A New Method of Singular Points Accurate Localization for Fingerprint

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Abstract

To solve singular points (SPs) rapid and accurate localization problem, a novel algorithm of SPs rapid detection is presented. Based on preprocessed fingerprint image, orient field is calculated out and homogeneous-zones-divide. Candidate small areas are then selected by successive approximation and candidate singular points are chosen from candidate small areas by Poincare Index Algorithm (PIA). Finally, the real singular points are precisely located by the mean algorithm. To evaluate arithmetic performance, Experiments on FVC2004 DB2_B, DB3_B and DB4_B database were carried out. Compared with PIA, the experimental result show that singular points localization of our method is more precise, and the False Detecting Ratio (FDR) and the Missed Detecting Ratio (MDR) decrease by 5.86% and 6.8% respectively. At the same time, the speed of our algorithm is 7.6 times faster than PIA. This performance proved that our method present a feasible and effective way to detect and locate the SPs of fingerprint image.

Keywords: fingerprint image; Orientation field; Singular point; Homogeneous-zones-divide

1. Introduction

With development of science and technology, automatic fingerprint identification system (AFIS) has been used more and more widely. In the process of AFIS’ development, an effective solution of pre-alignment is precisely finding out the singular points (SPs) of fingerprint. As one of the most important global features, SPs play an important role in synthesis of artificial fingerprints, fingerprint classification and fingerprint match [1-2]. The main function of SPs is to provide a stable reference point in fingerprint
and it can be classified into two typologies: core and delta. Henry defined the core point as the north most point of the innermost ridge line and the delta point as the center of triangular regions where three different direction flows meet [3], as shown in Fig.5.

In detection and Localization of SPs in fingerprint two difficulties exists: precision and reliability. So far, a lot of approaches for SPs detection and localization have been proposed, and mainly divided into the following categories [4]: (1) based on PIA [5-6], such as Bazan and Gerez compute the “rotation” of the orientation image (through a further differentiation) instead of summing angle differences along a closed path and then perform a local integration in a small neighborhood of each element[6]; (2) based on local characteristics of orientation image[7-9], such as Park et al.[7] proposed a approach that the orientation of any two horizontally adjacent elements is checked against a set of pre-defined rules to detect candidate regions; (3) partitioning-based methods, such as Cappelli et al.[10] put forward to use an iterative clustering algorithm and a set of dynamic masks to partition orient image respectively; (4) based on a global model of the orientation image, such Wang, Hu and Phillips [11] use the FOMFE transform to obtain a $2 \times 2$ matrix, called the characteristic matrix, and according to the characteristic matrix to judge types of SPs.

Now, the popular and elegant detecting method is Poincaré index (PI) based approach [5, 12]. Poincaré index is computed by algebraically summing the orientation differences between the adjacent elements along a closed curve. According to the Poincaré index, SPs can be located and divided. In the case of fingerprint singularities:

$$\begin{align*}
\text{PI}(i,j) &= \begin{cases} 
0 & \text{if } (i,j) \text{ does not belong to any singular region} \\
360 & \text{if } (i,j) \text{ belong to a whorl type singular region} \\
180 & \text{if } (i,j) \text{ belong to a loop type singular region} \\
-180 & \text{if } (i,j) \text{ belong to a delta type singular region}
\end{cases}
\end{align*}$$

The method is simple and effective, but there are two main limitations of Poincaré index method: one is the contradiction of reliability and accuracy and another is that when the noise is heavy, more spurious SPs will be obtained or right points will be omitted due to increasing false orientations. In addition, computation of Poincaré index is too heavy so that the method is more time-consuming. So, in this paper, we present a new idea to improve Poincaré index.

2. Algorithm Description

2.1 Preprocess Image

In order to speed the algorithm and reduce influence of noise, our method preprocess the fingerprint image and the process of preprocess contain two sections: image shrinkage and image enhancement.

Image shrinkage is realized through reading image data at $r$ interval of rows and columns, which make the image shrink into $1/r^2$. Compare with PIA, this step is like to divide the image into $r \times r$ window to compute orient. In our experiment, $r$ value respectively took 2 and 3, but it’s not suitable for every image and $r$ will affect FDR and MDR, so it should be chosen according to image size.

Because of different influences of skin surface properties, acquisition environment, acquisition device and so on, images suffer from different levels of noise. These noises can produce many spurious SPs and severely impact the SPs’ accurate localization. To solve this problem, image enhancement is put forward and it effectively reduces the noise pollution. At present, there are many methods of image enhancement and 3 commonly used of them are: method based on Gabor filter [9], method based on FFT [13] and
method based on acknowledge [14]. In this paper, Verifinger SDK 5.0 [15] has been used for image enhancement, and the result is shown in Fig.1.

2.2 Oreint Field Computation

Orient field represents the essential characteristic of fingerprint image and the simplest and most natural approach for extracting local ridge orientation is based on computation of gradients in the fingerprint image. In this paper, method of [16] is adopted and the detail procedure is as follow:

step.1—Compute the gradients $\partial_x(i, j)$ and $\partial_y(i, j)$ at each pixel by using the simple Sobel operator. Next, estimate the local orientation of each pixel using (1), (2), (3) as follow:

$$V_x(i, j) = \sum_{i=w}^{i+w} \sum_{j=w}^{j+w} (2\partial_x(u,v)\partial_y(i,j))$$

(1)

$$V_y(i, j) = \sum_{i=w}^{i+w} \sum_{j=w}^{j+w} (\partial_x^2(u,v) - \partial_y^2(u,v))$$

(2)

$$\theta(x, y) = \frac{1}{2} \arctan\left(\frac{V_y(i, j)}{V_x(i, j)}\right)$$

(3)

step.2—Due to the presence of noise, corrupted ridge and valley structures, minutiae, etc. in the input image, the estimated local ridge orientation, $\theta(x, y)$, may not always be correct. The solution is to correct it by a low-pass filter. The detail procedure is to convert orient field into a continuous vector field using (4), (5) at first, and then smooth it using (6), (7). After smoothing, orient is obtained by (8).

$$\phi_x(i, j) = \cos(2\theta(i, j))$$

(4)

$$\phi_y(i, j) = \sin(2\theta(i, j))$$

(5)

$$\phi_x(i, j) = \sum_{u=-w/2}^{w/2} \sum_{v=-w/2}^{w/2} (h(u,v)\phi_x(i-uw, j-vw))$$

(6)

$$\phi_y(i, j) = \sum_{u=-w/2}^{w/2} \sum_{v=-w/2}^{w/2} (h(u,v)\phi_y(i-uw, j-vw))$$

(7)

$$O(i, j) = \frac{1}{2} \arctan\left(\frac{\phi_y(i, j)}{\phi_x(i, j)}\right)$$

(8)

$$O'(i, j) = O(i, j) \times 2 + \pi / 2$$

(9)

In (5), $h(u, v)$ is a two-dimensional low-pass filter with unit integral and $\omega_x \times \omega_y$ specifies the size of the filter. In this paper, two-dimensional Gaussian low-pass filter of $5 \times 5$ is adopted, and the effect is very well, as shown in Fig.2.
Due to the orient obtained from (8) is in the interval \([- \pi /4, \pi /4]\), it should be converted into \([0, \pi]\) by (9).

Fig. 1 Images after being preprocessed

2.3 SPs’ Detection

At first, we will give a couple of definition as follow:

**DEFINITION 1** [17] — Homogeneous-zones: If orient of point \((i, j)\) is \(O(i,j)\) in fingerprint image, homogeneous-zones is a set of points which satisfy:

\[ \alpha \leq O(x, y) < \beta \quad (0 \leq \alpha, \beta \leq \pi) \]

**DEFINITION 2** — Homogeneous-zones-divide: Homogeneous-zones-divide is the process of dividing an orient field into several homogeneous-zones.

In this paper, we divided orient field into 4 homogeneous-zones, that is, \(\Omega (0, \pi/4), \Omega (\pi/4, \pi/2), \Omega (\pi/2, 3\pi/2)\) and \(\Omega (3\pi/2, 2\pi)\), just as shown in Fig. 3. From the pictures we can see that there are some intersections of 4 homogeneous-zones. In fact, these intersections are the SPs, which accord with the theory that orient around SPs changes strongly and the feature of the intersections establish the foundation for locating SPs quickly.

1) Localization of candidate areas and points

The importance of localization of candidate areas is to quickly find out the mark of regions been consisted of SPs and their neighborhood without affecting the positioning accuracy. According to the feature of homogeneous-zones-divided SPs, we located the candidate areas through successive approximation and detected the candidate SPs in the candidate areas by PI. The procedure is as follow:

a) Divide homogeneous-zones-divided orient field into a few of \(m \times n\) blocks without overlapping each other. According to the feature of homogeneous-zones-divided SPs, that is, region of SPs located contain all sorts of homogeneous zones, returns the first pixel coordinates \((i, j)\) as the mark of the region. Because the size of block affect the speed of algorithm, the size should be chosen carefully. In the experiment, both \(m\) and \(n\) got the value of 20.

b) It is necessary to repeat step a) to get sub-blocks until the sub-blocks are suitable. The times of reiteration could be 1 or more, and the suitable sub-blocks is helpful to the speed of algorithm. In experiment of this paper, the size of sub-blocks is \(10 \times 10\).

Fig. 2 Image of Fig. 1 contrast before and after filtering
c) Compute PI for very pixel in the sub-blocks which obtained form step b). In order to reduce influence of noise and boost the accuracy of localization, it is useful to choose two closed curves to integrate, just as shown in Fig.4. According to (10) the PI of given point \((i,j)\) can be computed on the closed curve \(D_1D_2D_3D_4...D_{12}D_1\) and get the value \(PD\) of PI.

\[
PD(i, j) = \frac{1}{2\pi} \sum_{i=1}^{12} |D_i - D_{(i+1)mod12}|
\]  

(10)

d) Similarly, it’s easy to get PI on the closed curve \(d_1d_2d_3...d_8d_1\) and then a threshold is chosen for selecting the candidate points which satisfy with the condition as below:

\[
S_{\text{resp}} = \{(i, j) \mid |PD - 0.5| < Th \land |Pd - 0.5| < Th\}
\]

2) SPs types detection and precise localization

From the above steps we can get candidate SPs set \(S_{\text{resp}}\) and we should go further to remove the spurious ones. From Fig.3 we can see every homogeneous zone take a significant proportion of the orient field, so two larger closed curve are chosen to compute PI, which is useful to boost the accuracy of localization. The detail procedure is as follow:

a) Expand Fig.4 to \(9 \times 9\) and choose the outer two levels as the integration curve. Through (11), (12) and (13), we can get two PI values \(PI1(i, j)\) and \(PI2(i, j)\) on the chosen curves.

\[
PI(i, j) = \frac{1}{2\pi} \sum_{k=0}^{\varphi} \Delta(k)
\]  

(11)

\[
\Delta(k) = \begin{cases} 
\delta(k), & |\delta(k)| < \pi / 2 \\
\pi + \delta(k), & \delta(k) \leq -\pi / 2 \\
\pi - \delta(k), & \text{otherwise}
\end{cases}
\]  

(12)

\[
\delta(k) = O(\varphi_x((i + 1)mod\varphi), \varphi_y((j + 1)mod\varphi)) - O(\varphi_x(i), \varphi_y(j))
\]  

(13)

According to the values \(PI1(i, j)\) and \(PI2(i, j)\) of each point in set \(S_{\text{resp}}\), types, localizations of SPs can be detected. The rule of detection is: if both \(PI1(i, j)\) and \(PI2(i, j)\) are equal to -0.5, the point is delta; if both \(PI1(i, j)\) and \(PI2(i, j)\) are equal to 0.5 or 1, the point is core, otherwise, the point is common one. After this step, two sets can be get as follow:

\[
S_{\text{core}} = \left\{(i, j) \mid PI1(i, j) = \frac{1}{2} \land PI2(i, j) = \frac{1}{2}\right\}
\]

\[
S_{\text{delta}} = \left\{(i, j) \mid PI1(i, j) = -\frac{1}{2} \land PI2(i, j) = -\frac{1}{2}\right\}
\]
b) $S_{\text{core}}$ and $S_{\text{delta}}$ are a group of coordinates of true SPs and it may contain 1 or 2 units. That means, in a fingerprint image there are 1 or 2 cores or deltas. So it’s obligatory to divide the group of coordinates into units. In this paper, a size of $17 \times 17$ neighborhood was used. That is, when the point of Score or Sdelta is in the $17 \times 17$ neighborhood of a unit, which mean the point belong to the unit.

c) At last, several units can be obtained from step c) and it’s necessary to integrate the units into one point and it’s helpful to reduce MDR. But the point we get is of the shrunk image, it must be restored to original image. The result of our method is shown in Fig.5 and the solid circles and solid squares are cores and deltas respectively.

3. Experiment Result

Measuring the performance of algorithm of SPs detection and localization mainly depend on two standards: positioning accuracy and FDR, MDR. Judging from the precision, our method located the SPs at one single pixel in the shrunk image, which showed the performance was very well. We choose 240 images of FVC2004 DB2_B, DB3_B, DB4_B database to evaluate the performance of FDR and MDR. The result is shown in Table 1. In addition, our method take preprocessing image as the first step, so our method is robust against noise pollutions, which also can be seen in Fig 5.

Table 2. shows the result of our method compared with others. Compared with [17], our method is not better on speed and MDR aspects, but there is a great improvement on FDR, localization precision and robustness of algorithm; compare with PI algorithm, speed of our method is 7.6 times faster than PI, and FDR, MDR decrease by 6.8%, 5.86% respectively, at the same time, localization precision improve 6~8 times.

Finally, it should be declared that the experiment is done on the compute of Pentium processor of which frequency is 2.40 GHz and the memory is 1GB.

Table I. Result of experiment on database of FVC2004

|       | $r$ | Mean time (s) | Number of MD | Number of FD | Total Number | MDR (%) | FDR (%) |
|-------|-----|---------------|--------------|--------------|--------------|---------|---------|
| DB2   | 3   | 0.1739        | 9            | 6            | 106          | 8.49%   | 5.56%   |
| DB3   | 2   | 0.4393        | 7            | 5            | 120          | 5.83%   | 4.17%   |
| DB4   | 3   | 0.2420        | 13           | 8            | 161          | 8.07%   | 4.97%   |
| total | /   | 0.2851        | 29           | 19           | 387          | 7.49%   | 4.91%   |

Table II. The results compared with other algorithms

| Properties | Methods | Mean time (s) | MDR (%) | FDR (%) | localization precision ($w \times w$ rectangle) |
|------------|---------|---------------|---------|---------|-----------------------------------------------|
|            | PI      | 2.1749        | 13.35   | 11.71   | $17 \times 17$                               |
|            | [17]    | 0.1532        | 3.74    | 13.52   | $21 \times 21$                               |
|            | Ours    | 0.2420        | 7.49    | 4.91    | $2 \times 2$ or $3 \times 3$                 |
4. Conclusions and Future Work

This paper proposes a simple new idea to detect and locate SPs of fingerprint image. This method realized SPs fast and accurate detection and localization through orient field homogeneous-zones-divided. Compared with PI, this method have better robustness, faster speed, more precise localization and lower FDR and MDR. In the future research we will improve the method and apply it to classify fingerprint.
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References

[1] Luo Jing, Lin Shu-zhong, Zhan Xiang-lin, Ni Jian-yun. Fingerprint classification combining singularity and HMM. Opt. Precision Eng., vol. 17, no. 4, pp. 874-879, 2009 (in Chinese)

[2] Luo Jing, Lin Shu-zhong, Zhan Xiang-lin, Ni Jian-yun. A novel fingerprint recognition algorithm based on 2DPCA and EBFNN. Opt. Precision Eng., vol. 16, no. 9, pp. 1773-1780, 2008 (in Chinese)

[3] Henry E. Classification and uses of fingerprints [M], London: Routledge, 1900.

[4] Daide Maltoni, Dario Maio, Anil K. Jain, Salil Prabhakar. Handbook of fingerprint recognition (Second Edition). London: Springer-Verlag, pp. 398-399, 2009

[5] Kanwagoe M, Tojo A. Fingerprint pattern classification. Pattern Recognition, vol. 17, no. 3, pp. 389-303, 1984

[6] Bazan A.M. And Gerez S.H. Systematic methods for the computation of the directional fields and singular points of fingerprints. IEEE Transactions on Pattern Analysis Machine Intelligence, vol. 24, no. 7, pp. 905-919, 2002

[7] Park C.H., Lee J.J, Smith M.J.T., Park K.H. Singular point detection by shape analysis of directional fields in fingerprints. Pattern Recognition, vol. 39, no. 5, pp. 839-855, 2006

[8] Han Zhi, Liu Chang-ping. A robust method of singular point detection from fingerprint image. Computer Engineering, vol. 32, no. 20, pp. 30-32, 2006. (in Chinese)

[9] Wu Xu, Hu Jia-sheng, Liang Dian-liang. An algorithm for singularity detection and center point calculation based on fingerprint segmentation. Opt. Precision Eng., vol. 14, no. 2, pp. 229-235, 2006. (in Chinese)

[10] Cappelli r., Lumini A., Maio D, Maltoni D. Fingerprint classification by directional image partitioning, IEEE Transactions on Pattern Analysis Machine Intelligence, vol. 21, no. 5, pp. 402-421, 1999.

[11] Wang Y., Hu J. and Phillips D. A fingerprint orientation model based on 2D Fourier expansion (FOMFE) and its application to singular-point detection and fingerprint indexing, IEEE Transactions on Pattern Analysis Machine Intelligence, vol. 29, no. 4, pp. 573-585, 2007.

[12] Nojun Kwak, Chong-Ho Choi: Input feature selection by mutual information based on Parzen window. IEEE Trans. PAMI, vol. 24, pp. 1667-1717, 2002.

[13] Tian Jie, Yang Xin. Biometrics theory and application. Beijing: Tsinghua university press, 2009. (in Chinese)

[14] Luo Xi-ping, Tian Jie. Knowledge based fingerprint image enhancement. Proceedings of International Conference On Pattern Recognition, 2000, IV: 783-786.

[15] VERIFIER. Neurotechnologija Ltd. http://www.neurotechnologija.com

[16] Lin Hong, Yifei Wan, Anil Jain. Fingerprint image enhancement; algorithm and performance evaluation, IEEE Trans. On Pattern Analysis and Machine Intelligence, vol. 20, no. 8, pp. 777-789, 1998.

[17] Mei Yuan, Sun Huai-jiang, Xia De-sheng. Effective method for detection of fingerprints’ singular points. Computer Engineering and Applications. vol. 44, no. 28, pp. 1-3, 2008, (in Chinese)