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Fingerprint Image Enhancement With Dynamic Block Size

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Abstract- **The performance of any Automatic Fingerprint Identification System AFIS depends highly on the acquired fingerprint image quality, which is mostly exposed to degradation and noise during the acquisition process or because of fingerprint sweat, smut ..etc. Most AFIS use some form of image enhancement in order to improve the recognizer performance. This paper presents a simple modification to the enhancement method based on Gabor filtering algorithm in order to improve image quality. It has been noticed that the computations of the local ridge direction and also the enhancement is affected heavily by the block size used therefore, an attempt has been made to develop a more accurate approach wwhich is dynamically decides the block size. It is based on the local ridge frequency. The proposed enhancement algorithm has been tested to fingerprint images from FVC2002 and it shows a promising result.**

Keywords-Fingerprint, image enhancement, Gabor filter, block size.

I. Introduction

In an ideal fingerprint image, ridges and valleys flow in locally constant directions and minutiae can easily be detected by following the detected ridge lines to their endings and bifurcations (figure 1). However, in practice, this is not always the case. Actually, the fingerprint image can get corrupted due to a number of reasons. For example, the subject can have a non-cooperative attitude when giving the sample, there can be some sort of environmental condition that is not suitable for the scanning device or the user might have dry hands [7]. In [4] it is found that about 10 percent of all fingerprint images captured are of poor quality. This leads to the following main problems such as, number of spurious minutiae might be introduced, a number of genuine minutiae might be lost and large errors in minutiae orientation and position may be introduced. To overcome these problems, a number of fingerprint image enhancement techniques have been proposed in the literature [7].

In AFIS (Automatic Fingerprint Identification Systems) most operations are performed on block level such as estimating directional field, segmentation or singular point detection, therefore it is important to select a suitable block size for optimal extraction of features for fingerprint image, as it affects the computation of directional field. When values of block size are small they cause spurious patterns to appear while large values level out important ridge singularity information [3].

Several approaches to compute the block size dynamically to be suitable for each fingerprint have been proposed in literature. In [1] the block directional field computed with a constant block size then, a consistency level criteria is evaluated if it is above a certain threshold, then the local orientations around this region are re-estimated at a lower resolution, block size, level until the consistency level is below a certain level.

In [3] the proposed estimation method is, unlike in [4] that the ridge frequency is computed for each block of the image, in order to reduce the computational cost, the average ridge distance is computed once for the whole input image.

In order to compute a correct average ridge distance value a search is done all over the block-direction image to find a region having the least variance in direction sense, and hence to find a clear foreground area. According to the search result, the determined block and its nine neighboring blocks are selected to be used in the process. Based on the corresponding direction the summation along the ridge-dominant direction is computed to specify the ridge start points. The mean of the obtained distances is then assigned as the average ridge distance of the image. This parameter is then used to determine the block size as well as the filter mask size. Knowing the size of the mask, other proposed filter parameters can now be determined. The image is then enhanced using the directional filtering method.

In [5] a criterion is presented for selecting an optimal block size to reduce the number of spurious singularity detections. An approach [5] to extract both the directional field and singularities simultaneously in fingerprint impressions then chooses the appropriate block size and uses it to update feature extraction, is presented. The criteria for selecting the optimal block size is based on similarity measures of the extracted directional field with the true image gradients at singularity locations as well as at pre-specified locations in the fingerprint image.

The current work presents a simple and fast modification to the enhancement method that is based on the usage of Gabor filters [2, 4, 6] technique. The proposed method estimates the ridge frequency of fingerprint images quickly and then uses it to change the block size used in computing block directional field of the fingerprint and also as an input parameter to the Gabor filter (frequency and direction).

II. The Proposed Method

Firstly the input image is normalized to have a certain mean and variance. Then the whole fingerprint image is divided into 3 × 3 non-overlapping blocks and the local ridge orientations are computed using method proposed in [8]. This method also computes the strength for each block orientation with value between 0 and 1 to indicate the clarity of the ridge-valley structure of each block. Next the average ridge frequency is computed, as described in [4], by using the maximum strength block frequency. The suitable dynamic block size is computed using the proposed formula. Then, the fingerprint block directional field is computed using the estimated block size ***W***. Finally the Gabor [2, 4, 6] filter is implemented using the estimated dynamic block size, ridge frequency and directional field.

In summary the proposed method steps are:

1. Normalize the input image.
2. Divide the whole fingerprint image into 3 by 3 blocks and compute the local ridge orientations and strength using method proposed in [8, 11]
3. Compute the average ridge frequency for the maximum strength block.
4. Estimate the suitable block size as this work suggested and compute the fingerprint local ridge orientation according to the estimated size using method proposed in [8, 11]
5. Compute the directional field using the estimated block size ***W***.
6. Determine the used Gabor filter parameters.
7. Implement directional filtering to enhance the image.

The details of each stage are given in the next sections.

II.1. Image Normalization

The main purpose of normalization is to have input images with similar characteristics and also to reduce the variation in gray-level values along the ridges and valleys (without changing the ridge and valley structures) [4] i.e. normalization is used to remove the effect of sensor noise and gray level background due to finger pressure differences [3].

Let ***I(x,y)*** denotes the gray level values at pixel ***(x,y)***, ***M*** and ***VAR*** denote the estimated mean and variance of ***I***, respectively, and ***g(x,y)*** denotes the normalized gray-level value at pixel ***(x,y)***. The normalized image is defined as follows:

$$g(x,y)=\begin{cases} M_0+\sqrt{\dfrac{VAR_0(I(x,y)-M)^2}{VAR}} & if I(x,y)>M \\ M_0-\sqrt{\dfrac{VAR_0(I(x,y)-M)^2}{VAR}} & otherwise \end{cases} \quad (1)$$

Where M_0 and VAR_0 are the desired mean and variance values, respectively [4].

II.2. Directional Field Computation

After image normalization the whole fingerprint image is divided into 3 × 3 non-overlapping blocks and compute the local ridge orientations using method proposed in [8]. This method also computes the strength for each block orientation with value between 0 and 1 to indicate the clarity of the ridge-valley structure of each block.

The directional field describes the coarse structure, or basic shape, of a fingerprint. It is defined as the local orientation of the ridge-valley structures. [8].

A number of approaches to estimate the directional field from a fingerprint is known from literature such as using matched-filter methods to find a distinct number of orientations in a fingerprint image [9], [10] and 2-dimensional spectral estimation methods [9]. In order to determine the directional field the method based on PCA used in [8] have been used. The gradient vector $[G_x(x,y), G_y(x;y)]^T$,which is defined as:

$$\begin{bmatrix} Gx\ (x, y) \\ Gy\ (x, y) \end{bmatrix} = \nabla I(x,y) = \begin{bmatrix} \dfrac{\partial I(x,y)}{\partial x} \\ \dfrac{\partial I(x,y)}{\partial y} \end{bmatrix} \qquad (2)$$

where $I(x, y)$ represents the gray-scale image. Gradients can be considered as elementary orientations at each pixel of the image. The directional field is, in principle, perpendicular to the gradients. However, the gradients are orientations at pixel-scale, while the directional field describes the orientation of the ridge-valley structures, which is a much coarser scale.

Therefore, the directional field can be derived from the gradients by performing some averaging operation on the gradients, involving pixels in some neighborhood [4] and this operation was done by using principle component analysis PCA. PCA computes a new orthogonal base given a multi-dimensional data set such that the variance of the projections on the axes of this new base is subsequently maximized. It turns out that the base is formed by the eigenvectors of the autocovariance matrix of this data set. Applying PCA to the autocovariance matrix of the [Gx Gy]T gradient vectors provides the 2-dimensional Gaussian joint probability density function of these vectors. From this function, the main direction of the gradients can be calculated. The estimate of the autocovariance matrix C_G of the gradient vector pairs is given by:

$$C_G = \begin{bmatrix} G_{xx} & G_{xy} \\ G_{xy} & G_{yy} \end{bmatrix} = \sum_W \begin{bmatrix} G_x^2 & G_x G_y \\ G_x G_y & G_y^2 \end{bmatrix} \qquad (3)$$

in a window W in the given fingerprint.

The longest axis v_1 of the 2-dimensional joint probability density function is given by the eigenvector of the autocovariance matrix that corresponds to the largest eigenvalue λ_1. This axis corresponds to the direction in which the variance of the gradients is largest, and so to the 'average' gradient orientation. The ridge-valley orientations are perpendicular to this axis, and therefore given by the shortest axis v_2. This is the direction of the eigenvector that corresponds to the smallest eigenvalue λ_2 .The normalized orientation vector v_n is now given by:

$$v_n = \frac{v_2}{|v_2|} \qquad (4)$$

The average ridge-valley orientation θ is given by:

$$\theta = \angle v_2 \qquad (5)$$

The strength Str of the orientation can be determined as a simple function of the two eigenvalues. In order to limit the strength between 0 and 1, it is given by:

$$Str = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2} \qquad (6)$$

II.3. Ridge Frequency Computation

In the next step the average ridge frequency is computed for the maximum strength block using method described in [4]. In a local neighborhood where no singular points exists, the gray levels of a fingerprint image can be modeled as a sinusoidal shaped wave perpendicular to the local ridge orientation. Local ridge frequency is therefore an important tool in many fingerprint image enhancement algorithms. It can also be used to determine if an area of the image contains valid information or if it is totally corrupted. According to [4], valid ridge frequencies lie within [1/3, 1/25] for 500dpi images.

The following steps where introduced in [4] to estimate the local ridge frequency:

1. Divide the fingerprint image ***I*** into $w \times l$ pixel blocks.

2. For each block centered at ***(i, j)*** compute an oriented window of size $l \times w$ pixels. The orientation of the window is perpendicular to the local ridge orientation as shown in Figure 2

3. For each block compute the x-signature ***X[n]*** of the ridges and valleys within the oriented window defined as:

$$X[k] = \frac{1}{w}\sum_{d=0}^{w-1} I(u,v), \quad k = 0,1,\ldots,l-1 \qquad (7)$$

where,

$$u = i + (d - \frac{w}{2})\cos o(i,j) + (k - \frac{1}{2})\sin o(i,j)$$
$$v = j + (d - \frac{w}{2})\sin o(i,j) + (\frac{1}{2} - k)\cos o(i,j) \qquad (8)$$

and where ***O(i,j)*** is the local ridge orientation.

4. Let ***T(i,j)*** be the average number between two consecutive maximums in the x-signature, then the local frequency can be calculated as:

$$\Omega(i,j) = \frac{1}{T(i,j)} \qquad (9)$$

If no consecutive peaks can be detected or if the frequency is not within the valid range [1/3, 1/25], the area is marked to indicate that the frequency could not be estimated.

II.4. Estimate The Block Size

Estimate the suitable block size using Equation 10 and compute the fingerprint local ridge orientation according to the estimated block size using method proposed in step 2

$$W = (round((1/\Omega)*1.6+1))*\alpha \qquad (10)$$

where α is a chosen constant.

II.5. Gabor Filtering

The configurations of parallel ridges and furrows with well-defined frequency and orientation in a fingerprint image provide useful information, which helps in removing undesired noise. The sinusoidal shaped waves of ridges and furrows vary slowly in a local constant orientation. Therefore, a bandpass filter that is tuned to the corresponding frequency and orientation can efficiently remove the undesired noise and preserve the true ridge and furrow structures. Gabor filters have both frequency-selective and orientation-selective properties and have optimal joint resolution in both spatial and frequency domains. Therefore, it is appropriate to use Gabor filters as bandpass filters to remove the noise and preserve true ridge/valley structures [6].

The even-symetric Gabor filter has the general form:

$$h(x,y:\phi,f)= \exp\left\{-\frac{1}{2}\left[\frac{(x\cos\phi)^2}{\delta_x^2}+\frac{(y\sin\phi)^2}{\delta_y^2}\right]\right\}\cos(2\pi f x\cos\phi) \qquad (12)$$

Where ϕ is the orientation of the Gabor filter, f is the frequency of a sinusoidal plane wave, and δ_x and δ_y are the space constants of the Gaussian envelope along x and y-axes, respectively. Figure 3 shows Gabor filter with 0o and 90 o angles as an example.

To apply Gabor filters to an image, three parameters must be specified: (i) the frequency f of the sinusoidal plane wave, (ii) the filter orientation, and (iii) the standard deviations of the Gaussian envelope δ_x and δ_y.

The selection of the values of δ_x and δ_y involves a trade-off. The larger the values, the more robust to noise the filters are but the more likely the filters will create spurious ridges and furrows. On the other hand, the smaller the values, the less likely the filters will create spurious ridges and furrows but then they will be less effective in removing the noise.

III. Experimental Results

The purpose of a fingerprint enhancement algorithm is to improve the clarity of ridges and valleys of input fingerprint images and make them more suitable for the minutiae extraction algorithm. The ultimate criterion for evaluating such an enhancement algorithm is the total amount of ``quality" improvement when the algorithm is applied to the noisy input fingerprint images. Such an improvement can be assessed subjectively by a visual inspection of a number of typical enhancement results. However, a precise and consistent characterization of the quality improvement is beyond the capability of subjective evaluation [4].

Examples of the enhancement results are shown in Figure 4. From these examples, it can be seen that the proposed enhancement algorithm does improve the clarity of the ridge and valleys structures of input fingerprint images .

The results of the proposed algorithm have been compared with that obtained with the constant block size using the accuracy rate (AR) of the minutiae extraction as follows [12]:

$$AR=\frac{M_r-M_m-M_s}{M_t} \qquad (13)$$

where M_r is the number of the true minutiae that extracted from the singular point area by used minutiae extraction algorithms. M_m is the number of the missing minutiae. M_s is the number of the spurious minutiae, and M_t is the number of the true minutiae detected by fingerprint proficient.

The described enhancement method has been implemented and tested on fingerprint images from FVC2000 database 4 [14], synthetic generation based on an evolution of the method proposed in [13], 240 ×320 and 500 dpi resolution. The parameters of the synthetic generator were tuned to emulate a low-cost sensor with a small acquisition area; the maximum rotation and displacement and skin-distortion are adjusted to roughly reproduce the perturbations in the three previous databases. Images of poor quality are used to evaluate the performance of the proposed algorithm.

The experimental results show that the proposed algorithm is better than that uses constant block size and frequency. It was tested on 32 poor fingerprints obtained from the FVC2000 database 4. Firstly, the Accuracy Rate (Equation 13) is computed for the enhancement algorithm with constant block size and constant frequency then the Accuracy Rate is computed for the enhancement algorithm with dynamic block size and frequency. It achieves 90% of the Accuracy Rate when using dynamic block size compared with 83% of the Accuracy Rate with the enhancement algorithm that uses constant block size.

From the result, the proposed algorithm is better than other enhancement algorithm in improving the performance of the minutiae extraction. Thus, we can draw a conclusion that our enhancement algorithm does improve the quality of the fingerprint image and improve the accuracy of the minutiae extraction.

IV. Conclusions

A fingerprint enhancement algorithm with dynamic block size which can adaptively improve the clarity of ridge and valleys structures and is based on the local ridge orientation and ridge frequency estimated from the input images is proposed. The performance of the algorithm was evaluated using the accuracy rate of the extracted minutiae. Experimental results show that the proposed modified enhancement algorithm with dynamic block size is capable of improving accuracy rate.

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Figure. 1 (a) Fingerprint image, b) Ridge ending and c) Ridge bifurcation.

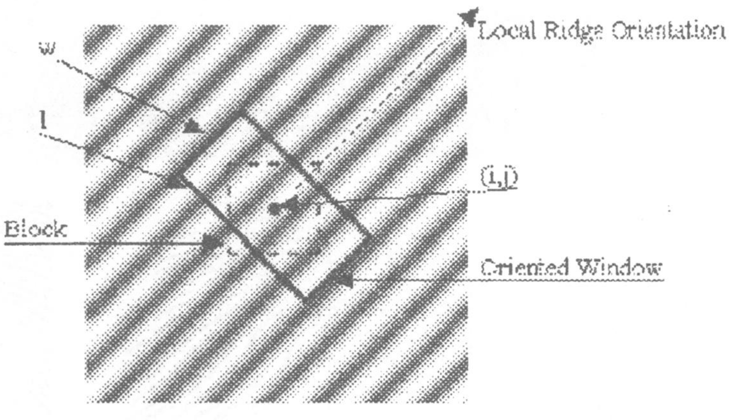

Figure. 2 Oriented window used in the ridge frequency calculation.

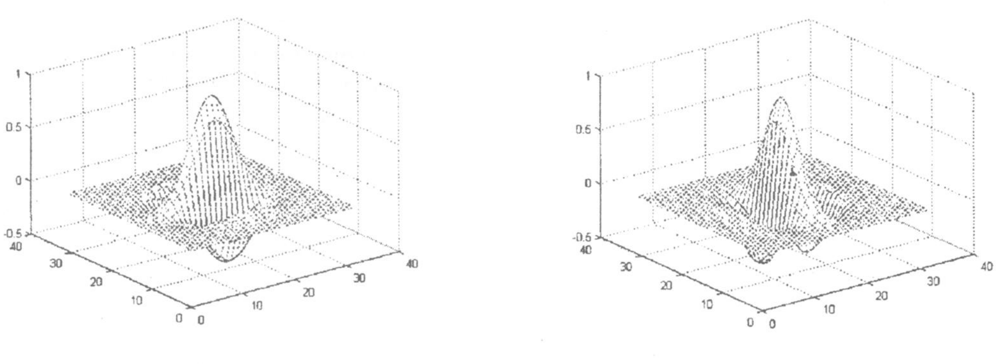

Figure. 3 Gabor filter, a) with 0 ^{o} orientation and b) with 90 ^{o} orientation.

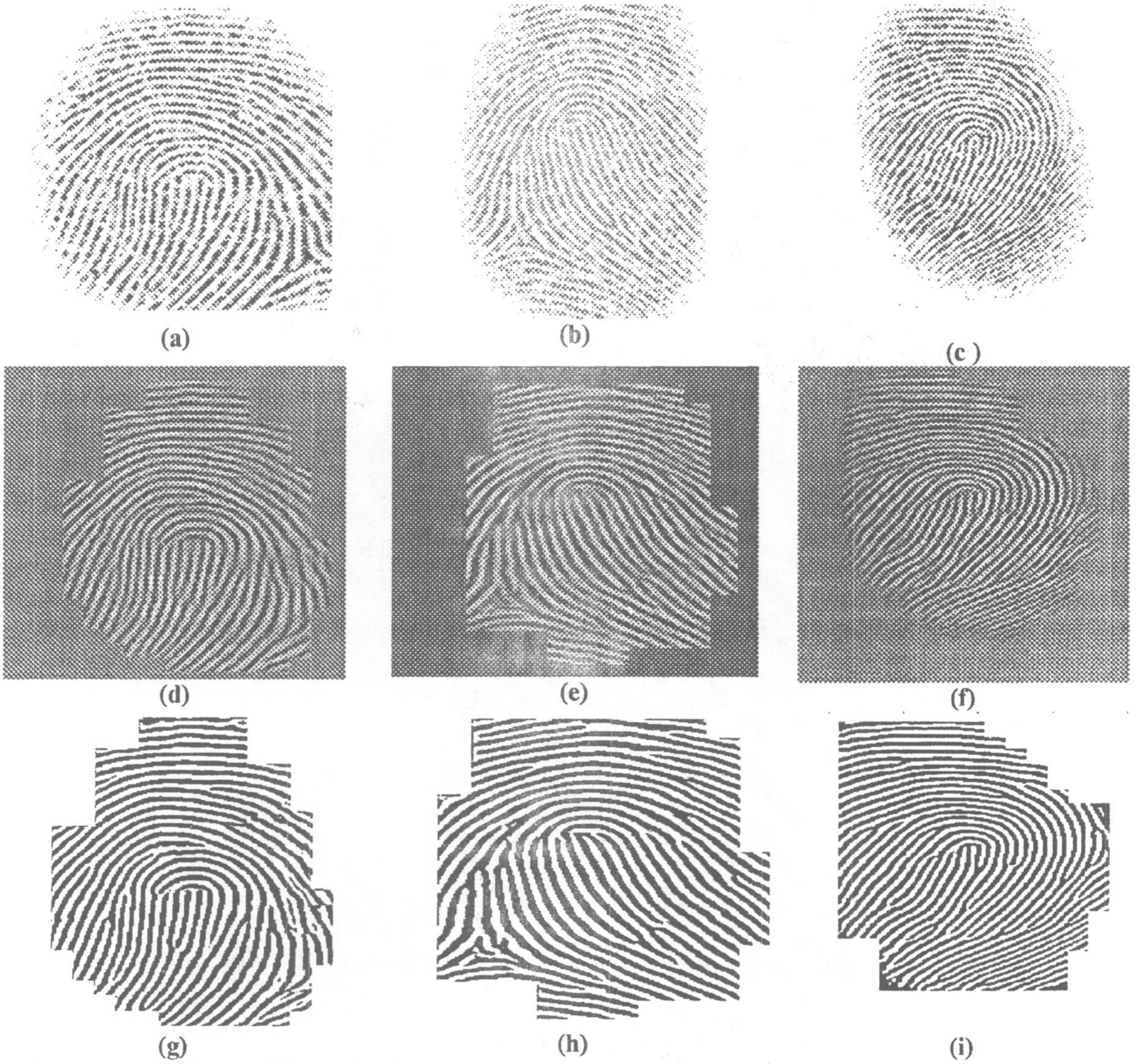

Figure 4 Example of the proposed enhancement method. (a)–(c) Original fingerprint images. (d)–(f) Results of the proposed method after Gabor filtering (g)–(i) Results after binarization.