Feature Extraction Using a Chaincoded Contour Representation of Fingerprint Images

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Abstract. A feature extraction method using the chaincode representation of fingerprint ridge contours is presented for use by Automatic Fingerprint Identification Systems. The representation allows efficient image quality enhancement and detection of fine feature points called minutiae. Enhancement is accomplished by binarization and smoothing followed by estimation of the ridge contours field of flow. The original gray scale image is then enhanced using connected component analysis and a dynamic filtering scheme that takes advantage of the knowledge gained from the estimated direction flow of the contours. The minutiae are generated using a sophisticated ridge contour following procedure. Visual inspection of several hundred images indicates that the method is very effective.

1 Introduction

Automatic Fingerprint Identification System (AFIS) is an important biometric technology. Fingerprint images can be obtained from ink impressions or by direct live scanning of the fingerprints by sensors [13] such as with ultrasound technology [9]. Feature (minutiae) extraction is a key step in accurate functioning of any AFIS. Due to imperfections of the image acquisition process, minutiae extraction methods are prone to missing some real minutiae while picking up spurious points (artifacts) [3, 8]. Image imperfections can also cause errors in determining the location coordinates of the true minutiae and their relative orientation in the image.

Most feature extraction algorithms described in the literature extract minutiae from a thinned skeleton image that is generated from a binarized fingerprint image. Thinning is a lossy and computationally expensive operation and the accuracy of the output skeletal representation varies for different algorithms. In this paper we introduce the use of chaincode representation as an efficient alternative for processing fingerprint images. It circumvents most of the problems associated with thinning and skeleton images. The first step is to binarize the

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fingerprint image (section 2.1). The next step averages neighboring pixels to generate smooth chaincodes without introducing spurious breaks in contours (section 2). This is important because an end point of a ridge contour is a vital minutia point. The ridge flow field is estimated from a subset of selected chaincodes as described in section 2.2. The original gray scale image is enhanced using a dynamically oriented filtering scheme together with the estimated direction field information (section 2.3). The enhanced fingerprint image henceforth can be used for all subsequent processing. The algorithm for extracting minutiae using chaincode contours of the enhanced images is described in section 3. Some experimental results using NIST datasets are presented in section 4.

The chaincode representation is procedurally described as follows. Given a binary image, it is scanned from top to bottom and right to left, and transitions from white (background) to black (foreground) are detected. The contour is then traced counterclockwise (clockwise for interior contours) and expressed as an array of contour elements (Figure 1(a)). Each contour element represents a pixel on the contour, contains fields for the x,y coordinates of the pixel, the slope or direction of the contour *into* the pixel, and auxiliary information such as curvature. The slope convention used by the algorithms described is as shown in Figure 1(b).

2 Fingerprint Image Enhancement

Direct binarization using standard techniques renders images unsuitable for extraction of fine and subtle features such as minutiae points. Therefore it is necessary to: (i) improve the clarity of ridge structures of fingerprint images (ii) maintain their integrity, (iii) avoid introduction of spurious structures or artifacts, and

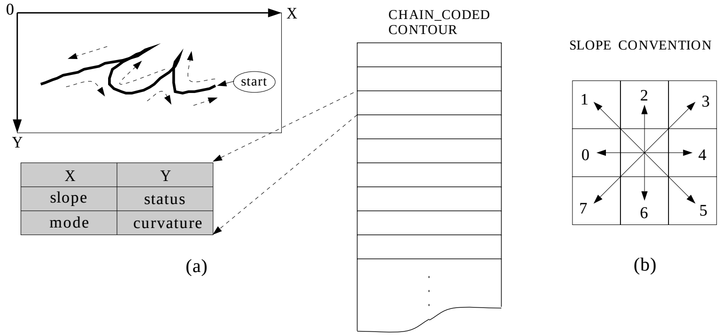

Fig. 1. Chain code contour representation: (a) contour element, (b) slope convention. *Data* field in the array contains positional and slope information of each component of the traced contour. Properties stored in the *information* fields are: coordinates of bounding box of a contour, number of components in the corresponding data fields, area of the closed contour, and a flag which indicates whether the contour is interior or exterior

(iv) retain the connectivity of the ridges while maintaining separation between ridges.

There are two types of fingerprint image enhancement methods described in the literature; those that work on binarized images and those that work on gray-scale images [6, 5, 10]. The binarization-based methods require a specially designed binarization algorithm to ensure the quality of the resultant images so that the connectivity information lost during binarization can be at least partially recovered. The gray-scale based methods start with a direction field that captures the local orientation information of the ridge contours, followed by the application of a bank of filters to improve the quality of the image [2]. The directional field itself is typically computed by the gradient method. However, computation of the gradients is inefficient and lacks robustness in noisy images.

The method presented in this paper combines aspects of both approaches described above. We first use a local-global binarization algorithm to obtain a binary fingerprint image that is of sufficient quality to retain and discern the ridges, and maintain local orientations. However, some of the ridge contours might fragment during this process. The local directional field is estimated using a fast chaincode-base algorithm [4] and is localized by the use of a 15×15 mask. The tradeoffs that affect the size of this mask are as follows. Larger masks retain the orientation while compromising the integrity of the ridges. To enhance the fingerprint image we apply a simple anisotropic filter on the gray-scale image. This method is similar to the one proposed in [1]. The filter is adaptive and has an elliptical shape. It is applied to the fingerprint image with it major axis aligned parallel to the local ridge direction. Since the shape of the filter is controlled by the estimated local ridge orientation, we avoid the need for computing local ridge frequency which is required by most filtering algorithms [2].

2.1 Binarization

Our binarization algorithm is tuned for efficiency. Experiments on images from database DB 4 NIST Fingerprint Image Groups show that a binarization algorithm using a single global threshold can not give satisfactory results. Noise in inked fingerprints produces non-uniform ink density, non-printed areas, and the presence of stains and noise. To overcome these problems posed by presence of noise, we apply a simple global threshold algorithm in each partitioned local area of size 15×15 pixels. Within this small local area the pixel density does not vary significantly, allowing the rendering of distinct ridge contours without much blurring.

In order to obtain smooth edges on the ridge contours, a 3×3 mask is applied to the gray-scale image as a quick equalization process before initiating the local-global thresholding described. Methods described in the literature use contrast enhancement or mean and variance based image normalization [1, 6, 12] which cause interference between sweat pores and ridge edges. For minutiae based feature extraction methods, it is preferable that the sweat pores be treated as noise and eliminated. Figure 2(b) shows the binary fingerprint image obtained by the method described.

(a) (b) (c)

Fig. 2. Direction field computed from chaincode: (a) enhanced gray-scale image, (b) binary image, and (c) direction field image generated using chaincode representation and contour following

2.2 Orientation Field Using Chaincode

Chaincode representation of object contours is extensively used in document analysis and recognition research [4]. It has proven to be an efficient and effective representation especially for handwritten documents. Unlike the thinned skeletons, chaincode is a lossless representation in the sense that the pixel image can be fully recovered from its chaincode representation.

The chaincode captures the contour boundary information from the edges of the fingerprint ridges. Tracing the chaincode contour provides the local ridge direction at each boundary pixel. To calculate the direction field for the local ridge orientations, we divide the image into 15×15 pixel blocks and use the ridge directions to estimate the ridge orientation in each block. Following are the algorithmic steps.

a. Filter the small components that could be from noise or other fragments using the width of the ridges as a guide for estimating the threshold under which components are likely to be noise.
b. End points are detected (section 3) and it is determined if they are actual ridge ending minutiae. These points are not used in the computation of the direction flow field as directions around end points can be ambiguous.

Figure 2(a) shows the direction field image generated from the chaincode image.

Other direction field estimation algorithms described in the literature compute the gradient at every pixel [1, 2, 12]. The method described using chaincode is more efficient and accurate (section 4).

2.3 Enhancement Using Anisotropic Filter

Fingerprint minutiae extraction algorithms depend on the quality of binarization. Imperfections in binarization often lead to broken ridges or touching ridges which in turn create spurious points. To maintain the separation between ridges one could lower the threshold level in binarization. Our approach equalizes the pixel values within the same ridges by raising the gray-values of the uneven pixels inside the ridges. Specifically, we use a directional anisotropic filter that has an elliptical shape with its major axis aligned parallel to the local ridge direction. The filter smoothes the pixels along the ridge direction as opposed to the direction across the ridges.

A structure-adaptive anisotropic filtering technique has been used by previous researchers for image filtering [1, 14].

$$H(x_0, x) = V + S\rho(x - x_0)\exp\left\{-\left[\frac{((x - x_0)\cdot n)^2}{\sigma_1^2(x_0)} + \frac{((x - x_0)\cdot n_\perp)^2}{\sigma_2^2(x_0)}\right]\right\}$$

where n and $n_\perp$ are mutually normal unit vectors and n is parallel to the ridge direction. The shape of the kernel is controlled by $\sigma_1^2(x_0)$ and $\sigma_2^2(x_0)$. The region constraint ρ satisfies the condition $\rho(x) = 1$ when $|x| < r$ and r is the maximum support radius. Two additional parameters, S and V are for phase intensity control and control of peripheral pixels (near the outskirts of the kernel) respectively. As per [1], we take $V = -2$ and $S = 10$ in our experiments. $\sigma_1^2(x_0)$ and $\sigma_2^2(x_0)$ control the shape of the Gaussian kernel. As functions of x_0 they should be estimated using the frequency information around x_0. But the filter is not sensitive to their values as long as $\sigma_2^2(x_0)$ is around the measure of the average ridge width. For our experiments we also set $\sigma_1^2(x_0) = 4$ and $\sigma_2^2(x_0) = 2$ [1]. Figure 2(b) shows the enhanced fingerprint image and Figure 2(c) shows the binary fingerprint image obtained from the enhanced image.

3 Minutiae Extraction Using Chaincode

Most of the fingerprint minutiae extraction methods are thinning-based by which the skeletonization process converts each ridge contour to one pixel wide. The minutiae points are detected by tracing the thin ridge contours. When the trace stops, an end point is marked. Bifurcation points are those with more than two neighbors [12]. In practice, thinning methods have been found to be sensitive to noise and the skeleton structure does not match up with the intuitive expectation.

The alternate method of using chaincoded contours is presented here. The direction field estimated from chaincode gives the orientation of the ridges and information on any structural imperfections such as breaks in ridges, spurious ridges and holes. The standard deviation of the orientation distribution in a block is used to determine the quality of the ridges in that block. For example in Figure 2 the directions of the ridges at the bottom of the image are misleading.

We have used contour tracing in other handwriting recognition applications [4, 11]. We consistently trace the ridge contours of the fingerprint images in a counter-clock-wise fashion. When we arrive at a point where we have to make a *sharp left turn* we mark a candidate for a ridge ending point. Similarly when we arrive at a *sharp right turn*, the turning location marks a bifurcation point (Figure 3 (a)).

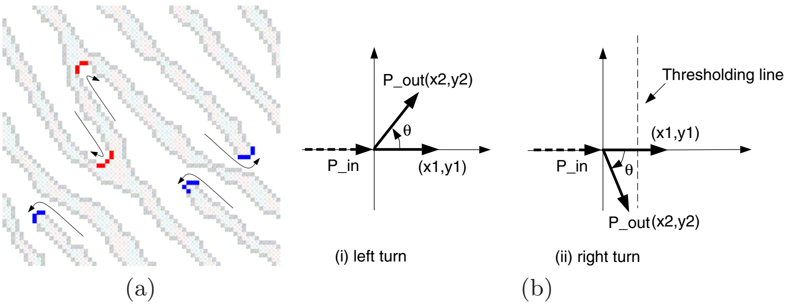

Fig. 3. (a) Minutiae location in chaincode contours, (b) the distance between the thresholding line and the y-axis gives a threshold for determining a significant turn

To determine the *significant* left and right turning contour points from among the candidates marked during the trace, we compute vectors P_{in} leading in to the candidate point P from its several previous neighboring contour points and P_{out} going out of P to several subsequent contour points. These vectors are normalized and placed in a Cartesian coordinate system with P_{in} along the x-axis (Figure 3 (b)). The turning direction is determined by the sign of

$$S(P_{in}, P_{out}) = x_1 y_2 - x_2 y_1$$

$S(P_{in}, P_{out}) > 0$ indicates a *left turn* and $S(P_{in}, P_{out}) < 0$ indicates a *right turn*. A threshold T is then selected such that any significant turn satisfies the conditions:

$$x_1 y_1 + x_2 y_2 < T$$

Since the threshold T is the x-coordinate of the thresholding line in Figure 3(b), it can be empirically determined to be a number close to zero. This ensures that the angle θ made by P_{in} and P_{out} is close to or less than 90°.

The turning point locations are typically made of several contour points. We define the location of a minutiae as the center point of the small group of turning pixels. The minutiae density per unit area is not allowed to exceed a certain value. If we consider groups of candidate minutiae forming clusters, all the candidate minutiae in a cluster whose density exceeds this value are replaced by a single minutiae point located at the center of the cluster.

4 Experimental Results

Experiments are underway with the NIST datasets. Using the *Goodness Index* (GI)(equation 1) described in [7, 2] we compute the *goodness* of the minutiae detected.

$$GI = \frac{\sum_{i=1}^{r} q_i (p_i - d_i - i_i)}{\sum_{i=1}^{r} q_i t_i} \tag{1}$$

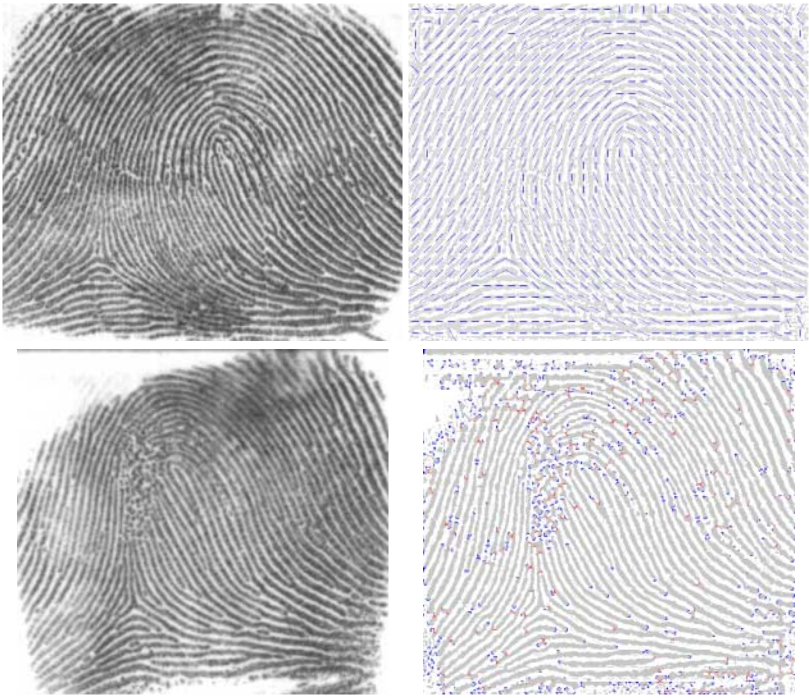

Fig. 4. Example images showing our preliminary test. Original gray-scale fingerprint image and corresponding direction field images generated from chaincode representation shown on the top and the corresponding candidate minutiae detected using the chaincode based minutiae extraction method on another fingerprint image

where r is the total number of 15×15 image blocks; p_i, is the number of minutiae paired in the ith block; d_i is the number of missing minutiae according to the algorithm in the ith block; i_i, is the number of spuriously inserted minutiae generated by the algorithm in the ith block; t_i is the true number of minutiae in the ith block; and q_i is a factor which represents the image quality in the ith block (good=4, medium=2, poor=1). A high value of GI indicates a high degree of reliability of the extraction algorithm. The maximum value, $GI = 1$, is reached when all true minutiae are detected and no spurious minutiae are generated. Our test on a few hundred NIST images shows the GI index range from 0.25 to 0.70. Figure 4 shows some examples from our preliminary tests.

5 Conclusion

This paper describes novel use of the chaincode image representation for the purpose of fingerprint image enhancement and minutiae extraction. This method is more efficient and accurate when compared to thinning based methods with the additional advantage of being a lossless representation.

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References

[1] Greenberg,S. Aladjem,M. and Kogan,D.: Fingerprint Image Enhancement using Filtering Techniques, Real-Time Imaging 8 ,227-236 (2002) 270, 271, 272
[2] Hong,L., Wan,Y.and Jain,A.: Fingerprint Image Enhancement: Algorithm and Performance Evaluation. IEEE Transactions on Pattern Analysis and Machine Intelligence 20: 777 -789. 1998 270, 271, 273
[3] Jain,A., Hong,L. and Bolle,R.: On-Line Fingerprint Verification. IEEE-PAMI, Vol.19, No.4, pp. 302-314, Apr. 1997. 268
[4] Madhvanath,S., Kim,G., and Govindaraju,V.: Chain Code Processing for Handwritten Word Recognition. IEEE Transactions on Pattern Analysis and Machine Intelligence 21: 928-932, 1997. 270, 271, 272
[5] Maio,D. and Maltoni,D.: Direct Gray-Scale Minutiae Detection in Fingerprints. IEEE Transactions on Pattern Analysis and Machine Intelligence 19: 27 -40, 1997 270
[6] O'Gorman,L.and Nickerson,J. V.: An Approach to Fingerprint Filter Design. Pattern Recognition 22 :29 -38, 1989 270
[7] Ratha,N. K., Chen,S., and Jain,A.: Adaptive Flow Orientation-Based Feature Extraction in Fingerprint Images. Pattern Recognition, Vol. 28, No. 11, pp. 1657-1672, Nov. 1995. 273
[8] Ratha,N., Karu,K., Chen,S., and Jain,A.: A Real Time Matching System for Large Fingerprint Databases. IEEE-PAMI, Vol. 18, No. 8, pp. 799-813, Aug. 1996. 268
[9] Schneider,J. K., and Glenn,W. E.: Surface Feature Mapping Using High Resolution C-Span Ultrasonography. US Patent 5587533, 1996. 268
[10] Sherlock,D., Monro,D. M. and Millard,K.: Fingerprint Enhancement by Directional Fourier Filtering. IEEE Proceedings on Visual Imaging Signal Processing, 141: 87-94, 1994 270
[11] Shi,Z., and Govindaraju,V.: Segmentation and Recognition of Connected Handwritten Numeral Strings. Journal of Pattern Recognition, Pergamon Press, Vol. 30, No. 9, pp.1501-1504, 1997. 272
[12] Simon-Zorita,D, Ortega-Garcia,J., Cruz-Llanas,S. Sanchez-Bote,J. L., and Glez-Rodriguez,J.: An Improved Image Enhancement Scheme for Fingerprint Minutiae Extraction in Biometric Identification, Proc. of 3rd International Conference on Audio- and Video- Based Biometric Person Authentication AVBPA'01 (Halmstad, Sweden, June 2001), J.Bigun and F.Smeraldi Eds, LNCS2091, pp. 217-222 270, 271, 272
[13] Xia,X. and O'Gorman, L.: Innovations in fingerprint capture devices. Journal of Pattern Recognition, Pergamon Press, Vol. 36, No. 2, pp. 361-370, 2002. 268
[14] Yang,G. Z., Burger,P., Firmin,D. N. and Underwood,S. R.: Structure Adaptive Anisotropic Filtering.Image and Vision Computing 14: 135-145, 1996 272