Fingerprint Reference Point Detection Based on Local Axial Symmetry

Tong Liu[1], Chao Zhang[1] and Pengwei Hao[1,2]
[1]National Laboratory on Machine Perception, Peking University, Beijing, 100871, China
[2]Deptartment of Computer Science, Queen Mary, University of London, E1 4NS，UK
chzhang@cis.pku.edu.cn

Abstract

Reference point detection is an important process for fingerprint analysis. In this paper, we propose a novel feature which is named local axial symmetry (LAS) and present an algorithm to calculate reference point of a fingerprint based on this kind of feature. Experimental results demonstrate its feasibility, validity and the ability to detect reference points of all classes of fingerprints including arch-type fingerprints which is difficult to locate a stable reference point with other methods.

1. Introduction

The reference point is one of the most important global features of fingerprint images. Its reliable localization and accurate direction estimation lead to a dependable registration which provides a stable ground for fingerprint analysis such as classification, indexing and recognition.

Most of the algorithms to detect reference point of fingerprint image in the literature treat reference point as the upper core (one of the Singular Points (SPs)) and its detection is a byproduct of SP detection. Tico et al. [1] proposed an algorithm based on multi-resolution representation of orientation field and certainty level. Nilsson et al. [2] designed a multi-scale filter for a complex valued directional tensor field image and measured certainty of SPs with intensity of the response. Liu et al. [3] introduced a "T" shape model to detect SPs and estimate their directions. There is an implied limitation of such approaches: no singular point exists in plain arch-type fingerprints, so the approaches will fail in such situations. Otherwise, Jiang et al. [4] proposed a hierarchical analysis of orientation coherence to locate a unique reference point. In [5], Park et al. presented a reference point detection algorithm based on orientation pattern labeling.

All the above approaches exploited orientation field or Poincaré index as the features to perform localization work. In noisy fingerprint images, these two features are not very consistent and reliable. Moreover, the directions of reference points are rarely estimated in the above literature. In this paper, we introduce a novel feature called local axial symmetry (LAS) and present an approach for straightforward localization and direction estimation of reference points based on it. Our LAS can deal with the noise in images sophisticatedly and is stable to image rotation, translation and small distortion, which is shown by the satisfied experimental results.

This paper is organized as follows. In Section 2, the LAS is introduced and discussed in detail. In Section 3, it is utilized to localize reference points and estimate their directions simultaneously. In Section 4, some experimental results are presented. Finally, the conclusion is drawn in Section 5.

2. Local Axial Symmetry

For fingerprint analysis, orientation field (OF) and Poincaré index (PI) are two important features. OF is computed directly from fingerprint images, so we call it a 1-order feature. For convenience, we name the pixel-wise computed OF as POF and the block-wise computed OF as BOF. PI, which was first introduced in [6], is a widely exploited feature in detection of SPs. It is computed from OF, so we call it a 2-order feature. PI is not very robust to noise, so a lot of spurious SPs are detected from PI based on origin OF. To overcome this drawback, PI calculation is always performed alternately with OF smoothing till valid SP numbers are reached. Such mechanics can not guarantee SP detection and further reference point localization. Another limitation of PI is its incapacity to detect reference points of arch-type fingerprints. In this paper, we present a novel feature also obtained from OF but more robust to noise and efficient to arch-type fingerprints.

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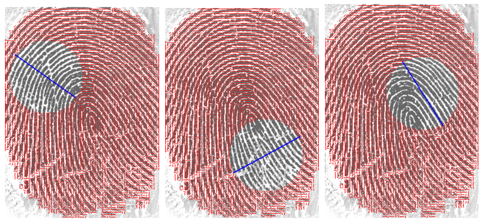

Fig. 1 Illustration of LAS: the sections in the round regions represent their optimized symmetry axes.

As can be easily seen, the OFs in most regions of fingerprint images exhibit high axial symmetry, which is illustrated in the first two images in Fig. 1. But in region like that in the last image, even axis which maximizes the axial symmetry is picked out, the divided two parts seem to be very dissimilar to each other. Due to their sparsity, if the latter type of regions can be recognized steadily, they can be utilized to detect reference points of fingerprint images.

Based on above observations, we proposed a novel fingerprint feature which is named as Local Axial Symmetry (LAS). It is also obtained from OF. The approach used to calculate POF in our work is squared gradient averaging method in [7], which is briefly described by equation (1), where $[G_x, G_y]'$ is the gradient vector of point (x_0, y_0) and W is the averaging window. Note that POF here presents the doubled value of pixel-wise orientation angle.

$$\begin{bmatrix} POF_x(x_0,y_0) \\ POF_y(x_0,y_0) \end{bmatrix} = \begin{bmatrix} G_{xx} - G_{yy} \\ 2G_{xy} \end{bmatrix}$$
$$G_{xx} = \sum_W G_x^2$$
$$G_{yy} = \sum_W G_y^2 \tag{1}$$
$$G_{xy} = \sum_W G_x G_y$$

To measure the local axial symmetry of a given region, we first cut out a circle in POF with a certain radius as the region of interest (ROI) centered at (x_0, y_0) which is also the center of the region. Then we divide it into N homocentric sectors with a series of equally distributed radii which are also the set of candidate symmetry axes of the region. The average orientation of every sector, namely AOS, is calculated according to (2) and (3), where S_i is the *i-th* sector of the ROI and $|S_i|$ is the number of pixels in S_i.

$$\begin{bmatrix} AOS_x(S_i) \\ AOS_y(S_i) \end{bmatrix} = \begin{bmatrix} \frac{1}{|S_i|}\sum_{(x,y)\in S_i} POF_x(x_0,y_0) \\ \frac{1}{|S_i|}\sum_{(x,y)\in S_i} POF_y(x_0,y_0) \end{bmatrix} \tag{2}$$

$$AOS(S_i) = \arctan2(AOS_y(S_i), AOS_x(S_i)) \tag{3}$$

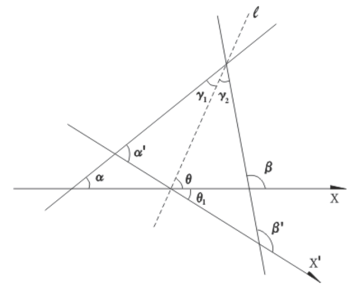

Fig 2. Illustration of the calculation and rotation independence of LAS.

Consider the *i-th* candidate axis, which the corresponding direction is $\frac{i*2*PI}{N}$. The counterpart sector of S_{i+j} is S_{i-j-1}. As illustrated in Fig. 2, if the conjugated sectors which orientations are α and β take a line of direction θ as their symmetry axis, (4) must be satisfied. Thus we can use $\cos(2\alpha + 2\beta - 4\theta)$ to weigh the axial symmetry: the larger this value is, the more axial symmetry with regard to l can be expected.

$$\begin{aligned} &\gamma_1 = \gamma_2 \Leftrightarrow \theta - \alpha = \beta - \theta \\ &\Leftrightarrow \alpha + \beta - 2\theta = 0 \Leftrightarrow 2\alpha + 2\beta - 4\theta = 0 \end{aligned} \tag{4}$$

In fact, $AOS(S_i)$ is twice the orientation angle of sector S_i, so the symmetry value with respect to *i-th* candidate axis and local axial symmetry of point (x, y) are defined as (5) and (6) respectively. The corresponding orientation of $\hat{i}$ which maximizes (5) gives the symmetry axis of this region.

$$Sym(i) = \frac{2}{N}\sum_{j=0}^{N/2-1}\cos\left[AOS(S_{i+j}) + AOS(S_{i-j-1}) - \frac{4*i*2*PI}{N}\right] \tag{5}$$

$$LAS(x,y) = \max\{Sym(i) \mid i \in [0,1,..N/2)\} \tag{6}$$

In Fig. 2, x and x' are the origin x-axis and rotated x-axis of the image. l is the candidate symmetry axis. θ is the direction angle of l. α, α', β and β' are the average orientations of the sector pair (half of AOS) in the two coordinate systems. Then (4) and (7) prove that the LAS is rotation-independent. Obviously it is also translation-independent according to its definition.

$$\begin{aligned} &\because \alpha' = \alpha + \theta_1, \beta' = \beta + \theta_1, \theta' = \theta + \theta_1 \\ &\therefore 2\alpha' + 2\beta' - 4\theta' = 2\alpha + 2\beta - 4\theta \end{aligned} \tag{7}$$

The consideration of choosing a circle as ROI is the spatial isotropy and of choosing average orientation of a sector as the element feature is to facilitate the selection of the symmetry axis. There are 2 parameters in calculating LAS. The radius, which is set to 60 in our experiments, describes the range of ROI which implies the extent of LAS's locality. The number of sectors (set to 50) influences the computational expense and localization precision.

3. Localization of the reference point

Now we are about to apply our new feature to detect reference points of fingerprint images. First the image is segmented and the POF is computed. As mentioned above, POF is rather noise-sensitive. So smoothing must be performed to restrain the noise. Here we choose Gaussian filter to gain our ends. For FVC2000 DB2, σ is set to 20. Experimental results show that such intensity of smoothing can suppress most noise and keep enough information for efficient LAS calculation.

To reduce the computational complexity, the foregrounds are divided into several square blocks of equal size. The choice of the side length is a tradeoff between speed and localization accuracy. Here we set it to 4. Note that the POF after Gaussian smoothing is continuous, so in each small block LAS value and direction is approximately equal. And then LAS of a block is calculated as the LAS of its center. After this process, the fingerprint image is converted into a discrete matrix of LAS that we call it LAS Field.

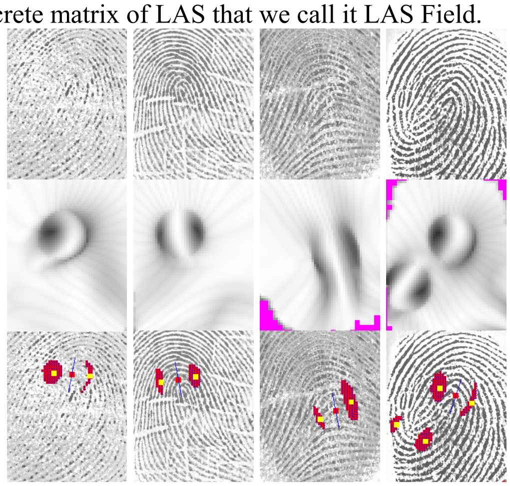

Fig 3. Demonstration of reference point detection: images in the first row are original fingerprint; images in the middle row are corresponding LAS Field where the grayscales represent the corresponding blocks' LAS; images in last row are binarized images according the LAS with detected reference points which orientation are indicated by line segments.

As can be easily seen in Fig. 3, in LAS Field of different qualities and types of fingerprint images including the plain arch, there are two regions with lower LAS value on the two opposite sides of the reference point. Many experiments have shown this character is an inherent one of fingerprint LAS Field except that the reference point or at least one of these two regions is out of the foreground. These two regions are so reliable that we can obtain them by a simple binarization. Then we take the upmost two low LAS regions' centers of gravity as landmarks and take their midpoint as the reference point and the direction of the symmetry axis of its corresponding block in LAS Field as the direction of the reference point. The flow chart of our approach is in Fig. 4 and the constant threshold in our experiments is set to 0.6.

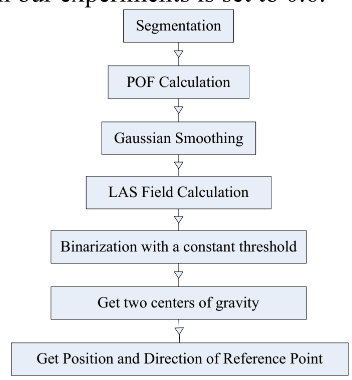

Fig 4. The flow chart of our approach

4. Experimental results

As illustrated in Fig. 5, due to smoothing effect, the reference point localization result may be translated from its conventional positions, which often further brings varying in the following direction estimation step. Fortunately these offsets are systematic errors as to the same finger and similar smoothing intensity. That is to say, for different images of the same finger, their reference points always "move" along the same track in the registered coordinate systems during the smoothing process.

To justify it, the proposed approach has been tested on the FVC2000 fingerprint database DB2 set A, in which 800 fingerprints from 100 fingers (with 8 images from each finger) are captured. First, the conventional reference points and their directions are recorded manually. According to these data, coordinate systems are built to all images which are called ideal coordinate systems. Then the resulting position of reference point localization and their estimated direction are obtained by our approach. Unlike [4] directly computed distance between the reference point coordinates in the same coordinate system acquired in the two different ways, we first calculate the detected reference points' coordinates in ideal coordinate systems and register their estimated direction by the manually marked direction. Then the accuracy of the proposed approach is evaluated among these registered coordinates and directions through the same finger's 8 different images.

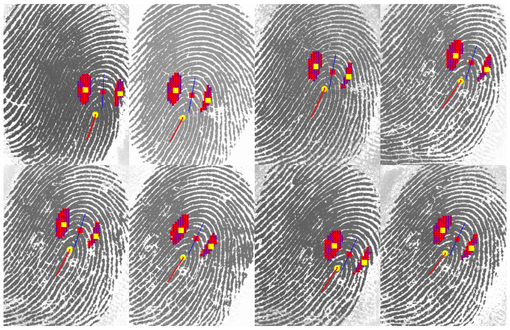

Fig 5. Reference point localization and direction estimation results of 8 images from one finger from FVC2000 DB2 set A.

Consider the all images successfully processed by our approach from the same finger. The distance between each pair of detected reference points' ideal coordinates describes the localization veracity and the feasibility of the approach -- less distance means more accuracy and reliability. To quantize it, we adopt three statistics: max distance, mean distance and standard deviation of distance. To different precisions such as 10 and 20 pixels, if the finger-wise statistics of these pair-wise distances do not meet the criteria, the samples with the largest distances to the others are excluded until the criteria is met. After counting the total excluded prints of whole database, Table 1 summarizes the experimental results of localization. As can be easily seen, the performance of the strictest statistics — max distance is close to algorithm in [4] and the results of other two statistics are evidently superior to it.

Table 1. First row is the absolute distance Stat. of the algorithm in [4] and the others are statistics educed from excluded fingerprint numbers on different statistics and precisions of our approach

Precision (Pixels)	**≤10 (%)**	**>10& ≤20(%)**	**>20 (%)**
Distance Statistics in [4]	*81.07*	*13.72*	*5.21*
Max Distance	*82.68*	*11.50*	*5.82*
Mean Distance	*94.94*	*3.42*	*1.64*
Standard Deviation of Distance	*96.97*	*1.51*	*1.52*

We also analyze the accuracy of direction estimation. Similarly, the statistics are performed finger-wise: for all processed images, we calculate the difference between each pair of registered direction of detected reference points and obtain a mean error of direction for the finger. Further, the average error of all fingers is acquired. In our experiments it is 5.60°. As far as we know, the spatial and directional accuracy of our approach is considerably high, compared to the published algorithms in the literature. The low refusal rate also shows a broader applicability of our approach. Among the 800 images, only 9 images are refused and the corresponding number is 13 in [4].

5. Conclusion

In this paper, we propose a novel feature of fingerprint images called local axial symmetry and develop a straightforward reference point detection and direction estimation approach based on it. As a translation- and rotation-independent feature derived from smoothed orientation field, LAS gives the intrinsic nature of fingerprint images which is more robust to noise and convenient for following further process. Experimental results on FVC2000 DB2 set A show the spatial and directional accuracy of our approach and further the reliability of LAS.

6. Acknowledgments

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