Fingerprint Enhancement using Improved Orientation and Circular Gabor Filter

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ABSTRACT

In an automatic fingerprint identification system (AFIS), the fingerprint enhancement algorithm is mainly used to improve the visual quality of the input fingerprint image. The factors affecting the quality of an input fingerprint image may be the presence of scars, cuts, pressure variation between the finger and sensor, worn artifacts, and humidity during acquisition process. An enhancement algorithm is applied on the input fingerprint image to improve image quality and to repair broken ridges.

This paper proposes a new method of enhancing fingerprint image. The method uses a hybrid approach of a new orientation scheme and a Circular Gabor filter to improve the visual quality of the fingerprint image. The proposed approach is compared to other enhancement algorithms using structural similarity index (SSIM). Experimental results and comparative analysis show that the new method performs better than the previous methods .

Keywords

Fingerprint image, Histogram Equalization, Fast Fourier Transform, Orientation, Circular Gabor filter, SSIM.

1. INTRODUCTION

Fingerprint is a pattern of ridges and valleys in a finger, which is unique and permanent in every human being. Fingerprints have some unique features by which they are distinguished from each other. There are three types of features found in a fingerprint: level-1 features (core and delta), level 2 features (minutiae), and level 3 features (sweat pores). Out of these features, minutiae are the mostly used features for recognizing fingerprints because they mimic the way human experts recognize fingerprints. Minutiae are minute details present in the fingerprint in the form of points that either abruptly end (*terminations*) or fork into two branches deriving from a point (*bifurcations*).
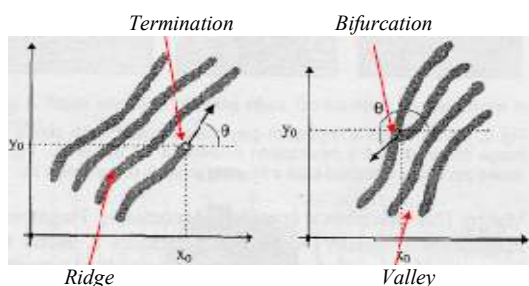

Figure 1. Minutiae: Termination & Bifurcation

2. FINGERPRINT ENHANCEMENT

Fingerprint enhancement is a process to improve the clarity of ridge structures in a fingerprint image and filling broken ridges so that genuine minutiae could be extracted at the later stage. The enhancement process should not produce any false ridges as they may change the individuality of input fingerprints. Since the fingerprint images acquired from sensors or other media are not of perfect quality, some enhancement process is needed to increase the contrast between ridges and valleys and to connect the ridges broken due to insufficient amount of ink. Enhance-ment is useful for higher accuracy of the fingerprint recognition. There have been several enhancement algorithms devised so far [1-8], but still there is enough space for improvement in finger-print image quality.

2.1. Histogram Equalization

Histogram equalization [1] is to expand the pixel value distribution of an image so as to increase the perceptional information. The original histogram of a fingerprint image has the bimodal type, the histogram after the histogram equalization occupies all the range from 0 to 255 and the visualization effect is enhanced. Figure 2 depicts the original image and the enhanced image after histogram equalization.
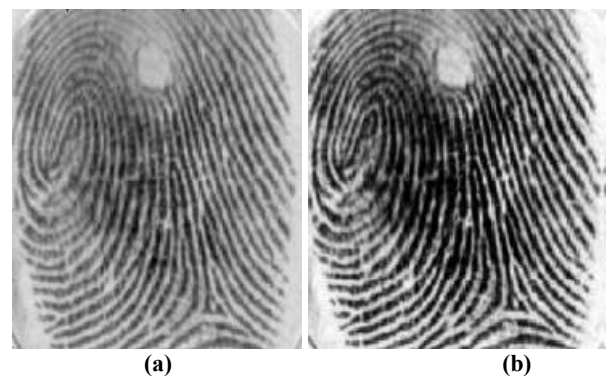

(a)   **(b)**

F**igure 2. (a) Original image (b) histogram-equalized image**

2.2 FFT-Based Enhancement

Cikkerur et al. [5] proposed Fast Fourier Transform (FFT) based enhancement of the fingerprint image. The algorithm is given as follows:

Divide the image into small processing blocks (32 x 32 pixels) and perform the Fourier transform according to:

$$F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) e^{-j.2\pi(\frac{ux}{M}+\frac{vy}{N})} \qquad (1)$$

$$u,v = 0,1,2,\ldots,31$$

To enhance a specific block by its dominant frequencies, multiply FFT of the block by its magnitude a set of times as:

$$g(x,y) = F^{-1}\{F(u,v).|F(u,v)|^k\} \qquad (2)$$

where $F^{-1}(F(u,v))$ is given as:

$$f(x,y) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} F(u,v) e^{-j.2\pi(\frac{ux}{M}+\frac{vy}{N})} \qquad (3)$$

$$for\ x,y = 0,1,2,\ldots,31$$

We take $k = 0.43$ in the formula (2). A higher value of "k" may improve the appearance of the ridges by filling up small holes in ridges, but too high a "k" may result in false joining of ridges causing a termination to become a bifurcation or vice-versa. An FFT-based fingerprint enhancement is depicted in figure 3..
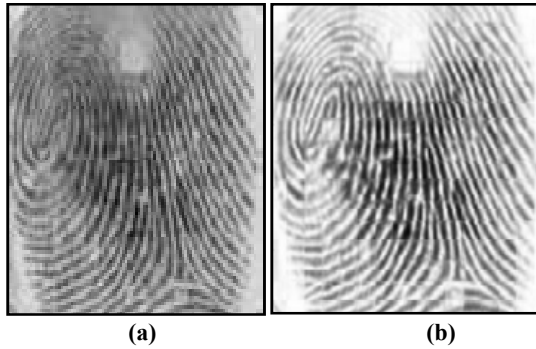
(a) **(b)**
Figure 3. (a) Original image (b) FFT-enhanced image

2.3 Gabor-filter Based Enhancement

Hong et al. [3, 4] used Gabor filter for fingerprint enhancement, which has both frequency-selective and orientation-selective properties. Gabor-filtering an image demands 3 parameters: (a) frequency f of the sinusoidal wave, determined by the local ridge frequency (b) the filter orientation O, determined by the local ridge orientation, and (c) the standard deviations of the Gaussian envelope – σ_x, σ_y. Hong et al.'s algorithm uses even-symmetric square Gabor filter defined as the real part of the Gabor function given by a cosine wave modulated by a Gaussian

$$h(x,y : \emptyset, f) = e^{-\frac{1}{2}\left[\frac{x_\emptyset^2}{\sigma_x^2}+\frac{y_\emptyset^2}{\sigma_y^2}\right]} \cos(2\pi f x_\emptyset) \qquad (4)$$

$$x_\emptyset = x\ cos\emptyset + y\ sin\ \emptyset \qquad (5)$$

$$y_\emptyset = -x\ sin\emptyset + y\ cos\ \emptyset \qquad (6)$$

Here, $\emptyset$ is the orientation of the Gabor filter, f is the frequency of a sinusoidal plane wave, σ_x and σ_y the standard deviations of the Gaussian envelope along x and y axes, respectively, and $x_\emptyset$ and $y_\emptyset$ the x and y axes of the filter coordinate frame. This square Gabor filter is applied to the fingerprint image by spatially convolving the image with the filter. The

convolution of a pixel *(i, j)* in the image requires the corresponding orientation value *O(i, j)* and ridge frequency value *F(i, j)* of that pixel. Let G be the normalized fingerprint image, and *R* be the recoverable mask, then enhanced image *E* is obtained as:

$$E(i,j) = \begin{cases} 255 & ,if\ R(i,j) = 0 \\ \sum_u \sum_v h(u,v : O(i,j), G(i-u,j-v), & else \end{cases} \qquad (7)$$

where, $-w_g/2 \leq u,v \leq w_g/2$, and w_g specifies the size of the Gabor filters. The problem with HWJ approach is that the standard deviation of the Gaussian envelope (σ_x, σ_y) are empirically selected, computational complexity, filter size selection depends on the frequency feature of the image, and it doesn't work well for noisy images.
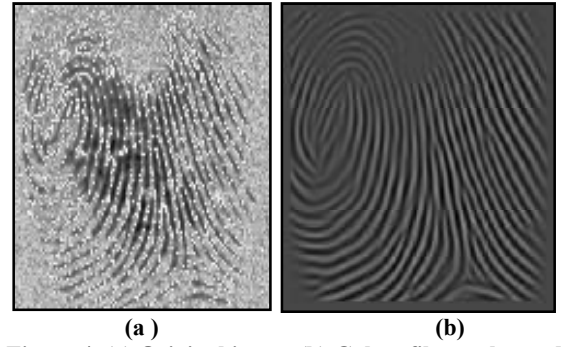
(a) **(b)**
Figure 4. (a) Original image (b) Gabor-filter enhanced image

The Hong et al. [6] orientation estimation algorithm is,
1. Normalize the input image I to get normalized image N.
2. Divide N into wxw blocks; centre each block B at N(i,j)
3. At each pixel N(i, j), compute gradients ∂_x(i, j) & ∂_y(i, j)
4. Compute V_x and V_y as,

$$V_x(i,j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} 2\ \partial_x(u,v)\ \partial_y(u,v) \qquad (9)$$

$$V_y(i,j) = \sum_{u=i-\frac{w}{2}}^{i+\frac{w}{2}} \sum_{v=j-\frac{w}{2}}^{j+\frac{w}{2}} \partial_x^2(u,v)\ \partial_y^2(u,v) \qquad (10)$$

5. Find local orientation θ of B as:

$$\theta(i,j) = \frac{1}{2}\tan^{-1}\frac{V_y(i,j)}{V_x(i,j)} \qquad (11)$$

6. θ(i, j) is smoothened (as it may be noisy) by

 (i) first converting it into a continuous vector field.

$$\Phi_x(i,j) = \cos(2\theta(i,j)) \qquad (12)$$
$$\Phi_y(i,j) = \sin(2\theta(i,j)\ ) \qquad (13)$$

   Φ_x, Φ_y are x and y components of the vector field.

(ii) performing Gaussian smoothening at the block level.

$$\Phi'_X(i,j) = \sum_u \sum_v G(u,v)\emptyset_x(i-uw,j-vw) \qquad (14)$$
$$\Phi'_Y(i,j) = \sum_u \sum_v G(u,v)\emptyset_y(i-uw,j-vw) \qquad (15)$$

where, $\frac{w_\phi}{2} \le u, v \le \frac{w_\phi}{2}$, and G is a Gaussian low-pass filter of size w_Φ x w_Φ. ($w_\Phi = 5$).

7. finally, the smoothed orientation O at pixel (i, j) is computed:

$$O(i,j) = \frac{1}{2}\tan^{-1}\frac{\acute{\phi}_y(i,j)}{\acute{\phi}_x(i,j)} \qquad (16)$$

Hong et al.'s method of estimating orientation map is simple to implement and has a high resolution, but the averaging of the doubled trigonometrically calculated values has high computa-tional cost and the large areas of heavy corrupted data still affect final orientation values. The orientation map is rough in case of noisy images or images with ridge breaks. An orientation map obtained using hong et al.'s approach [6] is depicted in Figure 5.
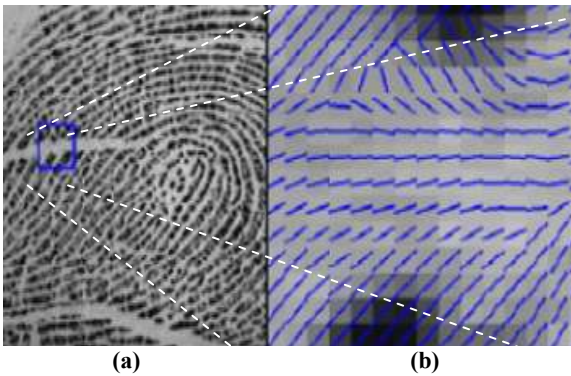

(a)   **(b)**
Figure 5: a) Original low quality fingerprint image; b) magnified area with corrupted orientation values marked

Another problem area of Hong et al.'s approach is *square* Gabor filter that enhances different blocks with different frequencies and directions, to different clarities. This creates a *blocky effect* due to the filter's square support (see Figure 6).

3. FINGERPRINT ENHANCEMENT USING IMPROVED ORIENTATION AND CIRCULAR GABOR FILTER

We introduce a new fingerprint enhancement technique that takes on a hybrid approach of improving orientation map as well as filtering the image using circular Gabor filter.
First, we improve the orientation map obtained by Hong et al.'s algorithm[6]. The method used here tries to improve orientation
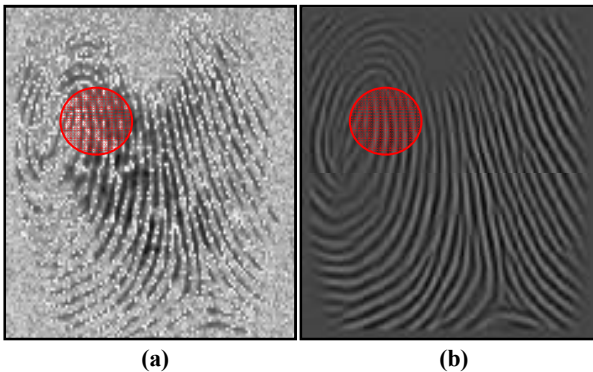
(a)   **(b)**
Figure 6: a) Original image ; b) Gabor-filtered image. The blocky effect depicted by red circle in both the images.

estimation in heavy noise and broken-ridge areas. It also tries to preserve the orientation values of singular points area. This is a two-step process:

Step-I: a 2-D low-pass Gaussian is used to modify the rough local ridge orientation. The weighted averaging is computed for two ranges of orientation values separately. For $45° > \theta(u, v) > 135°$, the vertical weight W_v, and the vertical weighted mean factors $M_v(i, j)$ in w×w blocks is computed as,

$$W_v(i,j) = \sum_u \sum_v \partial(u,v)\, G(u-i,v-j) \qquad (17)$$

$$M_v(i,j) = \sum_u \sum_v (\theta(u,v) - z)\partial(u,v)G(u-i,v-j) \qquad (18)$$

$$z = \begin{cases} 0, & if\ \theta(i,j) < 45^o \\ \pi, & otherwise \end{cases} \qquad (19)$$

and, for $45° \le \theta(u, v) \le 135°$, horizontal weight W_h, and horizontal weighted mean factors $M_h(i, j)$ in wxw blocks is computed as,

$$W_h(i,j) = \sum_u \sum_v \partial(u,v)\, G(u-i,v-j) \qquad (20)$$

$$M_h(i,j) = \sum_u \sum_v \theta(u,v)\partial(u,v)G(u-i,v-j) \qquad (21)$$

Finally filtered orientation is calculated using weighted mean:

$$O(i,j) = \begin{cases} \dfrac{M_v(i,j)\,W_v(i,j) + (M_h(i,j)+\Pi)W_h(i,j)}{W_v(i,j) + W_h(i,j)}, & if\ M_d(i,j) > \dfrac{\pi}{2} \\[3mm] \dfrac{M_v(i,j)\,W_v(i,j) + M_h(i,j)W_h(i,j)}{W_v(i,j) + W_h(i,j)}, & if\ M_d(i,j) \le \dfrac{\pi}{2} \end{cases} \qquad (22)$$

$$M_d(i,j) = M_v(i,j) - M_h(i,j) \qquad (23)$$

where, $i - \frac{w}{2} \le u, v \le i + \frac{w}{2}$

Step-II: The orientation smoothing is based on the reliability of estimated orientation that corresponds to differentiation values of neighboring pixels. A larger neighborhood (16×16) is used to compute the differentiation values:

$$D(i,j) = \sum_u \sum_v |O(i,j) - o(u,v)| - z \qquad (24)$$

where, $i - \frac{w}{2} \le u, v \le i + \frac{w}{2}$

$$z = \begin{cases} \pi, & if\ |O(i,j) - O(u,v)| > 90^o \\ 0, & otherwise \end{cases} \qquad (25)$$

Finally, the entire first stage is performed once again, but now the Gaussian filter G(x, y) is replaced by multiplicative inverse of differentiation, i.e.

$$G(x,y) = \frac{1}{D(x,y)} \qquad (26)$$

The zoomed portions of the fingerprints with cuts and noise in figure 3 show that this new approach to smooth the oriented fingerprint image has very pleasing results.
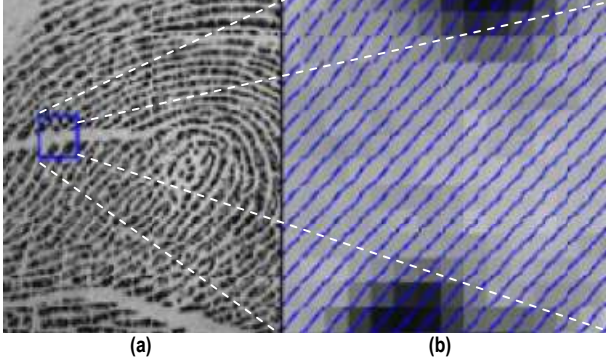
Figure 7: a) low quality fingerprint image; b) magnified area with improved orientation values marked

In order to remove the blocky effect, we use a circular Gabor filter (CGF) with the diameter adjusted to trice the ridge width just crossing one ridge and two valleys (Figure 2) defined as:

$$h'(x,y: \emptyset, f) = \begin{cases} h(x,y: \emptyset, f) & if\ x^2 + y^2 \leq \tau^2 \\ 0 & otherwise \end{cases} \qquad (27)$$
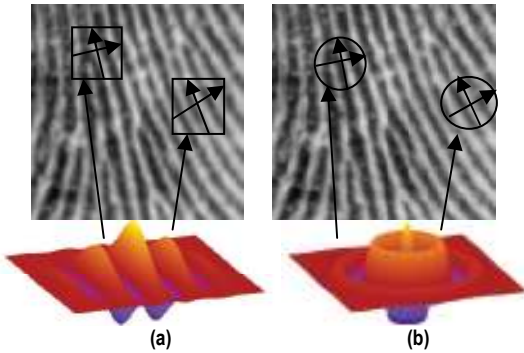
Where,

$$\tau = \frac{3}{4}T \qquad (28)$$

T being the average distance between two peaks.

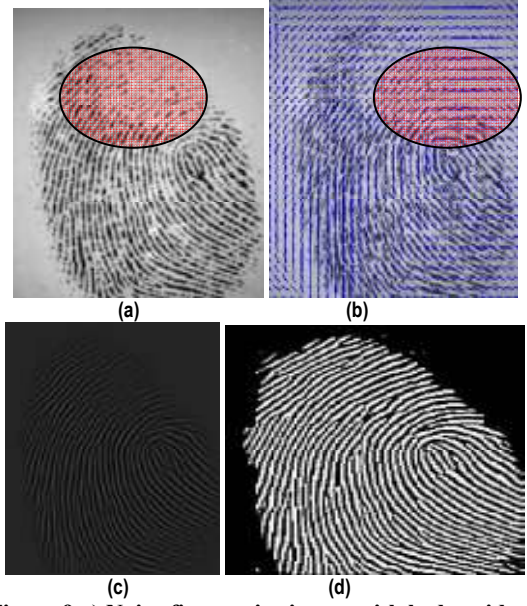The enhanced image *E'* using the CGF is obtained as:

$$if\ R\left(\left\lfloor\frac{i}{w}\right\rfloor, \left\lfloor\frac{j}{w}\right\rfloor\right) = 0$$
$$then\quad E'(i,j) = \sum_u \sum_v h'\left(u,v: O\left(\left\lfloor\frac{i}{w}\right\rfloor, \left\lfloor\frac{j}{w}\right\rfloor\right), f\right) G(i',j')$$
$$else\quad E'(i,j) = 255 \qquad (29)$$

$$where\ i' = i - u, j' = j - v, and\ -\tau \leq u,v \leq \tau$$

Figure 8. (*a*) square Gabor filter (*b*) Circular Gabor filter

The effect of improving the orientation and filtering by CGF enhances blocks with different orientations to the same clarity.

(a)   **(b)**
(c)   **(d)**

Figure 9 a) Noisy fingerprint image with hedgy ridges marked; b) Improved Orientation; c) Enhanced image; d) binary image by proposed method. The highlighted portion has hedgy ridges that are repaired by improved orientation in (b) and CGF filtering in (c). the affect of this approach is clearly seen in the binary image (d) that shows the hedgy ridges have been repaired.

Figure shows the effect of the proposed method on a noisy fingerprint image taken from FVC2000 DB1 database.

4. EXPERIMENTAL RESULTS AND COMPARISONS

Though there are many methods to assess fingerprint image quality (like SNR, PSNR, MSE, etc.), but structural similarity (SSIM) index proposed by Wang et al. [8, 9, 10] proves to be the best among them. The structural similarity between the input fingerprint image x and enhanced image y is given as,

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1L)(2\sigma_{xy} + c_2L)}{(\mu_x^2 + \mu_y^2 + c_1L)(\sigma_x^2 + \sigma_y^2 + c_2L)} \qquad (30)$$

μ_x, μ_y are means and σ_x^2, σ_y^2 are variances of *x* and *y* respective-ly, $\sigma_x\sigma_y$ is covariance of *x* and *y*, c_1, c_2 are adjustable constants, and *L* is the maximal possible value of *x*. Different fingerprint images from FVC2002 DB1 database were taken for assessing the SSIM index between original and enhanced images was observed as shown in the table 1.

The comparison chart based on SSIM indices given in table is shown in figure 5. The chart shows the proposed enhancement scheme in sky blue color, which clearly shows that the proposed scheme's similarity indices attain the maximum possible values against other schemes. This clearly indicates that the proposed scheme enhances given input fingerprint images in a better way as compared to other schemes.

Table 1. SSIM index of fingerprint images (FVC2002) for different enhancement schemes. Proposed scheme clearly shows the best indices (for all the fingerprint images) among all the four schemes.

Fingerprint image	Histogram based	FFT-based	Gabor based	Proposed
101_1.tif	0.98455	0.99033	0.99189	0.99684
101_2.tif	0.98546	0.99381	0.99269	0.99753
101_3.tif	0.98151	0.99397	0.99045	0.99742
101_4.tif	0.98991	0.99117	0.99356	0.99611
101_5.tif	0.99188	0.99240	0.99414	0.99591
101_6.tif	0.98346	0.99574	0.99065	0.99847
101_7.tif	0.98783	0.99029	0.99559	0.99500
101_8.tif	0.98195	0.99254	0.99358	0.99510
102_1.tif	0.99370	0.99181	0.99540	0.99507
102_2.tif	0.99044	0.99261	0.99436	0.99590
102_3.tif	0.99110	0.99319	0.99469	0.99566
102_4.tif	0.98861	0.99451	0.99275	0.99791
102_5.tif	0.99243	0.99228	0.99183	0.99496
102_6.tif	0.99081	0.99159	0.99404	0.99701
102_7.tif	0.99060	0.99449	0.99541	0.99688
102_8.tif	0.99114	0.99090	0.99240	0.99422
103_1.tif	0.98895	0.99139	0.99331	0.99622
103_2.tif	0.99065	0.98984	0.99261	0.99522
103_3.tif	0.98946	0.99054	0.99253	0.99685
103_4.tif	0.98926	0.99129	0.99234	0.99665
103_5.tif	0.98902	0.99403	0.98972	0.99824
103_6.tif	0.98709	0.99427	0.99082	0.99844
103_7.tif	0.98866	0.99372	0.99080	0.99826
103_8.tif	0.98696	0.99449	0.98879	0.99836

5. CONCLUSIONS

The paper proposes a new way of enhancing the input fingerprint images, and compares the proposed scheme with previous enhancing schemes such as histogram equalization, FFT-based enhancement, and Gabor-filter based enhancement. The comparative study shows that the proposed scheme produces the maximum structural similarity indices in most of the cases, which means that it enhances the fingerprint in such a way that preserves the image's pattern and also enhances it in a nice manner. So the proposed method of enhancement is better than its previous counterparts.

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7. AUTHORS PROFILE

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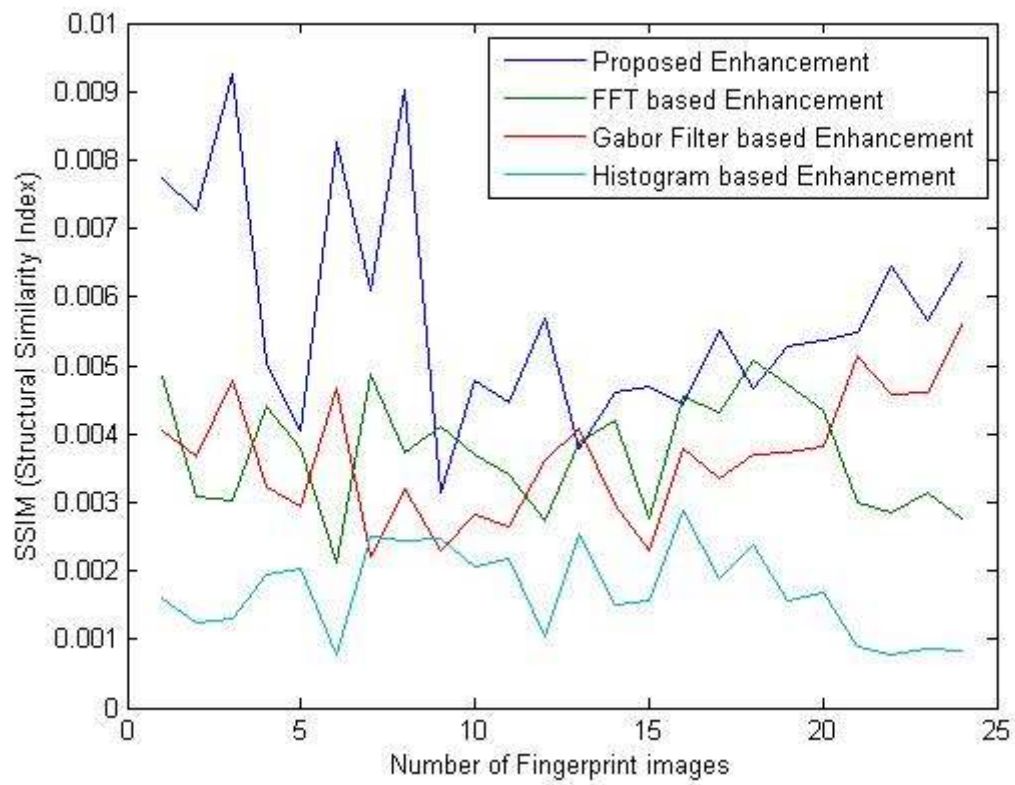
Figure 10. Comparison chart of histogram-based, FFT-based, Gabor filter based, and proposed enhancement schemes