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Walking to singular points of fingerprints

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ABSTRACT

Singular point is an essential global feature in fingerprint images. Existing methods for singular points' detection generally visit each pixel or each small image block to determine the singular point. That is to say, existing methods require scanning the image to compute a quantity at each pixel or block, and hence they are inevitably time-consuming. We propose a fast algorithm for detecting singular points by walking directly to them instead of scanning the image. Walking Directional Fields (WDFs) are established from the orientation field. Then following the walking directions on WDFs, we can rapidly walk to the singular points. The walking algorithm is extremely fast and easily implemented with acceptable accuracy. Further more, its accuracy can also be improved by combining with state-of-the-art methods: we can rapidly walk to a candidate singular point, then refine its location using existing more accurate method in the local area. Experimental results on datasets of SPD2010 and FVC validate the high efficiency and satisfactory accuracy of the proposed algorithm.

1. Introduction

Fingerprint singular points (upper core, lower core and delta), defined as where the orientation field is discontinuous or the ridge curvature is the highest, are essential for registration and identification (specially for image-based approach instead of minutiae-based approach) [1,2]. Singular points' detection methods have been well studied, including Poincaré index (PI) technique [3–8], model-based technique [9–12], complex filter technique [13–18] and others [19–22]. However, these methods are based on scanning process which consumes a lot of processing time as shown below.

The Poincaré index of a point is defined as the cumulative orientation differences counterclockwise along a simple closed path surrounding this point. For core, delta and non-singular point, the values of Poincaré index are π, $-\pi$ and 0 respectively. The Poincaré index method, first proposed by Kawagoe and Tojo [3], calculates Poincaré index for each point in the orientation field to determine whether it is a singular point. The Poincaré index method is the most classical way to detect singular points, because it can detect singular points accurately if the closed path is not too long. However it is sensitive to the noise of fingerprint image and easy to detect many spurious singular points. To improve the robustness, different strategies are used, such as replacing closed line integral with surface integral [4], fusing global features [5–7] and combining with other local characteristics [8]. They surely need extra processing time compared with the original Poincaré index method.

Model-based methods use mathematical formula to represent the orientation field and detect singular points by analyzing the corresponding model. The most popular model is the Zero-Pole Model, first introduced by Sherlock and Monro [9], which reveals that the orientation at a point is determined by the number and positions of singular points (cores as zeros and deltas as poles) plus a constant correction term. According to this constraint, special relationship between singular points and their neighbor points can be derived, then a Hough transform method [11] or a modified convergence index filter [12] is utilized to detect singular points. Although the accuracies of these methods are satisfactory, the efficiencies are not promising because Hough transform needs to scan all pixels to fill the parameter space and the modified convergence index filter needs to be applied to each pixel to find maxima and minima. Wang et al. [10] proposed a singular point detection method using the fingerprint orientation model based on 2D Fourier series expansions (FOMFE). The FOMFE detects singular point by analyzing the attributes of the characteristic matrix **A**, while the construction of **A** dominates the computation as it is conducted at each point on the orientation field, which constrains the efficiency of this method.

A complex filter technique [13–18] designs two complex filters to capture the symmetry properties of core and delta. Then the

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convolution of the complex orientation field image with each complex filter is computed and the point with high filter response is taken as the singular point. Similar to the Poincaré index method, the complex filter technique can be accurate when the size of complex filter is small but will report more spurious singular points. If the filter size is too large, the accuracy and the efficiency degrade. Nilsson and Bigun [15] make a tradeoff between detection rate and false alarm rate by applying a complex filter to the orientation field in multiple resolution scales, but more time is needed.

Other methods like sine-map-based technique [19], shape analysis method [20], multi-scale Gaussian filter method [21] and multi-scale orientation entropy method [22] all need to visit every pixel or block to extract enough information to detect singular points.

To sum up, almost all of state-of-the-art methods for detecting fingerprint singular point can hardly avoid visiting every pixel or small block to determine whether it is a candidate singular point, which fundamentally constrains the efficiency of these methods from being improved extraordinarily.

Based on the analysis of orientation fields derived from the Zero-Pole Model and those estimated from real fingerprint images, in this paper we propose a novel fast algorithm termed the *walking* algorithm which can directly walk to the singular points on some defined Walking Directional Fields (WDFs) without scanning the fingerprint image. The rotation characteristics of WDFs are used to make the walking algorithm insensitive to the rotation of fingerprint image. We also introduce a simple strategy to combine the walking algorithm with the state-of-the-art method to improve the accuracy. The code of the walking algorithm can be available at http://cn.mathworks.com/matlabcentral/fileexchange/54588-walking-algorithm-for-sp-detection. The rest of this paper is organized as follows. Section 2 introduces the WDFs which are the basis of the proposed algorithm. Then the walking algorithm is described in Section 3. Section 4 shows some experimental results. Finally we give conclusions in Section 5.

2. Walking directional fields

2.1. Zero-Pole Model

The Zero-Pole Model for orientation field estimation was first proposed by Sherlock and Monro [9]. This model considers core as zero and delta as pole in the complex plane, and uses the argument of complex function $p(z)$ to approximate the orientation $o(z)$ of a point z in the fingerprint. $p(z)$ and $o(z)$ are defined as follows:

$$p(z) = \sqrt{e^{2jo_\infty}\frac{(z-z_{c1})(z-z_{c2})\cdots(z-z_{cm})}{(z-z_{d1})(z-z_{d2})\cdots(z-z_{dn})}}, \tag{1}$$

$$o(z) = \arg(p(z)) \bmod \pi. \tag{2}$$

where z_{ci} and z_{dj} are the ith core and jth delta of fingerprint respectively, and o_∞ is a constant correction term. According to the knowledge of complex function, orientation at point z is the sum of effects of all cores and deltas, so Eq. (2) can be rewritten as

$$o(z) = o_\infty + \frac{1}{2}\left(\sum_{i=1}^{m}\arg(z-z_{ci}) - \sum_{j=1}^{n}\arg(z-z_{dj})\right) + k\times\pi, \quad k\in\mathbb{N}. \tag{3}$$

According to [11], orientation field in area Ω is mainly determined by its closest singular point, while the other singular points just have a constant influence on Ω. So the orientation of point z near core point z_c and that near delta z_d can be respectively approximated by Eqs. (4) and (5).

$$o_c(z) = o_{c\infty} + \tfrac{1}{2}\arg(z-z_c) + k\times\pi, \quad k\in\mathbb{N}, \tag{4}$$

$$o_d(z) = o_{d\infty} - \tfrac{1}{2}\arg(z-z_d) + k\times\pi, \quad k\in\mathbb{N}. \tag{5}$$

Fig. 1 shows the orientation fields around a core and delta generated by the above two equations with $z_c=(50,50), z_d=(50, 50)$ and $o_{c\infty}=o_{d\infty}=0$. We define the directions of a core and a delta as the positive directions of the x-axis in Fig. 1. Then when o_∞ changes, the directions of a core and a delta will equal $2o_{c\infty}$ and $(2o_{d\infty}/3)$ respectively. The proof is as follows:

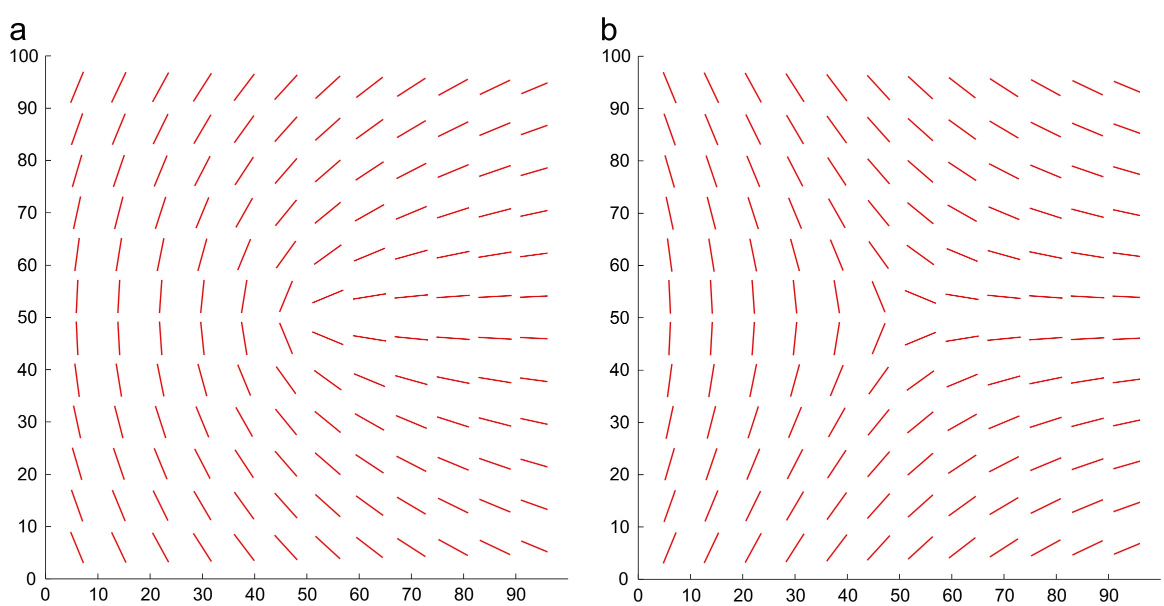

Fig. 1. Orientation field around (a) a core and (b) a delta, simulated by the Zero-Pole Model.