FINGERPRINT RIDGE LINE RECONSTRUCTION

Using Sampling-based Tracing Method

Yaxuan Qi
Department of Automation , Singh University , Beijing China, 100084 , qiyx98@mails.tsinghua.edu.cn

Abstract: Reconstruction of fingerprint ridge lines is a critical pre-processing step in the identification of poor quality fingerprint images. This paper presents a new fingerprint ridge line reconstruction approach by way of ridge line tracing. In our research, the fingerprint ridge line in a gray scale image is viewed as a track of a ridge segment moving along the ridge. The curve tracing problem is solved by the target tracking technique in computer vision. We first formulate the model of fingerprint ridge line segments and then apply a target tracking method to trace each of the ridge lines. In addition, a feedback technique is adopted to correct the fingerprint directional image in each tracing step in order to improve tracing accuracy. By connecting all the traced ridge line segments, a polyline reconstruction of the ridge line can be obtained. We objectively assess the performance of this approach by using NIST fingerprint images.

Key words: sampling, fingerprint, reconstruction.

1. INTODUCTION

Because of the uniqueness and immutability, fingerprint identification is adopted in many highly reliable automatic authentication systems. Fingerprints in a gray scale image appear to be ridges and ravines. The uniqueness of fingerprint identification is mainly determined by the ridge structure characteristics and their correlation [3]. The most prominent ridge characteristics, called minutiae, are ridge bifurcations and ridge endings.

In fingerprint identification, minutiae are taken as discriminating and reliable fingerprint features. Most fingerprint identification or verification systems are so far based on fingerprint minutiae matching. Various approaches to automatic minutiae detection have been proposed. Most of these approaches consist of a series of processing steps:

- Getting ridge line structure;
- Binarization and thinning;
- Minutiae extraction.

Since the last two steps may produce false minutiae without clear ridge line structure, the first step becomes much more important. Our research focuses on the problem of how to obtain clear and reliable ridge line structures. In this paper we present a new approach to reconstruct fingerprint ridges through ridge line tracing.

The difficulty of ridge line structure reconstruction lies in the fact that the quality of the input fingerprint image is usually poor. Noise, deformation and contrast deficiency may produce false ridge line structures. Therefore, it is considerably difficult to achieve reliable fingerprint ridge line structures from poor quality images. This problem has been thoroughly studied but not yet completely solved.

In the published literatures, most approaches to obtain ridge line structures are based on two different techniques: One technique first enhances the ridge line structure by applying filtering approach to the original images and then obtain ridge lines through binarization and thinning process. The other technique extracts ridge lines directly from gray scale images. O'Gorman and Nickerson proposed an enhancement technique based on the convolution of the image with a filter oriented according to the directional image [2]. Hong Lin and A.K. Jain presented a formula that Gabor function is used in fingerprint enhancement, taking fingerprint ridge orientation and ridge frequency as filtering parameters [3]. In addition, M. T. Leung introduced a neural network based approach to minutiae detection by employing a multilayer perception in analyzing the output of a rank of Gabor's filters applied to the gray scale image [5]. To binarize the fingerprint image, several thresholding methods, local thresholding for instance, have been proposed. Moayer and Fu presented a binarization technique based on the iterative application of a Laplacian operator and a dynamic threshold [6]. Some thinning algorithms have been studied in order to obtain a skeleton of the fingerprint ridge lines. These methods are listed in the Reference section of this paper [7] [8]. Instead of using a conventional thinning method Weber proposed an algorithm which detects the minutiae starting from the thick-ridges in the binary image [9].

Though some of the techniques presented so far provide good results by producing high-quality fingerprint images, they are sometimes either inaccurate or not robust enough for poor quality images. The poor performance of these methods when inputting low quality fingerprint images is due to the following reasons. Firstly, filtering techniques rely on global data such as ridge line direction and ridge line frequency. These data are obtained area by area in fingerprint images and fail to provide enough local information of fingerprint ridge line structures. Secondly, a lot of data are lost during binarization processes, especially when applied to poor quality images.

Maio and Maltoni proposed a new approach in their resent work to detect minutiae directly from the gray scale fingerprint images [4]. The method does not follow the binarization and thinning steps. The principle of their method is to trace the ridge lines on the gray scale image by "sailing" in accordance with the fingerprint directional image. Their results are far superior in terms of efficiency and robustness to the conventional thresholding and thinning approaches. However, the method is still limited in the following two aspects. On one hand, it still depends on the accuracy of the directional image. In practice, it is difficult to obtain precise ridge direction from low quality images. On the other hand, the approach adopts a symmetric gauss silhouetted mask to do convolution with lines of pixels on the ridge and orthogonal to the ridge line direction. Because convolution can change the local gray scale distribution, the ridge line structures may thus be deformed in some area of fingerprint images.

This paper presents a new ridge line reconstruction approach through ridge line tracing. In our study, each ridge line in the input fingerprint image is treated as a track of a ridge segment moving along the ridge line. Within the framework of tracking technique in computer vision, a sampling-based tracing method is applied to the fingerprint ridge line reconstruction. We first formulate a ridge line model and then use a sampling method to trace each ridge line piecewise. The approach does not change any of the original fingerprint gray scale images so as to exploit more useful information directly from the original image. In addition, a feedback technique for directional image is employed in this study. To obtain more accurate ridge line structure information, the directional image after each tracing step is adjusted in accordance with the ridge line has been traced.

The rest of the paper is organized as follows: In Section 2, we built the ridge line model for sampling-based ridge line tracing. Section 3 is devoted to the feedback technique applied to the directional image. Experimental results are reported in Section 4 and conclusions are outlined in Section 5 of the paper.

2. RIDGE LINE MODELLING

Let I be an $a*b$ gray scale image with 0 to $g-1$ gray levels, and $G(i,j)$ be the gray level of pixel (i,j) of I , $i=1,...,a, j=1,...,b$. Let $z=G(i,j)$ be the discrete surface corresponding to the image I . By associating the dark pixels with the gray levels near $g-1$ and the bright pixels with the gray levels near zero, the fingerprint ridge lines correspond to the surface ridges and the spaces between the ridge lines correspond to the surface ravines (Fig. 1).

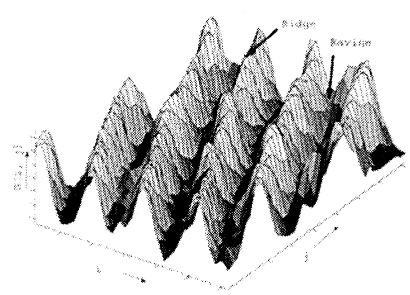


Figure 1. A surfaces corresponding to a small area of a fingerprint gray scale image. Fingerprint ridges and ravines are shown.

At each ridge line tracing step, our algorithm attempts to locate a point representing the local ridge line segment in a section along the ridge line direction. By connecting all the traced points, a polyline approximation of the ridge line can be obtained.

Both the structure and the distribution of ridge lines in fingerprint images have some specific characteristics. Out of these characteristics, there are two main aspects:

- *Continuity*. Each of the fingerprint ridge lines distributes continuously, i.e., the directions of a series of ridge line segments do not change abruptly;
- *Correlation*. The neighboring fingerprint ridge lines have some strong correlation. For example, if a ridge line has an up-left direction in a certain area; its neighboring ridge lines in a near area follow the same direction.

Starting from these two characteristics, we take the ridge line as a track of a ridge segment moving from one end of the ridge line to the other. Based on such a tracking technique in computer vision, we adopt sampling-based tracking technique to trace the fingerprint ridge line. In order to apply the tracking technique to static fingerprint images, a dynamic model is built for the ridge line tracing problem. The following part of this section illustrates the proposed ridge line tracing model as compared with the general dynamic model for target tracking.

2.1 Formulation of Ridge Line Tracing Problem

In the framework target tracking (see [10]), the target state at time t is denoted by X_t. The task of tracking is to infer X_{t+1} based on both the last state X_t and the observed image evidence Y_{t+1}, where Y_t is the image measurement at time t, i.e., to estimate $p(X_{t+1} | Y_{t+1}, X_t)$. Such a probabilistic dynamic system can be depicted graphically by Fig. 2.

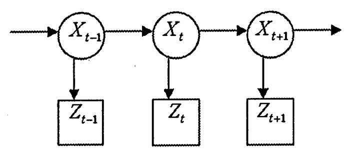


Figure 2. Relationship between target state X_t and image observation Y_t

In the fingerprint ridge line tracing problem, the moving target in visual tracking is taken as a segment on the ridge line. The segment is represented by its center point at $P_t = (i_t, j_t)$ which is the coordinates of the center point in the fingerprint image. Target state X_t is defined as the ridge line direction D_t at point P_t and the observation Y_t is defined as the gray level distribution Z_t in a certain area centered at point P_t. Their relations are shown in Fig. 3.

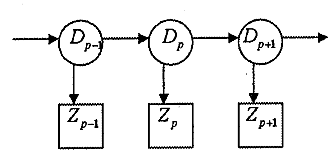


Figure 3. Relationship between ridge line direction D_t and fingerprint image observation Z_t

The key problem is the estimation of D_{t+1} given Z_{t+1} and D_t. The expectation of D_{t+1} over $p(D_{t+1} | Z_{t+1}, D_t)$ is:

$$
\begin{aligned}
& E(D_{t+1} \mid Z_{t+1}, D_t) \\
&= \int D_{t+1} p(D_{t+1} \mid Z_{t+1}, D_t) \\
&= \int D_{t+1} p(D_{t+1}, D_t \mid Z_{t+1}) p(D_{t+1} \mid D_t) \\
&= \int D_{t+1} p(D_{t+1} \mid Z_{t+1}) p(D_{t+1} \mid D_t)
\end{aligned} \tag{1}
$$

2.2 Sampling

If we have N i.i.d samples $D_{t+1}^{(i)}$ ($i = 1, \ldots, N$) and associate each sample with a weight $w(D_{t+1}^{(i)}) \propto p(D_{t+1} \mid Z_{t+1}) p(D_{t+1} \mid D_t)$ then, by Monte Carlo simulation,

$$
E(D_{t+1} \mid Z_{t+1}, D_t) = \sum_{i=1}^{N} \tilde{w}^{(i)} D_{t+1}^{(i)} \tag{2}
$$

Where

$$
\tilde{w}^{(i)} = \frac{w(D_{t+1}^{(i)})}{\sum_{j=1}^{N} w(D_{t+1}^{(j)})} \tag{3}
$$

Direction samples $D_{t+1}^{(i)}$ ($i = 1, \ldots, N$) are formed by point samples $P_{t+1}^{(i)}$ ($i = 1, \ldots, N$) and the starting point P_t. Since ridge line points can be defined as a sequence of maximum and saddle points in fingerprint gray scale image *imgD* [11], samples of $P_{t+1}^{(i)}$ are all local maximum and saddle points in area A_t. Here A_t is a searching area defined as a circular sector with radius r and is oriented to the direction of D_t. The central angle of A_t is $\pi/2$. Fig. 4 is an illustration of the sampling step.

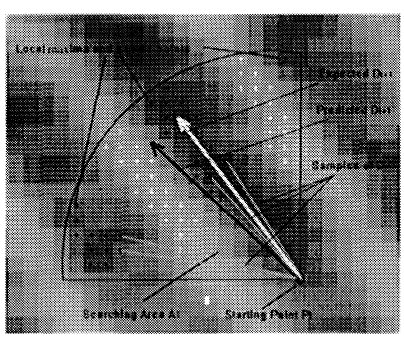


Figure 4. Search for the samples of $P_{t+1}^{(i)}$ in area A_t.

For computation convenience, $p(D_{t+1} | D_t)$ is set to be a uniform distribution. Thus the weight for each sample point is in direct proportion to $p(D_{t+1} | Z_{t+1})$. The weight $w(D_{t+1}^{(i)})$ is then obtained from the following three aspects:

- Let $D_{t+1}^{(i)}$ be the direction defined by the starting point P_t and sample point $P_{t+1}^{(i)}$. Then from P_t to $P_{t+1}^{(i)}$, a rectangle is established. The average gray level within this rectangle is recorded by $G^{(i)}$;
- The variance of the gray level within this rectangle is recorded by $V^{(i)}$;
- The variance of the gray level within this rectangle is recorded by $V^{(i)}$. There is an included angle between $D_{t+1}^{(i)}$ and D_t for each sample point. This angle is recorded by.

  Thus the weight is computed by

$$w(D_{t+1}^{(i)}) = w(P_{t+1}^{(i)}) = \exp(-K(g - G^{(i)})V^{(i)}I^{(i)}) \quad (4)$$

Where K is a constant through 10 to 100. By applying Equ.2 and 3, we obtain the expected tracing direction D_{t+1} along which the starting point D_t is to be moved to the next point P_{t+1} with μ pixels (in the proposed algorithm, μ is set to be 5 to 8 pixels).

3. DIRECTION FEEDBACK AND STOP CRITERIA

3.1 Direction Feedback

Once the ridge line tracing direction is obtained, the directional image can be corrected in accordance with it. Because of the continuity and correlation of fingerprint ridge lines, the directions in area A_t around point P_t are similar to a certain extent. Therefore, the feedback of the included angle convoluted with a 2D gauss mask can be used to correct the directions in area A_t. Precision of the directional image is thus increased with the feedback of the local ridge line information.

3.2 Stop criteria

The stop criteria are some events which stop the ridge line tracing, including:

- Exit from the interested area. The new point P_{t+1} is external to a rectangular window representing the sub-image whose ridge lines are to be traced;
- Termination. The searching area A_t is lack of local maxima as compared with the number of local minima. According to this criterion the ridge line tracing stops independently on the gray level of the current region,

and the algorithm can work on both saturated regions and contrast-deficient regions without particular enhancement;

- Intersection. The next starting point P_{t+1} has been previously labeled as a point belonging to another ridge line.

As an overview of the approach, Figure 5 is a flowchart of the fingerprint ridge line tracing algorithm.

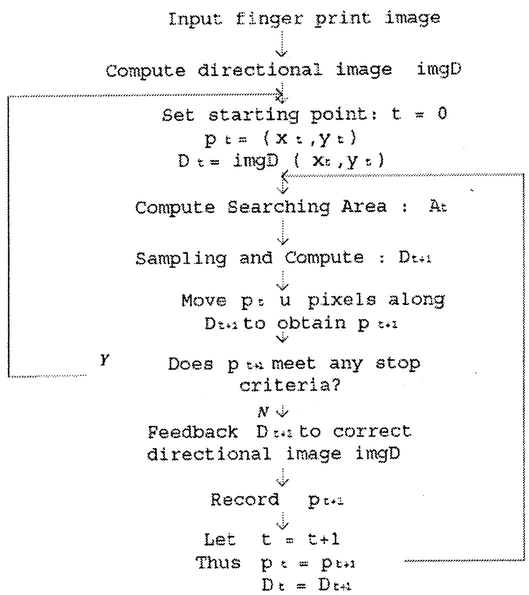
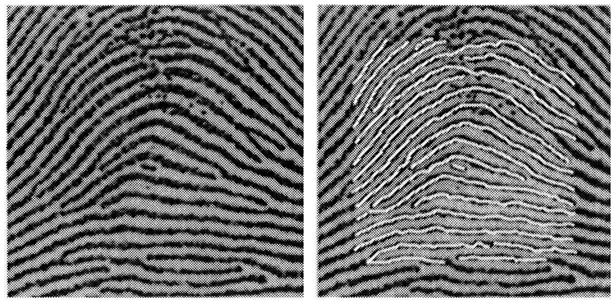


Figure 5. The flowchart of the ridge line tracing algorithm.

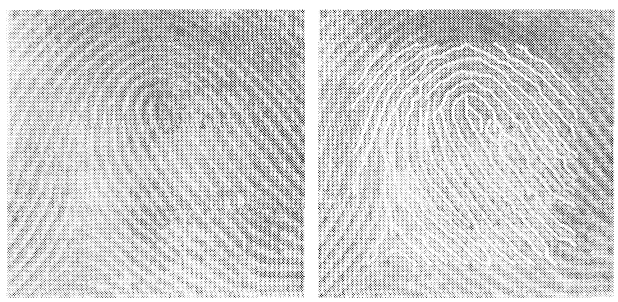
4. RESULTS AND PERFORMANCE ANALYSIS

The aim of this section is to demonstrate the experimental results of the proposed ridge line tracing approach. We objectively assess the performance of this approach by using NIST fingerprint images. Figure 6(a) is a high quality fingerprint image, and the result of ridge line reconstruction is shown in Figure 6(b). For poor quality image, such as the one shown in Figure 7(a), the proposed ridge line reconstruction algorithm can also provide clear and accurate ridge line structures (see Figure 7(b)).



(a) (b)

Figure 6. (a)A NIST fingerprint image of high quality. (b) The ridge line reconstruction result. The ridge structures are shown in (b) by bright polylines.



(a) (b)

Figure 7. (a) A NIST fingerprint image of poor quality. (b) The ridge line reconstruction result. The ridge structures are shown in (b) by bright polylines.

5. CONCLUSION AND FUTURE WORK

We have described a sampling-based method to reconstruct the fingerprint ridge lines regardless of fingerprint image noise, contrast deficiency and effects of lighting conditions. Our approach fits the target tracking techniques widely used in computer vision in estimating the tracing direction of fingerprint ridge lines. A prominent advantage of the proposed approach is that, in order to obtain more accurate result, we just focus on how to give a more precise ridge line model without changing the framework of the approach.

The contribution of this study can be summarized as follows. Firstly, we introduce a sampling approach for tracing lines directly in a gray scale image, depending on the continuity and correlation of the lines. This is considerably different from the tracing method in computer vision where series of images are required. Secondly, we use a feedback technique to make the directional image more accurate in local areas. Both of these two techniques can be adopted to general continuous curve tracing problems in static images.

One of the goals in our future study is to solve the print-to-print matching problem. The resulting ridge line structures can be directly used to address the minutiae detection problem for fingerprint matching. Another consideration in our future work is to generate fingerprint representations normalized with respect to scale and rotation. Such representations are to be worked out to avoid rotating fingerprint images and to match fingerprints among all possible orientations in print-to-print matching.

ACKNOWLEDGEMENTS

We gratefully acknowledge our many useful discussions with Prof. Qi from Hainan M.C. and Dr. Ma from National AI Laboratory.

REFERENCES

1. Xudong Jiang, Wei-Yun Yau, Wee Ser: Detecting the Fingerprint Minutiae by Adaptive Tracing the Gray-level Ridge, Pattern Recognition 34 (2001) 999-1013
2. L. O'Gorman, J.V. Nickerson: An Approach to Fingerprint Filter Design, Pattern Recognition 22 (1989) 29
3. L. Hong, Y. Wan, A.K. Jain: Fingerprint Image Enhancement: Algorithm and Performance Evaluation, IEEE Trans. Pattern Anal. Mach. Intell. 20 (1998) 777
4. D. Maio, D. Maltoni: Direct Gray-scale Minutiae Detection in Fingerprints, IEEE Trans. Pattern Anal. Mach. Intell. 19
5. M. T. Leung, W. E. Engeler, and P. Frank: Fingerprint Image Processing Using Neural Networks, Proc. Tenth Conf. Computer and Communication System, pp. 582-586, Hong Kong, 1990
6. B. Moayer, K. Fu: A Tree System Approach for Fingerprint Pattern Recognition, IEEE Trans. Pattern Anal. Mach. Intell. 8 (1986) 376
7. R. Stefanelli, A. Rosenfeld: Some Parallel Thinning Algorithms for Digital Pictures, J. ACM 18 (1971) 255
8. C. Arcelli, G.S.D. Baja: A Width Independent Fast Thinning Algorithm, IEEE Trans. Pattern Anal. Mach. Intell. 7 (1984) 463
10. Michael Isard and Andrew Blake: Contour Tracking by Stochastic Propagation of Conditional Density. In Proc. of European Conf. on Computer Vision, Cambridge, UK, 1996
11. Carlotta Domeniconi, Sibel Tari, Ping Liang:Direct Gray Scale Ridge Reconstruction in Fingerprint Images. 1997