Fingerprint Recognition System

by

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Next, I want to thank my parents. You give me financial support, and both of you are excellent parents for me. To be your daughter is the luckiest thing I experienced.

At last, thank my friends, all of you love me so much. You support when I upset and
share happiness with me. You are my precious wealth in my life.
How to process the low-quality/resolution fingerprint images and how to extract the minutiae features reliably from fingerprint images are the most two challenging and difficult problems in the field of fingerprint image identification. This paper implements a fingerprint recognition system which can read the input of fingerprint images, verify the fingerprint image by extracting the minutiae features, and so can be matched with another fingerprint image to compute the similarity between those two fingerprint images. At this paper, we integrated previous papers’ work, combined these algorithms’ steps, and explored on similarity scores estimation between two comparison fingerprint images. The goal of this paper is to give a systematic technology system to deal with the low-quality/resolution fingerprint image for extracting the minutiae features.
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Chapter 1

Introduction

The fingerprint is an impression left by the friction ridges of a human finger[7]. There are three characteristics of human fingerprint: detailed, unique, difficult to alter, and durable over the left of an individual[7]. Those characteristics make fingerprint as an ideal marker for human identity and derive lots of field applications around it. In recently years, fingerprint recognition technologies are used widely and deeply in the field of forensic science, helps human to build the log-in authentication and other electric lockers to ensure and protect the security of private and country, assistants the special electronic registration, and applied for unlocking the mobile, shopping and payment apps.

Fingerprints could be classified by global and local features. There are three main patterns for global: arch, loop, and whorl[7]. Moreover, in some papers, people use orientation map to illustrate the same concept[1].

The minutiae are the most important feature to identify the fingerprint local feature even fingerprint. In general, the major three types of minutiae features in the fingerprint are ridge ending, bifurcation, and short ridge (or dot)[7]. Ridge ending is a terminates of a ridge, bifurcation is the point which a single ridge where it divides into two ridges, and short ridges (or dots) are shorter than average ridge length on the fingerprint [7].

How to estimate the fingerprint orientation and frequency is an important core technology has been researched by many papers. It decides the reliable level of fingerprint
identifies. The ridge orientation map is used for many utilization. For example, Srinivasan, VS and Murthy, used ridge orientation map to find out and detect the singular points[6], Kawagoe, Masahiro and Tojo, Akio used the map to process the features of minutiae and classify the fingerprint[3]. Moreover, Sherlock, BG and Monro, DM and Millard, K used it to enhance the fingerprint images[5]. There exists different methods to implement the estimation of fingerprint image orientation maps. Kawagoe, Masahiro and Tojo, Akio utilize the comparison of template[3], Hong, Lin and Wan, Yifei and Jain, Anil used the concept of gradients[2], and Sherlock, BG and Monro, DM and Millard, K used the
ridge projection[5]. Local fingerprint frequency indicates the average inter-ridge distance within a block[1]. Hong, Lin and Wan, Yifei and Jain, Anil used projection sum [2] and Maio, Dario and Maltoni, Davide used the concept of variation at gray-level in different directions[4] to estimate the fingerprint frequency from the fingerprint images. Moreover, there some papers researched how to extract singular points[3, 6].

The rest of the paper is: Chapter 2 presents the implementation of the algorithm for this paper, include the normalization, extraction of ridge orientation and frequency, segment and enhancement, and compute similarity. Chapter 3 analyzed the results and chapter 4 concluded this fingerprint recognition system and some works may consider in future.
Chapter 2

Design and Implementation

2.1 Database

The database source is FVC2002. For this paper’s research, it includes 80 images totally. There exists 10 different fingerprint sets, each fingerprint set contains 8 complete or partition images. Moreover, there are four image types among the same fingerprint set. The first type is high resolution with complete fingerprint images, in this paper, high resolution and the complete fingerprint image is set as a reference sample. The second type is high resolution with non-complete fingerprint images, some are fingertip detect and others are fingertip fingerprint images. The third type is low resolution with complete fingerprint images, it is used for enhancement research. The last type is low resolution with partition parts of fingerprint images which are used for comparison.

Figure 2.1: Sample of one set of fingerprint images
2.2 Algorithm

The main implement for the algorithm has five parts: The First step is normalization, second is to estimate fingerprint orientation and frequency. Thirdly, implement the segmentation and enhancement. Next step is to estimate the region mask and build the filters bank. The last step is to compute the similarity between two images.

Figure 2.2: Algorithm flow chart

2.2.1 Normalization

Normalization[2] is a necessary processing for pixel-wise which maintains the original resolution of fingerprint ridges structures. Moreover, it could decrease the ridges’ variations at gray-level[2]. The processed images will assistant the following steps.
Define $D(i, j)$ as the gray-level value at pixel $(i, j)$, while $M$ and $\text{VAR}$ express the estimated mean and variance of $D$, and $B(i, j)$ means the normalized gray-level value at pixel $(i, j)$\[2\]. Then we can define a normalized fingerprint image as below:

\[
G(i, j) = \begin{cases} 
M_0 + \sqrt{\frac{\text{VAR}_0 (I(i,j) - M)^2}{\text{VAR}}} & \text{if } I(i, j) > M \\
M_0 - \sqrt{\frac{\text{VAR}_0 (I(i,j) - M)^2}{\text{VAR}}} & \text{otherwise}
\end{cases}
\]  \[2\]

- $D(i, j)$: pixel $(i, j)$’s gray-level value\[2\]
- $B(i, j)$: pixel $(i, j)$’s normalized gray-level value\[2\]
- $M_0$: estimated mean values of $D(i, j)$\[2\]
- $\text{VAR}_0$: variance values of $D(i, j)$\[2\]

### 2.2.2 Estimate fingerprint orientation and frequency

A wave model could be built to estimate the ridge in practice, and the Fourier spectrum is used to described the orientations and frequencies of fingerprint images’ energies distribution\[1\]. Then we could use a probabilistic method\[1\] to estimate every orientation and frequency at every split block. Fourier spectrum in polar form as $F(r, \phi)\[1\]$. By using the concept as above, a probability density function $f(r, \phi)$ and the marginal density functions $f(\phi)\[1\]$, $f(r)$ could be defined as:
Orientation $\phi$ is taken as a random variable which has the probability density function $f(\phi)$\[1]. The estimated orientation is defined as:

$$f(r, \phi) = \frac{|F(r, \phi)|^2}{\int \int |F(r, \phi)|^2 d\phi dr} \quad (1)$$

$$f(\phi) = \int_r f(r, \phi) d\phi, \quad f(r) = \int_\phi f(r, \phi) d\phi \quad (2)$$

The estimation of frequencies is nearly the same way as the estimation of orientation. Frequency is assumed as a random variable with the probability density function $f(r)$ as Equation (2)\[1]. Moreover, to improve and smooth the orientation and frequency, we could consider the using of gaussian mask\[1]. And the estimated frequency is defined as:

$$E\{r\} = \int_r r \cdot f(r) d\phi \quad (3)$$

2.2.3 Segment and enhancement

The fingerprint image could be segmented by detecting the wave model where the areas do not have ridges and valleys. That’s because, in the Fourier spectrum, neither the background nor the noisy areas will have effective structures and contents.

A Fourier domain based block-wise contextual filter is approached for the propose of fingerprint images enhancement\[1]. Fingerprint images will split into 16 x 16 blocks and
are filtered in the Fourier domain. The Fourier domain orientation and frequency filters parameters are estimated by computing the local ridge orientation and frequency[1].

The filters are expressed as in [5] and are below:

\[
H_r(r) = \sqrt{\frac{(rr_{BW})^{2n}}{(rr_{BW})^{2n} + (r^2 - r_{BW}^2)^{2n}}}
\]

\[
H_\phi(\phi) = \begin{cases} 
\cos^2 \frac{\pi(\phi - \phi_c)}{2\phi_{BW}} & \text{if } |\phi - \phi_c| \leq \phi_{BW} \\
0 & \text{otherwise}
\end{cases}
\]

\[r_{BW}: \text{radial bandwidth, } \phi_{BW}: \text{angular bandwidth, } \phi_c: \text{mean orientation.}\] [1]

2.2.4 Estimate region mask and build filters bank

Since the block may be either in a recoverable area or unrecoverable area, the category of it could be implemented based on the estimation of the shape of the wave formed by the local ridges and valleys[2]. In this algorithm, we use amplitude (a), frequency (b), and variance (g) as in [2] to distinguish the sinusoidal-shaped wave.

We could eliminate the unwanted noise of fingerprint images by the information of the arrangements of the conforming ridges with pre-set orientation and frequency. The sinusoidal-shaped waves of ridges and valleys vary lentamente at a local invariable orientation[2].

Moreover, we build a bandpass filter[2] which adjusts to the target orientation and frequency could maintain the useful ridge structures when eliminating the unwanted noise. However, the Gabor filters which include orientation and frequency special properties even could be used instead of using the bandpass filters.
2.2.5 Computation of similarity

Defined T1 as first fingerprint image’s transformed minutiae and T2 as the second one, and count1 is the numbers of minutiae of image1 and count2 for image2. Defined n as matching numbers of minutiae. To estimate the similarity index, we could count the minutiae matching numbers which the second fingerprint image matched to first one. We compute each Euclidean Distance and angular between minutiae and set the threshold to count the valid matching minutiae if minutiae satisfied both thresholds of distance and angular.

\[
\text{Similarity} = \sqrt{\frac{(n^2)}{(\text{count1} \times \text{count2})}};
\]
Chapter 3

Result and Analysis

3.1 Minutiae Detection and Similarity

The left one is original fingerprint image and the right one is minutiae detection image. We marked the different ridges as different colors and we could see that all of the minutiae are marked significantly. The green one is picked as the reference marker for comparison, other fingerprint images will adjust their orientation by this marker. Compared the two images with unaided eyes, we can conclude that all of the minutiae are detected and it generates none fake minutiae markers.

![Figure 3.1: Minutiae detection for set1_1](image)

Below is one sample of two fingerprint images’ :set1_1 and set1_2 minutiae matching
diagram. The blue color marks the set1_1’s minutiae and red for set1_2. We could see that the red one almost overlap the set1_1’s minutiae marks. In fact, set1_2 and set1_2 is the same resolution fingerprint images. However, set1_2 misses some fingertip part which shows as Figure 3.2.

3.2 Evaluation

We take three fingerprint images sets to discussion the evaluation parts. Among the first fingerprint set, set the high resolution with complete fingerprint image as a reference sample to compare other images to analyze the similarity, we find the lowest similarity image is the seventh fingerprint images. Since the first one is a reference image and the seventh one is low-resolution fingerprint image for this set, we set the value of 0.58 as a bar value for identity whether two fingerprint images mean the same fingerprint set. Notice that the lowest similarity value is generated between image set1-5 and image set1-6, we can see that the former one is a low-resolution with fingertip detect of while the later
Figure 3.3: Set1_1 and Set1_2 fingerprint images

Among the second fingerprint set, set the first high resolution with complete fingerprint image as a reference sample to compare other images to analyze the similarity, we find the lowest similarity image is the fifth fingerprint images. Also, use the bar value of set1, we could notice fifth fingerprint image comparisons are the lowest. Even fifth itself’s similarity value is not 1.00. In fact, if the image compare with itself, it should be 1.00, 100% similarity, since they are the same images. This result shows the enhancement part may

one is low-resolution fingertip image. Since the partial fingerprint images always exist bias and may generate the fake result, we should avoid to use them.
Table 3.1: Similarity for fingerprint set 1

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remove some useful ridges information when we try to improve the low resolution images.

Figure 3.5: Fingerprint images set 2

Among the three fingerprint set, set the high resolution with complete fingerprint image as a reference sample to compare other images to analyze the similarity, we find the lowest similarity image is the fourth fingerprint images. Apply the bar value, we could notice fourth fingerprint image comparisons are the lowest.

From figure 3.6, we could find the fourth fingerprint image in this set misses most area of fingertip and most minutiae features are at the region of fingertip. That’s why the similarity score are low.
Table 3.2: Similarity for fingerprint set 2

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Figure 3.6: Fingerprint images set 3

Table 3.3: Similarity for fingerprint set 3

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Chapter 4

Conclusions

4.1 Current Status

This system can recognize and identify two fingerprint images are the same or not. Using the enhancement algorithm to deal with the low-resolution image is reliable, but low-resolution images may make more error and the enhancement part may have the space to improve. Moreover, If two images are different partition parts of a fingerprint, for example, one is fingertip and another is the bottom, it difficult to identify and compare. Heavy fingerprint image also makes the trouble of identifying since it can provide spurious details. However, we should avoid using the fingerprint images which missing most part of it since the missing information may serious disturbances the comparison.

4.2 Future Work

Explore more at how to improve the details of low resolution image, and integrate those methods. Also, develop the identify part for special singular points which may improve the accurate of minutiae features abstraction. Moreover, develop additional function to the application, such as store the fingerprint images as database, user interface, and applied this fingerprint recognition system into practical apps.
Bibliography


