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Gabor Filter Based Finger Print Enhancement Techniques: A Comparative Study

R. Sivaranjani
Associate Professor, CSE Department
GMRIT
Rajam,India

Abstract: A critical stage in finger print based authentication is to automatically match the finger print by extracting the minutiae from the input fingerprint images. However, the performance of the minutiae extraction algorithm is heavily rely on the quality of the given finger print. In order to ensure that the performance of the automatic finger print authentication system will be robust with respect to the quality of the given input image. It is requisite to incorporate finger print enhancement techniques to improve the visibility of the ridges and valley present in the image. This paper concentrates on three different image enhancement filtering techniques namely Gabor filter, Log based Gabor filter and modified Gabor filter. We have tested all the three techniques by submitting different images, evaluated the performance by using PSNR and MSE. Experimental results show that MGF is having remarkable advantages over the LGF and GF.

Keywords: Log based Gabor Filter, Modified Gabor Filter, modified Gabor Filter

I. INTRODUCTION

Fingerprint analysis/ verification is being widely used in the person identification for the purpose of high degree of security system. However, some of the fingerprint images are having poor in quality, which will reduce the system performance or corrupts the accuracy of the fingerprint identification. Fingerprint image quality enhancement techniques are usually preferred, in order to improve the quality of the image. There have existed a variety of research activities along the stream of reducing noises and increasing the contrast between ridges and valleys in the gray-scale fingerprint images. Image enhancement approaches are implemented in spatial domain, and in frequency domain. In 1998 O'Gorman and Nickerson and in 1993 Mehre proposed an image enhancement technique based on directional filters. In 1994 an algorithm based on non-stationary directional Fourier domain filtering is proposed by B. G. Sherlock et al. Willis and Myers (2000) and Kamei and Mizoguchi (1995) denoised fingerprint images in frequency domain. S.Greenberg et al. [11] has proposed fingerprint image enhancement using local histogram equalization, Wiener filtering, and image binarization. Later another method is carried out by a unique anisotropic filter for gray scale image enhancement. In 1998, Hong et al. had used Gabor filter banks to enhance fingerprint images and reported to achieve good performance. Kim et al. [2] presented an improved algorithm for enhancement of fingerprint image on the basis of the image normalization and Gabor Filter. Firstly, the adaptive normalization, based on block processing is suggested for improvement of fingerprint images. There are advantages and disadvantages of analysis merely in spatial domain or frequency domain. In 2000 Almansa and Linderberg proposed a Fingerprint enhancement by shape adaptation of scale-space operators with automatic scale selection. Later Jianwei Yang et al. proposed a modified Gabor filter based finger print enhancement technique. An integration of Anisotropic Filter and directional median filter (DMF) based finger print. Adaptive Fingerprint Binarization by Frequency Domain Analysis is proposed by J. Strom Bartunek, M. Nilsson, J. Nordberg and I. Claesson in 2006. Sepasian et al. [10] presented a method to investigate the performance of a three-step procedure for the fingerprint enhancement, Using CLAHE (contrast limited adaptive histogram equalization) together with Clip Limit, standard deviation and sliding neighborhood as stages during processing of the fingerprint image. Jun-tao et al. [16] proposed an enhancement algorithm based on edge filter and Gabor filter, where a gray based algorithm is used in enhancing the edge and segment of an image. Yoon et al. [13] proposed a latent fingerprint enhancement algorithm which requires manually marked region of interest (ROI) and singular points. K. Srinivasan et al. [8] developed an efficient fingerprint enhancement technique via fuzzy based filtering, also employed a fuzzy modeling approach for removing the noise as well as for improving the luminosity of the ridges. I.G. Babatunde et al. [9] modified some of the sub models of an existing mathematical algorithm for the fingerprint image enhancement to obtain new and improved versions. The new versions consist of different mathematical models for fingerprint image segmentation, normalization, ridge orientation estimation, ridge frequency estimation, Gabor filtering, binarization and thinning. This paper is mainly concentrates on various filtering approaches like Gabor, modified Gabor and log based Gabor approaches, which were used in finger print image enhancement.

Organization of this paper is as follows: section 2 describes various phases in image enhancement process. Technical analysis of Image filtering using Gabor, modified Gabor and log based Gabor is explained in section 3. Experimental results and its performance are compared in section 4. Finally, the summary of the present work is in section 5.

II. FINGERPRINT ENHANCEMENT

A finger print enhancement technique receives a fingerprint image as an input, applies some set of intermediate steps on the received image and produces enhanced image as an output. Figure 1 shows the intermediate phases used in the image enhancement algorithm. Detailed description of individual phases is described in the next coming sections.

a) Normalization:

Normalization procedure normalizes the image global statistics, by reducing each image to a fixed mean and variance. Although the pixel wise operation does not change the ridge structure, the brightness and contrast of the image will change as a result. Let $\mathcal{I}(i, j)$ denote the gray-level value at pixel(i, j), M and VAR denote the estimated mean and variance of $\mathcal{I}$, respectively, and $\mathcal{G}(i, j)$ denote the normalized gray-level value at pixel (i, j). The image normalization is defined as follows:

$$\mathcal{G}(i, j) = M_0 + \sqrt{\frac{VAR_0\,(\mathcal{I}(i,j)-M)^2}{VAR}} \quad \text{if } \mathcal{I}(i, j) > M \qquad \text{---------------------------(1)}$$

$$= M_0 - \sqrt{\frac{VAR_0\,(\mathcal{I}(i,j)-M)^2}{VAR}} \quad \text{otherwise} \qquad \text{---------------------------(2)}$$

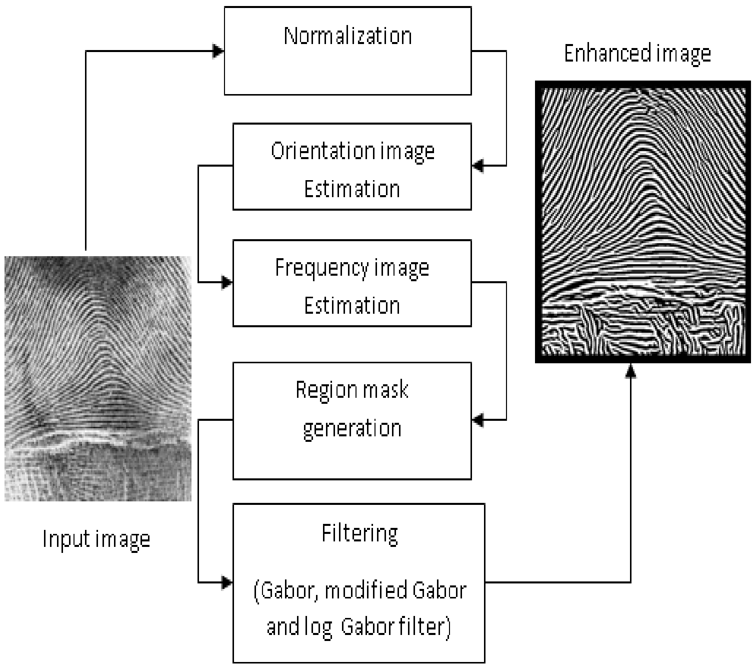

Figure 1: Fingerprint Enhancement algorithm flowchart

2.1 The main steps of the algorithm include:

$$M(I)=\frac{1}{N^2}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} I(i,j) \qquad \text{---(3)}$$

$$VAR(I)=\frac{1}{N^2}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(I(i,j)-M(I))^2 \qquad \text{---(4)}$$

Where

M(I)=mean of the image

VAR(I)=variance of the image

M_0 and VAR_0 = the craved mean and variance values respectively. Figure 2(b) shows the example of normalization:

b) Orientation Image Estimation:

The orientation image algorithm determines the dominant direction of the ridges in different parts of the normalized finger print image. This phase is the critical phase, errors occurred in this step will be carried to next phase and then propagated to the filtering stages. So many, methods have been proposed to estimate the orientation field of the finger print, but we have used the least mean square orientation estimation algorithm. For the given normalized image $\mathcal{G}$, the algorithm for orientation image estimation [28], [29], [30], [31] is as follows:

Step 1: Divide the normalized image $\mathcal{G}$ into blocks of size wxw(8x8)

Step 2: compute the horizontal and vertical gradients *Gx(x, y)* and *Gy(x, y)*, respectively, are computed using simple gradient operators such as a Sobel mask [2]. Estimate the block orientation $\theta$of each block centered at pixel (i,j) is obtained using the following equations:

$$G_{xx}= \sum_{u \epsilon w}\sum_{v \epsilon w} 2G^2{}_x(u,v)G^2{}_y(u,v) \qquad \text{---(5)}$$

$$G_{yy}= \sum_{u \epsilon w}\sum_{v \epsilon w} 2G_x(u,v)G_y(u,v) \qquad \text{---(6)}$$

$$\theta = \frac{1}{2}tan^{-1}\frac{G_{yy}}{G_{xx}} \qquad \text{---(7)}$$

Due to presence of noise, corrupted image and valley structures, minutiae in the normalized image, the estimated θ may not be good or correct. Since the local ridge orientation is not correct, a low-pass filter can be used to correct or modify the incorrect local ridge orientation. In order to perform the low-pass filtering, the orientation image needs to be converted into continuous vector field, which is defined as follows:

$\emptyset_x(i,j)=\cos(2\theta(i,j))$ and $\emptyset_y(i,j)=\sin(2\theta(i,j))$,

where $\emptyset_x$= x component of the vector field and $\emptyset_y$= y component of the vector field.

With this result $\emptyset_x$ and $\emptyset_y$, the low-pass filtering can then be performed as follows:

$\theta'(i,j)=\frac{1}{2}tan^{-1}\{\frac{G(x,y)*\emptyset_y(i,j)}{G(x,y)*\emptyset_x(i,j)}\}$, here G(x,y) Gaussian smoothening function

c) Frequency image Estimation:

Ridge frequency is the other intrinsic property of the finger print, which is a slowly varying property and hence it is computed only once for non-overlapped block of image. Ridge frequency is estimated based on the projection sum taken along a line oriented orthogonal to the ridges or by varying the gray levels in the window oriented orthogonal to the ridge flow . Let $\mathcal{G}$ be the normalized image and O be the orientation image, then the algorithm for ridge frequency estimation is as follows:

Step 1: Divide the normalized image $\mathcal{G}$ into blocks of size wxw(8x8)

Step 2: For each block centered at the pixel (i,j), compute an oriented window of size lxw(16x8).

Step 3: for each block centered at pixel(i,j) compute the x-signature x[0],x[1],---,x[l-1] of the ridges and valleys within the oriented window.

$X[k]=\frac{1}{w}\sum_{d=0}^{w-1}\mathcal{G}(u,v)$ for k=0,1,---,l-1 ---------------------(8)

Where $u=i+(d-\frac{w}{2})\cos O(i,j) +(k - \frac{l}{2}) \sin O(i,j)$

$v= j+(d-\frac{w}{2})\sin O(i,j) +(k - \frac{l}{2}) \cos O(i,j)$

If no minutiae and singular points appear in the oriented window and the x-signature forms a discrete sinusoidal shape then it has the same frequency as that of the ridges and valleys in the oriented window. Let τ(i,j) be the average number of pixels between two peaks in x-signature, then the frequency is computed as $\Omega(i,j)=1/\tau(i,j)$. The frequency value -1 is assigned when no consecutive peaks can be detected from the x-signature. For a fingerprint scanning at a fixed resolution the frequency of the ridges and valleys in the local neighborhood lies in a certain range. For an image with 500dpi, the range is [1/3,1/25]. Therefore, if any estimated frequency is out of this range then the values of -1 is assigned to indicate a valid frequency cannot be obtained.

Step 4: The block where the minutiae and singular points appear and ridges and valleys are corrupted which does not form the well defined sinusoidal wave, then the frequencies for these blocks need to be interpolated from the frequency of the neighboring blocks which have a well defined frequency. The interpolation process formula is as follows:

i. **For each and every block centered at (i,j)**

$\Omega^1(i,j)= -1$ if $\Omega(i,j)=-1$ --------------------------(9)

$=\frac{\sum_{u=-w_{\Omega/2}}^{w_{\Omega/2}}\sum_{v=-w_{\Omega/2}}^{w_{\Omega/2}} w_g(u,v)\mu(\Omega(i-uw,j-vw))}{\sum_{u=-w_{\Omega/2}}^{w_{\Omega/2}}\sum_{v=-w_{\Omega/2}}^{w_{\Omega/2}} w_g(u,v)\delta(\Omega(i-uw,j-vw)+1)}$ otherwise ------------------------(10)

Where w_g= discrete Gaussian kernel with mean and variance of zero and nine

w_Ω = size of the kernel with value 7.

$$\mu(x) = \begin{cases} 0 & if\ x \le 0 \\ x & otherwise \end{cases}$$

$$\delta(x) = \begin{cases} 0 & if\ x \le 0 \\ 1 & otherwise \end{cases}$$

ii. **Swap Ω^1 and Ω if there exists at least one block having the frequency value of -1 and go to step (i).**

Step 5: An interridge distances can change slowly in a local neighborhood, a lowpass filter can be utilized to remove the outliers in f^1.

$F(i,j)= \sum_{u=-w_{\Omega/2}}^{w_{l/2}}\sum_{v=-w_{\Omega/2}}^{w_{l/2}} W_1(u,v)\mu(\Omega^1(i-uw,j-vw))$ -----------------------(11)

Where W_1= two dimensional lowpass filter with unit integral

w_l=size of the filter , value of 7 is assigned.

d) Region mask:

A pixel in the image could be present in recoverable or non recoverable region. The categorization of recoverable and non recoverable pixels in the given input image can be performed based on the assessment of the shape of the wave formed by the local ridges and valleys present on the finger print. Three features amplitude(α), frequency(β) and variance (γ) were considered in our algorithm to characterize the sinusoidal shaped wave. Let (i,j) be the block foe the block considered with the pixels X[1],X[2],---,X[n], the three features corresponding to the pixel(i,j) is calculated as follows:

a. α = average height of the peaks - average depth of the valleys.

b. $\beta = 1/T(i,j)$, where $T(i,j)$ is the average number of pixels between two consecutive peaks.

c. $\gamma = \frac{1}{n}\sum_{i=1}^{n}(X[i] - (\frac{1}{n}\sum_{i=1}^{n}(X[i]))^2$ -----------------------(12)

If a block centered at (i,j) is placed in the recoverable region then R(i,j)=1, otherwise R(i,j)=0. After processing the entire image the percentage of the recoverable regions are computed. If the percentage of recoverable region is lesser than specified threshold then the finger print image is rejected. An accepted image is passed to the filtering phase.

e) Filtering:

A fingerprint image with well defined frequency and orientation will provide a useful information, helps in taking out undesired noise from the image. The sinusoidal waves of ridge and valleys will vary slowly in a local constant orientation. Therefore a bandpass filter is tuned in such way that, it removes the undesired noise and preserves the accurate ridge and valley structures. Gabor filters are having both frequency selective and orientation selective properties and also having optimal joint resolution in special and frequency domains[32][33]. Therefore, Gabor filters are the appropriate filters to remove noise from the image to preserve the clear ridge and valley structures. Detailed description of the various Gabor filters will be discussed in the next section. Figure 2 shows the all the phases results we obtained on the taken image finger.jpg.

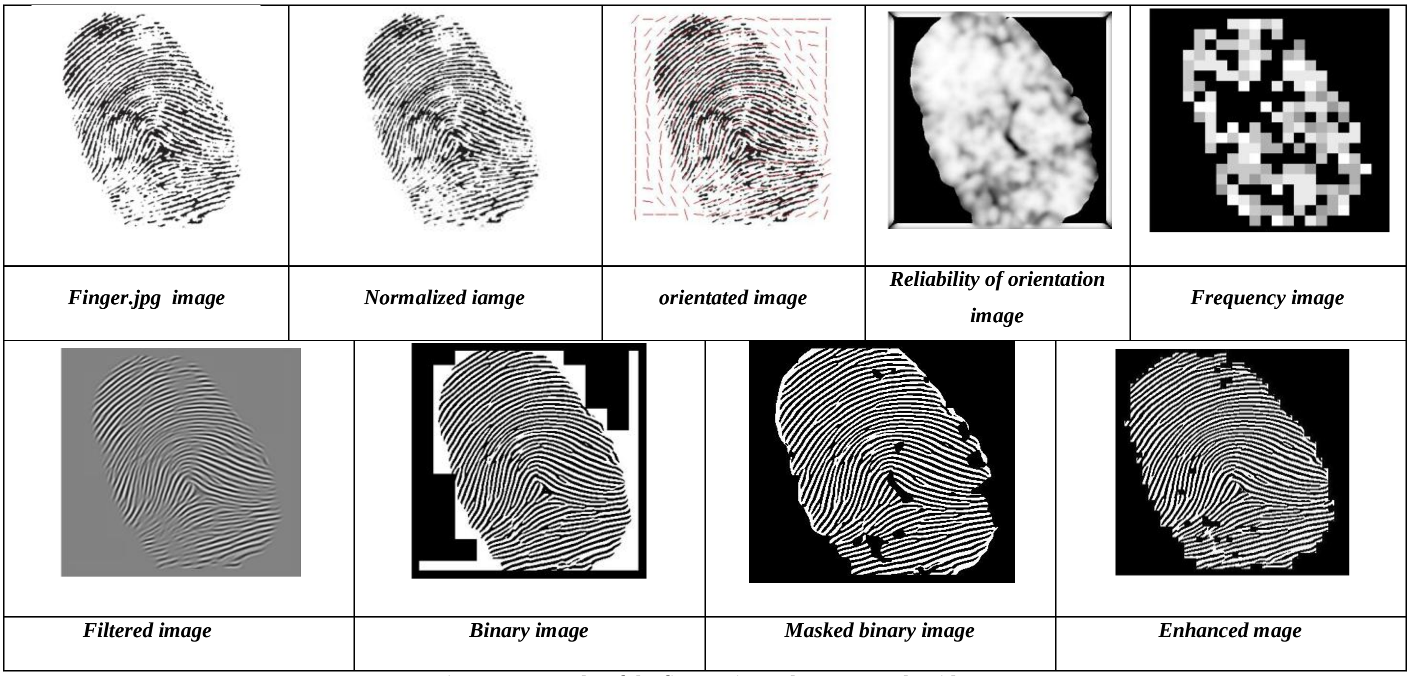

Figure 2: Results of the fingerprint enhancement algorithm

III. TECHNICAL DESCRIPTION

The motto of fingerprint enhancement algorithms is to improve the quality of the blur image, indirectly it will improve the clarity of ridges and valleys of the input fingerprint image. The ultimate criteria for assessing the performance of an algorithm are the total amount of quality improvement in the image after applying the algorithm. Such improvement can also be assessed subjectively by the visual appearance of the resulted enhanced image. However, a consistent characterization of the quality improvement is beyond the capability of the subjective evaluation. A goal-directed performance evaluation assesses the overall improvement in the system performance that incorporates the enhancement module as a component. Therefore, it is capable of providing a more reliable assessment of the performance benchmark and is directly associated with the ultimate goal of the system [22]. In the following, we present the results of Gabor, modified Gabor and Log based Gabor algorithms performances.

A. Gabor filter: Gabor filter function is an useful function in computer vision and image processing especially for texture analysis, due to optimal localization properties in frequency and special domain. In 1946 Gabor proposed a 1-D Gabor function, after words in 1980 a family of 2-D Gabor filters were proposed by Daugman as a framework for understanding the orientation and frequency selective neurons in the brain and further elaborated mathematically in 1985. The 2-D Gabor function composed of a sinusoidal plane of particular frequency and orientation within the Gabor envelope. A complex 2-D Gabor filter over the image domain (x,y) is defined as

$$G(x,y)=\exp(-\frac{(x-x_0)^2}{2{\sigma_x}^2}-\frac{(y-y_0)^2}{2{\sigma_y}^2})*\exp(-2\pi i(u_0(x-x_0)+v_0(y-y_0))) \quad \text{------------------------(13)}$$

Where

(x_0, y_0) = location in the image

(u_0, v_0)= modulation that has spatial frequency ω_0 =sqrt(${u_0}^2$+${v_o}^2$)

σ_x =standard deviation of 2-D Gaussian function along the x-axis

σ_y =standard deviation of 2-D Gaussian function along the y-axis

Figure 3 shows the results of the fingerprint images using Gabor filtering for different values of lambda and sigma. The even symmetric general form of Gabor filter is given as

$$g(x,y,\emptyset,f)=\exp\{-\frac{1}{2}\left[\frac{x_\emptyset^2}{\delta_x^2}+\frac{y_\emptyset^2}{\delta_y^2}\right]\} \cos(2\Pi f x_\emptyset) \quad \text{-------------------(14)}$$

$$x_\emptyset = x\cos\emptyset + y\sin\emptyset \quad \text{-------------------(15)}$$

$$y_\emptyset = -x\sin\emptyset + y\cos\emptyset \quad \text{-------------------(16)}$$

Where ∅= orientation of the Gabor filter

f= frequency of the sinusoidal plane wave

δ_x and δ_y= sapce constants of the Gaussian envelope along x and y axes respectively.

Figure 5(a) shows the even symmetric general form of the Gabor filter.

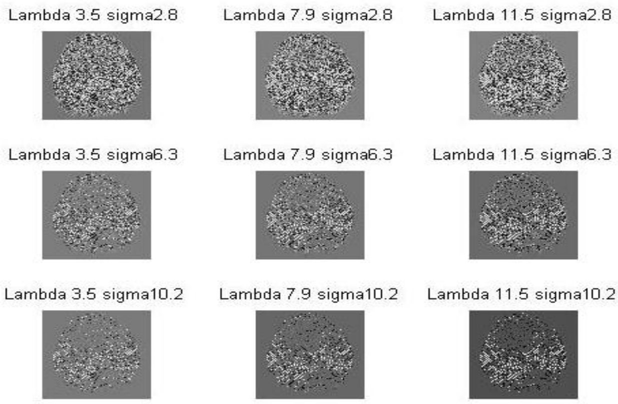

Figure 3: Gabor filter based fingerprint enhancemnet results coreresponding to different values of lambda and sigma

B. Modified Gabor filter: The drawback with Gabor filter is, it cannot pass entire harmonics except the signal with particular frequency. However, the low frequency components usually carry useful texture information like, slow variation in intensities near the ridge centers is represented with low frequency component, in turn lose the useful information. To overcome this drawback modified Gabor filter functions was proposed. Modified Gabor filter is a periodic function incorporating two different periodic functions T_1 and T_2. A modified Gabor function $F(x; T_1, T_2)$ comprises of two parts one is a cosine functional curve with a period T_1 above the x-axis and the other is a cosine functional curve with a period T_2 below the x-axis. The elaborated mathematical representation of modified Gabor filter is given as follows:

$$F(x; T_1, T_2)=f(x-\left\lfloor \frac{x}{(\frac{T_1}{2}+\frac{T_2}{2})} \right\rfloor * (\frac{T_1}{2}+\frac{T_2}{2})) \qquad \text{--------------------(17)}$$

From the above equation, $F(x; T_1, T_2)$ is a periodic even symmetric oscillator with the period $(\frac{T_1+T_2}{2})$, became a true cosinusoidal function when T_1=T_2. Now this can be extended into 2-D Gaussian function, then the formula (14) is changed into

$$g^1(x,y; T_1, T_2, \emptyset)=h^1{}_x(x,y; T_1, T_2, \emptyset)* h^1{}_y(y; \emptyset) \qquad \text{--------------------(18)}$$

$$=\{\exp(- -\frac{x^2{}_\emptyset}{2\sigma^2{}_x})F(x; T_1, T_2)\}.\{\exp(- -\frac{y^2{}_\emptyset}{2\sigma^2{}_y})\}$$

$$=\{\exp(-\frac{x^2{}_\emptyset}{2\sigma^2{}_x}).f(x-\left\lfloor \frac{x}{(\frac{T_1}{2}+\frac{T_2}{2})} \right\rfloor * (\frac{T_1}{2}+\frac{T_2}{2}))\}.\{\exp(-\frac{y^2{}_\emptyset}{2\sigma^2{}_y})\}$$

Where $\emptyset$=orientation value

σ_x =standard deviation of 2-D Gaussian function along the x-axis

σ_y =standard deviation of 2-D Gaussian function along the y-axis

$\lfloor t \rfloor$=floor(t) means the largest integer not greater than t.

$$f(x)=\begin{cases} \cos\left(\frac{2\pi x}{T_1}\right) & 0 \le x \le \frac{T_1}{4} \\ -\cos\left(\frac{2\pi x-\frac{T_1}{4}-\frac{T_2}{4}}{T_2}\right) & \frac{T_1}{4} < x < \frac{T_1}{4}+\frac{T_2}{2} \\ \cos\left(\frac{2\pi x-\frac{T_1}{2}-\frac{T_2}{2}}{T_1}\right) & \frac{T_1}{4}+\frac{T_2}{2} \le x \le \frac{T_1}{4}+\frac{T_2}{2} \end{cases} \qquad \text{------------------(19)}$$

Figure 5(c) shows the even symmetric general form of the Modified Gabor filter of equation (18)

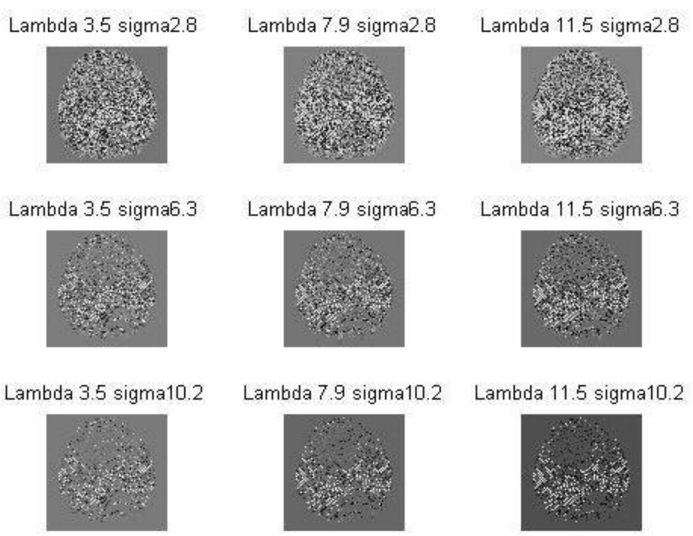

Figure 4: Modified Gabor filter based fingerprint enhancemnet results coreresponding to different values of lambda and sigma

C.Log Gabor filter: Like Gabor filter: Log Gabor filter will be used to encode the images. The formula for 1-D Log Gabor filter function is given as:

$$G(f)= \exp\left(\frac{-log\left(\frac{f}{f_0}\right)^2}{2log\left(\frac{\sigma}{f_0}\right)^2}\right), \qquad \text{--------------------(20)}$$

where f_0=center frequency and σ= bandwidth of the filter

The 1-D log Gabor filter is extended to 2-D, with this the filter is not only designed for the frequency , it is designed for a particular orientation. The orientation according to the angle in polar coordinates is given as :

$$G(f, \theta)= \exp\left(\frac{-log\left(\frac{f}{f_0}\right)^2}{2log\left(\frac{\sigma_f}{f_0}\right)^2}\right).\exp\left(\frac{(\theta-\theta_0)^2}{2\sigma^2{}_\theta}\right) \qquad \text{------------------(21)}$$

Where σ_f = width parameter for the frequency

θ_0= center frequency

σ_θ= width parameter of orientation

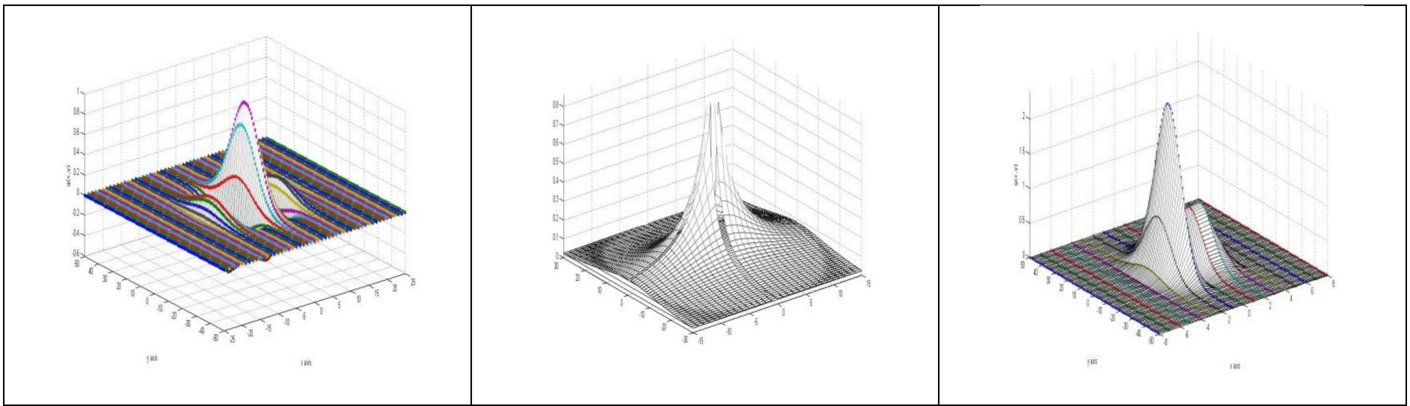

Figure 5: (a) Gabor filter	*(b) Log Gabor filter*	*(c) Modified Gabor filter*

Another form of the Log Gabor filter function is viewed on logarithmic frequency scale. On the linear frequency scale the Log-Gabor function has the transfer function in the form

$$G(w)=e^{\frac{\left(-\log\left(\frac{w}{w_0}\right)^2\right)}{2\log\left(\frac{k}{w_0}\right)^2}} \qquad \text{-----------------------(22)}$$

Where w_0=the filter's centre frequency.

Figure 5 (b) shows the log Gabor filter form of the equation.

IV. Experimentation Results

The performance of all the three approaches is compared by using some fingerprint images collected from the database bank. Figure 6 shows the sample images taken as the input for performing the analysis. Table 1 shows the computation time of all the phases in image enhancement in seconds. Table 2 shows the computation time of Gabor, modified Gabor and log-Gabor filtering techniques in seconds. The next, Table 3 shows the

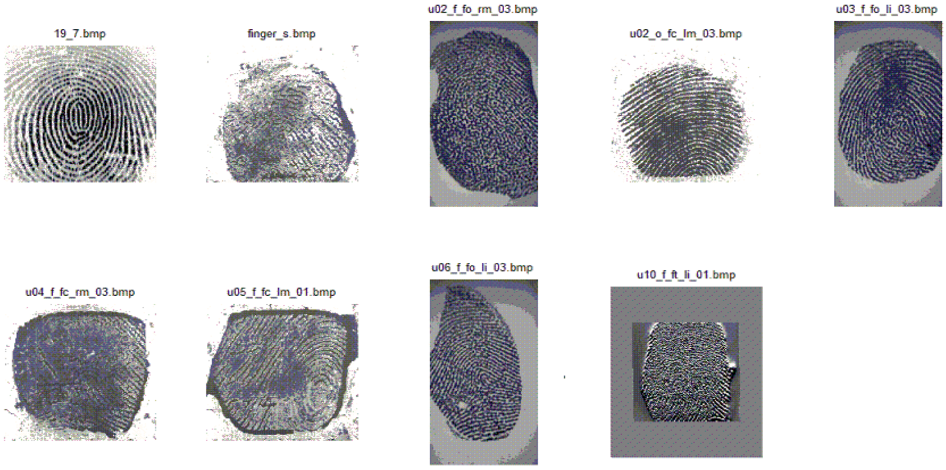

Figure 6: Sample Images

Table 1: Fingerprint enhancement phases computation time

Figure Name	Size	normalization	Orientation	Ridge frequency	Ridge masking
19_7.bmp	256X256	0.3297	1.9562	1.4407	8.5581e-004
finger_s.bmp	300X300	0.1132	0.3219	0.3505	4.3520e-004
u02_f_fo_rm_03.bmp	296X560	0.2226	3.5678	1.7125	0.0019
u02_o_fc_lm_03.bmp	300X300	0.1086	0.3255	0.3597	4.5263e-004
u03_f_fo_li_03.bmp	296X560	0.2435	1.7987	1.0002	8.6757e-004

Table 2: Computation time of filtering phase

Figure Name	Gabor Filter	Modified Gabor	Log Gabor Filter
19_7.bmp	22.5205	1.1289	1.1850
finger_s.bmp	6.5863	0.5404	0.3423
u02_f_fo_rm_03.bmp	8.2238	0.3468	1.3890
u02_o_fc_lm_03.bmp	8.0103	0.3433	0.5017
u03_f_fo_li_03.bmp	6.6424	0.3452	1.4042

Table 3: MSE and PSNR values of Filtering phase

	GF		MGF		LGF	
Figure Name	MSE	PSNR(DB)	MSE	PSNR(DB)	MSE	PSNR(DB)
19_7.bmp	100.84	28.128272	0.39	52.2545882	210.05	24.941519
finger_s.bmp	95.01	28.387207	0.51	51.0844431	207.58	24.9928486
u02_f_fo_rm_03.bmp	96.12	28.336515	0.62	50.2631026	215.28	24.8347956
u02_o_fc_lm_03.bmp	99.01	28.207952	0.43	51.8419667	211.50	24.9117918
u03_f_fo_li_03.bmp	83.87	28.928706	1.06	47.9250446	217.09	24.7983550

GF: Gabor Filter MGF: Modified Gabor Filter LGF: Log Based Gabor Filter

V. CONCLUSION

We have adapted three fingerprint enhancement algorithms which can adaptively improve the clarity of ridge and valley structures based on the orientation of the local ridge and estimated frequency from the inputted image. The performance of these algorithms was evaluated based on the PSNR and MSE of the considered algorithms. Experimental results shows that the modified Gabor filter will do better enhancement than the remaining two algorithms. This algorithm identifies an uncoverable corrupts regions in the fingerprint and removes them from further processing. This is the important property because such regions will be seen in some of the corrupted fingerprint images and they are extremely harmful to minutiae extraction. This property suggests that our enhancement algorithm should be integrated into an online fingerprint authentication identification and verification system.

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