# A Chaincode Based Scheme For Fingerprint Feature Extraction

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**Abstract.** In this paper a fingerprint feature extraction algorithm for automatic fingerprint recognition is presented. The algorithm utilizes the well-known chaincode image representation in both of its image quality enhancement and fingerprint feature extraction. For its 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. Then the original gray scale image is enhanced using a dynamic oriented filtering scheme together with the estimated direction field information. For its feature extraction, the enhanced fingerprint image is carefully binarized using a local-global binarization algorithm for generating the chaincode representation. Ridge selection is done based on a connected component analysis and finally the minutiae features are generated using a stroke following scheme.

# 1 Introduction

Automatic identification of fingerprint is one of the most important biometric technologies. In any fingerprint identification system feature extraction always plays a critical role. As a condensed representation of a fingerprint image, features such as minutiae biometric patterns are extracted from the captured fingerprint images. In some cases, the fingerprint images come from inked fingerprints; in other cases, the images are obtained directly from scanning the fingerprints. Due to imperfections of the acquiring process, in some cases the extraction algorithm can miss certain minutiae, and in other cases spurious minutiae can be inserted [2, 4]. Image imperfections can also generate errors in determining the coordinates of each true minutia and its relative orientation in the image.

On the other hand, most popular feature extraction algorithms extract minutiae based on a thinned skeleton image that is generated from a binarized fingerprint image. Thinned skeleton image is a loosy representation of the fingerprint image. Its accuracy highly relies on the design of the thinning algorithms. Spurious features points are often added during the thinning process. Besides thinning algorithms are always expensive in term of processing time. In this paper we introduce a new feature extraction algorithms using chaincode representation of the fingerprint images. The algorithm utilizes the well-known chaincode image representation in both of its image quality enhancement and fingerprint feature extraction. For its 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. Then the original gray scale image is enhanced using a dynamic oriented filtering scheme together with the estimated direction field information. For its feature extraction, the enhanced fingerprint image is carefully binarized using a local-global binarization algorithm for generating the chaincode representation. Ridge selection is done based on a connected component analysis and finally the minutiae features are generated using a stroke following scheme.

# 2 Fingerprint Image Enhancement

The objective of fingerprint image enhancement is to improve the clarity of ridge structures of fingerprint images. For our feature extraction algorithm to extract minutiae features, we wish to enhance the image so that the binary fingerprint image from the enhanced image keeps the integrity of its ridges. The enhancement algorithm should not result in any spurious ridge structures. A general binarization method directly applied on finger print images can not give a satisfactory result for keeping the connectivity of the ridges as well as not creating touching between ridges.

There are two types of fingerprint image enhancement methods proposed in the literature. One is called binarization-based methods that apply to binary images. Other methods are applied directly on gray-scale images [5,7,8]. Most of the binarization-based methods require a specially designed binarization algorithm to ensure the quality of the binary images so that the information lost in the process of binarization could be recovered. In the methods directly applied on gray-scale images, the general approach is started with build a direction field that carrying the local orientation information of the finger ridges. Then a bank of filters is used for the enhancement [6]. Almost all of the proposed methods in the literatures for calculating the direction field are based on a gradient method. The computation of the gradients is very inefficient and also inaccurate for the direction field due to noise often appears in poor quality fingerprint images.

The method we proposed in this paper combines both binarization-based approach and directly gray-scale enhancement approach. We first use a local-global binarization algorithm to get a binary fingerprint image. The binary image is good enough to keep the finger ridges, although may not be complete, to maintain the local orientations. Then the local direction field is estimated using a fast chaincode-base algorithm. Since the direction field is for small local areas (in our case, in each 15x15 windows), to ensure the binarization algorithm good enough for maintaining orientation information is generally easier than to ensure fingerprint ridge integrity. The chaincode-based method is not only efficient, its ability for noise removal makes it more accurate in estimating the direction field as well. To enhance the fingerprint image we apply a simple anisotropic filter similar to that proposed in [9] on the gray-scale image. The anisotropic filter is a structure-adaptive filter that have a ellipse shape when 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 do not need to compute local ridge frequency as most filter algorithms did [6].

## 2.1 Local-Global Threshold Algorithm

Our binarization algorithm is designed for getting a binary fingerprint image quickly while keeping the local ridge direction structures. Our experiments on images from database DB 4 NIST Fingerprint Image Groups show that a binarization algorithm using one single global threshold can not give satisfactory result. The inked fingerprints makes imperfections often arise from non-uniformity of the ink density, appearance of non-printed areas and existence of stains and noise. To overcome the difficulty we apply a simple global threshold algorithm in each partitioned local area of size 15x15 pixels. Within the small local area the pixel density does not vary significantly so that we could get clear ridgelines without otherwise too much blurring.

For getting smoother edges of the ridges in the binary image, a 3x3 window is applied on the gray-scale image as a quick equalization process before our local-global thresholding. Other proposed methods use contrast enhancement [6, 9, 10] or mean and variance based image normalization. The drawback of these normalization processes may sometimes bring up the small detail such as sweat pores inside ridges and rough edges therefore end up with noisy binary image. For minutiae based feature extraction methods, we rather eliminate these noise. Fig. 1 shows the binary fingerprint image after our local-global binarization algorithm comparing with its original NIST fingerprint image.



**Fig. 1.** Local-global binarization for maintaining ridge orientation: (a) original gray-scale fingerprint image from NIST, (b) binary image after binarization.

### 2.2 Calculation of Orientation Field Using Chaincode

Chaincode image representation is used intensively in document analysis and recognition research. It has been proven to be an efficient and effective representation especially for handwritten documents. Unlike the thinned skeleton representation that is also often used in pattern recognition, chaincode is an equivalent representation of the pixel image in the sense that the pixel image can be fully recovered from it chaincode representation.

We generate the chaincode on the binary fingerprint image to carry the boundary information for the edges of the finger ridges. Tracing along the chaincode, we have the local ridge directions at each boundary pixel. To calculate the direction field for the local ridge orientations, we divide the image into 15x15 pixel blocks and use the ridge directions to estimate the ridge orientation in each block. In order to get the ridge directions as accurate as possible, we pre-process the chaincode to eliminate the boundary points that may not contribute accurate ridge directions:

- a. We filter out the small pieces that could be from noise or other fragments, and empirical parameter for ridge width is used as a guideline.
- b. An end point detection algorithm proposed in later of this paper is use for detecting the possible end points. These end points may not be real ridge endings, but the boundary directions around these points are rather misleading. We take off the directions contributed from these points in direction field estimation.

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



**Fig. 2.** Direction field computed from chaincode: (a) direction field image generated from the binary fingerprint image using its chaincode representation, (b) enhanced gray-scale image and (b) binary image on enhanced image.

Most of other direction field estimation algorithms calculate gradient at every pixel [6,9,10]. Compare with the gradient-based algorithms, our method using chaincode is much more efficient in terms of computation time. It is also shown to be a more accurate method.

### 2.3 Enhancement Using Anisotropic Filter

Fingerprint minutiae extraction algorithms using binary images heavily rely on the quality of the binarization algorithms to provide them a good binary image that carrys true feature points. Imperfections in binarization often end up with broken ridges or ridge touching therefore false feature points being added while true feature points are lost.

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The goal of enhancement algorithms is to keep the finger ridge integrity as well as to maintain separations of different ridges. To maintain separations of different ridges we could lower the threshold level in binarization. To keep the integrity of the ridges our approach is to equalize the pixel values within same ridges by bringing up the uneven pixels inside the ridges. Specifically, we use a directional anisotropic filter that has an ellipse shape with it major axis aligned parallel with the local ridge direction. The filter smoothes the pixels along the ridge direction rather than the direction across the ridges.

A structure-adaptive anisotropic filtering technique is proposed by Yang [11] for image filtering. We use a structure-adaptive anisotropic filter kernel proposed in [9] that has the following form:

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

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 through  $\sigma_1^2(x_0)$  and  $\sigma_2^2(x_0)$ . The region constraint  $\rho$  satisfies condition  $\rho(x) = 1$  when |x| < r where r is the maximum support radius. Another two parameters, S is for phase intensity control and V that usually takes negative value is for a negative impact to the pixels far from the center of the kernel around  $x_0$ . According to [9], we take V = -2 and S = 10 in our experiment too.  $\sigma_1^2(x_0)$  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  $\sigma_2^2(x_0) = 2$  [9]. Fig. 2(b) shows the enhanced fingerprint image and Fig. 2(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. The thinning or skeletonization process is to convert a binary fingerprint image into a new image in which each ridge line is represented by lines of one pixel width. Then the minutia points are detected by tracing the one pixel lines. At a point the tracing has to stop, an end point is found. The bifurcation points are found at such points whose neighbors consist of more than two points [10]. There are many problems in the thinning approaches. For example, most algorithms are very susceptible to noise or can generate skeletons that do not closely correspond to the intuitive idea of the skeleton.

In this section we propose a novel approach of minutia extraction algorithm based on chaincode image representation. As an equivalent representation of a binary image, chaincode representation faithfully carrys all the information in the binary fingerprint image. Compare to thinning base methods, the generation of chaincode is also noticeably efficient.

#### 3.1 Imperfection Mark-off

The direction field estimated from chaincode gives us not only the orientation information of the ridges but also the structural imperfection information in a local area. The structural imperfection results in breaking ridges, spurious ridges and holes. It is necessary to apply an algorithm for removing all the noise not corresponding to ridges. The standard deviation of the orientation distribution in a block is used to determine the quality of the ridges in the block. For example in Fig. 2 the directions of the ridges at the bottom of the image are misled. We will mark that area as either off-interest region or interest region with low reliability.

#### 3.2 Minutiae on Chaincode

The concept of minutia points in terms of chaincode contour point representation comes from a chaincode tracing. The original idea of contour tracing is for a stroke following in our earlier handwritten digit segmentation algorithms [1]. When a chaincode is constructed by tracing the ridge contours, we always trace along a counter-clock-wise direction. When we come to a point where we have to make a *sharp left turn* we find a location for a ridge ending point. Similarly when we come to a point where we have to make a *sharp right turn*, the turning location marks a bifurcation point. See Fig. 3 (a).



**Fig. 3.** (a) Minutia location on chaincode. (b) The distance between the thresholding line and the *y*-axis gives a threshold for determining a significant turn.

### 3.3 Calculation of the Turning Points

To determine the *significant* left and right turning contour points, we first compute vectors  $P_{in}$  leading in to a contour point P from its several previous neighboring contour points and  $P_{out}$  going out of P to its next several contour points. These vectors are normalized and placed in a Cartesian coordinate system with  $P_{in}$  along the x-axis (Fig. 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:

$$x_1y_1 + x_2y_2 < T$$

Since the threshold T is the x-coordinate of the thresholding line in Fig. 3b(ii), it can be determined experimentally 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°.

### 3.4 Post Processing

The detected turning locations make a group of candidate minutiae. The turning locations are usually 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

Our preliminary testing using both type of images for the proposed chaincode base image enhancement and minutiae extraction shows very promising results. At the time when we prepare this paper, we have not finished our experiment running on large set of images. At this conference time, We will present a detailed result of using our method on NIST inked fingerprint images and on a set of scanned fingerprint images using Ultra-scan's high-performance and high-quality scanners.

Our ongoing testing procedure is manually compare the minutiae pattern obtained by visual inspection with the minutiae pattern obtained by the automatic extraction algorithm. We use the *Goodness Index (GI)* described in [3, 6] as a quantitative measure in the evaluation process. The Goodness Index(GI) of the extracted minutiae is defined in (1) where an 8x8 pixel tolerance box to evaluate matching between the minutiae in the two patterns is considered:

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

where r is the total number of 15x15 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 spurious 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 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 few NIST images shows the GI index range from 0.25 to 0.70.

# 5 Conclusions

In this paper we have propose a novel mathod of using chaincode image representation in fingerprint image enhancement and minutia extraction. Compare to the existing image enhancement methods found in the literatures, the proposed chaincode based method is more efficient and accurate as well. The difference can be clearly seen from visual inspection in the direction field generated by our method and other methods.

The proposed chaincode based minutia extraction algorithm clearly outperforms the thinning based methods in terms of efficientcy. Most importantly due to the equivalency of the chaincode representation to its original binary image, the proposed minutia extraction method minimize the possibility of losing and inserting minutiae, which happens in many other methods.

Our current and future work includes adjusting the filter algorithm with the chaincode based direction field generation for better enhancement result. For minutiae extraction we want to add a post process method to further minimize the inserted spurious minutiae.

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