

## A Novel Hybrid Gabor Filter Based On Automatic Wavelet Selection With Application To Fingerprint Enhancement

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### Abstract

*For decades, Image enhancement techniques have been pushing the envelope of image processing applications. The aim of image enhancement is to recover the information perception contained in the image for human eyes besides delivering the best input for image processing systems. Fingerprint system is one of the most popular image processing system, The performance of any fingerprint system highly depends on the fingerprint image quality; therefore, fingerprint image enhancement is an essential stage in fingerprint systems. Gabor filtering has been widely used to facilitate various fingerprint applications. Meanwhile, enhancement using Gabor filter still has several drawbacks.*

*In the present enhancement approach, we propose an active hybrid contextual module used for image enhancement. In order to prove the efficiency and effectiveness the proposed algorithm applied to fingerprint image. The proposed filter methodology includes eight stages, each one designed for a particular image defect, which can much improve the clarity and continuity of ridge structures, link broken ridges and reduce the false minutia. The experimental results show that the enhanced image quality by using our algorithm has higher performance, robustness and versatility. Presented approach might be useful for many applications related to digital image processing, computer vision.*

**Keywords:** *Image Enhancement, Wavelet Transform, Wavelet Basis, Gabor Filter, Fingerprint Recognition*

### 1. Introduction

Image enhancement is a process which changes the pixel's intensity of the input image so as to make the output image looks better. Contrast enhancement of an image is an important challenge in the field of digital image processing which is well-defined as the ratio between the brightest and the darkest pixel intensities of an image. There are several descriptions for an image to have poor contrast: due to the poor quality of the used imaging device. As a result, such images may not expose all the details in the captured scene [1]. Biometric technologies are playing a vital role to provide highly secure identification and personal verification methods. Fingerprint recognition is one of the most popular and reliable biometric techniques because it holds many desirable features such as universality, permanence, collectability, and distinctiveness. Fingerprint image quality is a vital issue to measure the performance of fingerprint identification system. So quality assessment of fingerprint data leads to identify the fingerprints in a better way [2]. Wavelet Transform uses multi-resolution technique by which different frequencies are

analyzed with different resolutions. Wavelet transform have been widely applied in image processing and pattern recognition [3].

Hong *et al.* use Gabor filter as bandpass filters to remove the noise and prevent true ridge/valley structures [4]. Like other contextual filter their characteristics adapted depending on the local context. Contextual filters are designed to make ridges clearly differentiated from each other, they also connect broken ridges, Fill pores and remove noise and dust, these filters provide a low pass along the ridge direction in order to link small ridge gabs and reduce some pores and noise, and these filters perform band-pass in the direction orthogonal to the ridges in order to separate ridges from each other.

This paper classified as the following: Section 2 we'll introduce Gabor filter and Variety of modified filtering technologies used for fingerprint enhancement, rather than review its main disadvantages. Section 3 discusses wavelets transform and its application. Section 4 explained our proposed method with all the stages involved. The experimental results are presented in Section 5. Finally, Section 6 concludes the paper.

## 2. Related Works

Gabor filter have optimal joint resolution in both spatial and frequency domains. The Gabor-based enhancement algorithm focuses on the characteristic of local ridge orientation and frequency simultaneity in spatial domain for improving the quality of the fingerprint image, but the estimation of local ridge orientation is often affected by noise, so the orientation estimated is not reliable in over/under inking regions [4]. Gabor wavelet has good time-frequency resolution characteristic, which is suitable for image processing and pattern recognition [5].

A Variety of contextual filtering approaches used for fingerprint enhancement, Since Lin Hong *et al.* [4] Proposes a Gabor filter for fingerprint image enhancement. Yang *et al.* [6] Propose a novel filter design method for fingerprint image enhancement. They develop an improved version of the traditional Gabor filter (TGF), called the modified Gabor filter (MGF). Its parameter selection scheme is image-independent. Kim *et al.* [7], Zhu *et al.* [8], Greenberg *et al.* [9] And Yin *et al.* [10] offer a Gabor filter with orientation and frequency parameters. The fingerprint image is enhanced by adjusting the local orientation and frequency parameters. Hsieh *et al.* [11] use algorithm based on the multiresolution analysis of global texture and local orientation by the wavelet transforms; they combine the texture unit of global information with the ridge orientation of local information. Zehang Sun [12] *et al.* Propose an optimal Gabor filter based on genetic algorithms (GAs). Chen *et al.* [13] enhance a binary fingerprint image with Gabor filter. Because the binary image has less information than the gray image, the method has some limitations. Zhu *et al.* [14] give a circular Gabor filter with average frequency. Chen *et al.* [15] give a fast Gabor filter. The equations of the 2D Gabor filter in the space domain are as follows:

$$G(x, y) = g(x, y) \cdot s(x, y) \quad (1)$$

$$g(x, y) = e^{-\pi[(x-x_0)^2/a^2+(y-y_0)^2/b^2]} \quad (2)$$

$$s(x, y) = e^{-2\pi i[u_0(x-x_0)+v_0(y-y_0)]} \quad (3)$$

Where  $g(x, y)$  is a two-dimensional Gaussian function,  $s(x, y)$  is a complex sinusoidal function.  $(x_0, y_0)$  represents the position of Gaussian window center,  $a$  and  $b$  control the width and length of the Gaussian window.  $(u_0, v_0)$  defines the frequency  $((u_0^2+v_0^2)^{1/2})$  and direction ( $\arctan(v_0/u_0)$ ) of the modulation. The output of a contextual fingerprint enhancement can be a gray-scale, near-binary, or binary image depending on the filter parameters chosen.

The main drawbacks of (Gabor filter) are:

- a. Bad enhancement quality when fingerprint image have a low contrast or high contrast.
- b. False estimate of local ridge direction will lead to poor enhancement.
- c. Does not handle high curvature regions well due to block wise approach.
- d. Fail when image regions are contaminated with heavy noises.

### 3. Wavelet Transforms

Wavelet Transform uses multi-resolution technique by which different frequencies are analyzed with different resolutions. Wavelet transform have been widely applied in image processing and pattern recognition, The Discrete Wavelet Transform (DWT) decomposes an input image into multiple subbands [15]. In the image processing field, there are two kinds of discrete wavelet transform (DWTs) and they are orthogonal wavelet and compact supported wavelet.

The orthogonality can provide the convenience in computations. A wavelet filter with compact support is non-zero only in a finite interval and the compact support decides the filter width. A wavelet vector  $\{g_l : l= 0, \dots, L - 1\}$  with length  $L$  should have three basic properties [16-17]:

$$\sum_{l=0}^{L-1} g_l = 0 \tag{4a}$$

$$\sum_{l=0}^{L-1} g_l^2 = 1 \tag{4b}$$

$$\sum_{l=0}^{L-1} g_l g_{l+2n} = \sum_{l=-\infty}^{\infty} g_l g_{l+2n} = 0 \tag{4c}$$

For all nonzero integer ,  $g_0 \neq 0$  and  $g_{L-1} \neq 0$ . Figure. 1 shows an image and its wavelet transform with both orthogonality and compact support.



**Figure 1. Fingerprint Image and Wavelet Decomposition**

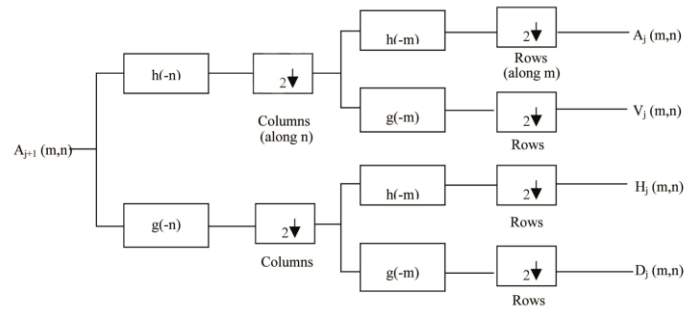
After the wavelet transform is applied to an image, the bellow four functions  $\phi(x, y)$ ,  $\psi^V(x, y)$ ,  $\psi^H(x, y)$  and  $\psi^D(x, y)$  will be generated:

$$\begin{aligned} \phi(x, y) \\ = \phi(x), \phi(y) \end{aligned} \tag{5}$$

$$\begin{aligned} \psi^V(x, y) &= \phi(x), \psi(y) \\ \psi^H(x, y) &= \psi(x), \phi(y) \end{aligned} \tag{6}$$

$$\psi^D(x, y) = \psi(x), \psi(y)$$

They are denoted by functions  $A$ ,  $V$ ,  $H$ , and  $D$ , where; Function  $A$  is the trend of the image, and functions  $V$ ,  $H$ , and  $D$  measure the fluctuations along the horizontal, vertical and diagonal directions. The image ( $m \times n$ ) decomposing by Two-dimensional fast wavelet transform (FWT2) from level  $j+1$  to level  $j$  is shown in Figure 2 [16].



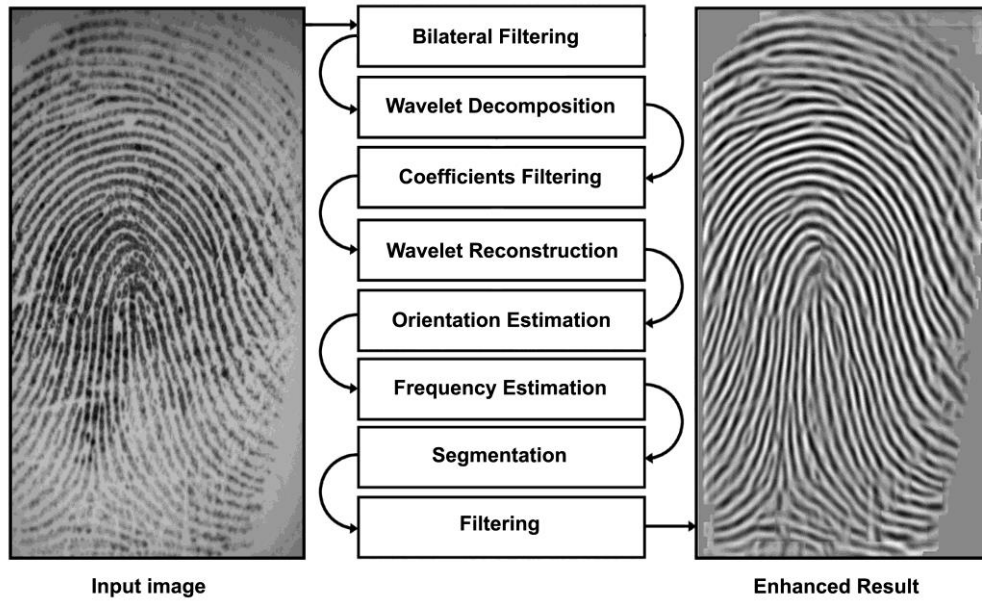
**Figure 2. Decomposition of the Two-dimensional Fast Wavelet Transforms**

#### 4. Proposed Method

Fingerprint identification is most important identification method in different fields such as employee identification, physical access control, commercial application, information system security. A robust enhancement algorithm is necessary for constructing an effective fingerprint identification system. Unfortunately, the fingerprint images are not always provided with good quality due to skin conditions (wet or dry, cuts, and bruises), sensor noise, incorrect finger pressure, and worn-off ridges fingers (elderly people, manual workers), etc. We developed a novel approach for automatic selection wavelet bases for fingerprint image enhancement.

Our proposed hybrid Gabor enhancement method is designed to fix the main problems with contextual filters (check Section 2) moreover, it's handling the Contrast and Brightness enhancement where the input fingerprint image is normalized. Wavelet transform gives attention to the features both in the space domain and frequency domain. Our algorithm involved the following steps:

- 1- **Bilateral Filtering:** this step presented a bilateral filter to blur input fingerprint image while respecting strong edges.
- 2- **Wavelet Decomposition:** choose a specific wavelet transform to convert the fingerprint image and obtain wavelet coefficients.
- 3- **Coefficients Filtering:** here we propose a novel filter to adjust the wavelet coefficients.
- 4- **Wavelet Reconstruction:** in this step we reconstruct wavelet transforms to map the result.
- 5- **Orientation Estimation:** determines the dominant direction of the ridges in different parts of the fingerprint image.
- 6- **Frequency Estimation:** This step is used to estimate the inter-ridge separating in different regions of the fingerprint image.
- 7- **Segmentation:** a region mask is derived that distinguishes between 'recoverable' and 'unrecoverable' portions of the fingerprint image.
- 8- **Filtering:** Using the context information consisting of the dominant ridge orientation and ridge separation, a band pass filter is used to enhance the ridge structure.



**Figure 3. Scheme for the Proposed Algorithm**

#### 4.1 Bilateral Filtering

Bilateral filtering is a technique to smooth images while preserving edges. The bilateral filter is also defined as a weighted average of nearby pixels, bilateral filter takes into account the difference in value with the neighbors to preserve edges while smoothing. The key idea of the bilateral filter is that for a pixel to influence another pixel, it should not only occupy a nearby location but also have a similar value [18].

The bilateral filter has several qualities that explain its success:

- Its formulation is simple: each pixel is replaced by a weighted average of its neighbors. This aspect is important because it makes it easy to acquire intuition about its behavior, to adapt it to application-specific requirements, and to implement it.
- It depends only on two parameters that indicate the size and contrast of the features to preserve.
- It can be used in a non-iterative manner. This makes the parameters easy to set since their effect is not cumulative over several iterations, and It can be computed at interactive speed even on large images,

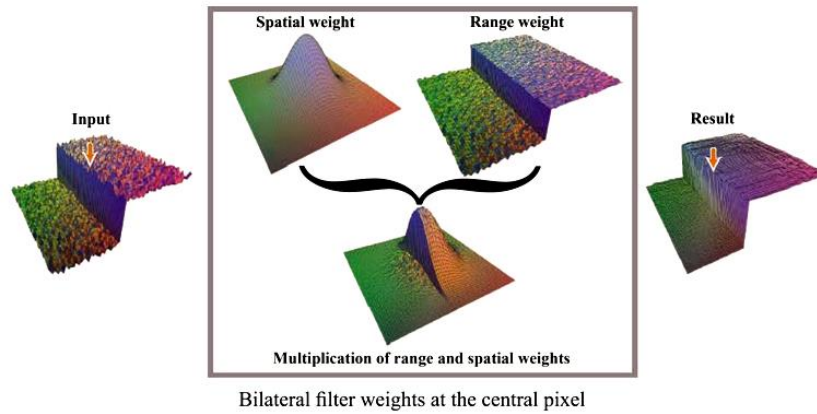
The bilateral filter is defined by:

$$BF[I]_P = \frac{1}{W_P} \sum_{q \in S} G_{\sigma_S}(\|P - q\|) G_{\sigma_r}(|I_P - I_q|) I_q \quad (7)$$

Where normalization factor  $W_P$  ensures pixel weights sum to 1.0:

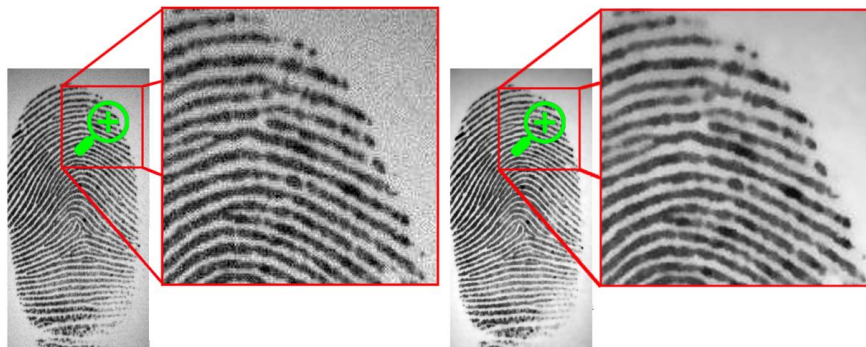
$$W_P = \sum_{q \in S} G_{\sigma_S}(\|P - q\|) G_{\sigma_r}(|I_P - I_q|). \quad (8)$$

Parameters  $\sigma_S$  and  $\sigma_r$  will specify the amount of filtering for the image



**Figure 4. Bilateral Filter Simulation**

In Figure 4, The bilateral filter smooths an input image while preserving its edges. Each pixel is replaced by a weighted average of its neighbors. Each neighbor is weighted by a spatial component that penalizes distant pixels and range component that penalizes pixels with a different intensity. The combination of both components ensures that only nearby similar pixels contribute to the final result. The weights shown apply to the central pixel (under the arrow).



**Figure 5. Bilateral Filter Result Image**

#### 4.2 Wavelet Decomposition

As we explain (in Section 2), wavelet transform decompose the fingerprint image to obtain the wavelet coefficients. The selection of suitable Discrete Wavelet Transform (DWT) is very critical for implementing wavelet algorithms [19]. The choice of wavelet type made automatically according to the degree of contrast in the input image. Generally, in our experiments were having 66 commonly used compact support DWTs with orthogonal bases and all available wavelets able to perform contrast enhancement at a certain degree. Our proposed algorithm designed to choose wavelet with the smallest length among all applicable wavelets. Table 1 lists Discrete Wavelet Transform (DWTs) data base.

**Table 1. Wavelet Database**

Wavelet Type	Parameter	Number of Wavelets
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Haar	n/a	1
Daubechies	N. N = 1.2.....30	30
Coiflets	N. N = 1. 2. 3. 4. 5	5
Symlets	N. N = 2. 3. ...30	29
Discrete Meyer	n/a	1

Wavelets in the database were applied to images and the coefficients of  $H (\sum_{x \in H} |x|)$  and  $V (\sum_{x \in V} |x|)$  were computed, and  $\bar{x}$  is defined as:

$$\bar{x} = \frac{\sum_{x \in H} |x| + \sum_{x \in V} |x|}{2m \times n} \quad (9)$$

Here,  $\bar{x}$  is the wavelet coefficients, and  $m \times n$  is the size of  $H$  and  $V$ .

According to Eqs. (5) and (6), the coefficients of  $H$  and  $V$  are the measurements of the horizontal and vertical edges. If wavelet window size in horizontal direction is exactly matched with the section of objects in this direction,  $\sum_{x \in H} |x|$  is 0 according to Eq. (4a), conclusion similarly holds in the vertical direction,  $\sum_{x \in V} |x| = 0$ . Therefore, the wavelet with the smallest  $\bar{x}$  is the optimal wavelet which best matches the objects.

### 4.3 Coefficients Filtering

Wavelet coefficient adjustment done by using designed filter, this filter consists of three major steps. After the wavelet is selected, four parts  $A$ ,  $H$ ,  $V$ , and  $D$  at each level will be extracted. Fluctuation coefficients changed ( $H$ ,  $V$ , and  $D$ ) and Trend coefficient ( $A$ ) leaves unchanged. For each part ( $H$ ,  $V$ , and  $D$ ) in the decomposition at level  $j$ , we applied the following designed filter.

**4.3.1 Coefficients Normalization:** Normalization is a method to improve the image quality by eliminating noise and correcting the deformations of the image intensity caused by non-uniform finger pressure during the image capture. The idea of normalization consists of changing the intensity of each pixel. The normalization preserves the clarity and contrast of the ridges [2]. Normalized coefficient calculated according to the following equation:

$$x_{nor}^j = x_{old}^j / MM \quad (10)$$

Where  $M = \max\{|x_{old}^j|\}$ ,  $x_{old}$  is original value at level  $j$ ,

**4.3.2 Coefficients Adjusting:** The following formula used to adjust the wavelet coefficients:

$$x_{adj}^j = \begin{cases} (|x_{nor}^j|^p \cdot T^{1-p}) \text{sign}(x_{nor}^j) & 0 \leq |x_{nor}^j| \leq T \\ (1 - (1 - |x_{nor}^j|)^p) (1 - T)^{1-p} \text{sign}(x_{nor}^j) & T < |x_{nor}^j| \leq 1 \end{cases} \quad (11)$$

The Selection of Parameter  $p \in (1, \infty)$ ,  $p$  decides the enhancement strength. Because  $p$  is an exponential value, a standard linear model with two parameters is developed for estimating the value of  $p$ .

$$p = \beta_0 + \beta_1 \ln \bar{x} + \beta_2 \ln T \quad (12)$$

Where  $\beta_0$ ,  $\beta_1$  and  $\beta_2$  are constants. We can easily observe that  $p$  should be greater than 1 for enhancement from Eq. (12). Therefore, if the estimate of  $p$  is less than or equal 1, the fingerprint image is de-enhanced or not enhanced.

The Selection of Parameter  $T \in [0,1]$ , The selection of  $T$  depends on the wavelet function and the noise level in the original fingerprint image. As mentioned above, after a wavelet transform is applied to an image, noise is more distinguishable in wavelet coefficient  $D$  than other subbands. Since the threshold value  $T$  is mainly for eliminating noise,  $T$  could be computed as follows:

$$T = \frac{\sum_{x \in D} |x|}{m \times n \cdot \max_{x \in D} (|x|)} \quad (13)$$

Where  $m \times n$  is the size of  $D$ .

The regions whose wavelet coefficients are less than threshold  $T$  are de-enhanced, while other regions are enhanced. A larger  $p$  will make the image sharper; however, if  $p$  is too large, the image may be over-enhanced. Function  $sign(x)$  compute as:

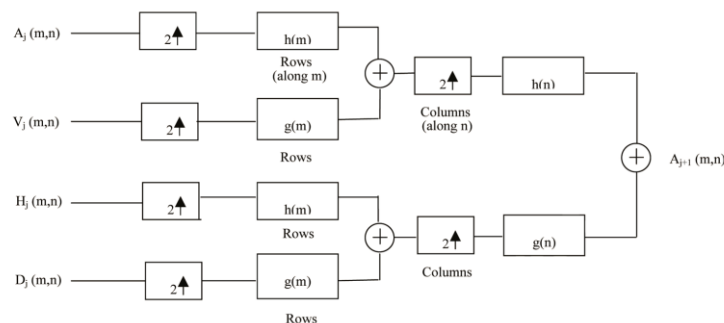
$$sign(x) \begin{cases} 1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

**4.3.3 Compute Enhanced Coefficients :** Using the following equation to calculate the enhanced coefficients:

$$x_{enh}^j = x_{adj}^j \cdot M \quad (14)$$

#### 4.4 Wavelet Reconstruction

Reconstruct the result fingerprint image by the same wavelet used for the decomposition process. Two-dimensional inverse fast wavelet transform (IFWT2) is an inverse process of FWT2 which uses the scaling and wavelet vectors that are exactly the same as those of FWT2.



**Figure 6. Inverse Wavelet Transforms Reconstruction**

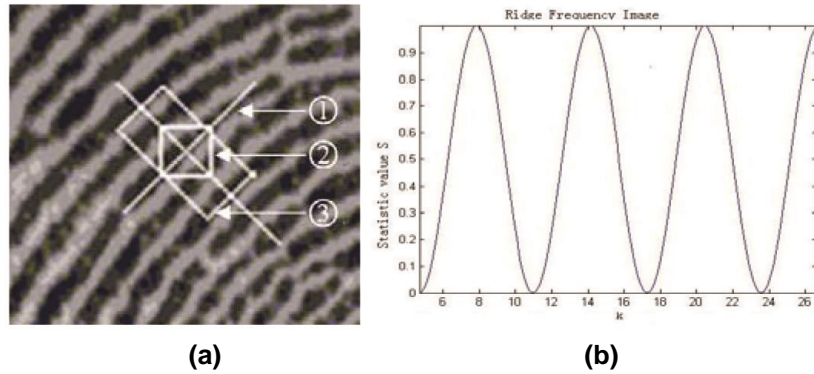
#### 4.5 Orientation Estimation

The orientation field of fingerprints is usually defined as the local orientation of the ridge and valley. There is an orthogonal relationship between the orientation field and the gradient field. Therefore, the orientation field is usually computed by calculating the gradient field. However, the orientation field is not able to automatically capture the especially structural information of local regions [20]. The orientation image represents an intrinsic property of the fingerprint images and defines invariant coordinates for ridges and valleys in a local neighborhood. The local orientation filtering technique taking advantage of the local ridge orientation, which is the intrinsic property of the fingerprint images is widely used in the fingerprint verification system. In practice, this stage could obtain a reliable orientation estimation, even for corrupted fingerprint images.



#### 4.6 Frequency Estimation

The main activity of this stage is to remove the noise and preserve true parallel ridge structures, taking the advantage of the local orientation and local frequency [4]. The local ridge frequency is another intrinsic property of a fingerprint image. The Gabor filters have both frequency-selective and orientation-selective properties and have optimal joint resolution in both spatial and frequency domains (see Figure 7).



**Figure 7. (a) Ridge Frequency Image, (b) Ridge Frequency Image**

In order to estimate the local frequency, a local frequency window is introduced (see Figure 7(a)). The steps involved in local ridge frequency estimation are as follows:

- Divide the image into blocks of size  $w \times w$ , for which centered at pixel  $(i, j)$ .
- Compute the local frequency window of size  $l \times w$  centered at the pixel  $(i, j)$ , which is normal to the local orientation.
- Compute the  $S[0], S[1], \dots, S[l-1]$  of the ridges and valleys within the frequency window. Where:

$$S[k] = \frac{1}{w} \sum_{n=0}^{w-1} N(u, v) \quad k = 0, 1, \dots, l-1 \quad (15)$$

$$u = i + \left[ \frac{w}{2} - n \right] \sin \theta (i, j) + \left[ k - \frac{1}{2} \right] \cos \theta (i, j) \quad (16)$$

$$v = j + \left[ n - \frac{w}{2} \right] \cos \theta (i, j) + \left[ k - \frac{1}{2} \right] \sin \theta (i, j) \quad (17)$$

Where  $\theta(i, j)$  is the local orientation and  $N(i, j)$  is the normalized image. The  $S[0], S[1], \dots, S[l-1]$  form a discrete sinusoidal-shape wave, which has the same frequency as that of the ridges and valleys in the frequency window (see Figure 3(b)). In a local neighborhood where no minutiae and singular points appear, the gray levels along ridges and valleys can be modeled as a sinusoidal-shaped wave along a direction normal to the local ridge orientation. Therefore; local ridge frequency is another intrinsic property of a fingerprint image [4].

#### 4.7 Segmentation

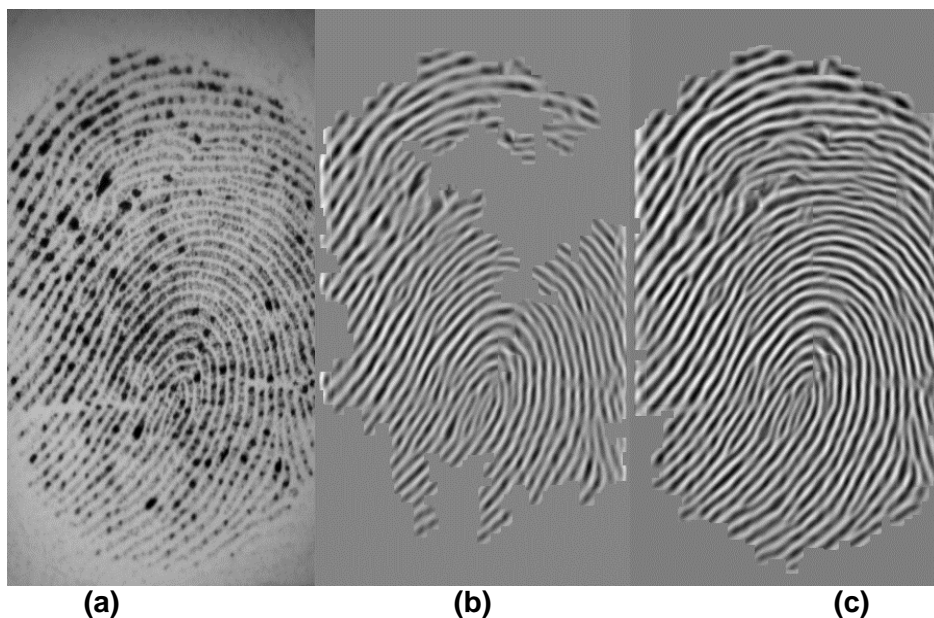
A pixel in an input fingerprint image could be either in a recoverable region or an unrecoverable region. Classification of pixels into recoverable and unrecoverable categories can be performed based on the assessment of the shape of the wave formed by the local ridges and valleys [4].

#### 4.8 Filtering

The configurations of parallel ridges and valleys with a 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 valleys structures [4].

### 5. Experimental Results

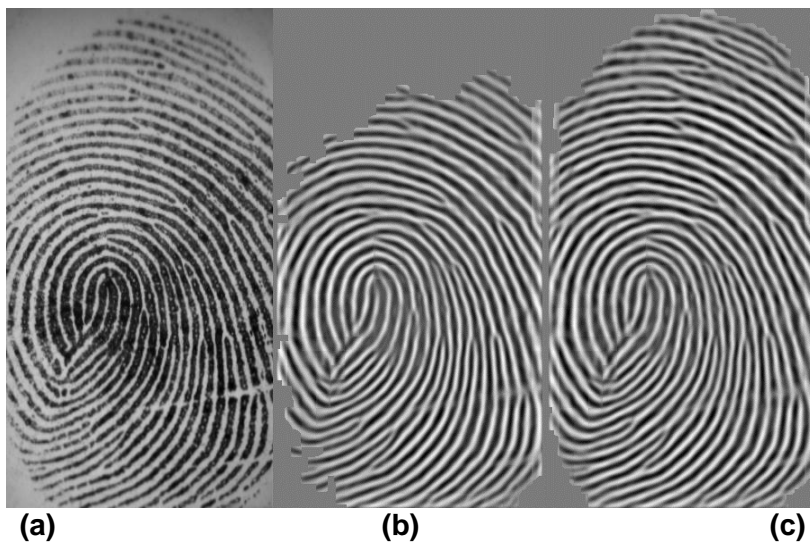
Our proposed hybrid contextual filter Implemented using MATLAB version R2012a. The input fingerprint images selected from Fingerprint Verification Competition database (FVC 2006) [21]. (FVC 2006) is an online database consisting of four data sets (Database1, Database2, Database3 and Database4). In (FVC 2006), data collection is done with introducing difficulties as wet/dry impressions, rotated fingerprint and light/dark fingerprint impression. Through selection of input fingerprint images, we used different types of fingerprint image like: (good quality fingerprint image, middle quality fingerprint image and bad quality fingerprint image). Execution time for implementing the proposed algorithm is very fast. Selecting best bases of wavelets are critical and important for implementing wavelet algorithms. Wavelet transform utilizes local information to decompose an image. The maximum absolute value of each part of the coefficients is used for adjusting the coefficients. It should be noted that only 1-level wavelet is employed in the experiments. Because, the experiments show that in Multiple-level wavelets the improvement is not significant, and it is much more time-consuming to use high level wavelets. The experimental results demonstrate that the proposed method is superior to other existing contextual methods. The result enhanced images are compared with recently modified state-of-the-art Gabor filter algorithm as the below figures.



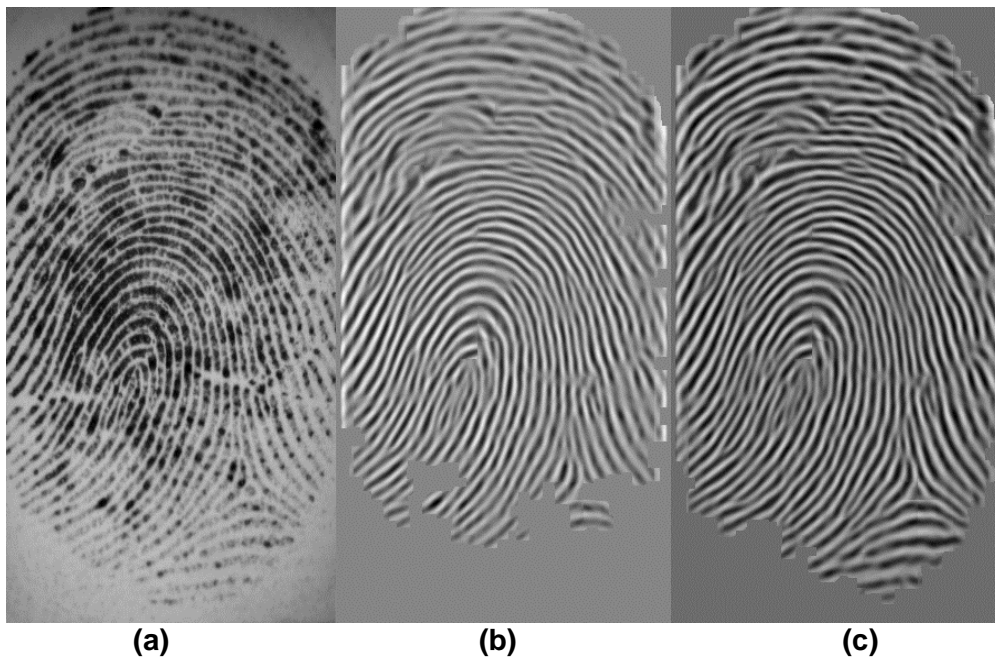
**Figure 8. a) Middle Quality Image, b) Gabor Enhancement, c) Proposed Method Result**



**Figure 9. a) Bad Quality Image, b) Gabor Enhancement, c) Proposed Method Result**



**Figure 10. a) High Quality Image, b) Gabor Enhancement, c) Proposed Method Result**



**Figure 11. a) Good Quality Image, b) Gabor Enhancement, c) Proposed Method Result**

## 6. Conclusions

We have introduced a novel approach for image enhancement and its implementation on fingerprint image. Proposed algorithm consists of eight steps; each step designed to deal with specific defects in image enhancement criteria and tests it on a variety of fingerprint images to ensure the efficiency of the proposed method. Our method employs contextual filters' properties that have the ability to link broken ridges, fill gaps, which would lead best enhancement result. A modified bilateral filtering involved to smooth images while preserving edges. Normalizing the global statistics of the input image this leads to handle contrast and brightness issue. Another achievement in our method is the automatic selection of the best wavelet base in the decomposition process. Design a novel filter for adjusting the wavelet coefficients. It is observed that the proposed algorithm has better performance than Gabor filter. The experiment results indicate that noise in the image could be reduced significantly and enhanced image quality is much better than the other existing methods for improving the minutiae detection. The proposed approach may be very useful for in image processing applications and pattern recognition technologies.

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