Singular Point Detection for Efficient Fingerprint Classification

Ali Ismail Awad† and Kensuke Baba‡

† Graduate School of Information Science and Electrical Engineering
‡ Kyushu University Library
10-1, Hakozaki 6, Higashi-ku, Fukuoka, 812-8581, Japan
{awad, baba}@soc.aist.kyushu-u.ac.jp

ABSTRACT
A singular point or singularity on fingerprint is considered as a fingerprint landmark due to its scale, shift, and rotation immutability. It is used for both fingerprint classification and alignment in automatic fingerprint identification systems. This paper presents a comparative study between two singular point detection methods available in the literature. The comparative study has been conducted on the Poincaré index and the complex filter methods, and it aims to catch the optimum singular point detection method in terms of the processing time and the detection accuracy. Moreover, discovering the processing time bottlenecks for both methods is an advanced step to improve the their performance. The optimum detection method in both processing time and detection accuracy will be updated to suite our efficient classification method. The conducted experimental evaluation for both methods proved that the maximum accuracy achieved by the complex filter is up to 95% with a considerable processing time and 90% with the Poincaré index method with a higher processing time.

Keywords: Fingerprints, Singular Point, Poincaré Index, Complex Filters.

1 INTRODUCTION
Fingerprint is the dominant trait between different biometrics like iris, retina, and face. It has been widely used for personal recognition in forensic and civilian applications because of its uniqueness, time immutability, and low cost. Fingerprint structure is defined by the interleaved ridges and furrows constructed on the finger tip. It falls under two categories, local and global structure. Fingerprint global features are considered as a coarse level structure, and it highly depends on the ridge flow orientation inside overall fingerprint image [1].

Singular Points are the most important global characteristics of a fingerprint. A core point is defined as the topmost point of the innermost curving ridge, and a delta point is the center of triangular regions where three different direction flows meet [2]. A global structure of different fingerprint images with core and delta points is shown in Fig.1. A singular point area is generally defined as a region where the ridge curvature is higher than normal and where the direction of the ridge changes rapidly. Singular points detection is an essential concept of fingerprint recognition and classification.

Automatic Fingerprint Identification Systems (AFIS) that supporting instant identification in large databases are increasingly used, and reducing the matching time is a key issue of any identification system. Fingerprint classification becomes indispensable choice for reducing the matching time between the input image and the large database. Singular points have been used in many fingerprint classification techniques. In our research, we try to reduce the AFIS response time by building an efficient classification mechanism as an application of singular point detection. It is important to our proposed classification method [3] to choose a time efficient and accurate singular point detection method to avoid any bad impact of the processing time. Some explanations of the efficient usage of the singular point is written in Section 2.1.

As a related work for using singular points in fingerprint classification, principal axes feature [4] has been used as a secondary stage of singularity-based classification algorithm. The algorithm takes into account not only the number of singular point, but also
the relation between them and their orientations on \((x, y)\) coordinates. Pseudo ridge tracing [5] has been proposed to use the ridge tracing mechanism in parallel with the orientation field analysis to compensate the missing singular points and improve the accuracy of the fingerprint classification. Singular point characteristics can also be used to construct a feature vector for training different learning based classification approaches such as Multi-layer Preceptron (MLP) Neural Networks [6] and Bidirectional Associative Memory (BAM) Neural Networks [7].

Many proposed approaches for detecting singular point are available in the literature, and most of them are working on orientation field images. By the definition of singular point, the regions which include singular point must have abrupt changes in the directions orientation inside. The Poincaré Index method (PI) [8] is the most famous approach of singular point detection. It has been used by many researchers like [9], [10], and [11]. However, the Poincaré index method has the ability to detect both types of singularity, it is very sensitive to noise and the variations of the grayscale level of the input image. Driven from the former definition, Complex Filters method (CF) [12] is another proposed method to extract regions with high orientation changes using a first order complex filter. These two methods have been especially selected due to the lack in processing time evaluation in both.

The contributions of this paper fall under catching the optimum singularity detection method in terms of the detection and localization accuracies, and the processing time. Moreover, detecting the processing time bottlenecks of both algorithms will open the doors to improve their performance dramatically. In addition to its applicability by many researchers in the area of fingerprints, the optimum algorithm will be updated and applied to our proposed classification method [13], [14] that uses the singular point location as a base for fingerprint image partitioning to achieve a higher robustness for fingerprint image shift and rotation.

The reminder part of this paper is organized as follows: Section 2 explains the two methods for singular point detection, the Poincaré index method and the complex filter method. The experimental results for the selected two methods and the comparative study are reported in Section 3. The conclusions are written in Section 4.

2 SINGULAR POINT DETECTION METHODS
Orientation image is an important characteristic of fingerprint image. Singular points can be extracted using several fingerprint characteristics including the usage of the raw orientation image as in the Poincaré index, the local characteristics of the orientation image by calculating the low and the high coherence areas, or using the complex filter with the orientation image for detecting the point of rotational symmetry [1]. The process of extracting the orientation image transforms the raw fingerprint image into a matrix of ridge orientations, and hence it preserves the global structure of the input fingerprint. The pixel gradient method [9] and the direction mask are the common ways to extract pixel orientation in fingerprint images. The gradient calculation is varying from using simple method like "Sobel operator" into more complex filters such as "Prewitt" [15]. In our implementations, a simple direction mask technique has been used to estimate the orientation fingerprint image for the Poincaré index method, and the gradient method has been used for extracting the orientation image prior to the complex filter.

2.1 Classification Requirements
As the application of singular point detection on fingerprint image, we consider classification of fingerprint images. Especially, we are planning to apply the result of this work to the fingerprint classification method we proposed [3]. In this subsection, we make clear the requirements of the singular point detection methods for the application.

Fingerprints are generally classified into 4 or 5 categories based on their global pattern of ridges and valleys. Fig. 1 is an example of classified fingerprint images with singular points. Briefly, the main idea of our classification method in [3] is dividing an input image based on a singular point to improve the accuracy. We consider the orientation characteristic of each divided image, and the characteristic tends to change drastically at a singular point. The proposed method utilizes the location (position) of a single core point, hence the required output of a singular point detection method is at least the position of one core point.

One of the differences between the two singular point de-
The Poincaré index is defined for each position in the orientation field image using the direction mask method with eight directions. The transformation of the input fingerprint image into an orientation field image is performed in itself and hence the effect of this difference is not clear. However, the classification method in [3] also has the robustness about image rotation in fingerprint classification, a singular point. This advantage seems to be usable to improve the robustness of our method, we can skip almost half of the processes of the method. Another difference is that the complex filter method extracts not only the position but also the orientation of a singular point. This situation is illustrated from the input image by

\[ \Delta_{k}(i,j) = \begin{cases} \delta_{k}(i,j) & \text{if } |\delta_{k}(i,j)| < \pi/2 \\ \pi + \delta_{k}(i,j) & \text{if } \delta_{k}(i,j) \leq -\pi/2 \\ \pi - \delta_{k}(i,j) & \text{otherwise}. \end{cases} \]

The Poincaré index have the value $-1/2$, 0, 1/2, or 1. A core point and a delta point are expected to occur at the position of which Poincaré index is 1/2 and $-1/2$, respectively (see Fig. 3(b) and 3(c)).

Since the method computes the Poincaré index for every position, the time complexity is $O(n^2)$ for the size $n^2$ of the input image. By the definition of the Poincaré index, it is clear that the value is preserved for any rotated image.

### 2.3 Complex Filter Method

The complex filter method detects symmetric parts in the complex orientation field by applying two kinds of complex filters for core and delta points. The complex orientation field image is obtained from the input image by

\[ z(x,y) = (f_x + is_f)_y^2, \]

**2.2 Poincaré Index Method**

The first step before applying the Poincaré index method is to transform the input fingerprint image into an orientation field image using the direction mask method with eight directions. The Poincaré index is defined for each position in the orientation field and generally computed by considering some elements around the position. Let $\theta(i,j)$ be the $(i,j)$-element of an orientation field image and $0 \leq \theta(i,j) < 2\pi$ for any $(i,j)$. Fig. 2 is an example of orientation field images for a core and a delta point.

In this paper, we consider the 8 elements contiguous to the target position. For a position $(i,j)$, let $(i_0,j_0) = (i,j+1)$, $(i_1,j_1) = (i+1,j+1)$, $(i_2,j_2) = (i+1,j)$, $(i_3,j_3) = (i+1,j-1)$, $(i_4,j_4) = (i,j-1)$, $(i_5,j_5) = (i-1,j-1)$, $(i_6,j_6) = (i-1,j)$, and $(i_7,j_7) = (i-1,j+1)$. This situation is illustrated in Fig. 3(a). Let

\[ \delta_k(i,j) = \theta(i_{k+1},j_{k+1}) - \theta(i_k,j_k), \]

for $0 \leq k \leq 6$ and $\delta_7 = \theta(i_0,j_0) - \theta(i_7,j_7)$. Then, the Poincaré index of an element $(i,j)$ is defined to be

\[ P(i,j) = \frac{1}{2\pi} \sum_{k=0}^{7} \Delta_k(i,j), \]
where $i$ is the imaginary unit and $f_x$ and $f_y$ are the derivatives of the input image in the $x$- and $y$-directions, respectively [12].

The complex filters for core points and delta points are respectively

$$F_c = (x + iy)^m g(x, y)$$  \hspace{1cm} (5)$$

and

$$F_d = (x - iy)^m g(x, y),$$  \hspace{1cm} (6)$$

where $m$ is the filter order and $g$ is the Gaussian such that

$$g(x, y) = \exp \left( -\frac{x^2 + y^2}{2\sigma^2} \right)$$  \hspace{1cm} (7)$$

with the variance $\sigma$. The convolution of the complex orientation field image with each complex filter is computed, and then a point with high filter response is considered as a singular point corresponding to the filter type (see Fig. 4).

In this method, the computation of the convolution takes an $O(n^2 \log n)$ time for the size $n^2$ of the input image, and the other processes are constant or linear to $n^2$. Therefore the time complexity of the method is $O(n^2 \log n)$.

### 3 EXPERIMENTAL RESULTS

Through our experimental work, we will shed lights on the processing time as an important evaluation factor of singularity detection algorithms beside the total detection accuracy. In the experimental work, both algorithms have been evaluated using two Fingerprint Verification Competition 2002 (FVC2002) [1], [16] subsets. DB1_B and DB2_B are two FVC2002 subsets captured by optical sensors "TouchView II" by Identix and "FX2000" by Biometrika, respectively. A sample from the FVC2002 database subsets is shown in Fig. 5. Each data set contains 80 images, and all images have been used to evaluate the both algorithms. A first order $m = 1$ complex filter has been constructed with an optimal size as $(32 \times 32)$ pixels, and the Gaussian variance is empirically set to 7 to achieve the maximum performance. All output results in the following tables have been generated using Intel® Core 2 DuoTM Processor (T9300, 2.5 GHz, 6 MB L2 cash), 3 GB of RAM, Windows XP® Pro 32 bit, and Matlab® R2009b version.

#### 3.1 Processing Time

Tables 1 and 2 point out the huge difference between the Poincaré index method and the complex filter one for the selected two database subsets in terms of the minimum, the maximum and the average of the processing times. From both tables, we have believed that the Poincaré index method imposes some processing time impact on the total response time of the system that uses singular point in classification or alignment. The overall performance of the automatic fingerprint identification system will get degraded in terms of the processing time after embedding the Poincaré index method for detecting fingerprint singularity.

Detecting processing time bottleneck is an important contribution of this work. To achieve that, we have measured the time

| Table 1. The processing time of the singular point detection algorithms in DB1_B (second). |
|-----------------|----------------|----------------|
| Poincaré Index  | 2.21           | 4.52           |
| Complex Filter  | 0.126          | 0.143          |
| Average         | 3.14           | 0.133          |

| Table 2. The processing time of the singular point detection algorithms in DB2_B (second). |
|-----------------|----------------|----------------|
| Poincaré Index  | 2.44           | 7.12           |
| Complex Filter  | 0.151          | 0.164          |
| Average         | 4.52           | 0.157          |
Figure 6. The processing time of each step in the Poincaré index method.

Table 3. The accuracy of the singular point detection algorithms in DB1_B.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Correct</th>
<th>Incorrect</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poincaré Index</td>
<td>68</td>
<td>12</td>
<td>85.0</td>
</tr>
<tr>
<td>Complex Filter</td>
<td>73</td>
<td>7</td>
<td>91.3</td>
</tr>
</tbody>
</table>

Figure 7. The processing time of each step in the complex filter method.

Table 4. The accuracy of the singular point detection algorithms in DB2_B.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Correct</th>
<th>Incorrect</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poincaré Index</td>
<td>72</td>
<td>8</td>
<td>90.0</td>
</tr>
<tr>
<td>Complex Filter</td>
<td>76</td>
<td>4</td>
<td>95.0</td>
</tr>
</tbody>
</table>

consumed by each processing step in both algorithms. Fig. 6 and Fig. 7 show the output of the measurement process. By Fig. 6, the process of orientation field normalization is the bottleneck of the Poincaré index method. By Fig. 7, the image segmentation is considered as the highest process of complex filter method. In order to improve the processing time for both algorithms, we should put some efforts to enhance these two bottlenecks before going further to use any of them in fingerprint classification or alignment.

It is worth noticing that our implementations of the Poincaré index method is less time consuming than the implementation in [17] which takes 10 seconds for processing a single fingerprint image. However, the detection accuracy in [17] is higher than the rate we achieved, especially with noisy fingerprint images which taken from the same database.

3.2 Accuracy

The accuracy of a singular point detection method is measured as the number of images in which the singularities have been correctly detected to the total accessed images in the whole database. Tables 3 and 4 show the accuracy of both algorithms in the two selected databases. By the both tables, the complex filter algorithm has an advanced step over the Poincaré index method. Moreover, all fingerprints in the two selected database subsets have been visually inspected to judge the accuracy of the \((x, y)\) location of the detected singular point. In this context, we found that both of the evaluated algorithms produce closed locations of the detected singularities in the range of \(\pm 16\) pixels.

In the rest of this subsection, we report the robustness of both algorithms with respect to image noise, shift, and rotation. Fig. 8 shows some examples of singular point detection results by both explained methods under different fingerprint image conditions. By Fig. 8, the complex filter method performs well under little noise, but both methods fail under the heavy noise. On the other side, the Poincaré index method fails under shifting condition even for a good image. We observe that the image rotation imposes a little effect on the accuracy of the Poincaré index method. In contrary, the complex filter method is immutable to the rotation condition.

4 CONCLUSIONS

Fingerprint singular point is considered as a landmark of fingerprint topology, it is scale, shift, and rotation invariant. These singularities can be used for both classification and alignment processes in the automatic fingerprint identification systems. This paper was seeking for catching the best singular point detection algorithm in terms of the processing time and the accuracy. The selected algorithm will be developed and extended for a novel fingerprint classification technique. The comparison has been carried out on two singular point detection algorithms. Our experimental work concludes that the complex filter method is working very well and it achieves a high detection accuracy in a very considerable processing time. Driven from this conclusion, the complex filter method will be orientated to suite our proposed classification method.

5 REFERENCES