Fingerprint Enhancement by Adaptive Filtering in Frequency Domain

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Abstract – **Fingerprint image enhancement is an essential preprocessing step in fingerprint recognition applications. A method described in this paper is based on the adaptive filtering in frequency domain using Gabor filters. Algorithm based on varianse calculation is presented and compared with one based on orientation field estimation .**

Keywords – **fingerprints, enhancement, image processing, image filtering, Gabor filter**

I. Introduction

Reliable person identification is an important problem in diverse businesses such as finance, law enforcement, access control, health care etc. Often, it is necessary to do it remotely and automatically. Biometrics, as automatic identification of people based on their physiological or behavioral characteristics, are becoming dominant over traditional means of authentication such as knowledge-based (password) and token-based (key) authentication. Among several human characteristics that can be used in biometric systems (face, retina, iris, voice, hand etc.), fingerprints are, due to their characteristics, one of the most researched, used and mature method of authentication. [1]. They have been extensively used by forensic experts in criminal investigations for decades. [2]. Popularity of fingerprint identification is based on the following properties of fingerprints: the fingerprint of a person is unique and its features remain invariant with age [3, 4].

There were different realizations of automatic fingerprint identification systems (AFIS) in the last 50 years. We can either digitalize fingerprint image taken by ink, or use inkless optical scanners to provide input image for AFIS. In either way spatial resolution of 500 dpi and amplitude resolution of 256 gray values (8 bits per pixel) are recommended. A number of operations are applied in order to extract features later used in matching process.

The goal of feature extraction in pattern recognition system (in general) is to extract information from the input data that is useful for determining its category. In the case of fingerprints a natural choice are features based directly on the fingerprint ridges and ridge-valley structure. However, the effectiveness of a feature extraction depends greatly on the quality of the images. Consequently, fingerprint image enhancement is usually the first step in most AFIS.

The rest of this paper is organized as follows. In Section II we briefly describe fingerprint structure and some methods for fingerprint image enhancement. In Section III 2-D Gabor filter is introduced, and adaptive filtering is described in Section IV. Some results and conclusions are shown in Section V.

II. Fingerprint structure

A fingerprint represents the image of the surface of the skin of the fingertip. A typical structure of a fingerprint consists of ridges (black lines) separated by valleys.

The ridge pattern in a fingerprint can be described as an oriented texture pattern with fixed dominant spatial frequency and orientation in a local neighborhood. The frequency is depending on inter-ridge spacing, and orientation on flow pattern exhibited by the ridges. The global pattern of fingerprint is used to determine the class [5]. Classification process was performed manually in police departments from the end of the 19^{th} century [6], and is, with small modifycations, still in use today. Region of a fingerprint where the ridge pattern makes it visually prominent are called singularities [7]. There are two types of fingerprint singularities: core and delta, and they are very useful for determining fingerprint's class.

A closer analysis of the fingerprint reveals some anomalies of the ridges, such as ridge endings, bifurcations, crossovers, short ridges, etc. These local features of fingerprints, called minutiae, can be used for manual or automatic fingerprint identification. These basic features of fingerprints (singularities and minutiae) are shown in Fig. 1.

Fig. 1. Basic features of fingerprints: minutia- ridge ending (in square), ridge bifurcation (in circle), singularities core (X) and delta (in triangle)

Enhancement may be viewed as a process of improving the clarity of the ridge structure in the fingerprint image [8, 9, 10]. Result is expected to be more suitable than the original, for visual examination and automatic feature extraction. Although noise content is reduced, enhancement process can also introduce false ridges, resulting in false or missing minutiae.

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There have existed a variety of algorithms for image enhancement that can be used in case if fingerprint images. One group of algorithms, such as change of contrast and histogram equalization [11], are dealing with each pixel independly. Other algorithms are considering local neighbourhood of pixel. Typicall algorithms from this class are linear filtering in spatial and frequency domain, nonlinear filtering, adaptive filtering etc.

Since in local area, the ridges and vallyes have well-defined frequency and orientation, it is natural to use oriented filters. There were some research in directional filtering in spatial domain [3, 12]. In frequency domain Fourier transforms [9, 13, 14], and Gabor filters [10, 15] are analyzed. If filters in use are adapted to ridge orientation, filtering process is called adaptive.

III. 2 - D Gabor filter

The Gabor filters are recognized as a very useful tool in computer vision and image processing applications such as texture analysis, image compresion etc. Gabor filters ere very useful both in frequency and spatial domain, due to their frequency-selective and orientation-selective properties. Impulse response of these filters, which are by the way band-pass filters, are very similar to impulse response of receptive fields in the brain's visual cortex [16]. By simple adjustment of mutualy independent parameters, Gabor filters can be configured for different shapes, orientations, different width of band pass and different central frequences. Properly tuned, Gabor filter can filter an image, maintaining only regions of a given frequency and orientation, and this has profound implications for research in fingerprint image analyse and enhancement using this filter [10, 15].

An even Symmetric Gabor filter general form in the spatial domain is [10]:

$$h(x,y,\phi,\omega) = e^{-0.5\{[x/\delta_x]^2+[y/\delta_y]^2\}}\cos[\omega(x\cos\phi + y\sin\phi)] \quad (1)$$

where ϕ is the orientation of the Gabor filter, ω is the frequency of the sinuusoidal plane wave along the x –axis, δ_x and δ_y are the standard deviations of the Gaussian envelope along the x and y axes, respectively.

Fig. 2 shows an example of Gabor filter and its response in spatial and frequency domain.

Parameters ω, δ_x i δ_y , for optimal Gabor filter depends on inter-ridge distance in fingerprint image. Since the variations of inter ridge distance, in the fingerprint database avaliable to the author, is small (distance is about 5 pixels,f=1/5=0.2) , we set parameter ω to be $\omega=2\pi\times0.2$, and $\delta_x = \delta_y = 4.0$. Trade-off in selection of δ_x and δ_y is done based on empirical data [10], so that the filter is robust to noise, but still can capture ridge information at fine level. 16 different orientations are examined, creating Gabor filter bank with orientations $\phi = i\pi/16$.

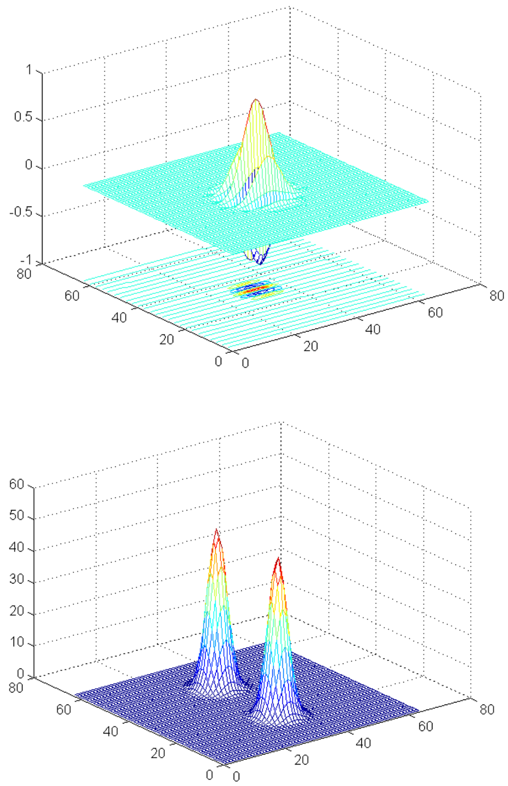


Fig. 2. The Gabor filter and its response in spatial and frequency domain

IV. Adaptive Filtering

Bank of oriented Gabor filters are applied to input fingerprint image. Filtering is performed in frequency domain resulting in set of 16 filtered images, where each of them emphasizes one ridge orientation (namely $\phi = i\pi/16$). Those filtered image are combined in order to get enhanced image. We applied and examined two different methods.

First we applied method described in [10]. Additional information about dominant ridge orientation is used. We create block-direction image by determination dominant orientation in blocks dimension of $w\times w$, by the following formula [17]:

$$\theta_d = \frac{1}{2}\tan^{-1}\left(\frac{\sum_{i=1}^{w}\sum_{j=1}^{w}2G_x(i,j)G_y(i,j)}{\sum_{i=1}^{w}\sum_{j=1}^{w}\left(G_x(i,j)^2 - G_y(i,j)^2\right)}\right), G_x, G_y \neq 0 \quad (2)$$

where, G_x and G_y are the gradient magnitudes obtained using 3×3 sobel masks. Smoothing process presented in [5] is then applied.

In enhancement process, pixels in one block of enhanced image take the value of pixels on the same position from the filtered image which emphasizes determined orientation for corresponding block.

Second realization is based on following idea:

- Each Gabor filter clearly emphasize ridge in certain direction, while the rest has no specific texture.
- The variance of the pixel intensities in block is high if there are ridges and valleys in those block, otherwise variance is low.

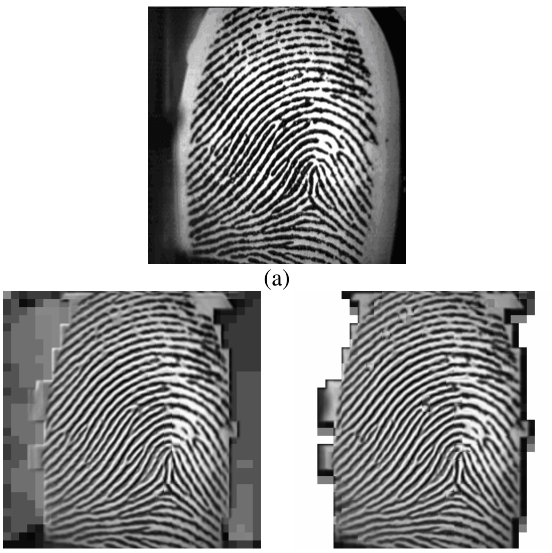
We propose the following enhancement process:

- For each filtered image we calculate the variance of intensities in block, in order to get rank of variance values;
- Pixels in one block of enhanced image take the value of pixels on the same position from the filtered image where maximal variance for the block is calculated;
- To avoid chess-field effect, we combined blocks (with appropriate ponder factor), of three filtered images: one with highest calculated variance and two other that are next in the rank.

V. RESULTS AND CONCLUSION

Original image and enhanced images obtained by described methods are shown in Fig. 3.

In order to compare effectiveness of presented methods, we applied algorithm for minutiae extraction described in [18]. Then we compared number of extracted minutiaes with the one determined by the expert. Thinned binarized images with extracted minutiae are shown in Fig. 4.



(a) (b) (c)

Fig. 3. (a) Original image, (b) enhanced image obtained by first method [10] (using information of block orientation), (c) enhanced image obtained by second method (max variance in block)

In enhanced image obtained by applying first method, total of 54 minutiae is found, opposite to 47 found by the expert. Among them, 36 are matched, 11 are missing, and 18 are false minutiae.

(a) (b)

Fig. 4. Thinned binarized enhanced image
(a) obtained by first method
(b) obtained by second method

In enhanced image obtained by applying second method, total of 57 minutiae is found, 39 are matched, 8 are missing, and 18 are false minutiae.

At the same time if we apply algorithm for minutiae detection directly on original image, a total of 128 minutiae is found, 36 are matched, 11 missing and 92 are false.

Relatively high number of false minutiae both in enhanced images, and in original one, is mostly result of binarization and thinning algorithms applied in minutiae extraction algorithm.

We can see what there a clear benefit in using presented enhancement techniques is. Although the number of false minutiae is still too high, it is reduced multiple times.

Similar results are obtained for other images in our database. So what method should be applied?

It seems logical that if we already spent some time in orientation image estimation, we should use that information without wasting more time in variance calculation.

However, second method is competitive in results with the first one. Since most algorithms for segmentation background from foreground of fingerprint image are based on variance calculation in block, it is optimal to use that information to perform enhancement as well. Since in that case there is no need for orientation image estimation, some time is obviously saved.

Also, some modification of second method can be used in artifacts removal (letters, interruptions etc.), and that will be object of our further research. We are also considering including the information of maximal dispersion of the pixel intensities in blocks, in enhancement process.

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