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Full Length Research Paper

Singular points detection using fingerprint orientation field reliability

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Singular points detection is the most challenging and important process in biometrics fingerprint verification and identification systems. Singular points are used for fingerprint classification, fingerprint matching and fingerprint alignment. This paper overcomes problems of the previous methods of miss-deducting or deducting spurious singular points. We propose a novel algorithm for singular point detection based on the fingerprint orientation field reliability. The algorithm starts by enhancing the fingerprint image using the short time Fourier Transform analysis (STFT), followed by calculating the orientation field reliability and locating the singular points. Experimental results have proven that the proposed algorithm locates singular points in a fingerprint image with high accuracy and can even locate the secondary core and delta if they exist.

Key words: Biometrics, security, fingerprint image, singular points, reliability.

INTRODUCTION

The fingerprint is a duplicate of a fingertip epidermis when a person touches a smooth surface, the fingertip epidermis characteristic transferred to the surface. The pattern of the ridges and valleys on the human fingertips forms the fingerprint images. Analyzing this pattern at different levels reveals different types of features that is, global feature and local feature. Global features shape a special pattern of ridge and valleys, called singularities or Singular Point (SP) and the important points are the core and the delta. The core defined as the most point on the inner most ridges and a delta defined as the center point where three different directions flows meet. The SP provides important information for fingerprint classification (Hong and Jain, 1999; Kawagoe and Tojo,1984; Zhanga and HongYan, 2004) fingerprint matching (Jain et al., 2000; Jain and Pankanti, 2000) and fingerprint alignment (Nilsson and Bigun, 2002; Yang and Park, 2008). Local features so-called minutiae are an important feature for fingerprint matching.

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Three types of degradations affect the quality of the fingerprint image. The ridges get some gaps; parallel ridges connected due to noise and natural effect to the finger like cuts, wrinkles and injuries. The Fingerprint enhancement is anticipated to improve the contrast between ridges and valleys and reduce noises in the fingerprint images. Much work has been devoted to fingerprint enhancement and a range of related approaches have been proposed. The most widely used method is based on contextual filters. O'Gonnan and Nickerson (1988) proposed the first method to use contextual filtering for fingerprint enhancement. Hong et al. (1998) proposed fingerprint enhancement based on the estimated local ridge orientation and frequency to improve the clarity of ridge and valley structures of input fingerprint images. Khmanee and Nguyen (2004) proposed a method using eight directions and four ridge frequencies to develop *8X4* 2-D Gabor filters. Furthermore, Wang et al. (2008) proposed a method using the log-Gabor filter. Cheng and Tian (2004) used the scale space theory to enhance the fingerprint image by decomposing the fingerprint image into a series of images and organized the images by courser to a finer scheme. Yun and Cho

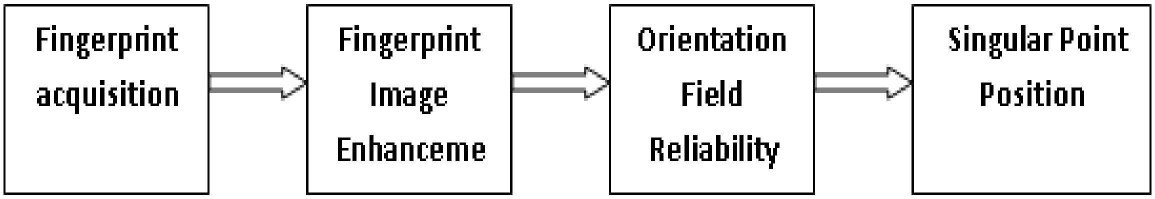

Figure 1. The proposed methodology for fingerprint verification.

Figure 2. Original fingerprint images.

(2006) proposed a method to enhance the fingerprint image by analyzing the quality of the fingerprint image. Çavuşoğlu and Görgünoğlu (2008) proposed a fast filtering method with a mask of parabolic coefficients based on the directions.

There are many approaches in literature about locating the singular points. Poincaré Index is the most commonly used method for locating the singular points (Hong and Jain,1999; Kawagoe and Tojo,1984; Bazen and Gerez, 2002; Arun, 2007) Nilsson and Bigun (2002) used a complex filter to locate the singular points. Koo and Kot (2001) used the scale-space analysis and curvature properties of the flow patterns of the fingerprint. Jiang et al. (2004) used the hierarchical analysis of orientation coherence to locate the singular points. Zheng et al. (2006) used the combination of curvature and orientation field of fingerprint images to extract the singular points. Rahimi et al. (2004) proposed a method to locate the singular point using the directional image and statistical analysis. Wang and Dai (2006) used Gaussian-Hermite moments (GHMs) behavior to extract singular points. Most of the previous methods suffered from poor quality images and multi-spectral noise.

This paper proposes a novel method to locate the Singular Points core and delta by calculating the orientation field reliability of the enhanced image. The main points of this method include: enhancing the fingerprint image, calculating the fingerprint orientation field reliability, finally locating the position of the singular point.

The paper is organized as follows: In section 2, the core and delta are located using the proposed algorithm. Experimental results and conclusion will be featured in sections 3 and 4.

PROPOSED METHOD

This section describes the proposed method and is organized into two main sections that is, 2.1 and 2.2. The proposed methodology is depicted in Figure 1.

Fingerprint image enhancement

High quality fingerprint image is very important for fingerprint verification to work properly. In real life, the quality of the fingerprint image is affected by noise like smudgy area created by over-inked area, breaks in ridges created by under-inked area, changing the positional characteristics of fingerprint features due to skin resilient in nature, dry skin leads to fragmented and low contrast ridges, wounds may cause ridge discontinuities and sweat on fingerprints also leads to smudge marks and connects parallel ridges.
Figure 2 shows original fingerprint images;
Figure 3 shows enhanced fingerprint images.

The short time Fourier Transform analysis (STFT) proposed by (Chikkerur, 2005; Chikkerur et al 2007) is applied here for fingerprint image enhancement. It consists of two stages, which are STFT analysis and fingerprint image enhancement. This method can be summarized as:

Firstly, the fingerprint image is divided into overlapping windows.
Stage I: STFT analysis
For each overlapping window *B(x,y)* in the image:
Remove the DC component of *B*, using *B=B-avg(B)*
Multiply by spectral window *w*
Acquire the FFT of the window *F=FFT(B)*
Execute root filtering on *F*

Execute STFT analysis. The analysis outputs are Ridge Orientation Image *O(x,y)*, Energy Image *E(x,y)* and Ridge Frequency Image *F(x,y)*
Smooth the orientation image *O(x,y)* using vector averaging to yield a smooth orientation image *O'(x,y)* and using the smooth orientation image *O'(x,y)* to generate the coherence image *C(x,y)*
Generate region mask *R(x,y)* by thresholding the energy image *E(x,y)*

Figure 3. Enhanced fingerprint image.

Stage II: Enhancement
For each overlapping window *B(x,y)* in the image
Generate the angular filter F_A centered on the orientation in the smooth orientation image *O(x,y)* with a bandwidth inversely proportional to coherence image *C(x,y)*
Generate the radial filter F_R centered around the ridge frequency image *F(x,y)*.
Filter the window in the FFT domain, $F=F*F_R*F_A$
Generate the enhanced window by the inverse Fourier transform *B'(x,y)* = IFFT(F)
Reconstruct the enhanced image by composing enhanced blocks *B'(x,y)*

Singular points detection

Singular point detection is the most challenging task; it is an important process for fingerprint image alignment, fingerprint classification and fingerprint matching. In the following subsections, we propose orientation reliability and singular point position methods.

Orientation field reliability

The fingerprint image is made up of pattern of ridges and valleys; they are the replica of the human fingertips. The fingerprint image represents a system of oriented texture and has very rich structural information within the image. This flow-like pattern forms an orientation field extracted from the style of valleys and ridges. In the large part of fingerprint topologies, the orientation field is quite smooth, while in some areas, the orientation appears in a discontinuous manner. These regions are called singularity or singular points, including core and delta and are defined as the centers of those areas. In addition, the reference point is defined here as the point with maximum curvature on the convex ridge. The reliability of the orientation filed describes the consistency of the local orientations in a neighborhood along the dominant orientation is used to locate the unique reference point constantly for all types of fingerprints. The reliability can be also computed using the coherence as proposed by (Kaas and Witkin, 1987) and (Bazen and Gerez ,2002). The implementation is elaborated on in the following:
(1) The orientation image is hardly ever computed at full-resolution. Instead each non-overlapping block of size $W \times W$ of the image is assigned a single orientation that correspond to the most apparent or dominant orientation of the block. In this proposed method, W is set equal to sixteen.
(2) The horizontal and vertical gradients $G_x(x, y)$ and $G_y(x, y)$ at each pixel *(x,y)* respectively are computed using simple gradient operators such as a Sobel mask (Gonzalez and Woods; 2008). The mask is set to $3 X 3$.
(3) Compute the ridge orientation of each pixel *(x,y)* by averaging the squared gradients within a $W \times W$ window centered at $[x_i,y_j]$ as follows (Ratha et al., 1995):

$$G_{xx} = \sum_{(x,y)\in w} G_x^2(x,y) \quad (1)$$

$$G_{yy} = \sum_{(x,y)\in w} G_y^2(x,y) \quad (2)$$

$$G_{xy} = \sum_{(x,y)\in w} G_x(x,y).G_y(x,y) \quad (3)$$

$$\theta(x,y) = \frac{1}{2}\tan^{-1}\left(\frac{2G_{xy}}{G_{xx}-G_{yy}}\right) \quad (4)$$

(4) Because of noise, corrupted ridge, valley structures and low gray value contrast, a low-pass filter can be used to adjust the erroneous local ridge orientation. However, to perform the low-pass filtering, the orientation image needs to be converted into a continuous vector field as follows:

$$\Phi_x = \cos(2\theta(x,y)), \quad (5)$$

and

$$\Phi_y = \sin(2\theta(x,y)) \quad (6)$$

where Φ_x and Φ_y are the x and y components of the vector field, respectively. With the resulting vector field, the Gaussian low-pass filter can be applied as follows:

$$\Phi'_x(x,y) = \sum_{u=-1}^{1}\sum_{v=-1}^{1} w(u,v)\Phi_x(x-uw, y-vw), \quad (7)$$

$$\Phi'_y(x,y) = \sum_{u=-1}^{1}\sum_{v=-1}^{1} w(u,v)\Phi_y(x-uw, y-vw), \quad (8)$$

where W is a two-dimensional low-pass filter with unit integral.

(5) Since the singular point has the maximum curvature. It can be located by measuring the strength of the peak using the following:

$$\min\_inertia(x,y) = ((G_{yy}+G_{xx}) - (\Phi'_x G_{xx} - G_{yy}) - (\Phi'_y G_{xy})/2, \quad (9)$$

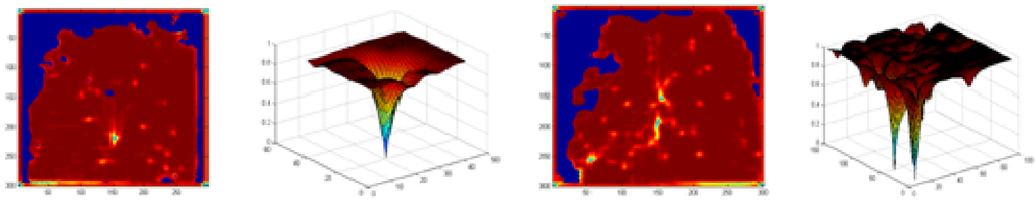

Figure 4. Orientation field reliability map and its peak indicating the singular points.

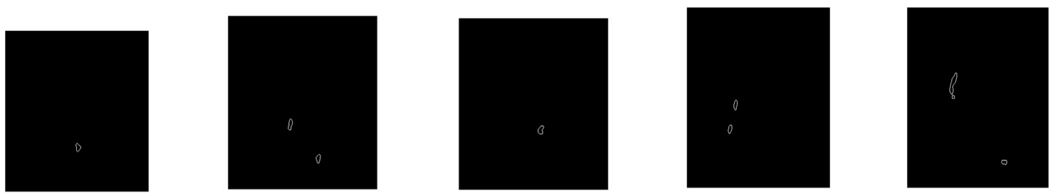

Figure 5. Morphological operation.

Figure 6. Singular points.

$$\max\_inerita(x,y) = G_{yy} + G_{xx} - \min\_inertia(x,y), \qquad (10)$$

$$reliability(x,y) = 1 - \frac{\min\_inertia(x,y)}{\max\_inertia(x,y)} \qquad (11)$$

Figure 4 shows the orientation filed reliability image map and the peak of the singular points, it shows the fingerprint images that have only one singular point and two singular points.

Singular point position

After the computation of the orientation field, the coordinate of the singular points is needed to be known in terms of *x* and *y* values so the following operations are applied to locate the exact coordinate:

(1) The orientation field reliability image contains the singular points and the rest of the information of the original fingerprint image as shown in figure 4. To locate the candidate areas of the singular points, a threshold 0.5 > t < 0.1 is applied to the orientation field reliability image from observing the values of the reliability singular points area.

(2) The image produced by the threshed still has an undesirable effect of noise and the size of the singular point contour is more than one pixel. For these reasons, the width of the structure is reduced to one pixel.

(3) After applying thinning to the singular point contour, it can be reduced to a single point through applying morphological opening and closing.

In Figure 5, the reference points can be seen clearly.

EXPERIMENTAL RESULTS

The proposed algorithm has been evaluated on the public fingerprint databases of FVC2002 (Lab, 2002). It is comprised of 800 fingerprints from 100 different fingers with 8 images captured from each finger using a low-cost capacitive sensor that produces many poor quality images. Since the location of the singular points is unknown, so manual evaluation is performed for the dataset Db_1. The experimental results were 2% locating the singular points with spurious and 1.5% miss locating the singular points.

Figure 6 shows the primary singular point and Figure 7 shows primary and secondary singular point. Table 1 shows the comparison between the proposed method and the methods proposed by Kawagoe and Tojo (1984) based on the Poincare index, which is derived from continuous curves, Zheng et al. (2006) using the combination of curvature and orientation field of fingerprint

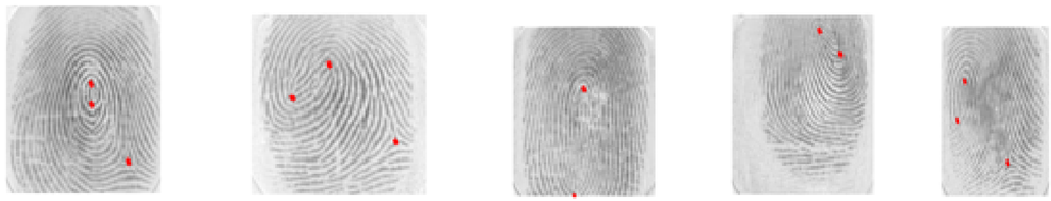

Figure 7. Primary and secondary singular points.

Table 1. Comparison of the proposed method with other methods.

Method	False SP (%)	Missed SP (%)
Kawagoe and Tojo (1984)	7.5	10.4
Zheng et al. (2006)	4.9	7.8
Rahimi et al. (2004)	12.5	25
Wang and Dai (2006)	3.2	8.4
Chikkerur and Ratha (2005)	4.4	8.3
Proposed method	2	1.5

images based on Poincaré index, Rahimi et al. (2004) using the directional image and absolute correlation function, Wang and Dai (2006) used Gaussian-Hermite moments (GHMs) behavior with Poincaré index and Chikkerur and Ratha (2005) based on the complex filtering principles; it indicates clearly that the proposed method is more accurate than other methods. The maximum difference between the compared methods for false detection is 10.5 and 8.9% for missing detection. The minimum difference between the compared methods for false detection is 1.2 and 6.3% for missing detection.

The experiments were performed in MATLAB 7.4.0 using HP Compaq Intel core-2 duo CPU E4400 with 2.00 GHz and 1.96 GB RAM. Some of the MATLAB functions have been downloaded from (Kovesi, 2008)

CONCLUSION

This paper proposes a novel method to consistently and precisely locate the singular points (core and delta) in fingerprint images. The method applied is based on the enhanced fingerprint image orientation reliability. In addition, an enhancement for the fingerprint image is applied using the Short Time Fourier Transform analysis (STFT). The experimental results demonstrate that the proposed algorithm is more accurate than the methods based on the Poincare index, which is derived from continuous curves, combination of curvature and orienttation field of fingerprint images based on Poincaré Index, the directional image and absolute correlation function and Gaussian–Hermite moments (GHMs) behavior with Poincaré Index. The result for the proposed method is 2% locating the singular points with spurious, 1.5% missing locating the singular points. This method also locates a secondary core and delta if it exists. Our future work will focus on improvements in locating the secondary singular points of fingerprint images.

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