A Chaincode Based Scheme for Fingerprint Feature Extraction

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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 minutiae feature points. For image enhancement a given fingerprint image is first binarized after a quick averaging to generate its chaincode representation. The direction field is estimated from a set of selected chaincodes. 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. For feature extraction, the enhanced fingerprint image is carefully binarized using a local-global binarization algorithm for generating the chaincode representation. The minutiae are generated using a sophisticated ridge contour following procedure. Visual inspection of the experiment images shows that the method is very effective.

Index terms: Fingerprint, minutiae, features extraction, biometrics, chaincode.
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 the ultrasound technology [9]. Feature (minutia point) extraction is a key step in accurate functioning of any AFIS. Due to imperfections of the image acquisition processes, minutiae extraction methods are prone to missing some real minutiae while picking up spurious points [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 fingerprint image (section 2.1) followed by averaging of neighboring pixels to generate smooth chaincode without introducing spurious breaks in contours (section 2). The ridge flow field is estimated from a subset of selected chaincode 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, and
Figure 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.

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 minutia points. The objective is to: (i) improve the clarity of ridge structures of fingerprint images (ii) maintain their integrity, (iii) avoid introduction of spurious structures, and (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 binary 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 direction field itself is typically computed by the gradient method. However, computation of the gradients is not only inefficient but also not robust in noisy images.

The method presented in this paper combines aspects of both the 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 in the process. The local direction field is estimated using a fast chaincode-base algorithm. It is localized by the use of a $15\times15$ mask ensuring. 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 a structure-adaptive with an elliptical shape. It is applied on the fingerprint image with it major axis aligned parallel with the local ridge direction. Since the shape of the filter is controlled by the estimated local ridge orientation, we avoid the need to compute local ridge frequency as 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 constitutes of non-uniform ink density, non-printed areas, and presence of stains and noise. To overcome the difficulty we apply a simple global threshold algorithm in each partitioned local area of size $15\times15$ 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 $3\times3$ 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 [6, 1, 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 be eliminated. Figure 2 shows the binary fingerprint image obtained by the method described.

2.2 Orientation Field Using Chaincode

Chaincode representation of object contours is extensively used in document analysis and recognition research [4]. It has been 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 it chaincode representation.

Chaincode captures the contour boundary information for the edges of the fingerprint ridges. Tracing the chaincode contour, provides the local ridge directions 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.
direction field computed from chaincode: (a) direction field image generated using chaincode representation and contour following. (b) enhanced gray-scale image and (c) binary image from the enhanced image.

b. End points are detected (section 3). These points are not used in the computation of the direction flow field as directions around end points can be ambiguous.

Figure 3(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 is to equalize 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 with 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 researchers for image filtering [1,
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 $\rho$ satisfies 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 3(b) shows the enhanced fingerprint image and Figure 3(c) is the binary fingerprint image obtained from the enhanced image.

### 3 Minutiae Extraction Using Chaincode

Most of the fingerprint minutia extraction methods are thinning-based where the skeletonization process converts each ridge contour to one pixel wide. The minutia 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 3 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 4 (a)).

To determine the significant left and right turning contour points, we first compute a vector $P_{in}$ leading in to a contour point $P$ from its several previous neighboring contour points and $P_{out}$ going out of $P$ to the following several contour points. These vectors are normalized and placed in a Cartesian coordinate system with $P_{in}$ along the $x$-axis (Figure 4 (b)). The turning direction is determined by the sign of

$$S(P_{in}, P_{out}) = x_1y_2 - x_2y_1$$

$S(P_{in}, P_{out}) > 0$ 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:

$$x_1y_1 + x_2y_2 < T$$

Since the threshold $T$ is the $x$-coordinate of the thresholding line in Figure 4b, it can be empirically determined to be a number close to zero. This ensures that the angle $\theta$ made by $P_{in}$ and $P_{out}$ is close to or less than $90^\circ$.

The turning point locations are typically made of several contour points. We define the location of a minutia as the center point of the small group of turning pixels. Since the minutiae density per unit
area cannot 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 minutia 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 [2, 7] we will compute the goodness of the minutiae detected.

\[
GI = \frac{\sum_{i=1}^{r} q_i (p_i - d_i - i_i)}{\sum_{i=1}^{r} q_i d_i}
\]  

(1)

where \( r \) is the total number of 15×15 image blocks; \( p_i \), is the number of minutiae paired in the \( i \)th
block; \( d_i \) is the number of missing minutiae by the algorithm in the \( i \)th block; \( i_i \), is the number of
spuriously inserted minutiae generated by the algorithm in the \( i \)-th block; \( t_i \) is the true number of minu-
tiae in the \( i \)-th block; and \( q_i \) is a factor which represents the image quality in the \( i \)-th block (good=4,
medium=2, poor=1). A high value of \( GI \) indicates a high reliability degree 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 small set of NIST images shows the \( GI \) index range from 0.25 to 0.70.
Figure 5 shows some examples from our preliminary tests.

5 Conclusions

This paper describes a 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.
Figure 5: Example images showing our preliminary test. From left to right, original gray-scale fingerprint images, direction field images generated from chaincode representation of binary images after enhancement and the candidate minutiae detected using the proposed chaincode based minutia extraction method.
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References


