A Modified Singular Point Detection Algorithm

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Abstract. Automatic Fingerprint Identification Systems (AFIS) are widely used for personal identification due to uniqueness of fingerprints. Fingerprint reference points are useful for fingerprint classification and even for fingerprint matching algorithms. In this paper, we present a modified algorithm for singular points detection (cores and deltas) with high accuracy. Optimally located cores and deltas are necessary for classification and matching of fingerprint images. The previous techniques detect only a single core point which is inefficient to classify an image. The basic feature of our technique is that it computes all the cores along with all the deltas present in a fingerprint image. The proposed algorithm is applied on FVC2002, and experimental results are compared with the previous techniques, which verify the accuracy of our algorithm.

1 Introduction

As the fingerprint technology is advancing abruptly along with the improvements in the efficiency and accuracy of the algorithms regarding fingerprint matching, the automatic fingerprint identification is becoming the most attractive solution over the traditional methods of identification [1]. A fingerprint is the flow of furrows and ridges on the fingertip surface. Ridges and valleys do not continue forever, they sometimes terminate and sometimes bifurcate. At a global level, depending upon the unique pattern, the regions are divided into different types (whorls arch and loops). Such regions are known as Singular Regions [2]. Centroid of such a region is called a Singular Point. A singular point can be a core or delta determined by its position in the singular region [3] as shown in the figure 1 below.

A core is a singular point in an orientation field, where the pattern in the singular region exhibits the semi-circular tendency, whereas a delta is the one, where the pattern splits into three different sectors, and each sector exhibits the hyperbolic tendency [3]. Most Automatic Fingerprints Identification Systems (AFIS) are based on local ridge features, known as minutiae (endings or bifurcations) [4]. In AFIS, singular points play a very important role and are widely used for fingerprint matching [2, 5, 6] and classification [7, 8]. The problem with the fingerprint related applications is to make a fingerprint image invariant with the help of a reference point (mainly core point) [6]. The solution to this problem is the optimal detection of cores and deltas.

A. Campilho and M. Kamel (Eds.): ICIAR 2008, LNCS 5112, pp. 905–914, 2008.

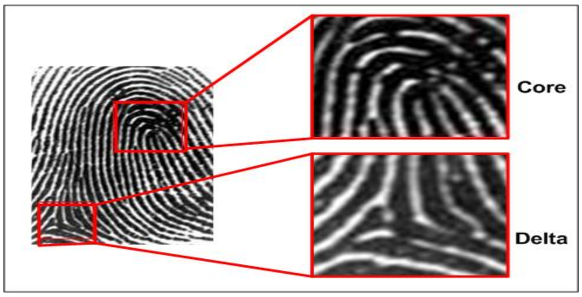


Fig. 1. Core and Delta Location

In many cases, there is no need to define a core or delta. But in some cases it is vital. Exactly located core and deltas play a vital role in fingerprint classification [9,10]. A number of algorithms have been proposed for the detection of core points. Most of them give good results for a single core point or two. But there was not a single technique which computes all the cores along with all the deltas so that to classify images accurately. To cope up with this problem, we devised this technique which is basically a modification to the previous Poincare index techniques[3].

This paper has six sections. In section 2, all the techniques used in the preprocessing of fingerprint image are described. Section 3 gives the insight to the different techniques for finding core and a delta point, which includes Poincare index technique based on two different orientation estimation techniques. In section 4, the proposed technique is described along with its algorithm. Section 5 presents the comparison and analysis based on experimental results of proposed technique with some other techniques (discussed in section 4). Section 6 is the conclusion.

2 Pre-processing

Before the detection of singular points, the input fingerprint image needs to be processed through following stages as shown in the Fig. 2. These steps are described in detail below:

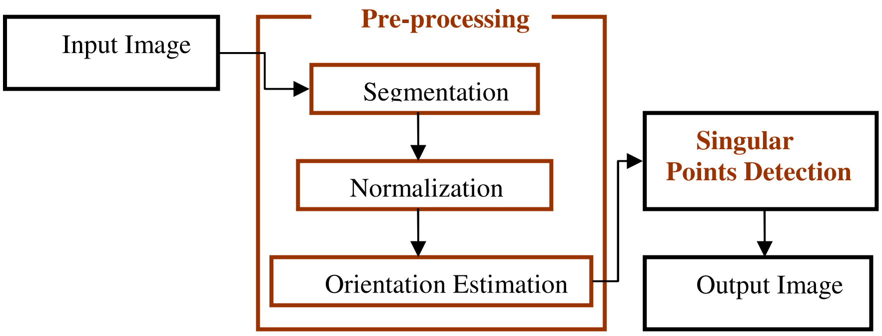


Fig. 2. Steps necessary to perform before singular point detection

2.1 Segmentation

The segmentation process is the separation of foreground pattern from background skin with high accuracy. The elimination of region containing noise and cropping out the region of interest plays a vital role in optimizing the core and delta points [11]. Steps for mean and variance based fingerprint image segmentation technique [6] are summarized as follows:

1. Divide the input image I into non-overlapping blocks of size w x w.
2. Compute the mean value M (I) and standard deviation sdv (I) for each block using equations (1) and (2) respectively, [6]

$$M(I) = \frac{1}{w^2} \sum_{i=-w/2}^{w/2} \sum_{j=-w/2}^{w/2} I(i,j) \tag{1}$$

$$sdv(I) = \sqrt{\frac{1}{w} \sum_{i=-w/2}^{w/2} \sum_{j=-w/2}^{w/2} (I(i,j) - M(I))^2} \tag{2}$$

3. If $sdv(I) > \tau_{sdv}$ (threshold value), it is a foreground region, otherwise, a background region.

2.2 Normalization

Due to difference in finger pressure applied during the scanning process, some noise is added. Normalization is performed to remove the effect of that noise [12]. The main purpose of the normalization is to reduce the variations of gray-level values along the ridges and valleys. Since the operation is pixel-wise so it does not change the lucidity of the ridges and valleys [4].

2.3 Orientation Field Estimation

Orientation field estimation is used both in singular point detection as well as fingerprint matching [4]. A number of algorithms have been proposed for orientation field estimation [13, 14, 15].
Some common techniques are described in detail as follows:

Fine Orientation Field Estimation. This technique is summarized as follows:[11]

1. Divide the input image I into non-overlapping blocks of size w x w.
2. Use 3 x 3 sobel horizontal and vertical masks to compute the gradients $\partial_x(i,j)$ and $\partial_y(i,j)$ for each pixel respectively.
3. Local orientation ϑ_x, ϑ_y, ϑ_z along three axes is now estimated [16]
4. Calculate the coherence (background certainty) using equation (3) [17]

$$coh = \sqrt{\frac{\left(\vartheta_x^2(i,j) + \vartheta_y^2(i,j)\right)}{w^2 * \vartheta_z}} \tag{3}$$

If coh>10,

$$\theta(i,j) = \frac{\pi}{2} + \frac{1}{2}\left(\frac{2\vartheta_x(i,j)}{\vartheta_y(i,j)}\right) \tag{4}$$

Ridge Verification. In an ideal fingerprint image, ridges and furrows are very precise and strictly defined in each local neighborhood. Whereas in poor-quality images, ridge pattern is not always sharp, and sometimes it is too vague, which may lead to: (a) inaccurate local ridge orientation and (b) wrong extracted ridges [3].

Since, optimal core and delta point detection is based on local ridge orientation, so inaccurate local ridge orientation leads to identification of erroneous cores and deltas. For finding correct local ridge orientation, another algorithm "ridge verification algorithm" [3] is used, which takes thinned ridge map as input and its outputs are refined thinned ridge map, a refined orientation field, and a quality index which indicates the goodness of the input ridge map.

3 Core Point Detection Techniques

This section details different techniques for finding core point (in some techniques, delta point too).The core point is calculated using either spatial domain [4, 18] or transformed domain [18]. The most commonly used technique is:

3.1 Poincare Index Technique

The above two techniques are used to detect only the core point. Poincare index technique is the most common technique used to detect cores along with deltas. In an orientation field, the Poincare index of a core-shaped singular region has a value of 0.5 and that of a delta-shaped singular region has a value of -0.5 [19]. The difference in values lies while estimating orientation field estimation. This technique has been used in different ways to give optimized results but the main calculation is the computation of Poincare index PC (i,j), where, for each pixel in orientation image, Poincare index is computed using,

$$PC(i,j) = \frac{1}{2\pi}\sum_{k=0}^{N_P-1}\Delta(k) \tag{5}$$

$$\Delta(k) = \begin{cases} \delta(k) & if\ \delta(k) < \pi/2 \\ \pi + \delta(k) & if\ \delta(k) \le -\pi/2 \\ \pi - \delta(k) & otherwise \end{cases} \tag{6}$$

Two of the methods based on the basis of different orientation field estimation techniques are described below:

3.2 Using Fine Orientation Estimation Field Technique

The steps are as follows [2, 8]:

1. Estimate the orientation field ε by using fine orientation field estimation technique (in section 2.2).
2. Locate the region of interest (ROI).
3. Initialize a label image A which is used to indicate the core point.
4. For each pixel in θ, compute poincare index, PC (i,j) using equation above, where, for particular number of points N_P

$$\delta(k) = \theta(x_{(k+1) \bmod N_P}, y_{(k+1) \bmod N_P}) - \theta(x_k, y_k) \tag{7}$$

5. If the Poincare index is 0.4-0.5 then such a block is the core block. Label the corresponding A (i,j) with 1. If the Poincare index is -0.5 then such a block is the delta block.
6. Calculate the centroid of the object having largest area in A with values 1

3.3 Using Ridge Verification Technique

Let Ψ x (.) and Ψ y (.) represent the x and y coordinates of a closed digital curvewith N_Ψ pixels (N_Ψ =25). The Poincare index at pixel (i, j) which is enclosed by the digital curve can be computed by equation above, where, [3]:

$$\delta(k) = O'(\psi_x(k'), \psi_y(k')) - O'(\psi_x(k), \psi_y(k)) \tag{8}$$

$$k' = (k + 1) \bmod N_\psi \tag{9}$$

The steps in this singular point detection algorithm are as follows:[3]

1. Initialize A, which is a label image used to indicate the singular points.
2. For each pixel (i, j) in O' (where O' is computed using ridge verification algorithm), compute the Poincare index and assign the corresponding pixel in A, a value 1 if the Poincare index is (1/2) and a value 2 if the Poincare index is (-1/2).
3. Find each connected component in A with pixel values 1. If the area of the connected component is larger than 7, a core is detected at the centroid of the connected component. If the area of the connected component is larger than 20, then two cores are detected at the centroid of the connected component.
4. Find each connected component in A with pixel values 2. If the area of the connected component is larger than 7, a delta is detected at the centroid of the connected component.

4 Proposed Technique

All the above techniques give good results but they were inefficient in finding deltas and cores at the same time. Some techniques only compute cores, some only deltas, some calculates only 1 core. But, 2 cores along with the 1 or 2 deltas could not be calculated using them. In the proposed technique, we also use Poincare index, but in a little bit different way, and by applying some changes to the above used equations. The steps for proposed technique (fig. 4) are given as:

4.1 Detection of a Binarized Segmented Image

This is a pixel wise operation. Let S be the segmented image and B be the binarized segmented image, then for a pixel (i, j),

i) If S (i, j) = = 0 (i.e., a background pixel),B (i, j) = 0

ii) Else, B (i, j) =1

4.2 Elimination of the Region Based Upon Confirmation Index, Where No Singular Point Could Lie

Initialize P, which is a label image used to indicate Poincare index. Let b_x (.) and b_y (.) represent the x and y coordinates of a closed digital curve with N_b pixels. The conformation index C at pixel (i, j) which is enclosed by the digital curve can be computed as follows:

$$C(i, j) = \sum_{k=0}^{N_b} B(b_x(k), b_y(k)) \tag{10}$$

Selection of N_b is important. A very small N_b can give suspicious singular points and a very large N_b can remove true singular points. So, after applying different N_b, we conclude that N_b=16 is the most optimal solution.

i) If C (i, j) >0, P (i, j) = 0; ii) Else, P (i, j) = -1;

See figure 3, where central box shows the central pixel (i,j), for which C is computed. If a single pixel in the closed digital curve is black, central pixel can never give Singular Points.

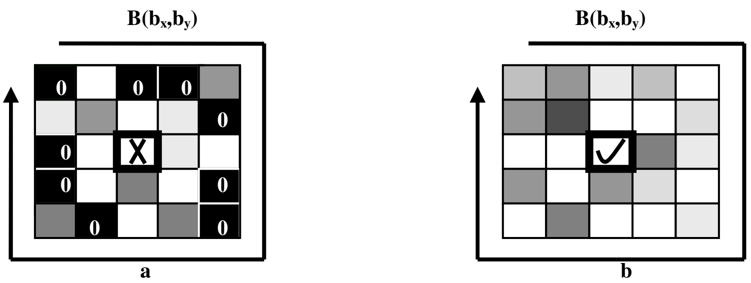


Fig. 3. Central box is the central pixel where (a) no Singular Point can exist (b) Singular Point can exist

4.3 Determination of Poincare Index for the Appropriate Image

Let O' be the oriented image calculated using any of the techniques mentioned in Section 2. Then for all the pixels for which P (i, j) = - 1 , calculate the Poincare index using equations (5) &(6) [3] in section 3 taking $N_P = (N_\Psi - 1)$.

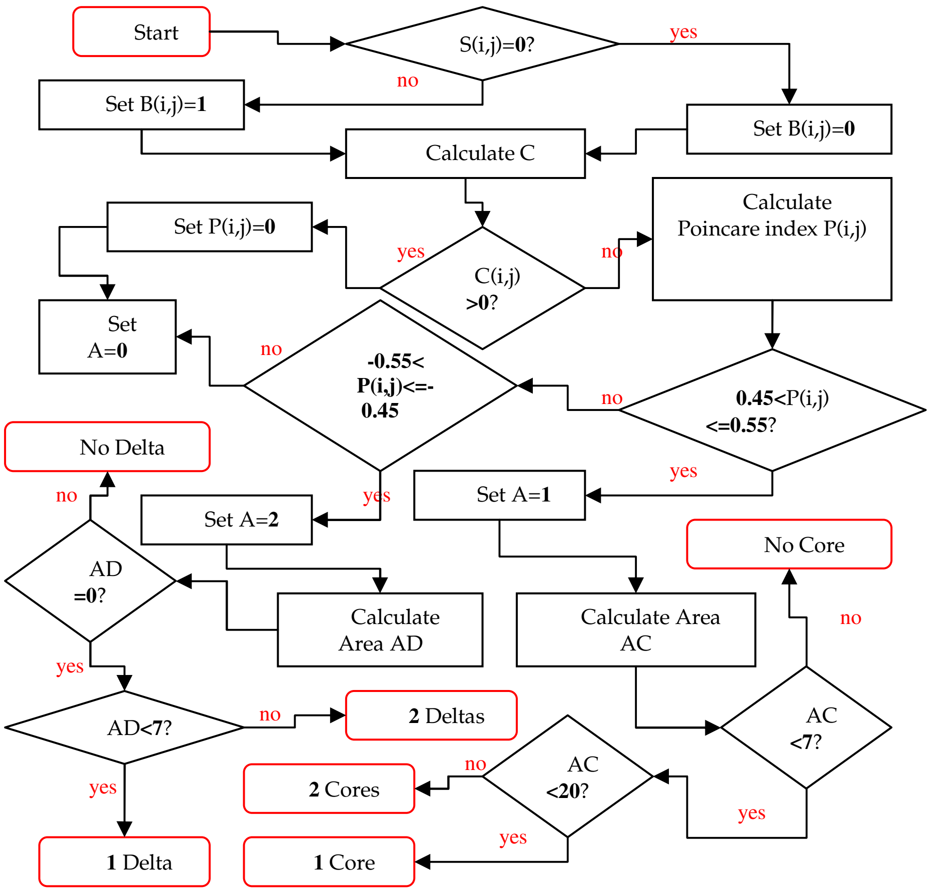


Fig. 4. Flow Chart of the Proposed Algorithm

4.4 Optimal Detection of Singular Points

1. Initialize a label image A used to indicate the singular points.
2. For each pixel (i,j) in P, assign the corresponding pixel in A a value 1 if 0.45<P(i,j)<=0.55, and a value 2 if -0.55<P(i,j)<=-0.45.
3. Find each connected component in A with pixel values 1. Calculate the areas of those components. Let AC be the largest area of those components, then
   3a. if AC<7,No core point.
   3b. if AC>7 && AC<20, Calculate the centroid of the component having largest area AC. That centroid is the location of optimal core point.
   3c. if AC>20, Calculate the centroids of the two connected components with the largest areas. That centroid gives us the location of two optimal core points.

4. Find each connected component in A with pixel values 2. Calculate the areas of those components. Let AD be the largest area of those components, then
   4a. if AD = = 0, No delta point,
   4b. if AD>0 && AD<7, Calculate the centroid of the component having largest area AD. That centroid is the location of optimal delta point.
   4c. if AD>7,
   i) Calculate the centroid of the component having largest area AD. That centroid is the location of first optimal delta point.
   ii) Calculate the centroid of the component having largest area less than or equal to 7. That centroid is the location of the second optimal delta point.

5 Experimental Results

We tested the accuracy of our algorithm by experimentation on a standard database FVC2002 [20]. The database is a good mixture of different types of images, regarding their quality(low and good), sizes(640x480, 296x560, 300x300, 288x384), and rotation. It contains 320 fingerprint images. Each has a resolution of 500dpi. ASP, the accepted number of singular points (cores and deltas) and the false number of singular points, FSP are calculated for the 2 Poincare index techniques defined in section 3 and on our proposed technique. Also their corresponding percentages ASP% and FSP% are calculated, and are shown in table 1I. Percentage for low and good quality images using all the three techniques mentioned above is also calculated and is given in table 2. The tables clearly show the accuracy and excellence of our proposed algorithm by acquiring high accepted no. of singular points percentage.

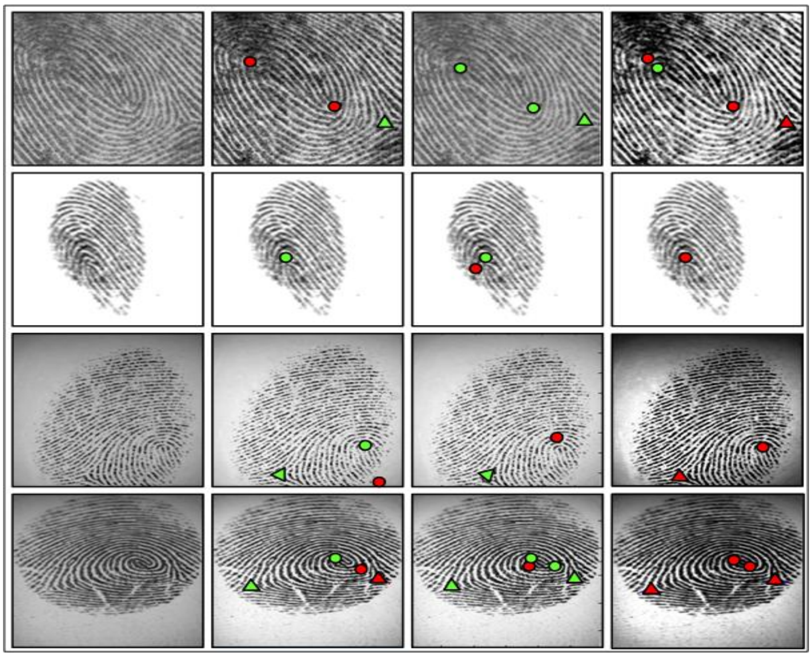
A comparative analysis is done for the above mentioned techniques and is shown in Fig. 5. Red circles and triangles are the detected cores and deltas respectively, while, green circles and triangles show the actual location of core and delta points. It clearly shows that previous techniques failed to give all the deltas and cores, while our technique compute all of them very accurately(last column of fig.5).In Fig. 6, the result of our proposed algorithm is shown for dry and very oily images, which shows that it can also give good results for low quality images.

Table 1. Singular Point Detection on FVC2002

Poincare	ASP(num)	ASP(%)	FSP(num)	FSP(%)
Technique 1.	153	47.8	167	52.2
Technique 2.	208	65	112	35
Proposed	274	85.6	46	14.4

Table 2. Performance Evaluation on the basis of quality of images

Quality of Image	Technique 1 (%)	Technique 2 (%)	Proposed Technique (%)
Low Quality	52.2	63.7	85.6
Good Quality	56.1	72.3	98.9



(a) (b) (c) (d)

Fig. 5. Pictorial comparison of the proposed technique with others. Column (a) contains original images, column (b) shows the result of Poincare index technique 1, column (c) shows the result of Poincare index technique 2, and column (d) shows the result of proposed technique.

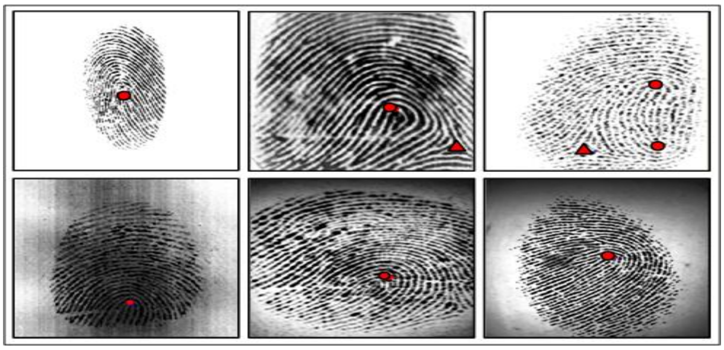


Fig. 6. Row 1 shows successful results of proposed algorithm on dry images. Row 2 shows successful results on oily images.

6 Conclusion

Our proposed technique for detection of singular points is very useful technique, because the previous techniques were good for detecting only a single core point, whereas our technique gives very good results for detection of all the cores and deltas present in the fingerprint image. Moreover, our technique works for all the orientation estimation techniques and gives almost same results. It not only gives accurate results for the good quality images but also for the low quality images, which includes dry and oily images too.

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