SINGULAR POINT DETECTION BASED ON ORIENTATION FILED REGULARIZATION AND POINCARE´ INDEX IN FINGERPRINT IMAGES

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ABSTRACT

Detection of singular points (SPs) in fingerprint images is an important task in fingerprint recognition. In this paper, we propose a novel technique for SPs detection using orientation field regularization and the Poincare´ Index (PI) technique. The squared orientation field is first extracted from a fingerprint image. In order to distinguish the local orientation patterns of genuine SPs from that of spurious SPs, a novel technique based on the Discrete Hodge Helmholtz Decomposition (DHHD) is proposed to reconstruct a regular orientation field of the fingerprint. Based on the regular orientation field, the PI technique is then applied to extract the SPs. Experimental results on the public fingerprint database FVC2002 show that, the proposed technique is rather accurate and robust in identifying SPs.

***Index Terms*—**Singular points, Discrete Hodge Helmholtz Decomposition, Poincare´ Index, orientation field regularization, fingerprint recognition

1. INTRODUCTION

Fingerprint recognition is one of the most reliable methods for verification and identification of people. In fingerprint analysis, fingerprints can be regarded as orientation patterns consisting of valleys and ridges, and the discontinuities or sudden changes of ridge orientation patterns are located at SPs [1]. As critical topological features of fingerprints, SPs (especially core points and delta points) are widely used in fingerprint alignment [2], fingerprint classification [3], fingerprint matching [4], etc. An example of fingerprint image and its SPs is illustrated in Fig. 1.

Many works have been proposed for SPs detection in fingerprint images. Among all related techniques, the PI technique is the most classical one and widely used [1][5][6][7]. However, the PI technique only utilizes the local information of SPs, so it is sensitive to noise, creases, scars and ridge breaks, which leads to many spurious detections. Zhou et al. [8] use the PI in conjunction with a novel Differences of the ORIentation values along a Circle (DORIC) feature to remove the spurious detections. Gao et al. [9] apply the DHHD to localize candidate SPs, and adopt the PI technique to refine positions of candidate SPs. Besides the above PI-based techniques, other techniques are also proposed. For example, Chen et al. [10] extract SPs in fingerprints by multiple-scale analysis of the orientation entropy.

In this paper, we propose a hybrid technique for SPs detection in fingerprint images. After the squared orientation field is estimated from a fingerprint image, a novel orientation field regularization technique based on DHHD is proposed, which implicitly incorporates the global discriminative information for distinguishing the orientation patterns of genuine SPs from that of spurious SPs. Then the PI algorithm is applied to extract the SPs on the basis of the regular orientation field. A post-processing module is adopted to further remove the spurious SPs.

The rest of the paper is organized as follows: Section 2 presents details of the proposed technique. Section 3 shows the experimental results tested on the public fingerprint database FVC2002 [11]. Section 4 describes the conclusion.

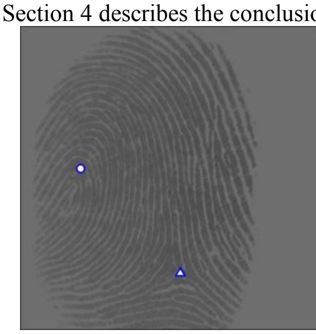


Fig.1 An example of fingerprint image and its SPs. The core is highlighted by circle whereas the delta is highlighted by triangle.

2. RELATION TO PRIOR WORK

The proposed technique has focuses on removing spurious detections of SPs in fingerprint images, using a novel orientation field regularization technique based on DHHD. The work by Liu et al. [12] only considers local orientation smoothing, and the work by Zhou et al. [8] applies the polynomial model-based technique to globally approximate a regular orientation field, which cannot provide good results near the singular regions in the fingerprint center. While the proposed technique utilizes the global discriminative features extracted from the orientation field, for distinguishing the orientation patterns of genuine SPs from that of spurious SPs. This was not considered in earlier studies.

3. THE PROPOSED TECHNIQUE

The proposed technique for SPs detection contains five modules: Preprocessing, Orientation Field Estimation, Orientation Field Regularization by DHHD, Singular Points Detection, and Postprocessing (see Fig. 2). And the details of each module are presented in the following sections.

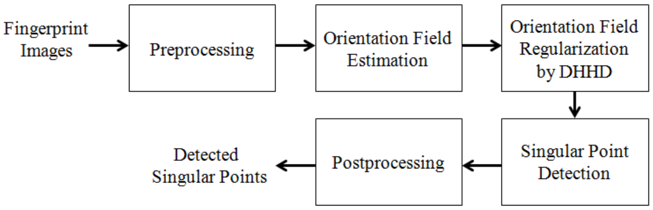


Fig.2 Schematic of the proposed SPs detection technique

3.1. Preprocessing of Fingerprint Images

Due to the fact that most of the real fingerprint images are noisy and poor quality, the preprocessing module is required before analyzing the image. The following two steps are involved in the preprocessing module.

1. Image Normalization: The object of normalization is to make all of the fingerprint images share a same gray scale range, which makes it more convenient to compare different fingerprint images. It can be described as follows [9],

$$I_{norm}(x,y)=\begin{cases}\mu_o+\sqrt{\dfrac{\sigma_o^2(I_o(x,y)-\mu)^2}{\sigma^2}}, & I(x,y)>M\\ \mu_o-\sqrt{\dfrac{\sigma_o^2(I_o(x,y)-\mu)^2}{\sigma^2}}, & otherwise\end{cases} \quad (1)$$

where $I_{norm}(x,y)$ and $I_o(x,y)$ denote a pixel in the normalized image and the original image respectively, and μ and σ^2 represent the mean and variance of the original image respectively, while μ_o and σ_o^2 are the desired mean and variance. In this work, we set $\mu_o=100$ and $\sigma_o^2=100$.

2. Image Denoising: In the subsequent processing, the orientation field extraction is based on intensity gradients of the image, which is significantly affected by image noise. Therefore, a 4×4 median filter [9] is used for image denoising.

3.2. Orientation Field Estimation

The orientation field is an estimation of direction of the ridge-valley structures in fingerprints. The detail of orientation field extraction module is summarized as follows,

1. For each pixel in the fingerprint image I, calculate intensity gradients G_x and G_y with respect to horizontal and vertical directions, respectively.

2. Divide the image I into non-overlapping blocks with the size of $w\times w$ pixels, in this work, we set $w=7$.

3. For each block, a single gradient vector is obtained by averaging the gradients over $w\times w$ pixels within the block. In order to avoid the situation that gradients in opposite directions will cancel out upon summation, the average squared gradient vector is calculated as follows,

$$\begin{bmatrix}\overline{G_{sdx}}\\ \overline{G_{sdy}}\end{bmatrix}=\begin{bmatrix}\sum_w\sum_w(G_x^2-G_y^2)\\ \sum_w\sum_w(2G_xG_y)\end{bmatrix} \quad (2)$$

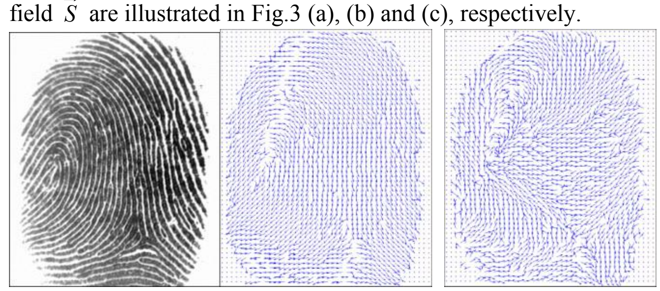
4. The orientation ϕ of the average squared gradient vector $(\overline{G_{sdx}},\overline{G_{sdy}})$, with $0\le\phi\le\pi$, is given by,

$$\phi=\frac{1}{2}\tan^{-1}\frac{\overline{G_{sdy}}}{\overline{G_{sdx}}}+\frac{\pi}{2} \quad (3)$$

Note that a discontinuity of π exists at certain locations of the estimated orientation field ϕ obtained by Eq.(3), will case the subsequent DHHD processing fail because the direction of flow is reversed abruptly [15]. To eliminate this discontinuity, the squared orientation field $\vec{S}$ [14] is calculated as follows,

$$\vec{S}=\cos 2\phi+i\sin 2\phi \quad (4)$$

The block with zero orientation in the field $\vec{S}$ is regards as the background of fingerprint. An example of fingerprint image, the resulting estimated orientation field $\vec{O}$ and squared orientation field $\vec{S}$ are illustrated in Fig.3 (a), (b) and (c), respectively.



(a) (b) (c)

Fig. 3 (a) A fingerprint image, (b) The orientation field $\vec{O}$, (c) The squared orientation field $\vec{S}$.

3.3. Orientation Field Regularization by DHHD

In the orientation field, the local orientation patterns of some spurious SPs actually are nearly the same as that of genuine SPs [8]. For spurious SPs caused by the impulse noise due to creases, scars and ridge breaks, local smoothing techniques [12][13] usually provide orientation patterns with large deviation from the actual local orientation patterns. In this work, we propose a novel orientation field regularization technique to address this problem. The proposed technique implicitly incorporates the global discriminative information for distinguishing the local orientation pattern of genuine detections from spurious detections.

DHHD is able to decompose the squared orientation field $\vec{S}$ into three components: a curl-free component, a divergence-free component, and a harmonic remainder. Mathematically, the decomposition is shown as follows [16],

$$\vec{S}=(\nabla E)+(\nabla\times\vec{W})+\vec{R} \quad (5)$$

where ∇E and $\nabla\times\vec{W}$ are the curl-free component and the divergence-free component respectively, and $\vec{R}$ is the harmonic remainder. Note that E is a scalar potential function of ∇E, and $\vec{W}$ is a vector potential function of $\nabla\times\vec{W}$. Theoretically, the harmonic remainder $\vec{R}$ satisfies $\nabla\cdot\vec{R}=0$ and $\nabla\times\vec{R}=\vec{0}$ simultaneously. In other words, both the non-curl and non-divergence information of $\vec{S}$ are left in $\vec{R}$, which includes constant and abrupt changes of local orientation patterns in the input field $\vec{S}$.

As illustrated in Fig.1, a core point can be defined as the point of the innermost curving ridge, and a delta point can be defined as the center point of triangular regions where three different directional flows meet [7]. Based on these definitions, the divergence-free component ∇E and the curl-free component $\nabla\times\vec{W}$ can be used to analyze the singularities in the squared orientation field $\vec{S}$ [9]. Therefore, we reconstruct an orientation field $\vec{D}$, which only incorporates ∇E and $\nabla \times \vec{W}$. And $\vec{D}$ can be expressed as,

$$\vec{D} = (\nabla E) + (\nabla \times \vec{W}) \quad (6)$$

Fig. 4 illustrates examples of spurious SPs and their local patterns in the squared orientation field $\vec{S}$, the reconstructed orientation field $\vec{D}$, and the harmonic field $\vec{R}$. It is noticeable that, the reconstructed orientation field $\vec{D}$ suppresses the topological patterns of spurious SPs (as shown in Fig. 4 (c)), while keeps the topological property of genuine SPs invariant (as shown in Fig. 5 (c)). Furthermore, the abrupt changes of local flow patterns in the squared orientation field $\vec{S}$ are reflected only in the decomposed harmonic field $\vec{R}$ (as shown in Fig. 4 (d)). The results verify that our assumption about the reconstructed field $\vec{D}$ is reasonable.

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

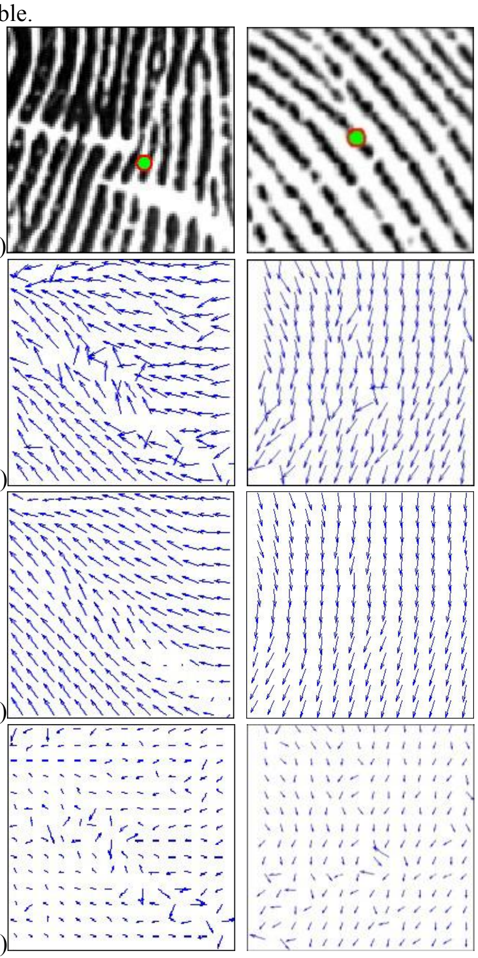


Fig.4 (a) Spurious SPs detected by PI technique, and their local patterns in (b) the squared orientation field $\vec{S}$, (c) the reconstructed orientation field $\vec{D}$, (d) the harmonic field $\vec{R}$.

3.4. PI-based SPs Detection

By computing the PI on the basis of the regular field $\vec{D}$, we can easily remove spurious SPs caused by the impulse noise. This will greatly speed up the SPs detection technique.

Let $\vec{S}(m,n)$ be a point in the squared orientation field $\vec{S}$, then the PI of $\vec{S}(m,n)$ is calculated by counterclockwise integrating the orientation differences along a closed curve γ around $\vec{S}(m,n)$, which is shown as [8],

(a)
(b)
(c)

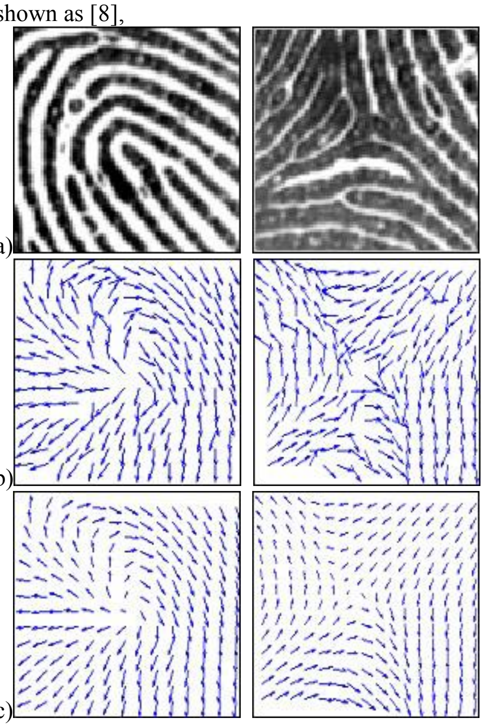


Fig.5 (a) Genuine SPs in fingerprint images, and their local patterns in (b) the squared orientation field $\vec{S}$, (c) the reconstructed field $\vec{D}$

$$P(m,n) = \frac{1}{2\pi} \int_{(x,y)\in\gamma} d\theta(x,y) \quad (7)$$

where *(x,y)* are locations of points on the closed curve γ, $\theta(m,n) = \arg \vec{S}(m,n)$, which is the orientation at *(x,y)* in the square d orientation field $\vec{S}$, and θ ranges from 0 to 2π.

A. M. Bazen et al. [7] first proposed to apply PI in identifying the SPs in the squared orientation field of fingerprints. In their technique, a point with *P(m,n)* as 1 is identified as a core point, while a point with *P(m,n)* as -1 is classified as a delta point.

3.5. Postprocessing Module

Three simple postprocessing steps are adopted after the PI-based SP detection:

1) If there is more than one core/delta exist in a small area (a circular area with a radius of 14 pixels), average the core/delta;

2) If the distance between a core/delta and the fingerprint background is smaller than 14 pixels, remove the core/delta;

3) If the distance between a core and a delta is smaller than 14 pixels, remove both the core and the delta.

4. PERFORMANCE EVALUATION

In this section, the experimental results of the proposed technique on the public fingerprint database FVC2002 [11] are presented.

The FVC2002 [11] has four databases, each database contains 800 fingers, which has 100 fingers and 8 prints for each finger, respectively. In our experiment, 100 fingerprint images are selected, covering the most difficult situations for SP detection, such as crease, scars, ridge breaks and blurred fingerprints.

4.1. Evaluation Metrics

In the evaluation of SPs detection, the ground truths of SPs are manually labeled beforehand, and the pixel distance between the ground truth SP and the detected SP is used for evaluating the detection performance. Denote a ground truth SP as (x_g,y_g) and a detected SP as (x_d,y_d). The ground truth SP is considered to be accurately detected, if the distance between the ground truth SP and the detected SP is smaller than a pre-defined threshold T; otherwise, it is considered to be a false alarm. If all SPs are accurately detected, and no false alarm exists in a fingerprint, it is called a correct detection [8]. In this work, we set $T=14$.

We also denote N_{GT} as the number of ground truth objects, N_{AD} as the number of accurately detected objects, N_{FA} as the number of false alarm objects, N_{CD} as the number of correct detection, and N_F as the number of fingerprints. The accurate detection rate (*ADR*), false alarm rate (*FAR*) and correct detection rate (*CDR*) are defined as follows,

$$ADR = \frac{N_{AD}}{N_{GT}} \times 100\% \quad (8)$$

$$FAR = \frac{N_{FA}}{N_{GT}} \times 100\% \quad (9)$$

$$CDR = \frac{N_{CD}}{N_F} \times 100\% \quad (10)$$

4.2. Evaluation on SPs detection

The comparison of statistical performance evaluation of the proposed technique, PI-based technique (Gao's) [9], non PI-based technique (Chen's) [10] is shown in Table 1. It is observed that, the proposed technique outperforms Gao's technique and Chen's technique in detecting SPs.

Table1. Performance comparison between the proposed technique, Chen's technique [10] and PI technique [7]

		Proposed	Gao's[9]	Chen's[10]
Cores	*ADR(%)*	85.42	83.33	82.29
	FAR(%)	7.29	14.58	10.42
Deltas	*ADR(%)*	78.26	52.17	43.48
	FAR(%)	4.35	34.78	13.04
Cores + Deltas	*ADR(%)*	84.87	76.47	74.79
	FAR(%)	5.88	16.80	10.92
Fingerprints	*CDR(%)*	82.95	73.86	70.45

Fig.6 presents examples of detection results based on Gao's technique [9], Chen's [10] and the proposed technique. It is observed that, with the proposed technique, false alarm detections in the PI-based detection and missing detections in the non PI-based detection are eliminated.

5. CONCLUSION

This paper presents a simple and novel technique for the detection of SPs in fingerprint images. First, the squared orientation field is extracted from a preprocessed fingerprint image. Second, an orientation field regularization technique based on DHHD is proposed to distinguish the local orientation patterns of genuine SPs from that of spurious SPs. Finally, the SPs are detected using the PI technique on the basis of the regular orientation field. Experimental results on the database FVC2002 [11] show the efficiency of the proposed technique.

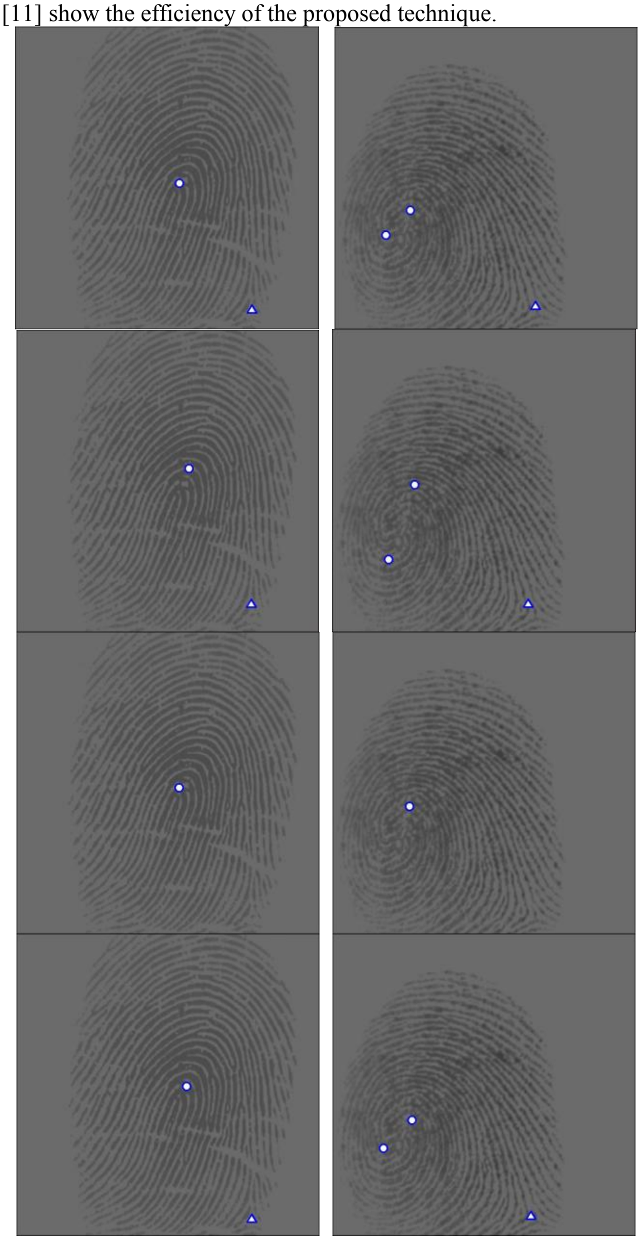


Fig. 6 Two examples of detection results. The first row shows two fingerprint images. The ground truth cores are indicated by circles, whereas the ground truth deltas are indicated by triangles. The following three rows (from top to bottom) illustrate the detection results based on the Gao's technique [9], Chen's technique [10] and the proposed technique, respectively. The most complex situations for SP detection, such as crease, scars, ridge breaks and blurred fingerprint, are covered in the shown fingerprints.

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