Singular Points Detection in Fingerprint Images using the Partitioning Region of Orientation Fields

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***Abstract*—Fingerprint classification is an important step in the Automated Fingerprint Identification System (AFIS). One popular approach to fingerprint classification uses singular points detection as reference points. However, it is not easy to detect singular points because it depends on the condition of the fingerprint. Fingerprints damaged by noise can result in spurious detection. This paper proposes a new algorithm for extracting the position and type of singular points in fingerprint images by combining the candidate regions of singular points (CRSP) and the Poincaré Index method. The results of the experiment using images with different image quality from NIST Special Database 14 demonstrate that the proposed algorithm has high accuracy in locating both the position and type of singular points.**

***Index Terms*—Fingerprint; Orientation Fields; Singular Point; Poincaré Index.**

I. Introduction

Fingerprint classification is a technique used to categorise fingerprints into one of several pre-specific types according to their features by comparing them to a subset of the database corresponding to that fingerprint type. A classification approach is a common strategy to reduce the number of comparisons in fingerprint retrieval and thus to improve the response time and reduce the computational complexity of the identification process. Most existing fingerprint classification approaches are based on global features, such as ridge orientation and singularity [10]. To improve fingerprint classification, algorithms for accurate singular points detection and direction estimation are required [1].

One global feature of a fingerprint image is orientation, which provides information about the local average directions of the fingerprint ridges and about valley structures. It is useful in the extraction of singular points. The difficulties associated with classification based on singularities are that the singular points may not appear in the image, especially if the image is small, and the noise in the fingerprint images makes the extraction of singular points unreliable, including missing singular points or the incorrect detection of singular points. The size of the closed digital curves is crucial in a singular point detection algorithm. If too small, a small perturbation caused by errors in calculating orientation may result in the detection of spurious singular points. Several methods have been proposed to detect singular points. However, the most common and widely used is the Poincaré Index [9], but this method is very sensitive to noise and is characterised by low contrast and low quality fingerprint images.

In this paper, we propose an algorithm to detect areas containing candidate singular points in the foreground of fingerprint images. For the purpose of detecting the position and type of singular points in fingerprint images, we first detect the candidate regions of singular points. We then apply the Poincaré Index method in examining candidate regions to judge the position and type of singular points. The remainder of this paper is organised as follows. In Section II, the related works are discussed. The detection algorithm is presented in Section III. Some experimental results are presented in Section IV, and Section V comprises the conclusion.

II. Related Work

There are two kinds of singular points in fingerprint images, core and delta points. The turning point of an innermost ridge is called the core point, whereas the place where two ridges run side by side and diverge is called the delta point [1]. Most approaches to detect singular points focus on the fingerprint orientation field, such as Poincaré Index method, the partitioning-based method and methods based on local characteristics of the orientation field.

A. Poincaré Index Method

The Poincaré Index originates from mathematical modelling. It is a numerical method to analyse the path of a continuous vector in an enclosed region and is defined by Thompson [15]. An interesting implementation of the Poincaré method for locating singular points is proposed by Bazen and Gerez [1]. Based on Green's theorem, a closed line integral of a vector field can be calculated as a surface integral of the rotation of this vector field. In practice, instead of summing angle differences along a closed path, the authors compute the 'rotation' of the orientation image (through further differentiation) and then perform a local integration (sum) in a small neighbourhood of each element.

Karu and Jain [8] propose iteratively smoothing the orientation fields until a valid number of singularities are detected using the Poincaré Index. The above constraints are nicely demonstrated by Zhou and Gu [17], who conclude that for each completely captured fingerprint there are the same number of core and delta points.

Zheng et al. [16] propose a technique that combines the curvature and characteristics of the orientation field to detect the location of singular points before applying the Poincaré

Index method. A practical way to enforce this constraint is to compute the Poincaré Index along the external boundary of the orientation image and then use the resulting value to limit the number of valid configurations.

Zhou et al. [5] propose an algorithm for singular points detection. First, the Poincaré Index is applied to detect singular points. Second, a differences of the orientation values along a circle (DORIC) feature is used to remove spurious singular points. Finally, the optimal combination of singular points is selected to minimise the difference between the original orientation field and the model-based orientation field reconstructed using the singular points.

Li et al. [11] propose a technique for singular points detection using orientation field regularisation and the Poincaré Index method. The squared orientation field is first extracted from a fingerprint image. In order to distinguish the local orientation patterns of true singular points from those of fake singular points, a technique based on discrete Hodge–Helmholtz decomposition (DHHD) is proposed to reconstruct a regular orientation field of the fingerprint. Based on the regular orientation field, the Poincaré Index method is then applied to extract the singular points.

B. Partitioning Based-Methods

Some studies propose partitioning orientation images into several distinct regions characterised by the homogeneous structural shape of orientation fields. Cappelli et al. [3] partition orientation images by grouping similar elements into several homogeneous connected regions that are used to build a relational graph summarising the fingerprint macro features. A set of dynamic masks and an optimisation criterion are used to conduct the partitioning. The adaptation of the masks produces a numerical vector representing each fingerprint as a multidimensional point, which can be conceived as a continuous classification. However, this method does not implicitly determine the singular points during the classification process.

Huang et al. [4] propose a pixel-wise orientation image using a directional template. The orientation image is smoothed by a median filter, and singular points are detected by analysing the direction sequence of the pixels. The resultant pseudo image consists of a number of uniform regions. The borderline between adjacent regions is called a fault line, which is used to determine the singular points and to distinguish core points from delta points. The experimental results show that 92% of the singular points are successfully detected. However, this method is time-consuming and has higher computational complexity due to pixel-wise operations.

C. Methods Based on Local Characteristics of the Orientation Fields

Hsieh et al. [6] use an octagon mask to search the centre point of the region of interest in the orientation fields and extract the feature from the lower half of the octagon mask. In the octagon mask, for the region of each triangle they assign different scores with different conditions for the corresponding pixels of the orientation fields. They also use the Poincaré Index but only to detect whether the region of interest includes any singular points.

Park et al. [12] propose a method to detect singular points by analysing the shapes of the orientation fields of fingerprint images. Candidate regions for singular points are detected from the calculated orientation fields. Finally, the singular points are extracted from the candidate regions. In the proposed method, two kinds of candidate regions are defined. One is the cap-shaped candidate region consisting of two consecutive blocks where the direction of the left block is between 0° and 90° and that of the right block is between 90° and 180°, and the inner angle between the two blocks is larger than or equal to 45° and smaller than or equal to 135°. These cap-shaped candidate regions are used for extracting the upper core and delta points. The other kind of candidate region is the cup-shaped candidate region where the direction of the left block is between 90° and 180°, that of the right block is between 0° and 90°, and the inner angle is larger than or equal to 45° and less than or equal to 135°. These cup-shaped candidate regions are used for detecting the lower core points. The idea to filter the singular points using the candidate regions is considered novel; however, since the size of the regions is too small (i.e. two consecutive orientation fields), some of the results for many candidate regions are worthless.

Li et al. [9] use a combination of the complex symmetrical filter method and the constrained nonlinear phase portrait to extract the singular points. The complex filter method is used to extract the candidate singular points, and true singular points are obtained from the constrained nonlinear phase portrait. The singular points are used for the classification of fingerprints. Reported accuracy of this fingerprint classification is good at 93.5%.

III. PROPOSED METHOD

There are several stages of the fingerprint process before the singular points detection stage. The first stage consists of foreground extraction, identification and marking of noise areas. The second stage consists of enhancement of the grey level, and the third stage consists of the estimation of orientation fields. The first and second stages are discussed in [19] and [18], respectively. The last stage is discussed in [14].

A. Region of Singular Point Detection

Some studies simply detect singular points using the Poincaré Index alone [1, 8, 9]. Others partition the orientation image in regions characterised by homogenous orientation to directly locate the singular points [3, 13]; yet their performance is unsatisfactory, as many false singular points are produced. Therefore, in this study, the partitioned regions are used instead to determine some potential candidate regions that may contain singular points. Hereinafter, the term candidate region of singular point (CRSP) will be used. A CRSP is considered to exist when all the different regions converge at one point (i.e. convergence block or CB) and the CB matches one of the four patterns of arches shown in Figure 1. In addition, there are four homogenous orientation regions, namely red, green, blue and purple, whose orientation field angles are [0°, 45°), [45°, 90°), [90°, 135°) and [135°, 180°), respectively.

Generally, the method of seeking a CRSP involves two stages. First, the CB is sought by scanning block by block in the orientation image to find a block of arches whose elements consist of all four homogenous regions with at least one member for each region. Second, the CB is then matched with pre-defined blocks of arches using a set of heuristic rules controlled by several parameters. A pre-defined block of arches is denoted by a set of 16 adjacent elements whose orientations comply with one of the four patterns depicted in Figure 1.

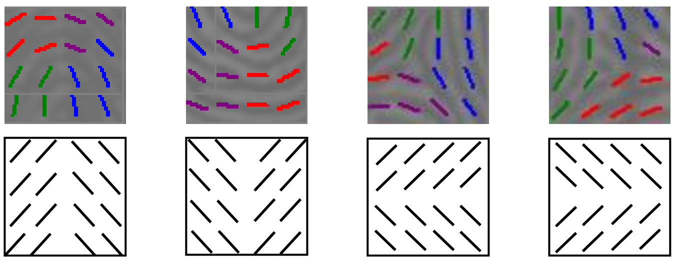

Figure 1: Set of four pre-defined block of arches

A detailed description of the approach is given below. However, for ease of discussion, let us first define all symbols and notations used, as follows:

a. Define an overlapping block of size 4×4 that contains 16 orientation fields as a block of interest (BoI) that acts as a mask. This mask-like BoI moves one column at a time from left to right and top to bottom within the orientation image, searching for a CB that is most likely to contain a singular point.
b. Let $Nt[1]$, $Nt[2]$, $Nt[3]$, and $Nt[4]$ represent numbers of orientation fields that have angles $0^o \le \theta'''(i,j) < 45^o$, $45^o \le \theta'''(i,j) < 90^o$, $90^o \le \theta'''(i,j) < 135^o$ and $135^o \le \theta'''(i,j) \le 180^o$, respectively.
c. Let $Nc[1,90]$, $Nc[2,90]$, $Nc[3,90]$, and $Nc[4,90]$ denote numbers of orientation fields of the 1st, 2nd, 3rd and 4th columns of BoI that have angles within $0^o \le \theta'''(i,j) < 90^o$, respectively.
d. Let $Nc[1,180]$, $Nc[2,180]$, $Nc[3,180]$ and $Nc[4,180]$ denote numbers of orientation fields of the 1st, 2nd, 3rd and 4th columns of BoI that have angles within $90^o \le \theta'''(i,j) \le 180^o$, respectively.
e. Let $Nr[1,90]$, $Nr[2,90]$, $Nr[3,90]$ and $Nr[4,90]$ denote numbers of orientation fields of the 1st, 2nd, 3rd and 4th rows of BoI that have angles within $0^o \le \theta'''(i,j) < 90^o$, respectively.
f. Let $Nr[1,180]$, $Nr[2,180]$, $Nr[3,180]$ and $Nr[4,180]$ denote numbers of orientation fields of the 1st, 2nd, 3rd and 4th rows of BoI that have angles within $90^o \le \theta'''(i,j) \le 180^o$, respectively.
g. Let $T1$ and $T2$ denote threshold values that determine the candidate region of singular points. In this study, the empirical values of $T1$ and $T2$ are 2 and 4, respectively.

A description of the above technique is as follows: Examine the orientation fields within the BoI:

1. If $\{ Nt[k] \ge T1 \}$ (for all $k = 1, 2, 3, 4$; signify four homogenous regions of orientation fields). Then
   If $\{((Nc[1,90] + Nc[2,90] \ge T2$
   and $Nc[3,180] + Nc[4,180] \ge T2$)) or ((
   $Nc[1,180] + Nc[2,180] \ge T2$ and $Nc[3,90] + Nc[4,90] \ge T2$))
   or (($Nr[1,90] + Nr[2,90] \ge T2$
   and $Nr[3,180] + Nr[4,180] \ge T2$)) or
   (($Nr[1,180] + Nr[2,180] \ge T2$)
   and $Nr[3,90] + Nr[4,90] \ge T2$))$\}$.
   Then the BoI is assigned as a candidate region of a singular point.
2. Otherwise, BoI is moved one column to the right.
3. Repeat Step 1 until the end of the orientation image.

The results of CRSP using the proposed method are shown in Figure 2.

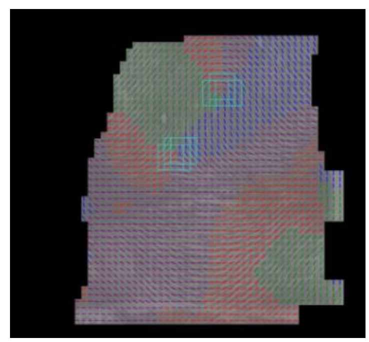

Figure 2: Results of CRSP using the proposed method (source: NIST Database 14, f0000023). Note: blue squares indicate CRSP

B. Singular Points Detection

Once the CRSP is obtained using the above procedure, the next step is to further analyse the shape of all elements in the CRSP to determine core and delta points using the Poincaré Index. However, some modifications must be made to the index to suit the proposed method. Details of the proposed method are as follows:

1. For each block of size 2×2 in a candidate region, compute the difference of closed-curve angles $\delta(k) = \theta'''(k \bmod 4) - \theta'''((k+1) \bmod 4)$, $k = 0, 1, 2, 3$, where $\theta'''(k)$ is the angle of orientation field estimation.
2. Now, define:

$$\Delta(k) = \begin{cases} \delta(k), & if\ 0 \le \delta(k) < \dfrac{\pi}{2}, \\ \pi - \delta(k), & if\ \dfrac{\pi}{2} \le \delta(k) \le \pi. \end{cases} \tag{1}$$

In the above, the Poincaré Index is represented by $P(i,j) = \dfrac{1}{2\pi} \sum_{k=0}^{N-1} \Delta(k)$. The angles' range of $[0, \pi]$ is used instead of $[-\frac{\pi}{2}, \frac{\pi}{2}]$, as in the original Poincaré Index. Figure 3 shows the results of the proposed method.

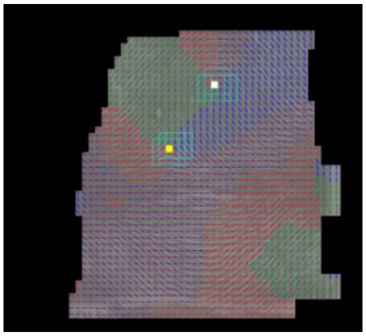

Figure 3: Core and delta detections using the proposed method (NIST DB 14: f0000023). Note: White and yellow squares indicate the core and delta points, respectively

IV. EXPERIMENT RESULT AND DISCUSSION

The experiment was conducted using 500 prints and 8-bit grey-scale fingerprint images from the NIST Special Database 14 (i.e. file names: f0000001–f0000500) to evaluate the performance of the proposed technique. The prints are 832 x 768 pixels. NIST Special Database 14 is a particular dataset used for fingerprint classification.

On visual inspection, a sample of the experimental results depicted in Figures 4–6 reveals that the proposed method performed superbly in terms of singular points detection accuracy for all image qualities, including dry, low contrast, bruise and cut. In fact, even for some poor quality images, bruised fingerprints in particular (see Figure 6. A. (a)–(b)), both core and delta points are precisely detected. These prints are actually very difficult to detect, even with the human eye. However, for the wet prints, the excessive amount of ink used resulted in defective ridge structure; the singular points sometimes could not be detected (see Figure 5.A. (b)). Moreover, for some prints that have a singular point located near the edges of the image, the proposed method failed to detect some delta points. Regardless of this deficiency, however, the filtering mechanism successfully reduced the number of fake singular points. In addition, for the sake of benchmarking, the proposed method is compared to the use of the Poincaré Index alone that has been employed by the majority of researchers in this field.

In order to accomplish singular points detection, an experiment was conducted and the results are compiled in Table 1. The results show that the proposed method has outperformed the Poincaré Index in terms of the false alarm rate for both core and delta points. However, the miss rates of deltas are worse. This is because in most cases, deltas are situated close to the border of the foreground. In other words, the area could not be reached by the algorithm when seeking the singular point. With regard to this shortcoming, the classification technique is implemented to resolve the problem by using the structure shape formed by the orientation field [15], thus perfectly complementing the singular point detection technique.

Table 1
Comparison results of singular points detection

Parameters	Poincaré Index	Proposed Method
Nco/Ndo	665	665
Ncore	815	672
Ndelta	742	570
Mc	29	32
Md	59	109
Fc	179	39
Fd	136	14
Mc(%)	4.96	4.81
Md(%)	9.47	16.39
Fc(%)	27.37	5.86
Fd(%)	20.90	2.11

Note: Nco/Ndo: number of core or delta points; Ncore: number of core points is found; Ndelta: number of delta points is found; Mc: miss rate of cores (i.e. discarded true cores); Md: miss rate of deltas (i.e. discarded true deltas); Fc: false alarm rate of cores (i.e. falsely accepted cores) and Fd: false alarm rate of deltas (i.e. falsely accepted deltas).

V. CONCLUSION

In this paper, an effective algorithm to detect areas containing candidate singular points in the foreground area of fingerprint images is proposed. For the purpose of detecting the position and type of singular points in the fingerprint images, the proposed technique consisting of two main steps was used. First, we found the candidate regions of singular points. Second, we used the Poincaré Index method to judge the position and type of singular points in candidate regions. This technique was successfully used to detect the core and delta points in the foreground of the fingerprint images. Experiments show that our algorithm is an improvement over the Poincaré Index method.

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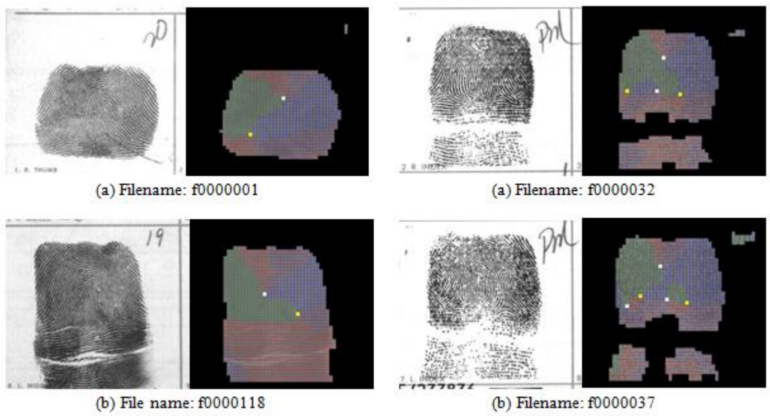

Figure 4: A. (a) and (b): Results of the singular points detection for good fingerprints
B. (a) and (b): Results of the singular points detection for dry fingerprints

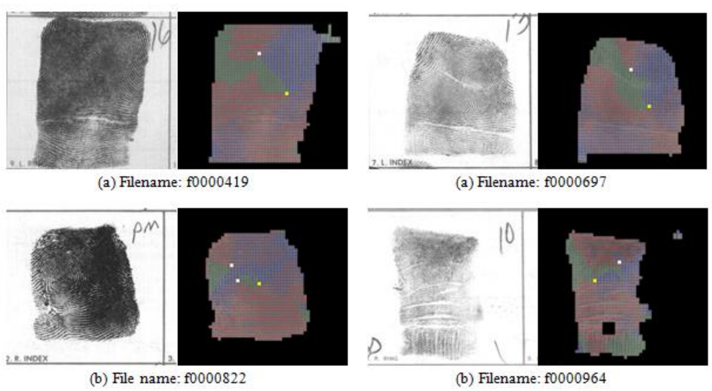

Figure 5: A. (a) and (b): Results of the singular points detection for wet fingerprints
B. (a) and (b): Results of the singular points detection for cut fingerprints

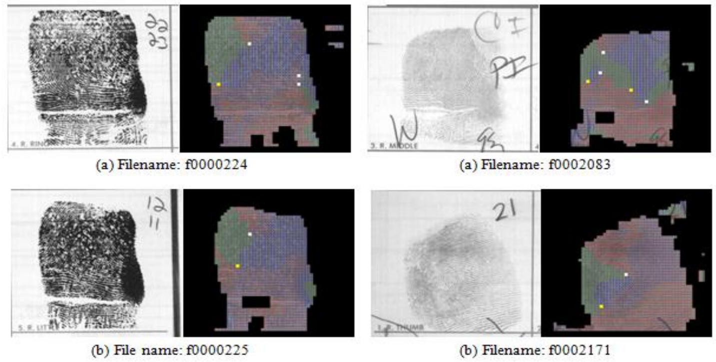

Figure 6: A. (a) and (b): Results of the singular points detection for bruises fingerprints
B. (a) and (b): Results of the singular points detection for low contrast fingerprints.