}, j_y), -n \leq y \leq n, \quad (2.7)$$

where $f(i, j)$ is the gray level of pixel (i, j) .

Step 2.5. Generate $q(y)$ by smoothing $p(y)$. Then, pixel (i_{Y_0}, j_Y) where,

$$Y = \{k | q(k) = \max_y q(y)\}, \quad (2.8)$$

is located.

Step 2.6. Confirm the datum point. In sequence $\{(i_{y_0}, j_y), y \in [-n, n]\}$, let,

$$\Delta i_1 = |i_{Y_0-\Delta n} - i_{Y_0}| \text{ and } \Delta i_2 = |i_{Y_0+\Delta n} - i_{Y_0}|, \quad (2.9)$$

where Δn is an offset. If both Δi_1 and Δi_2 are less than some threshold T_1 , the pixel (i_{Y_0}, j_Y) is defined as the point a ; if they are more than T_1 , the pixel $((i_{Y_0-\Delta n} + i_{Y_0+\Delta n})/2, j_Y)$ is as a ; if Δi_1 is more than T_1 and Δi_2 is less than T_1 , the pixel $(i_{Y_0-\Delta n}, j_Y)$ is as a ; otherwise, the pixel $(i_{Y_0+\Delta n}, j_Y)$ is as a .

It is evident that the improved directional projection algorithm can easily obtain datum points in a palmprint. Since these datum points have the remarkable advantage of invariable location, it is also simple to determine the midpoint o based on the endpoints a and b . In this way, a sole two-dimensional right angle coordinate system for a palmprint can be established to achieve the palmprint's registration.

3. Line Feature Verification

There are mainly two operations in our palmprint verification, feature extraction and feature matching. Owing to line features adopted to identify the individual, line feature extraction and line matching are proposed. Obviously, line feature includes curves and straight lines. In fact, most line features can approximate straight line segments except the principal lines. Based on our observation, the curvature of the principal lines is small enough to be represented by several straight line segments. The representation and matching of straight lines are simple, hence, line features are considered by using straight line segments in this section. The measurement of palmprint matching will be also described.

3.1. Line feature extraction

Line feature extraction is always an important yet difficult step in image verification and many line feature detection approaches have been proposed.⁹ Most of these

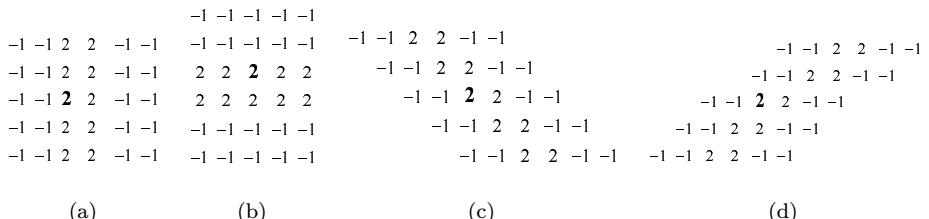


Fig. 5. Four different directional templates for line segments determination. (a) Vertical, (b) horizontal, (c) left diagonal, (d) right diagonal.

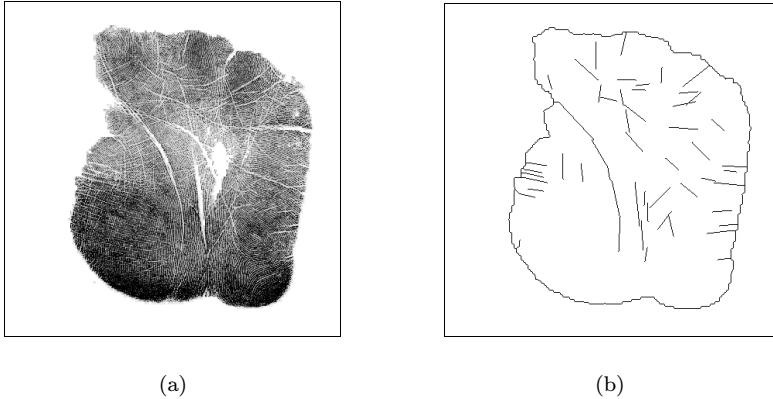


Fig. 6. Result of line feature extraction. (a) Original image, (b) map with line features extracted.

approaches cannot generate a precise line map for stripe images such as palmprint images besides template algorithm. Nevertheless, many ridges and fine wrinkles have the same width as coarse wrinkles except that they are shorter in inked palmprint image. Even using the template algorithm, it is also difficult to acquire the line features from a palmprint, this is because a mass of ridges and fine wrinkles could dirty the line features. Here, we will improve on this algorithm so as to extract and post-process line segments of each orientation respectively and then combine them. The improved template algorithm consists of the following steps:

- (i) Determine vertical line segments by using the vertical template [see Fig. 5(a)] and then thin and post-process these line segments. The rule of the post-processing is to clear up the short segments remained in the image.
- (ii) Similarly, detect horizontal, left diagonal and right diagonal line segments by the corresponding templates [see Figs. 5(b)–5(d)].
- (iii) Combine the obtained results by four different templates and then post-process once more to eliminate the overlapped segments.

After these steps, the result of extracting line feature by the improved template algorithm is shown in Fig. 6.

3.2. Line matching

In general, there are many ways to represent a line. One way which is always possible is to store the endpoints of every straight line segment.¹⁰ In a two-dimensional right angle coordinate system which is uniquely established by the datum points, line segments can be described by endpoints: $(X_1(i), Y_1(i)), (X_2(i), Y_2(i)), i = 1, \dots, I$ where I is the number of line segments. Without loss of generality, exchange the endpoints of each line segment so that $X_1(i) \leq X_2(i)$, $i = 1, \dots, I$. If $X_1(i) = X_2(i)$, exchange the endpoints so that $Y_1(i) \leq Y_2(i)$. Then, three parameters of each line segment including slope, intercept and angle of inclination can be calculated

as follows,

$$\text{slope } (i) = (Y_2(i) - Y_1(i))/(X_2(i) - X_1(i)), \quad (3.1)$$

$$\text{intercept } (i) = Y_1(i) - X_1(i) \times \text{slope } (i), \quad (3.2)$$

and,

$$\alpha(i) = \tan^{-1}(\text{slope } (i)). \quad (3.3)$$

The object of matching is to tell whether two line segments from a couple of palmprint images are the same. The two-dimensional right angle coordinate system established for a palmprint can act as the important registration in line feature matching. For example, two line segments extracted by different images can be represented as $(X_1(i), Y_1(i))$, $(X_2(i), Y_2(i))$ and $(X_1(j), Y_1(j))$, $(X_2(j), Y_2(j))$ respectively. And the Euclidean distances between the endpoints of two line segments are denoted as:

$$\nabla_1 = \sqrt{((X_1(i) - X_1(j))^2 + ((Y_1(i) - Y_1(j))^2}, \quad (3.4)$$

$$\nabla_2 = \sqrt{((X_2(i) - X_2(j))^2 + ((Y_2(i) - Y_2(j))^2}. \quad (3.5)$$

Without question, the following conditions for line segment matching can be proposed: (1) if both ∇_1 and ∇_2 are less than a threshold D , then, it is clear to indicate that two line segments are same; (2) if the difference of angle of inclination (difference between two line segments) is less than a threshold β and that of intercepts is less than a threshold B then, it shows that two line segments have the equivalent angle of inclination and intercept. Within class of equal angle of inclination and equal intercept, if one of ∇_1 and ∇_2 is less than D , two line segments clearly belong to the same one; (3) while two line segments overlap, they are regarded as one line segment if the midpoint of one line segment is between two endpoints of another line.

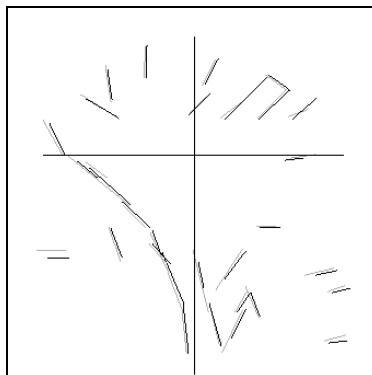


Fig. 7. Results of a pair of palmprint matching by using line features.

3.3. Verification function

By applying the above rules of line feature matching to a couple of palmprint images, we can achieve the corresponding pairs of lines (shown as Fig. 7). The verification function r is defined as:

$$r = N/(N_1 + N_2 - N), \quad (3.6)$$

where N is the number of these corresponding pairs; N_1 and N_2 are the numbers of the line segments determined from two different palmprint images respectively. In principle, it shows that two images are from one palm if r is more than a threshold T which is valued between 0 and 1.

4. Palmprint Classification

Palmprint classification is to compare the feature measures of a palmprint to known criteria and determine if this palmprint belongs to a particular class of palmprints. Although the coarse classification cannot identify a palmprint uniquely, it is helpful to determine if two different palmprints can match together. So far, there is no any paper working on automatic classification in palmprint verification.

In general, the number and the corresponding location of the principal lines may be applied to the coarse-level palmprint classification. However, it is difficult to detect some principal lines missed in the middle of inked palmprint image. In this section, we develop a classification method by using the orientation property of ridges on the palmprint image.

There are some classes of ridges in a palmprint such as loop and whorl, but, the techniques used in fingerprint classification are not suitable for palmprint since always more than one ridge class can appear in a palmprint image.¹¹ One of the effective methods is to classify them by the number of singular points obtained and the corresponding distribution. So, an important task in our classification method is to determine singular points and their relationship.

4.1. Singular point detection

A point in the directional image is classified as an ordinary point, core or delta by computing the field the Poincaré index (PI) along a small closed curve around the point.¹¹ We can obtain the PI by summing up the changes in the direction angle around the curve. It shows that the PI of delta point is positive and that of core point is negative when a full counter-clockwise turn is made around the curve in a directional image. In our palmprint application, the algorithm to detect singular points can be simplified as follows,

- (i) Generate a four-direction image. Four directions are defined as vertical, horizontal, left diagonal and right diagonal.¹² These directions can be represented by 90, 0, 135 and 45 degrees respectively.

- (ii) Detect singular points. In the directional image, a pixel whose eight neighborhoods have more than two directions can be confirmed as a singular point. According to their PIs, core and delta points are then distinguished.
- (iii) Eliminate the false singular points. Based on our experiments, some rules to delete the false points can be given. If a pair of core points (or delta points) is too close, then, they are considered as one core point (or delta point); if a core point nears to a delta point, all of them are taken away.

As a result, Fig. 8 shows that two singular points, core and delta represented in an original image and its directional image respectively. It is not doubtful that the singular points in the directional image can be simply found out.

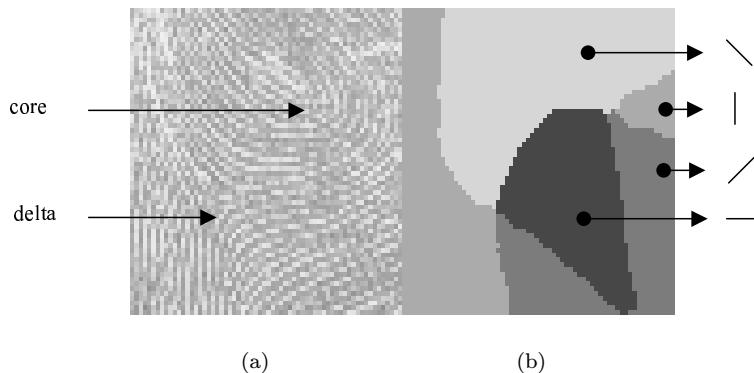


Fig. 8. Singular points in both original image and directional image. (a) Original image, (b) directional image.

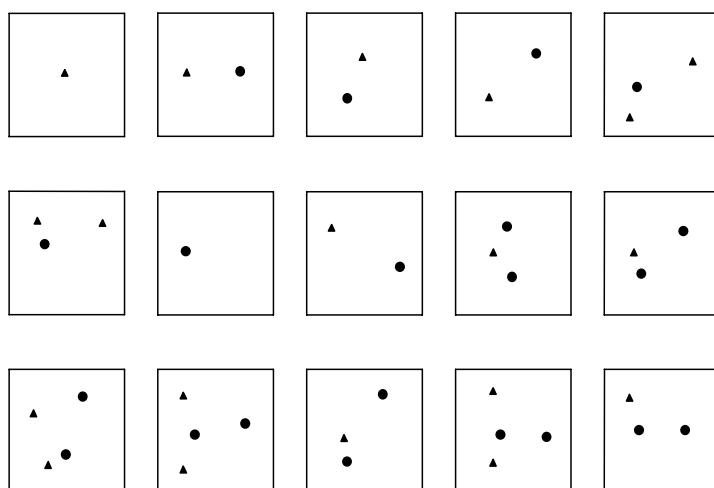


Fig. 9. Typical contribution map of singular points at outside region of palmprint (“ Δ ” — delta point and “.” — core point).

4.2. Outside region classification

We can always get a complete outside region from an inked palmprint image. There are abundance shapes consisting of the singular points at the outside region. From hundreds of palmprint images, we summarize sixteen different contribution maps based on the number and their location of singular points (see Fig. 9).

For simplicity, in this section, we use only the number of singular points at the outside region as known criterion to classify palmprint images. It shows that

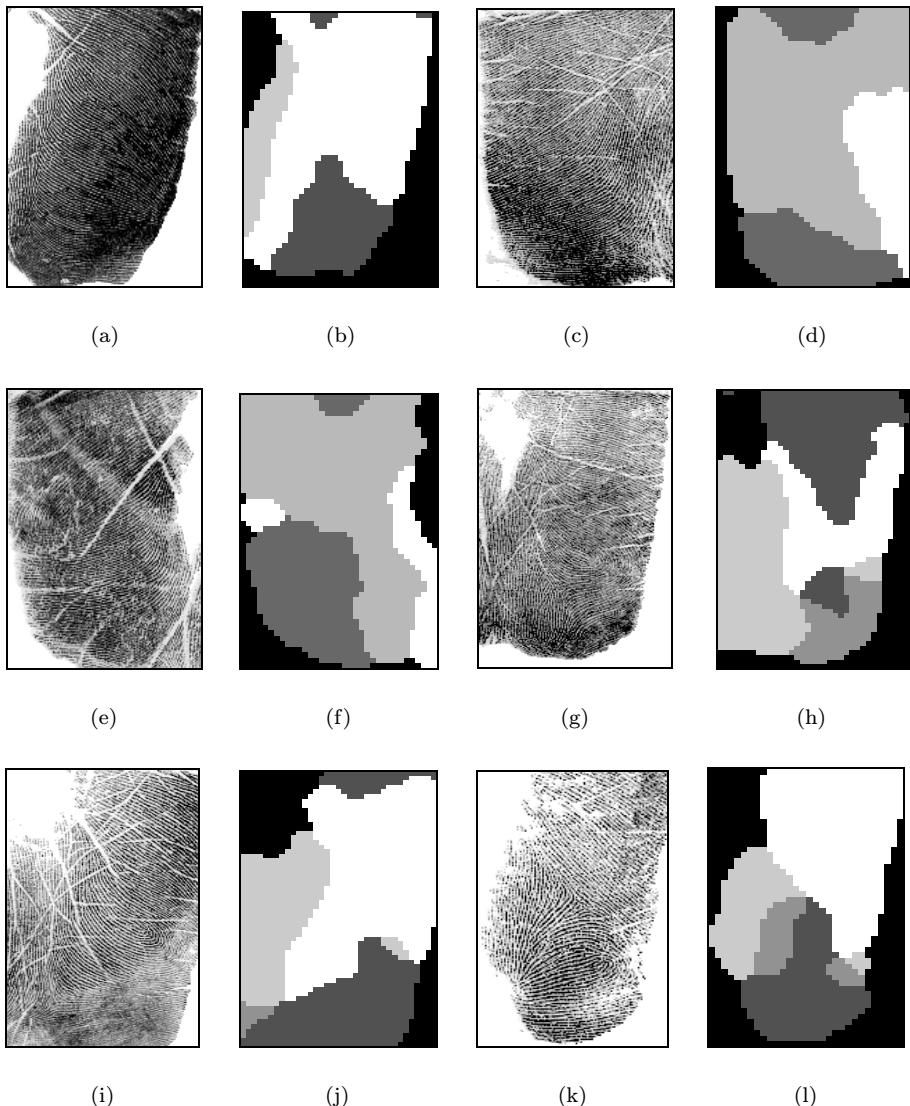


Fig. 10. Demonstration of six kinds of cases at outside region. (a) and (c) Original image, (b) and (d) directional image, (e), (g), (i) and (k) original image, (f), (h), (j) and (l) directional image.

there are six typical cases given in our palmprint classification, including (a) no singular point; (b) one delta point; (c) one core point; (d) one core point and delta point; (e) two delta points and one core point; and (f) others. All kinds of cases for palmprint classification, both original and directional images, are demonstrated in Fig. 10.

5. Experimental Results

The method of datum point determination has been tested by many 400×400 gray-scale inked palmprint images. Of the datum points calculated in the 300 palmprint images, 286 are found to be in excellent agreement with the manual estimate. In particular, this method can be used to estimate the datum points with 60 special palmprint images which 20 belong to under rotation, 35 to incomplete and 5 to those life line and head line flow out the palm at different points. Some typical palmprint

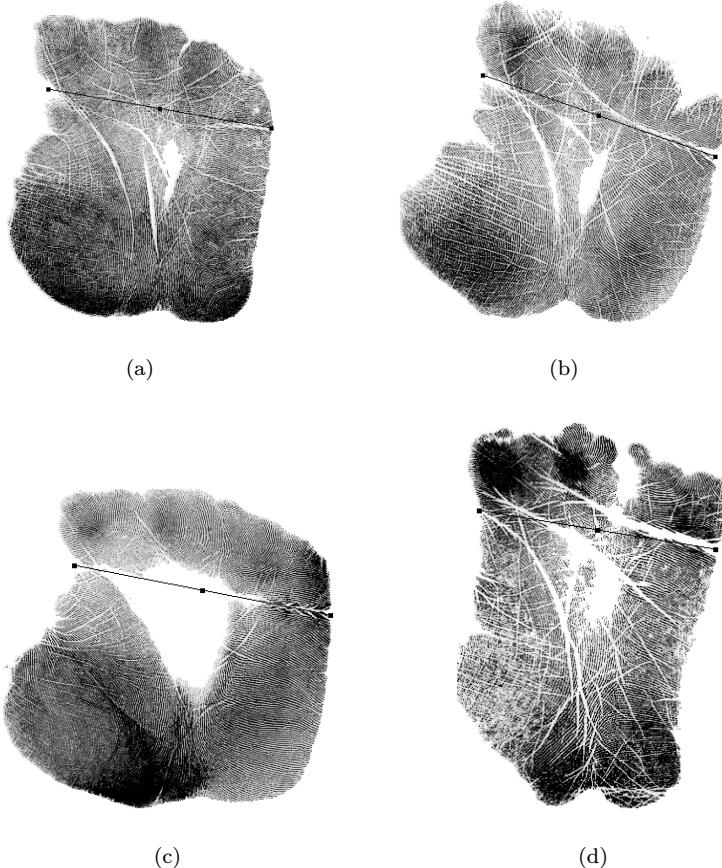


Fig. 11. Examples of datum points determination. (a) Normal palmprint, (b) rotated palmprint, (c) incomplete palmprint, (d) life line and head line unintersection.

images are shown in Fig. 11 and the results of the datum points detection to these special images are listed in Table 1.

Palmprint verification with both datum point invariance and line feature matching is also tested by 200 palmprint images from 20 right palms. A slippery pair of statistics known as false rejection rate (FRR) and false acceptance rate (FAR) represents the measure of experimental result. In this experiment, some thresholds are adopted as $D = 5$, $\beta = 0.157$ and $B = 10$. The results with various thresholds T are shown in Fig. 12 and the palmprint verification can obtain an ideal result while T is between 0.1 to 0.12.

In order to test our classification method based on singular points, 354 palmprint images at outside region are measured to classify six typical classes defined in

Table 1. Experimental results of datum points determination in special palmprint images. Note: R = rotated image; I = incomplete image; U = life line and head line unintersection.

Classification	R	I	U
Experiment images	20	35	5
Accurate determination images	19	33	4
The rate of accuracy (%)	95	94	80

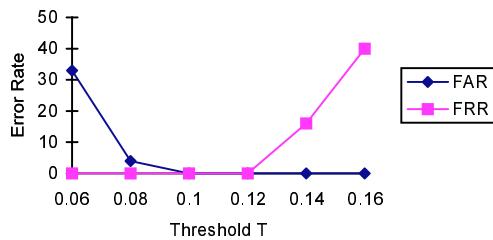


Fig. 12. Experimental results for FAR and FRR ($D = 5$, $\beta = 0.157$ and $B = 10$).

Table 2. Classification result in outside region.

Assigned class	True class					
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>
<i>a</i>	132	4	1	2	0	0
<i>b</i>	0	149	0	0	0	2
<i>c</i>	0	0	15	1	0	0
<i>d</i>	0	0	0	27	1	0
<i>e</i>	0	0	0	0	8	0
<i>f</i>	0	0	0	0	0	12

Sec. 4. Table 2 lists their classification results which around 97% correct rate can be obtained. The experiments show that our method is acceptable.

6. Conclusions

This paper develops some effective methods for automatic palmprint verification by using datum point registration, line feature extraction and palmprint classification. Datum points are defined in palmprint registration because of their stability. The improved directional projection is designed to locate the principal line as well as to accurately determine the endpoints. A number of palmprint images have been tested and the experimental results show that most of datum points are in excellent agreement with the manual estimate. The computation of the proposed method is simple and logical.

The template method of line feature extraction is improved and several rules are applied to match the line features in palmprint verification. Many palmprint images are determined by both datum point invariance and line feature matching and the experimental result shows that the verification accuracy is acceptable. The palmprint verification method based on line feature is also foolproof because these significant physiological features are unique, unchanging, and cannot be forged and transferred. In addition, the palmprint coarse-level classification is analyzed. The developed method by using the orientation property of ridges on the inked palmprint image is quite useful for six typical classes. As an important complement of automated biometric authentication, the palmprint verification proposed in this paper can be effectively used to identify individual.

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