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Analysis of Fingerprint Image Enhancement Using Gabor Filtering with Different Orientation Field Values

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Abstract

Fingerprint image enhancement is the key process in IAFIS systems. In order to reduce false identification ratio and to supply good fingerprint images to IAFIS systems for exact identification, fingerprint images are generally enhanced. A filtering process tries to filter out the noise from the input image, and emphasize on low, high and directional spatial frequency components of an image. This paper presents an experimental summary of enhancing fingerprint images using Gabor filters. Frequency, width and window domain filter ranges are fixed. The orientation angle alone is modified by 0 radians, $\frac{\pi}{2}$, $\frac{\pi}{4}$ and $\frac{3\pi}{4}$ radians. The experimental results show that Gabor filter enhances the fingerprint image in a better way than other filtering methods and extracts features.

***Keywords**: Biometrics, Fingerprints, Digital image processing, Gabor filter, Fourier transform*

1. Introduction

Biometrics provides highly scalable solutions for identification management security operations. Biometrics offers accurate identification, accountability, easy to use, time saving and user friendly systems that support business owners to tackle undocumented access, ID swapping, credential replacements and other security issues [1]. Today, one among several biometric features, fingerprints is most commonly used for personal identification systems. One of the important tasks of Integrated Automated Fingerprint Identification Service (IAFIS) is to perform fingerprint recognition [2].

Fingerprint recognition system compares the features of two different fingerprint images. The comparison is based on the features of ridges, minutiae points that are unique within the fingerprint patterns [3]. Three basic patterns that are available in fingerprints are arch, loop and whorl [4]. The fingerprint recognition system takes fingerprint images as input, extracts minutiae points of interest from input images, compares the extracted information with the stored ones, and recognizes the persons. The capability of the fingerprint recognition system is purely dependent on the quality of input image supplied to the system both in storing information as well as comparing [5].

Because of faulty image acquisition devices, AC and DC inference, lighting conditions during image acquisition, dirts in the fingers, moisture, etc., fingerprint images contain noise[6]. Since the input image is of bad quality, fingerprint recognition systems fail to recognize correctly and sometimes it may recognize a wrong person. This situation leads to non-reliability over fingerprint recognition systems [7]. Hence it becomes necessary to remove the noise from the input fingerprint images before it is being supplied to the system.

Image enhancement is the process of increasing the overall visual effects of the image so that it can look better and fit for further processing. Image enhancement removes the underlying noise that prevails in the image and then, enhances the visual effects of the image. Image enhancement is a well studied research area. There are two ways by which image enhancement can be performed viz. spatial domain and frequency domain [8].

In the spatial domain, enhancements are performed directly on image pixels, whereas in frequency domain, Fourier transform of an image is generated, all the necessary operations are performed and inverse Fourier transformation is applied to get back the output image [9]. It

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is also possible to perform image enhancement on fingerprint images so that noise can be removed and ridges and valleys can be made more visible for accurate recognition.

Filtering techniques, as the name suggests, are used in the image enhancement process to filter the noise. It also emphasizes on low, high and directional frequency components of an image [10]. Hence this paper presents a fingerprint image enhancement technique using Gabor filters. The paper is designed as follows: Section1 provides the basis of biometric identification systems, fingerprint identification systems and need to enhance the fingerprint images. Related research works carried out by the researchers are presented in section 2 as a small literature survey. Section 3 introduces the concepts of filters and deep explanation about the Gabor filters in the later part of the section. Fixing the values for various parameters and conducting the experiments are all discussed in section 4 and the paper ends by providing the findings as conclusion in section 5.

2. Related Work

Cartesan Gottschlich [11] proposed curved Gabor filters for fingerprint image enhancement. Traditional Gabor filtering has been modified so that it can enhance curved structures in noisy image. The proposed method enhances the fingerprint image, smoothens the image without creating artifacts. Two orientation field estimation methods are combined to achieve robust estimation for noisy image. Curved regions are constructed using local orientation values, which is used for calculating local ridge frequency. Previously estimated orientations and ridge frequencies are used for enhancing the input images.

Sharat Chikkerur, et al., [12] proposed fingerprint enhancement technique using STFT analysis. Short Time Fourier Transform (STFT) is a well-known technique used to analyze non-stationery signals. This method considers all the features of the input image such as a foreground region mask, local ridge orientation and local ridge frequency. The algorithm needs less memory for computation against traditional Fourier domain filtering techniques. The proposed method is more robust and overall improvement of 24% is achieved.

Joseph Storm Bartunek, et al., [13] proposed adaptive fingerprint image enhancement with stress on the preprocessing of data. It is based on contextual filtering and it adjusts the filtering parameters based on the input image. It uses special preprocessing procedures to remove noise from input images, and then it calculates local and global values of the image. During preprocessing, non-linear dynamic range adjustment is used which yields improved and adaptive image preprocessing method.

Mustafa Salah Khalefa, et al., [14] proposed fingerprint image enhancement using developed Mehter technique. Mehter technique is the combination of block filtering, histogram equalization and high pass filtering methods. Usage of histogram equalization and high pass filter increases fingerprint image contrast, and this enhances the ridges. It also enhances the structures that get accurate directional element of each ridge. Usage of median filter in block filtering corrects wrong block direction and removes noise.

Mihir Sahasrabudhe [15] proposed fingerprint image enhancement using unsupervised hierarchical feature learning. The proposed work addresses two models. In the first model, continuous restricted Boltzmann machines are used to learn fingerprint orientation field patterns. This learning is used to correct noise and local ridge orientations. In the second model, 3-layered convolutional deep belief network that learns features directly from gray scale fingerprint images are used. This helps in identifying the noisy regions.

From the above short literature study, it is clear that enough work regarding the enhancement of fingerprint images has already been carried out.

3. Filters

Filters are mainly used in images to prevent high frequencies or low frequencies in the image [16]. Filters smoothen the image or enhances the edges in the image. Filters play a major role both in the frequency domain as well as in thee spatial domain [17]. Generally filters are of two types, low pass filters and high pass filters. Low pass filters are used to remove noise. Again low pass filters have two main types viz. reconstruction filter which restores the image after degradation process is over [18]. Enhancement filters tries to improve quality of the image for machine or human interpretability. Apart from these, we have mean filters, median filters, Gaussian filters, Gabor filters, conservative filters, frequency filters, Laplacian filters, unsharp filters, etc. [19].

3.1. Gabor Filters

Gabor filter-based features are widely used in many biometric systems like texture segmentation, face and handwriting recognition, and fingerprint enhancements. The frequency and orientation in Gabor filter are similar to human visual system [20]. It is an important tool used for texture analysis under spatial and frequency domains. The Gabor filter g(x,y) is given by equation (1):

$$g(x, y, \lambda, \theta, \Psi, \sigma, r) = \exp\left(-\frac{x'^2+r^2y'^2}{2\sigma^2}\right) \cos\left(2\pi\frac{x'}{\lambda} + \Psi\right) \tag{1}$$

Where x' = x cosθ + y sinθ and y'= -x sinθ + y cosθ. And also 'θ' is the orientation of the normal to the parallel stripes of the Gabor function, 'λ' is the wavelength of the sinusoidal factor, 'γ' is the spatial aspect ratio, 'σ' is the standard deviation of the Gaussian function used in Gabor filters, ' Ψ' represents the phase offset.

The standard deviation defines the size of the receptive field of Gaussian factor. The frequency value is found to be in the range 0.23 to 0.92. The half-response spatial frequency bandwidth and the ratio are given by equation (2):

$$h = \log_2 \frac{\frac{\sigma}{\lambda}\pi + \sqrt{\frac{\ln 2}{2}}}{\frac{\sigma}{\lambda}\pi - \sqrt{\frac{\ln 2}{2}}} \tag{2}$$

The sinusoidal parameter attenuates or rejects the frequencies that are higher than 'σ'. As local ridge structures have accurate frequency and orientation, the sinusoidal parameter can be set by the reciprocal average of the ridge distance. Hence λ can be set as λ=1/k or λ = ½ $\sqrt{2}$, where 'k' is the inter ridge distance.

If the sinusoidal parameter is too large, noise is generated in filtered image and ridges can be interlaced when the value is too small. The orientation is given as equation (3):

$$\theta_k = \frac{\pi(k-1)}{m} \tag{3}$$

Where 'm' is the number of Gabor directions and 'k' is the inter ridge distance. The standard deviation with respect to Gaussian width modulates the Gabor filter. If it is too small, the filter fails to remove the noise and ridge details are not captured if standard deviation is too big. Hence the standard deviation should be constantly fixed as 0.5.

4. Research Method

In the fingerprint images, appropriate grey levels are not present in ridges and valleys. Some regions are dark and some regions are more contrast in both ridges and valleys. Such fingerprint images are enhanced by setting values for parameters are follows:

Frequency =0.33, width=0.7, angle=0˚ and spatial window domain filter is in the range -15 to +15. The Figure 1 presents the enhanced image with xθ in the first term of the Gabor filter. But the valleys in the output image are lighter and ridges with less noise. The image still contains noise in the inclined and vertical ridges. By finding the orientation angle of the Gabor filter, such small regions are enhanced.

By changing the yθ in the first term of Gabor filter expression, filtering is applied on the input image. The output image is presented in Figure 2. The valleys are lighter and better defined. Ridges provide better definition for the indirect $\frac{\pi}{2}$ radians. By changing xθ in the Gabor expression and orientation angle as $\frac{\pi}{2}$ radians, experiment is continued. This results in darker ridges and lighter valleys. The riges in the output image presents better definition whereas horizontal and inclined ridges present lower quality.

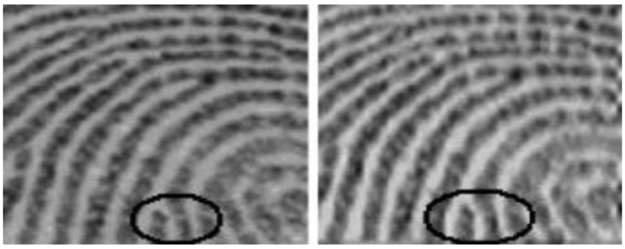

Figure 1. Original and filtered image with orientation angle as 0˚

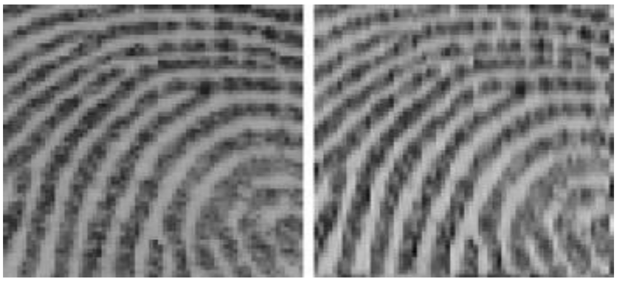

Figure 2. Original and filtered image with orientation angle as $\frac{\pi}{2}$

By changing orientation angle as $\frac{\pi}{4}$ radians, we continued our experiment. xθ is applied to the first term of Gabor expression and with same parameters, and a directional angle as $\frac{\pi}{4}$, filtering is applied on the input image. The output image is of good quality with ridges and valleys providing better definition. Change is made in the yθ component of first term of Gabor expression, with same parameters and a directional angle as $\frac{\pi}{4}$. The output image is same like the xθ component result, with reduced noise in ridges and valleys.

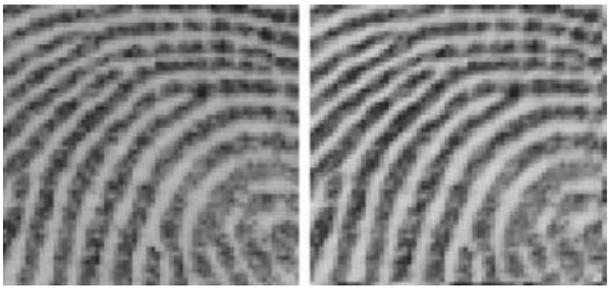

Figure 3. Original and filtered image with orientation angle as $\frac{\pi}{4}$

By having orientation angle as $\frac{3\pi}{4}$ radians, we continued our experiment and applied on xθ of the first term of Gabor expression. The gray levels of ridges and valleys exhibit a larger difference in the output image. But the inclined ridges of the image presents better definition. When we changed the yθ value of the first term of Gabor expression with $\frac{3\pi}{4}$ radians, the output image does not provide any better result in terms of ridges, valleys or noise reduction. The output image is depicted in Figure 4.

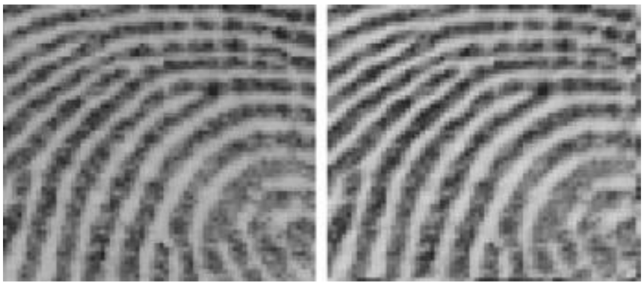

Figure 4. Original and filtered image with orientation angle as $\frac{3\pi}{4}$

Altering the directional angle and testing with different radian values gives better ridge definition and different gray levels for ridges and valleys. All the results obtained above are with parameter values frequency as 0.33, width as 0.8 and directional field from $\frac{\pi}{2}$, $\frac{\pi}{4}$ and $\frac{3\pi}{4}$.

Next, experiment is conducted on various different qualities of fingerprint images with fixed filtering parameters. A 256×256 size low quality input image, 128×128 size image, Gaussian width as 0.7, spatial window filter domains in the range +15 to -15, directional angle $\frac{3\pi}{4}$, frequency = 0.18 and inter ridge distance, k = 5.44. In the output image, it is observed that there is a reduction in noise. The ridges that are not located in $\frac{3\pi}{4}$ radians directional angle fails to reduce noise. Another test is made with 64×64 size partial image. All the filtering parameters used in the above two images were used except with k=3. The output image exhibits better definition with reduced noise in ridges. All the above experiments indicate that Gabor filter parameters can generate adequate results on each image region.

5. Conclusion

This paper provides a study on fingerprint image enhancement using Gabor filters. The study uses adaptive parameters viz. frequency, width and window domain filter range. The orientation angle alone is changed and applied to both $x\theta$ and $y\theta$ of the Gabor expression. With orientation field as 0 radians, output image is lighter, less noise. But image still contains noise in the inclined and vertical ridges. With orientation angle as $\frac{\pi}{2}$ radians, ridges are darker and valleys are lighter in output image. But horizontal and inclined ridges present lower quality. With orientation angle as $\frac{\pi}{4}$ as well as with $\frac{3\pi}{4}$ radians, experiments are performed. The experimental results show that $\frac{\pi}{4}$ radians as orientation angle along with adaptive parameters produce clearly visible, enhanced fingerprint image.

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