Fingerprint Retrieval by Complex Filter Responses

Manhua Liu, Xudong Jiang, Alex Chichung Kot
Nanyang Technological University, EEE, 50 Nanyang Avenue, Singapore, 639798
{pg05080538, exdjiang, eackot}@ntu.edu.sg

Abstract

This paper proposes an approach of fingerprint retrieval based on the continuous classification of two complex filter responses. Two complex filters are introduced and applied on the fingerprint orientation field to extract the local singularities, the similarities to the singular points. A numerical feature vector from the aligned fingerprint local singularities is constructed as the global feature for fingerprint retrieval. The continuous classification is employed to retrieve a subset of fingerprints similar to the query fingerprint for the finer matching. Experimental results on NIST fingerprint database 4 (NIST-4) show the effectiveness of the proposed fingerprint retrieval approach.

1. Introduction

Fingerprint as a kind of human biometric feature has been widely used for personal recognition in commercial and forensic areas due to its uniqueness, immutability and low cost. In general, fingerprint based biometric recognition systems work in two modes: authentication and identification [9]. In the authentication mode, the user inputs his fingerprint and claims an identity information, then the system verifies whether the input fingerprint is consistent with the claimed identity. In the identification mode, however, the user only input his fingerprint, and the system identifies the potential corresponding fingerprints in the database without the claimed identity. Therefore, fingerprint identification requires exhaustively searching the database for a matching, which is more complex than the authentication mode especially when the database is large. Currently, satisfactory performances have been reported for fingerprint authentication, while it is still a great challenge to improve the performance of fingerprint identification system. A simple solution to fingerprint identification is the naïve matching system, which repeats the authentication procedure for each fingerprint in the database until the matched one is found. However, both the efficiency and accuracy of fingerprint identification will deteriorate by using the naïve matching approach for a large database [9].

To avoid the exhaustive search of database in the finer matching, a coarse level matching, which was also called fingerprint retrieval in [9], was introduced to coarsely retrieve a subset of database for the finer matching. Generally, there are three approaches proposed for the coarse level matching, which are exclusive fingerprint classification, fingerprint indexing and continuous fingerprint classification. The exclusive classification has been widely investigated in [7, 6, 4, 11] which classifies each fingerprint exclusively into one of the predefined classes such as Henry five classes: plain arch, tented arch, left loop, right loop and whorl. Although exclusive classification has some advantages such as human-interpretable, fast retrieval and rigid database partitioning, most automated classification algorithms are able to classify fingerprints into only 4 or 5 classes. Moreover, fingerprints are not evenly distributed in these classes. The natural distributions of the Henry five classes are 3.7%, 2.9%, 33.8%, 31.7% and 27.9%, respectively. The retrieval on exclusive classification selects the fingerprints belonging to the same class as that of the query one. On average, the query fingerprint still need to compare with about 29.48% of the natural distributed database in the finer matching after the exclusive classification is applied. Obviously, the exclusive classification cannot narrow down the search space much for a large database. Another problem is that there are many ambiguous fingerprints, whose class membership cannot be exclusively stated even by human experts.

Actually, it is not necessary to classify fingerprints into human-interpretable classes for an automated identification system. A fingerprint indexing [2] was proposed to divide fingerprints into a number of bins based on the minutia triplets. It can classify fingerprints into much more classes (bins) than the exclusive classification by exploiting the much more discriminating features, fingerprint minutiae (ridge ending and bifurcation). However, the minutia points are widely used in fingerprint matching algorithms. This approach may construct a redundant fingerprint representation which will limit its ability to alleviate the accuracy deterioration of identification although it can speed up the identification process.
The continuous classification [8] was proposed to improve the performance of fingerprint retrieval by representing each fingerprint with a numerical feature vector. The similar fingerprints are mapped into close points in the multi-dimensional feature space by a given distance measure. The fingerprint retrieval is performed by comparing the query fingerprint with the database templates and retrieving the closer ones. The tradeoff between the retrieval efficiency and accuracy can be adapted by adjusting the size of retrieval neighborhood. The fingerprint orientation field as an important global feature has been used in the continuous classification techniques proposed in the literature [8, 5]. In this work, two complex filters are introduced and applied on the orientation field to extract the fingerprint local singularities. A fingerprint retrieval approach is proposed that is based on the continuous classification of the responses of these two complex filters. Finally, NIST-4 is used to test the proposed fingerprint retrieval approach.

2. Fingerprint Retrieval by Complex Filter Responses

Generally, fingerprint contains two kinds of features for recognition: global features such as singular points and orientation field and local features such as minutiae points. The global features are usually used for fingerprint retrieval while the local features are applied on the finer matching. To construct a numerical feature vector for the fingerprint retrieval, two complex filters are employed to extract the local singularities i.e. the similarities to the singular points.

2.1. Feature Extraction

Most fingerprint images consist of both the foreground originated from the contact of fingertip with the sensor and the background, the blank and heavy noisy areas. A reliable feature extraction should exclude the background. The fingerprint segmentation algorithm [1] is applied in this work to separate the foreground from the background.

The singular points i.e. core and delta points are two landmarks of fingerprint (see Figure 1a). Their locations and orientations usually determine the fingerprint ridge flow patterns so that they were used for the exclusive classification [7, 11]. A numerical vector is expected to describe the fingerprint local singularities for the continuous classification. A set of complex filters of order $k$ modelled as $e^{jk\varphi}$ were proposed for the detection of patterns with radial symmetries [3]. Let $x$ and $y$ denote two coordinates in image analysis, the complex filters can be computed as:

$$e^{jk\varphi} = \frac{x + jy}{\sqrt{x^2 + y^2}}$$

$$\varphi = \frac{1}{k} \tan^{-1}(y/x)$$

Therefore, we apply these two complex filters on the fingerprint orientation field represented with the phase angle $\theta_{m,n}(1 \leq m \leq M, 1 \leq n \leq N)$ to extract the local similarities to singular points, i.e. the local singularities. For the filtering window of size $(2w + 1) \times (2w + 1)$, the filter responses of each block $(m, n)$ are computed as:

$$h_{m,n} = \frac{\sum_{x=-w}^{w} \sum_{y=-w}^{w} \mu_{m+x,n+y} e^{\pm j2(\theta_{m+x,n+y} - \varphi_{x,y})}}{\sum_{x=-w}^{w} \sum_{y=-w}^{w} \mu_{m+x,n+y}}$$

where $\mu_{m+x,n+y} \in \{0, 1\}$ denotes the segmentation result of block $(m + x, n + y)$ and $\mu_{m+x,n+y} = 1$ indicates the block is segmented as foreground valid for feature extraction. $\varphi_{x,y}$ is computed in equation (2). We can see that these two filter responses are complex values. The magnitudes ($\in [0, 1]$) represent how close the fingerprint local

![Figure 1](image1.png)

**Figure 1.** (a) The fingerprint core and delta points denoted with $\circ$ and $\triangle$, respectively, and (b) the fingerprint orientation field.

![Figure 2](image2.png)

**Figure 2.** The orientation patterns of $\varphi$ with filter model $e^{j2\varphi}$ (left) and $e^{-j2\varphi}$ (right).
orientation patterns are similar to the orientation patterns of two filters, while the phase angles indicate the rotations between the local orientation patterns of fingerprint and filters. Let \( s_1(m, n) \) and \( s_2(m, n) \) denote the response magnitudes of filter \( e^{j2\phi} \) and \( e^{-j2\phi} \) applied on the fingerprint orientation \( \theta_{m,n} \), respectively. Figure 3 shows the \( s_1 \) and \( s_2 \) of Figure 1b with the filtering windows of two different sizes \( (w = 1 \text{ and } 2) \). We can see that \( s_1 \) and \( s_2 \) are large (white) in the core and delta points, respectively.

**Figure 3.** The magnitudes of filter responses \( s_1 \) (left) and \( s_2 \) (right) with filtering window \( w = 1 \) (above) and \( w = 2 \) (below), respectively.

More valid orientations included in the filtering window of equation (3) will produce more reliable filter responses. Large filtering window is more robust to noise and produce more smooth responses than small window (see Figure 3). But it also needs more computation. The filtering window \( w \) should be properly selected to balance these effects. Figure 4 shows the magnitudes of the filter responses \( (w=2) \) for a whorl and a plain arch fingerprint. We can see that these filter responses are significantly different from those in Figure 3. The responses of these two complex filters are thus discriminative for different types of fingerprints, which contain different number and locations of singular points. Therefore, the magnitudes of these two filter responses are used in this work as the feature for fingerprint retrieval.

Since the pose transformations i.e. translation and rotation usually exist in fingerprint images, the core points and the corresponding directions detected in [10] are employed for the translational and rotational alignments of the filter responses. Each fingerprint is represented with a numerical vector by concatenating the aligned magnitudes of two filter responses \( s_1(m, n) \) and \( s_2(m, n) \).

**2.2. Fingerprint Retrieval**

For a query fingerprint, the fingerprint retrieval in this work is to coarsely select a subset of candidate fingerprints from the database for the finer matching in fingerprint identification system. The query fingerprint is still required to match with 20-30% of the database templates after the exclusive classification is applied. Since our characterization of each fingerprint is a numerical vector extracted from two complex filter responses, the continuous classification is employed for the efficient fingerprint retrieval. The Euclidean distance is used to measure the difference of the feature vectors between two fingerprints. The database templates close to the query fingerprint (their distances smaller than a threshold) are retrieved for the finer matching.

**3. Experimental Results**

Most published fingerprint retrieval results on exclusive and continuous classifications as well as indexing are based on the NIST-4. To compare with other approaches, we also
test our approach on this database, which contains 4,000 fingerprints of size $480 \times 512$ pixels, taken from 2,000 fingers with two instances per finger. The Henry five classes are evenly distributed in this database, which is significantly different from their natural distributions. To resemble this real distribution, we reduce the number of fingerprints of less frequent classes and obtain 1204 pairs of fingerprints. This reduced database, called data set 2, and the original NIST-4, are both applied in our experiments. The first fingerprint instances form the database templates to be retrieved and the second instances are used as query fingerprints. In our experiments, each fingerprint is divided into blocks of size $27 \times 27$ to compute an orientation field of size $17 \times 18$. A numerical feature vector of size $2 \times 169$ is constructed from the aligned magnitudes of two complex filter responses with $w = 2$ for the continuous classification.

Efficiency and accuracy are two main performance measures widely used for fingerprint retrieval. In our experiments, the retrieval efficiency is indicated by a so called "penetration rate", which is the average percentage of the retrieved fingerprints for the finer matching over all query fingerprints. Smaller penetration rate indicates higher retrieval efficiency. The retrieval accuracy is calculated by the percentage of the query fingerprints whose corresponding database templates are correctly retrieved at a given retrieval efficiency. To compare with the continuous classification approach in [5] which outperformed the approach [8], we implement our approach on data set 2. The retrieval results (penetration rate vs. retrieval accuracy) are shown in Figure 5. We can see our approach performs better than [5], especially at the high retrieval efficiency.

![Figure 5. The comparison of the retrieval performances in our proposed approach and [5].](image)

To compare with the exclusive classification, we implement our approach on NIST-4. The classification accuracies for the Henry five classes reported in [7, 6, 11] are 85.5%, 90% and 84.3%, respectively. The classification accuracy in [6] is obtained at 1.8% rejection rate, which slightly increases the penetration rate. The penetration rates in exclusive classification are usually larger than 20%. The retrieval accuracy in our approach is 90.30% at penetration rate 20%. Although the classification accuracy is not equivalent to the retrieval accuracy, it shows the proposed approach can get high retrieval accuracy with better retrieval efficiency.

### 4. Conclusions

In this work, a fingerprint retrieval approach on continuous classification is proposed based on the responses of two complex filters. A numerical feature vector is extracted for the fingerprint retrieval from the aligned magnitudes of two filter responses which describes the fingerprint local singularities. Our experimental results on NIST-4 show the effectiveness of the proposed approach. A problem of our approach is the dependence on the consistent translational and rotational alignments. A substantial portion of retrieval errors are caused by the inconsistent alignments.

### References


