Fingerprint Image Enhancement Using the Directional Filter Bank and Oriented Anisotropic Gaussian Filters

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Abstract

This paper presents a filter bank based fingerprint image enhancement method that suppresses effectively directional and Gaussian distributed noise of fingerprints. To deal with directional noise, the proposed method uses the directional filter bank (DFB) that decomposes an image into several directional subbands efficiently. Directional filtering is performed by processing the decomposed directional subbands adaptively according to local directional characteristics and synthesizing the processed subbands. Finally, oriented anisotropic Gaussian filters are applied in order to improve contrast between ridges and valleys as well as suppress artifacts due to the previous directional filtering by removing Gaussian distributed noise. The experimental results demonstrate that combination of the DFB and anisotropic Gaussian filters is effective in suppressing two major noise components of fingerprints and the procedures of the proposed method are efficient as well.

1. Introduction

Fingerprints are one of the most reliable and well-known physiological features that can be used as personal authentication or identification [1]. In general, fingerprint based biometric systems consist of fingerprint image acquisition, quality estimation, image enhancement, feature extraction, matching, and decision. However, in noisy fingerprints, minutiae (ridge ending or bifurcation) used as fingerprint features are prone to be missing or spurious minutiae are likely to be detected (see Fig. 1). Therefore, acquired fingerprint images need to be enhanced properly for reliable fingerprint feature extraction.

Since intervals between adjacent ridges are almost similar and usually local ridges flow parallel showing a dominant directionality in about one direction except for singular regions, it is important to get rid of directional and frequency noises of fingerprints for effective fingerprint image enhancement. There are two famous approaches that attempted to suppress those two kinds of noise components at the same time. One is the directional Fourier filtering based method [2], and the other is the Gabor filter bank-based method [3]. The former method suppresses both directional and frequency noises effectively in the Fourier transform domain, but it has the disadvantage that it requires Fourier transform and inverse Fourier transform operations as many as the number of predefined directional band pass filters. For the latter, directional and frequency noises are removed in the spatial domain by using a set of Gabor filters that have the orientation and frequency selective characteristics. In this method, they assume that ridge-valley structures have a sinusoidal shape along the direction normal to the ridges, thus non-singular regions satisfying this assumption relatively well can be successfully enhanced while singular regions generally forming a high curvature are prone to be distorted. To solve this problem, Wang et al. employed an omni-directional band pass filter only in singular area [4], but simple establishment of singular region such as the square region around a singular point is not adequate and a discontinuity problem between singular and non-singular regions could occur.

Therefore, this paper proposes a fingerprint image enhancement method that suppresses two major noise components regardless of region. First, the proposed method decomposes an input fingerprint image into the 8 directional subband images using the directional filter bank (DFB) [5], and then generates a segmentation array including information on the local ridge curvatures by using the directional energy estimates calculated from the decomposed subbands. The decomposed directional subbands are processed considering the directional energy estimates of each block and the values of the segmentation array that is a result of segmentation. Thereafter, the directionally filtered image is obtained by synthesizing the processed subbands. In order to suppress some artifacts due to directional filtering by the DFB and to improve clarity between ridges and valleys, oriented anisotropic Gaussian smoothing is applied to the directionally filtered image.

The remainder of the paper is organized as follows: Section 2 describes the proposed fingerprint image enhancement method in detail. Thereafter, experimental results are presented in Section 3, and final conclusions and future works are given in Section 4.

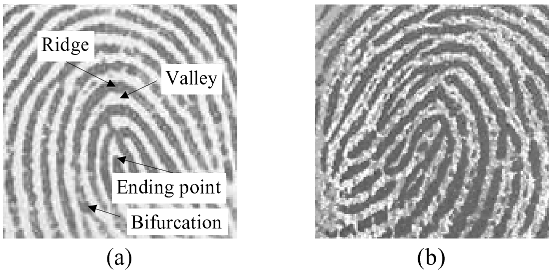


Figure 1. Fingerprint minutiae and a sample of noisy fingerprints. (a) Fingerprint ridge, valley, minutiae, and (b) sample noisy fingerprint.

2. Fingerprint Image Enhancement

The proposed method consists of two main parts. One is directional filtering using the DFB, and the other is post processing by oriented anisotropic Gaussian filters. In the first part, segmentation is performed and directional noises are removed. In the second part, Gaussian distributed noises as well as some artifacts by directional filtering are suppressed, which results in improvement of contrast between ridges and valleys.

2.1. Directional Filtering Using the DFB

The proposed directional filtering is for removing directional noises, and is composed of directional decomposition by the DFB, segmentation, subband image processing, and synthesis of the processed directional subbands. The regional characteristics are represented into a segmentation array, which plays an important role in deciding some critical parameters of the proposed directional filtering.

2.1.1. Directional Decomposition. Directional decomposition of a fingerprint image is performed by the DFB that decomposes an image efficiently and accurately into several directional subbands. Figure 1 shows the frequency partition map of the 8-band DFB and an example of directional decomposition by the DFB. The size of each directional subband image is illustrated in Fig. 2(b). For an NxN image, the size of each subband becomes N/4xN/2 or N/2xN/4 according to its direction. The down sized subbands result from quincunx down samplers and the rectangular shapes of the subbands are due to use of post sam-pling matrices to remove the frequency scrambling by down sampling.

Though there are lots of methods that perform directional filtering such as Gabor filters and directional Fourier filters, the DFB has several advantages over the other methods in that the directional separation is accurate and the procedures are efficient. The more detail description about the DFB used in this paper can be found in [5].

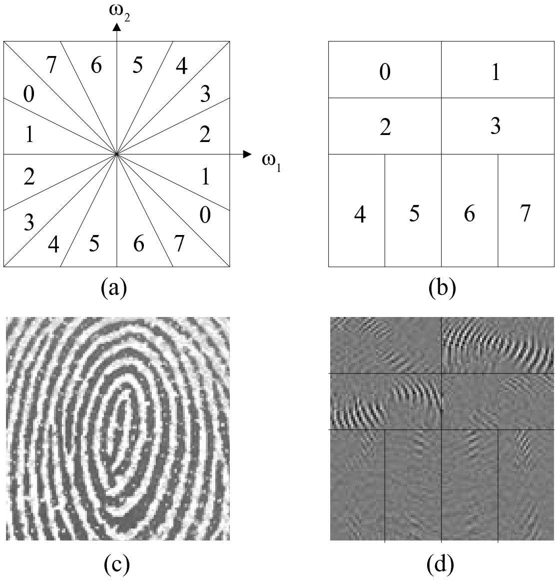


Figure 2. Directional Filter Bank (DFB). (a) Partition map of 8-band DFB, (b) size and position of each directional subband, (c) sample fingerprint image, (d) decomposed directional subband outputs of (c).

2.1.2. Segmentation. The proposed method performs segmentation on the input image using the directional energy estimates calculated from the decomposed directional subbands. The purpose of segmentation is to segment a fingerprint image into background, singular, and non-singular regions. First, the input image is divided into foreground and background regions by finding the blocks where the sum of directional energy is more than a certain threshold (T_1). Let $f^{\theta}(x,y)$ denote the coefficient at position (x,y) of the θ-directional subband, then the θ-directional energy of a block b_{ij} is calculated as follows:

$$e_{ij}^{\theta} = \sum_{x,y \in b_{ij}} \left| f^{\theta}(x,y) \right| \tag{1}$$

Thereafter, the foreground region is segmented into singular and non-singular regions by calculating the curvatures between adjacent blocks and the distance (d) from the nearest singular point. In other words, the high curvature regions within a certain distance (T_2) from the nearest singular point are considered as singular regions in the proposed method. The singular points are detected by checking out the Poincare index of each local region [6]. Let s_{ij} be the element of a segmentation array $\boldsymbol{S}$ corresponding to a block b_{ij}, the segmentation array value is determined as follows:

$$s_{ij} = \begin{cases} 1, & \text{if } e_{ij}^{\theta} > T_1 \text{ and } d > T_2 \\ 2, & \text{else if } e_{ij}^{\theta} > T_1 \text{ and } d \leq T_2 \\ 0, & \text{else.} \end{cases} \tag{2}$$

As a result of segmentation, a segmentation array is generated and its element has a value between 0 and 2. If the segmentation array value is 0, the region belongs to background regions and if it is 1, the region is a non-singular region in the foreground regions. Finally, if the value is 2, the region is considered as a singular region. This segmentation array is used for determining the parameters for subsequent oriented anisotropic Gaussian smoothing as well as the weight values for subband image processing.

2.1.3. Subband Image Processing and Synthesis of Processed Subbands. Since other directional components except for the dominant directional ones can be considered as noise components in fingerprints, the proposed method determines the weight values for subband processing in a way of assigning a higher weight values for the directional subband with dominant energy and a lower weight value for non-dominant directional subbands. Let w_{ij}^{θ} denote the weight value for θ-directional subband block corresponding to a block b_{ij}, then the weight value is calculated as follows [7]:

$$w_{ij}^{\theta} = \begin{cases} \dfrac{e_{ij}^{\theta}}{e_{ij}^{\max}}, & \text{if } s_{ij} \neq 0, \\ 0, & \text{otherwise,} \end{cases} \tag{3}$$

where $e_{ij}^{\max}$ is the maximum directional energy estimate among the 8-directional energy estimates for a block b_{ij}. The decomposed directional subbands are multiplied by the calculated weight values, then the processed directional subbands are synthesized to obtain an enhance image.

2.2. Oriented Anisotropic Gaussian Filtering

Since the directional filtering procedure sets the coefficients of directional subband blocks that do not belong to dominant directions to 0, we can see some artifacts in the directionally filtered image as shown in Fig. 3(a). In order to reduce such artifacts, the proposed method performs smoothing after directional filtering by the DFB. In addition, since the proposed directional filtering removes only directional noise in fingerprints, use of smoothing filters can be a way to suppress other kinds of noise components preventing accurate fingerprint feature extraction. The question is which smoothing method is suitable for accomplishing these two goals at the current stage.

If we obtain the intensities of the pixels on a certain line perpendicular to ridges, generally the signature shows a form of sinusoidal wave or Gaussian function, whereas if we get the intensity values from the line along the ridges, we can obtain a signature with almost uniform values unless the line meets a minutia point (refer to Fig. 4). These characteristics of fingerprints imply that it can be effective to use smoothing filters with a Gaussian-like envelope.

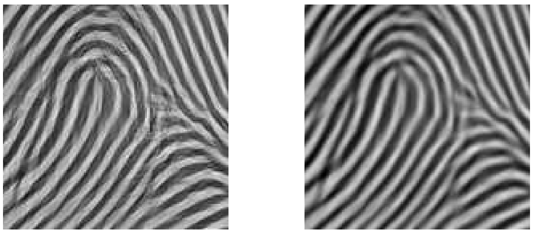
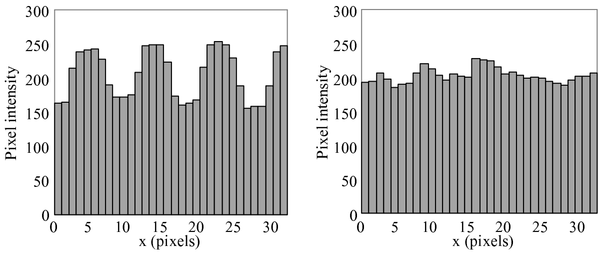

(a) (b)

Figure 3. Some artifacts by directional filtering and oriented anisotropic Gaussian smoothing. (a) Directionally filtered image by the DFB and (b) smoothed image by oriented anisotropic Gaussian filters.



(a) (b)

Figure 4. Sample signatures obtained from (a) a line perpendicular to ridges and (b) a line along ridges.

In the proposed method, oriented anisotropic Gaussian filters are used for effective smoothing. These oriented anisotropic Gaussian filters are advantageous over omni-directional Gaussian filters because they reasonably contribute to connecting the disconnected ridges and improving contrast between ridges and valleys by exploiting the local ridge orientations. In addition, Gaussian distributed noises are suppressed to some extent and white holes (pores) on ridges are filled effectively by them. The impulse response of the general case of an oriented anisotropic Gaussian filter in two dimensions is given by

$$g_\theta(x,y;\sigma_u,\sigma_v,\theta) = \frac{1}{2\pi\sigma_u\sigma_v}\exp\left\{-\frac{1}{2}\cdot\left(\frac{(x\cos\theta + y\sin\theta)^2}{\sigma_u^2} + \frac{(-x\sin\theta + y\cos\theta)^2}{\sigma_v^2}\right)\right\} \tag{4}$$

where $\sigma_u > \sigma_v$ [8]. An example of an anisotropic Gaussian filter is illustrated in Fig. 5.

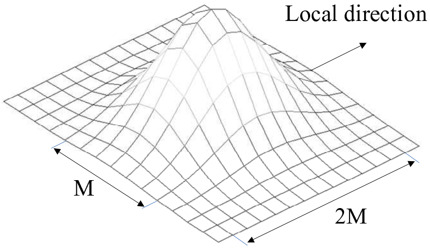


Figure 5. An example of an anisotropic Gaussian filter with aspect ratio 1:2 and certain orientation.

Fingerprint image enhancement based on anisotropic Gaussian filters was already proposed [9], [10], but the effect of the filtering is variable according to the values of the two standard deviations. If the standard deviation values are large, the current pixel to be smoothed is affected by large neighbourhood regions. On the contrary, if the values are small, the shape of curve will be steep and as a result, the more weight will be given to the current pixel and only small neighbourhood region only affect the smoothing. If the standard deviation values are set adequately, the smoothing process can get rid of noise components successfully, but if not, it might connect ridges falsely or the ridge structures could be distorted. Therefore, in the proposed method, the two standard deviation values (σ_u, σ_v) for the filters in Eq. (4) are determined using a segmentation array in order to remove noise components effectively and to preserve ridge information correctly at the same time. The orientation image is used for determining the orientation parameter of the anisotropic Gaussian filter.

Since oriented anisotropic Gaussian filtering is prone to distort the ridges in high curvature areas, an anisotropic Gaussian filter whose aspect ratio 1:$f(d_s)$ is close to 1:1 is applied to the high curvature regions. Here $f(d_s)$ is a value that is proportional to a distance d_s from the nearest singular point and is larger than 1. In low curvature regions, anisotropic Gaussian filters with a fixed aspect ratio of 1:a_1 where $a_1 > f(d_s)$ are used. The proposed method fixes the standard deviation value (σ_v) of the direction normal to ridge direction to a certain value, and adjusts the standard deviation value (σ_u) of the direction along ridge direction to a value bigger than σ_v by considering the distance from the singular point. The standard deviation value (σ_u) of the direction along ridge direction is obtained as follows:

$$\sigma_u(i,j) = \begin{cases} f(d_s), & \text{if } A_s(\tfrac{i}{2},\tfrac{j}{2}) = 2, \\ a_1 \cdot \sigma_v, & \text{otherwise,} \end{cases} \tag{5}$$

where $f(d_s)=\sigma_v\ [d_s(a_1-a_2)/d_{th}+a_2]$ and $1<a_2<a_1$. In the proposed method, the parameters of an anisotropic Gaussian filter for each block are determined on an 8x8 block basis. The use of anisotropic Gaussian filters not only suppresses the artifacts by directional filtering but improves the clarity of ridge and valley structures. In our experiment, we set the window size for the filter to 7x7 so that the window can consider approximately a half period region of a local ridge-valley structure. The block diagram for the proposed anisotropic Gaussian filtering is illustrated in Fig. 6 and an example of the enhanced images by anisotropic Gaussian smoothing is given in Fig. 3(b).

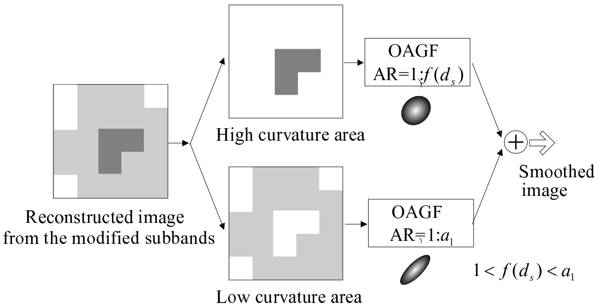


Figure 6. Block diagram for the proposed adaptive oriented anisotropic Gaussian smoothing (OAGF: Oriented anisotropic Gaussian filter, AR: Aspect ratio).

3. Experimental Results

The proposed method was first evaluated using the 5 fingerprint images sampled from FVC2000 2a database. The aim of fingerprint image enhancement is to facilitate the following fingerprint feature extraction, so we investigated how the proposed method affects accurate fingerprint feature extraction. Since the fingerprint features we want to extract here are fingerprint minutiae such as bifurcations and ending points, we evaluate the proposed method analyzing the accuracy of the extracted minutiae after applying the proposed fingerprint image enhancement method to fingerprints.

Once the enhanced image is obtained, it is binarized and thinned. From the thinned image, minutiae can be detected simply by analyzing neighbourhood pixels. In our experiments, we compared the proposed method with the Gabor filter bank-based method [3], and the results are shown in Table 1. In Fig. 7, we showed some examples of the fingerprint images enhanced by the proposed method and the Gabor filter bank-based method. We can see that the proposed method has a better performance in enhancing especially the singular region than the Gabor filter bank-based method.

Table 1. Error rate of each method. M: Number of missing minutiae, S: Number of spurious minutiae

Method	1		2		3		4		5	
	M	S	M	S	M	S	M	S	M	S
Gabor-based	0	2	2	10	6	3	3	5	0	7
Proposed	0	4	2	10	0	2	2	2	0	6

4. Conclusions

We have proposed a segmentation based fingerprint image enhancement method that is effective in suppressing directional noise and improving clarity of a ridge-valley structure. The proposed method is based on the DFB, and information obtained by the DFB is effectively exploited throughout the procedures. First, a fingerprint image is decomposed into 8 directional subband images, and then segmentation is performed using the directional energy estimates calculated from the decomposed subbands. Thereafter, the directional subbands are processed using the segmentation array that contains regional characteristics and the directional filtered image is obtained by synthesizing the processed subbands. Finally, segmentation based anisotropic Gaussian smoothing is performed to clarify ridge and valley structures as well as to suppress some artifacts by directional filtering of the previous step. The experimental results show that combination of the DFB and oriented anisotropic Gaussian filters is effective in suppressing the directional and Gaussian distributed noises and the segmentation-based approach is also effective in enhancing both singular and non-singular regions.

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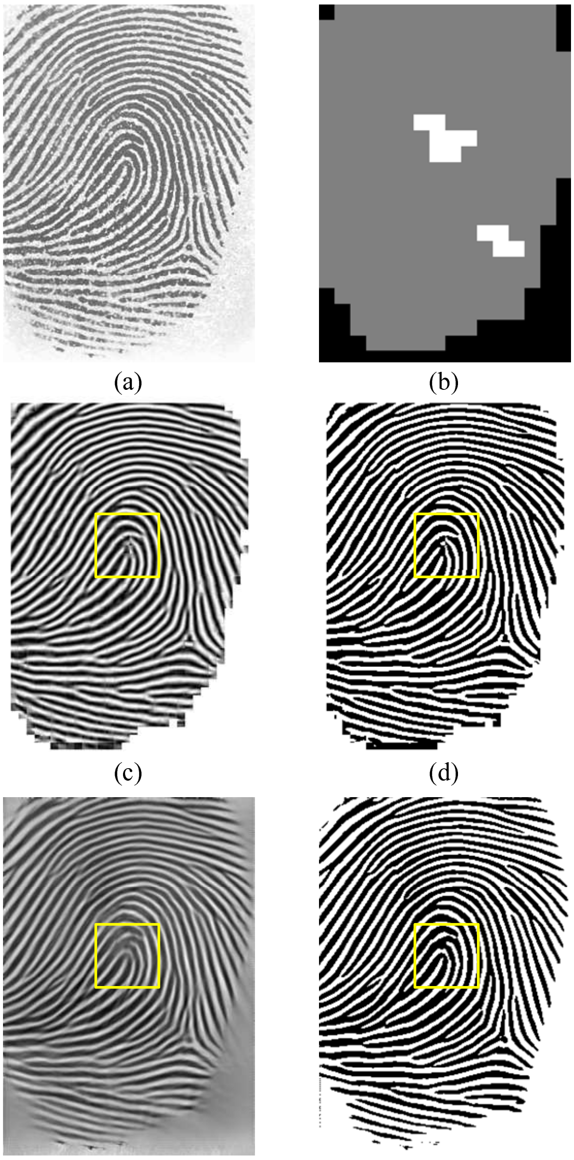

(a) (b) (c) (d) (e) (f)

Figure 7. Comparison of two enhancement methods. (a) Original image, (b) graphical representation of the segmentation array, (c) enhanced image by Gabor filter bank-based method, (d) binarized image of (c), (e) enhanced image by the proposed method, and (f) binarized image of (e).

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