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Fingerprint Enhancement Algorithm Based-on Gradient Magnitude for the Estimation of Orientation Fields

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ABSTRACT

An accurate estimation of fingerprint orientation fields is an important step in the fingerprint classification process. Gradient-based approaches are often used for estimating orientation fields of ridge structures but this method is susceptible to noise. Enhancement of fingerprint images improves the ridge-valley structure and increases the number of correct features thereby conducing the overall performance of the classification process. In this paper, we propose an algorithm to improve ridge orientation textures using gradient magnitude. That algorithm has four steps; firstly, normalization of fingerprint image, secondly, foreground extraction, thirdly, noise areas identification and marking using gradient coherence and finally, enhancement of grey level. We have used standard fingerprint database NIST-DB14 for testing of proposed algorithm to verify the degree of efficiency of algorithm. The experiment results suggest that our enhanced algorithm achieves visibly better noise resistance with other methods.

Keywords: Orientation fields, Gradient magnitude, Normalization, Coherence.

1. INTRODUCTION

Fingerprints are immutable physiological feature of human beings. It is well established in science that they are highly distinctive between individuals [1]. This has provided the theoretical basis to use fingerprints as a reliable evidences for personal identification. In fact, fingerprint has been used in forensic science over a century, even now used in recognising personality. In the early days, identifying fingerprints is conducted manually. The tedious work is expensive and time consuming. Therefore, automatic fingerprint recognition has become a popular research topic over the last decades.

The finger skin shows a flow like pattern of ridges and valleys. This pattern of ridges and valleys on each finger is unique and immutable. The structural features of these ridges and valleys, such as the overall global pattern of ridges, singularity regions (core and delta), ridge shape, width, minutiae (ridge ending or bifurcation) and sweat pores are used as characteristics of identification to distinguish between two fingerprints or find out the similarity between them. It has been found that two individuals does not have the same fingerprint features and even identical twins with similar DNAs have different ridge details and can be discriminated based on their fingerprint features [1][2]. Enhancement of fingerprint images improves the ridge-valley structure, increases the number of correct features thereby conducing the overall performance of the recognition system.

Fingerprint image enhancement is a process to modify low quality fingerprint image to high quality fingerprint image. Excellent quality of fingerprint image has high contrast between ridges and valleys, continuity of the ridges structures, and flow of ridges and valleys in a locally constant direction (see Figure 1 (a)). In such situations, the ridges structure can be easily detected and singular points can be precisely located in the image. However, in practice, due to skin conditions (e.g. wet, dry, cuts, and bruises), low contrast, noisy, broken, or smudgy, causing spurious, and others, a significant percentage of fingerprint images with low quality as shown in Figure 1 (b)-(f) cannot be correctly detected. In order to ensure good performance of ridge structure where the ridge orientations changes smoothly and obtain satisfactory results in high curvature regions in low quality fingerprint image, the noise removal and the enhancement algorithm is needed to improve the clarity and continuity of the ridge structure.

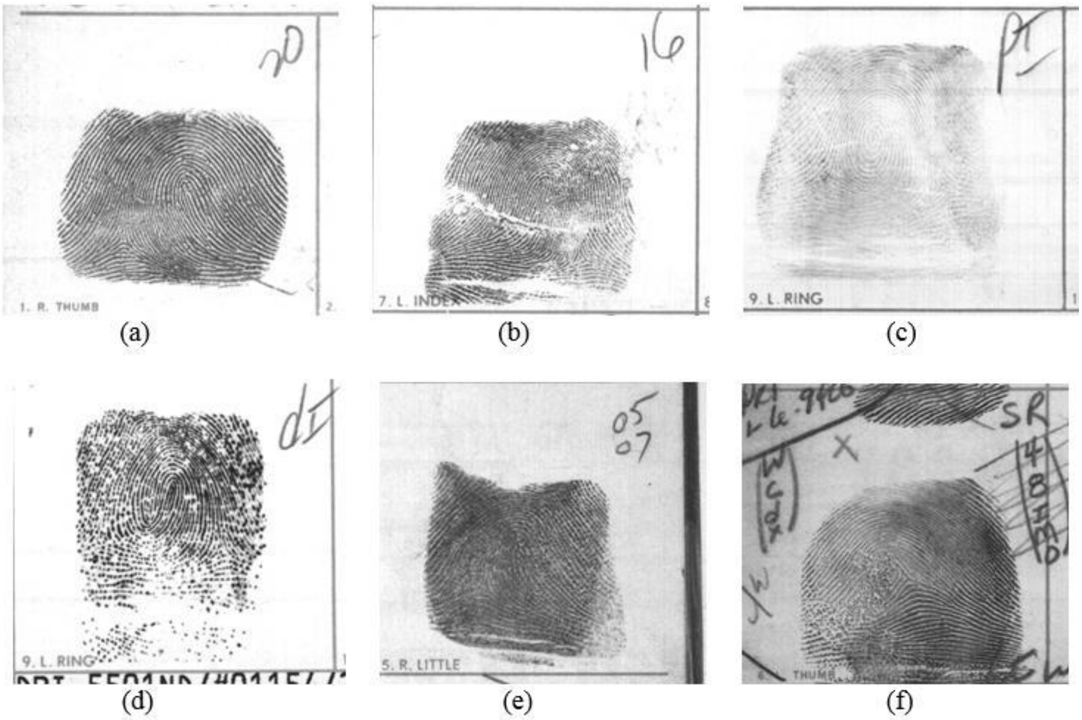

Figure 1. Quality of fingerprint image: (a) Good, (b) Broken/cut, (c) Low contrast, (d) Dry, (e) Wet, and (f) Stain.

2. RELATED WORK

Most of the noise removal methods are applied to operate directly on grey-scale images, while some others operate to enhance ridge structure of fingerprint images. Several approaches for fingerprint image enhancement are known from literature, such as Gaussian filter, and directional filter.

2.1 GAUSSIAN FILTER

Gaussian noises appear in the image caused by factors such as poor illumination and high temperature of sensor. Gaussian filter is a linear smoothing used to smooth the fingerprint image and removes the noises. This filter is similar to mean filter, but it uses a different kernel that represents the shape of Gaussian hump. The goal of

Gaussian Filter is to use this distribution as a point spread function that can be performed by convolution mask. This value is calculated by summing the products of the filter coefficients and the corresponding image pixels in the area spanned by the filter mask.

Normally, the filter mask is a two dimensional array in which the values of the mask coefficients affect the nature of the image. In literatures, Gaussian filter is widely used to enhance fingerprint image. For example, Hong, Wang and Jain used Gaussian filter kernel of size for smoothing directional image [3]. Bazen and Gerez, and Zhang and Yan also used Gaussian filter to smooth gradient [4][5]. Wang and Wang used Gaussian filter for fingerprint enhancement in the singular point area [6]. Chikkerur *et al*. and Mao *et al*. used Gaussian filter kernel of size for smoothing orientation image [7][8].

2.2 DIRECTIONAL FILTER

Directional filter is one of the enhancement techniques which recognizable in multi-resolution enhancement method [1]. The multi-resolution analysis has been proposed to remove noise from fingerprint image by decomposing the image into dissimilar frequency band (or sub-images). This allows compensating for different noise component at different scales: in particular, at higher levels (low and intermediate frequency bands) the rough ridge flow is cleaned and gaps are closed, whereas at the lower levels (higher frequencies) the finer details are preserved.

Hong. Wang, and Jain proposed fingerprint enhancement using local ridge orientation and frequency image estimation. Local ridges orientations are estimated using the least mean square orientation estimation algorithm. In a local neighbourhood where no minutiae and singular point appear, the grey levels along ridges and valleys can be modelled as a sinusoidal-shaped wave along a normal direction to the local ridge orientation. They compute an oriented window of size that is defined in the ridge coordinate system. For each block, centred at pixel, they computed the x-signature of ridges and valleys within oriented window. This algorithm is reported to give a good performance for fingerprint enhancement and also identifies the unrecoverable corrupted regions in the fingerprint and removes them from further processing.

Wu *et al.* proposed fingerprint enhancement method based on integration of anisotropic filter and Directional Median Filter (DMF) [9]. The fingerprint images are first convolved with anisotropic filter, then filtered by DMF. Eight DMF templates, with suitably pre-selected windows size , adopt different flow-like topological shapes and select more relative points to enhance ridge-flow continuity. This method is effective to reduce Gaussian-distributed noises and impulse noises along the direction of ridge. However, this algorithm may fail when image regions are contaminated with heavy noises and orientation field in these regions can hardly be estimated.

Wang *et al*. proposed an enhanced gradient-based method for estimation of fingerprint orientation fields using weighted averaging scheme that exploits the salient features of fingerprint ridge patterns [10]. The basic idea is to conduct redundant estimation over four overlapping neighbourhoods for each target block (Figure 2). The concept is similar to Kuwahara filter [11]. For each of the four overlapping block marked is determined coherence values . Then find the maximum value of coherences and assign the corresponding orientation angle to the target block.

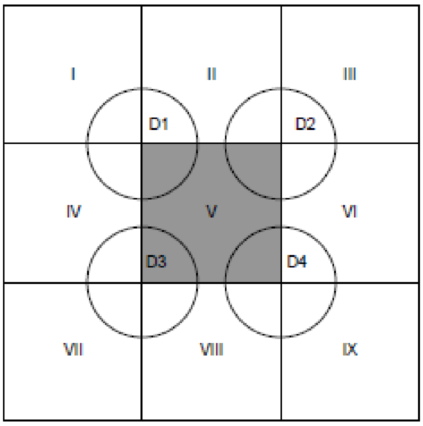

Figure 2. A site consists of blocks with four overlapping neighbourhood and the target block [10].

3 PROPOSED METHOD

Basically, a new scheme of enhanced fingerprint orientation fields is proposed based on gradient magnitude. With regard to this, there are eight main processes involved that link with the generic scheme, which include: foreground extraction, identification and marking of noise areas, and enhancement of grey level in the noise areas. The following paragraph briefly presents step-by-step of the proposed scheme above.

3.1 FOREGROUND EXTRACTION

Foreground extraction is actually part of fingerprint image segmentation, which aims to separate foreground from its background and other foreign objects like artefacts and handwritten annotations, which are common in inked fingerprints. It also tasks to detect noise regions found in the foreground.

The proposed extraction begins with normalization of the fingerprint’s intensity values by adopting normalization approach in [3]. Details of the approach are given by the following sub-section. Then, it is followed by foreground region separation from the background using the proposed segmentation technique. Finally, the gradient coherence approach, which is pioneered by Zhang and Yan in [5], it is adopted to detect the noise regions existed in the foreground.

3.1.1 GREY-SCALE NORMALIZATION

Normally, the intensity value of fingerprint images is greatly varied from one print to another over time of capturing. The normalization process aims at reducing variation in grey-level values along ridges and valleys without changing the clarity of their structures. Therefore, the input fingerprint image is standardized to a desired mean and variance. The Normalization method consists of three steps: Firstly, global mean value of fingerprint image is determined. Secondly, global variance value of fingerprint image is computed. Lastly, new intensity values are calculated.

Detailed process of the normalization is performed as follows:

1. Let denote the grey-level or intensity value of the pixel at the *m*-th row and *n*-th column of pixels of fingerprint image size. Let *Mg* and *Vg* denote the global mean and global variance values of fingerprint image, respectively.
2. Calculate the normalized grey-level value at pixel (*m*,*n*) of fingerprint image, which is denoted by *N*(*m*,*n*), and is defined as follows:

$$N(m,n)=\begin{cases}\sum_{m=0}^{W-1}\sum_{n=0}^{H-1}\left(Mg_0+\sqrt{\frac{Vg_0(I(m,n)-Mg)^2}{Vg}}\right) & \text{if } I(m,n)>Mg\\ \sum_{m=0}^{W-1}\sum_{n=0}^{H-1}\left(Mg_0-\sqrt{\frac{Vg_0(I(m,n)-Mg)^2}{Vg}}\right) & \text{otherwise}\end{cases} \quad (1)$$

where 0 Mg and 0 Vg are the desired mean and variance values, respectively. Ideally, the recommended value for both 0 Mg and 0 Vg is 100. Once the normalised grey-level values of the fingerprint image are obtained, the next process is to extract the foreground from the fingerprint image. With regard to that, a new segmentation approach, which combines local mean value of the normalised grey-level and local variance value of the gradient magnitude, is proposed in [12]. This method consists of three main steps: First, global mean (i.e. Mn in short) and local mean (i.e. Mb(i, j) in short) values of normalized fingerprint image are calculated. Second, local variance (i.e. Vgr (i, j) denoted by) and threshold (i.e. th G in short) values of gradient magnitude are computed. Finally, the target block is assigned as a part of foreground if the following conditions are fulfilled: (i) if the local mean is smaller than global mean, or (ii) the local variance is greater than the threshold.

a. Computation of global mean and local mean values

Global mean is obtained by computing the average of grey-scale values of the whole normalized image, whereas local mean value is computed based on block of pixels. The calculation is performed as follows.

1. Let *WxH* be the size of the normalized image. Let *BxB* pixels be a non-overlapping block of the normalized image. In this case *B*=16 . Let *N(u, v)* be the intensity value of the pixel at the *u*-th row and *v*-th column of the block. Let *P* be the number of blocks in the entire image.
2. Calculate the global mean value *Mn* and local mean of each block *Mb(i, j)*. Where *(i, j)* is first pixel at i-th row and j-th column of the *BxB* block, *i = 0, 16, 32, ..., W-16 , and j = 0, 16, 32, ..., H -16.*

b. Computation of local variance of gradient magnitude

The local variance of gradient magnitude of each block is computed according to the following steps:

1. For each pixel *(m, n)* of the normalized fingerprint image *N(m,n)* ; estimated gradients in horizontal and vertical directions, which are symbolized by $G_x(m,n)$ and *Gy(m,n)*, respectively are computed using the following Horizontal Sobel mask 3 x 3 operator $S_x(p,q)$ and Vertical Sobel mask operator *Sy(p,q)*.

$$G_x(m,n) = \sum_{p=-1}^{1} \sum_{q=-1}^{1} (S_x(p,q) \times N(m+p, n+q)) \quad (2)$$

$$G_y(m,n) = \sum_{p=-1}^{1} \sum_{q=-1}^{1} (S_y(p,q) \times N(m+p, n+q)) \quad (3)$$

2. Calculate the gradient magnitude $|Gr(m, n)|$ for each pixel (m, n) as follows

$$|Gr(m,n)| = \sqrt{(G_x^2(m,n) + G_y^2(m,n))} \quad . \quad (4)$$

3. Determine the threshold value th G of the gradient magnitudes using Zhang and Yan's method in [5] as follows:
   a. Let $|Gr(m, n)|$ denote the gradient magnitude at each pixel (m, n) of the $W \times H$ image size.
   b. Determine the maximum and minimum of the gradient magnitudes, $|Gr(m, n)|_{\max}$ and $|Gr(m, n)|_{\min}$ respectively.
   c. Calculate threshold value using the following equation.

   $$Gth = c \times (|Gr(m, n|_{max} - |Gr(m, n)|_{min}) + |Gr(m, n)|_{min}) \quad (5)$$

   where c is the threshold factor that can be chosen within a range of [0.05, 0.3] depending on the image contrast. A smaller value of c will encourage the block to become foreground, while larger value will transform the block to background. Empirically, c = 0.1 is chosen.
4. Local variance of gradient magnitude can be determined as follows.
   a. Let $|Gr(u, v)|$ be the gradient magnitude of the pixel at *u-th* row and *v-th* column in the $B \times B$ block.
   b. Calculate the local mean values of gradient magnitude $Mgr(i, j)$ of each block (i, j) as follows:

   $$Mgr(i,j) = \frac{\sum_{u=i}^{i+B-1} \sum_{v=j}^{j+B-1} |Gr(u,v)|}{B \times B} \quad (6)$$

   where $i = 0, 16, 32, ..., W - 16$, and $j = 0, 16, 32, ..., H - 16$.
   c. Calculate the local variance values of gradient magnitude $Vgr(i, j)$ of each *block* (i, j) that are defined as follows:

   $$Vgr(i,j) = \frac{\sum_{u=i}^{i+B-1} \sum_{v=j}^{j+B-1} (|Gr(u,v)| - Mgr(i,j))^2}{B \times B}, \quad (7)$$

   where $i = 0, 16, 32, ..., W - 1$, and $j = 0, 16, 32, ..., H - 1$.

c. If $(Mb(i,j) > Mn$ and $th\ Vgr(i,j) < G)$, then the target block is assigned as a part of background region, otherwise is designated as foreground region.

3.1.2 NOISE AREAS IDENTIFICATION AND MARKING USING GRADIENT COHERENCE

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Generally, gradient coherence is used to describe the variation of grey-level values in an image. It can also be applied to investigate on how each pixels-block behaves in terms of its gradient value in relation to fingerprint ridge flows. The larger value indicates that every pixel of the block shares a common direction, which is in accordance to ridge direction. On the contrary, the smaller value signifies that the majority of the pixels have non-uniform directions, and does not resemble true ridge flow. The gradient coherence value is usually larger in foreground of the fingerprint image, where the grey values are much smoother along the direction of the ridge than on the perpendicular direction of the ridge. The gradient coherence measures range in *[0, 1]* . Gradient coherence value of 0 indicates that the gradients in the block are equally distributed over all directions. On the other hand, gradient coherence value of 1 indicates all pixels of the block share the same orientation. Since gradient coherence is based on the block information of the fingerprint image, the fingerprint image is divided into non-overlapping blocks of $B \times B$ sized, in this case $B = 16$. For a given normalized fingerprint image, gradient coherence $Coh(i, j)$ of each block at pixel (i, j) is calculated as follows:

1. Let $G_x(u, v)$ and $G_y(u, v)$ denote the gradients in x and y directions of the pixel at u-th row and v-th column in the $B \times B$ block.
2. Calculate the gradient coherence $Coh(i, j)$ as follows:

$$Coh(i,j) = \frac{\sqrt{V_x(i,j)^2 + V_y(i,j)^2}}{V_z(i,j)}, \tag{8}$$

Where

$$V_x(i,j) = \sum_{u=i}^{i+B-1} \sum_{v=j}^{j+B-1} (G_x^2(u,v) - G_y^2(u,v)) \tag{9}$$

$$V_y(i,j) = \sum_{u=i}^{i+B-1} \sum_{v=j}^{j+B-1} 2G_x(u,v)G_y(u,v) \tag{10}$$

$$V_z(i,j) = \sum_{u=i}^{i+B-1} \sum_{v=j}^{j+B-1} (G_x^2(u,v) + G_y^2(u,v)) \tag{11}$$

where $i = 0, 16, 32, ..., W - 16$, and $j = 0, 16, 32, ..., H - 16$.

An example of the resultant image after undergone the above process is given in Figure 2. In this case, $Coh(i, j) <= 0.5$.

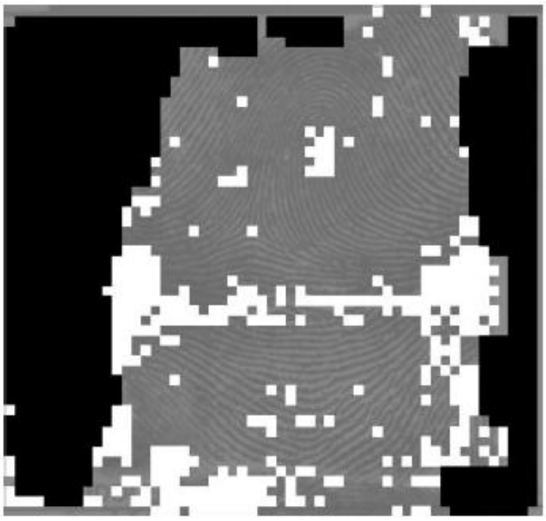


Figure 2. Noise areas of the foreground are identified and labelled. The white coloured blocks indicate the noise areas.

3.2 ENHANCEMENT OF GREY-LEVEL

Fingerprint enhancement aims at improving the clarity (contrast) and continuity of the ridge or valley structures in order to extract ridges or valleys. The input of enhancement process is a grey-level fingerprint image. The output may be either a grey-level or binary image, depending on the algorithm and goal. A new method is proposed to enhance grey-level in the noise regions. The idea of this method is inspired by Wang et al. in [10].

The proposed method exploits variances of the gradient magnitude in a newly designed block of pixels named Cross Centre Block of size $H \times H$ (see Figure 3) hereinafter called CCB, in order to improve the intensity value of the pixels in the noise regions. Generally, the grey-level enhancement method consists of five steps: First, define overlapping CCB sub-blocks of the noise block that contains gradient magnitude. Second, define four groups of pixels of the CCB according to their positions: north-east, north, north-west and west or in short D_1 , D_2 , D_3 , and D_4, respectively. The intersection point of the four groups is defined as the target pixel. Third, for each group, calculate: (i) variance of gradient magnitudes, and (ii) mean value of grey-scale. Fourth, select the group, which has minimum variance. Finally, replace the intensity value of the target pixel with the mean value of the selected group. The following are the detailed processes of proposed method:

1. Input image: noise regions of size $B \times B$ obtained earlier in sub-section 3.1.2.
2. Define each overlapping sub-blocks of size $H \times H$, namely CCB , in the noise block. This mask-like CCB moves one column at a time from left to right and top to bottom within the block.
3. To facilitate the gradient magnitude computation for each group, let's create one dimensional array $D = \{Gr_0, Gr_1, Gr_2, \ldots, Gr_{H^2-1}\}$, whose elements represent gradient magnitude Gr(i, j) of each pixel in the sub-block. Define subsets of D as follows.

$$\left.\begin{aligned} D_1 &= \{Gr_k \in D \mid k = (u-1)(H+1)\}, \\ D_2 &= \{Gr_k \in D \mid k = \frac{(H-1)}{2} + (u-1)H\}, \\ D_3 &= \{Gr_k \in D \mid k = (H-1)u\}, \\ D_4 &= \{Gr_k \in D \mid k = \frac{H(H-1)}{2} + (u-1)\}, \end{aligned}\right\} \qquad (12)$$

   where $u = 1, 2, 3, \ldots, H$.
   In this case, $H = 5$ is decided empirically. Figure 3. shows subsets $D_1 = \{Gr_0, Gr_6, Gr_{12}, Gr_{18}, Gr_{24}\}$, $D_2 = \{Gr_2, Gr_7, Gr_{12}, Gr_{22}\}$, $D_3 = \{Gr_4, Gr_8, Gr_{12}, Gr_{16}, Gr_{20}\}$, and $D_4 = \{Gr_{10}, Gr_{11}, Gr_{12}, Gr_{13}, Gr_{14}\}$ of D in a CCB of size 5x5.
4. Calculate the mean value $Mgm|D_1$ and the variance value $Vgm|D_1$ for $l = 1, 2, 3, 4$ of gradient magnitude in each CCB using the following equations:

ns:

$$Mgm|D_l = \frac{\sum_{u=1}^{H} Gr_k|D_l}{H}, \tag{13}$$

$$Vgm|D_l = \frac{\sum_{u=1}^{H} (Gr_k|D_l - Mgm|D_l)^2}{H}, \tag{14}$$

5. Build an array of one dimensional $P = \{N_0, N_1, N_2, \ldots, N_{H^2-1}\}$, which represents the grey-level of normalized fingerprint image $N(m,n)$ for each pixel in the CCB sub-block.
6. Calculate mean grey-level of normalized fingerprint image $Mi|P_l$, for $l = 1, 2, 3, 4$ in CCB using the following equations:

$$Mi|P_l = \frac{\sum_{u=1}^{H} N_k|P_l}{H}, \tag{15}$$

where P_1 is defined as D_1 in equation (12) with k Gr_k replaced by N_k .

7. Replace intensity value of the target pixel at the centre block $N_{\frac{(H-1)(H+1)}{2}}$ with $Mi|P_1$ for which $Vgm|D_1$ attains its minimum value. So that mathematically,

$$N_{\frac{(H-1)(H+1)}{2}} = Mi|P_l, \text{ if } \min_{l=1,2,3,4} (Vgm|D_l) \tag{16}$$

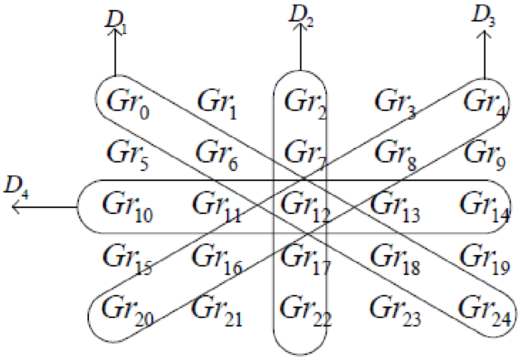


Figure 3. CCB gradient magnitude of size 5 x 5

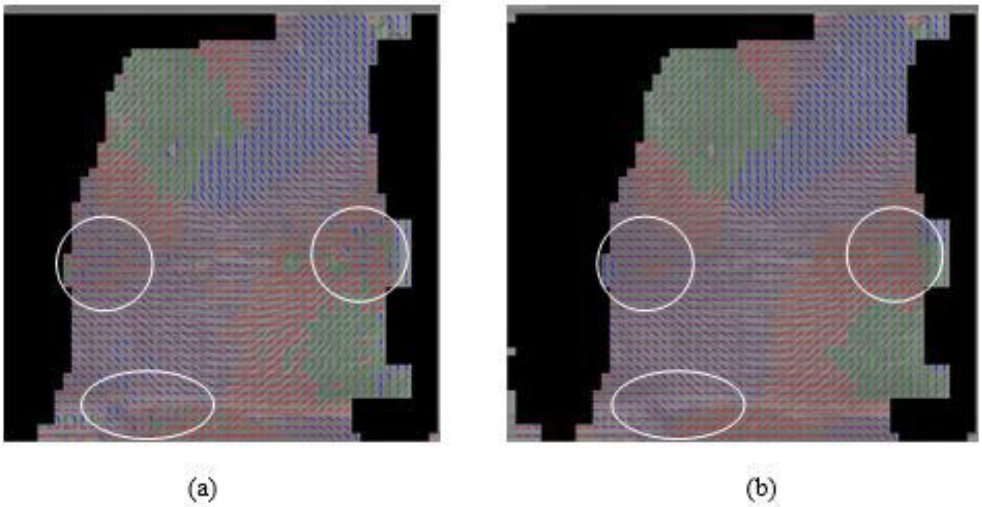


Figure 4. Result of the enhancement process in the noise areas (circles highlight the noise areas), (a) Orientation image before enhancement, (b) Orientation image after the enhancement. (Note: the input is the foreground image in Figure 2 above)

Once all the pixels of the noise areas have been enhanced, Gaussian filtering mask *Gs(p,q)* (with a σ = 1.4) is then applied for smoothing all pixels in the foreground region. The process is carried out performed by using the following equation.

$$N'(m,n)=\sum_{p=-1}^{1}\sum_{q=-1}^{1}Gs(p,q)\times N(m+p,n+q), \qquad (17)$$

where *N' (m, n)* is new pixel value after Gaussian smoothing.

Figure 4 shows fingerprint image before and after the enhancement process, which is represented in terms of orientation image points of view.

4 EXPERIMENT RESULT AND DISCUSSION

A fingerprint image enhancement is not aimed to produce a good visual appearance of the image but aimed at facilitating the subsequent feature detection like ridge orientation field and at the same time avoiding undesired side effects in the subsequent processing [13]. Evaluation for the enhancement process can be done either qualitatively or quantitatively, by evaluating the performance measurement of orientation field [14] or minutiae detection [3][15]. Thus, in order to perform the task of evaluating the performance of orientation fields, images of various qualities viz. good, dry, wet, cuts, bruises, and low contrast are used.

Figure 5 to Figure 10 show some results of the fingerprint enhancement process in terms of orientation fields’ structure points of view.

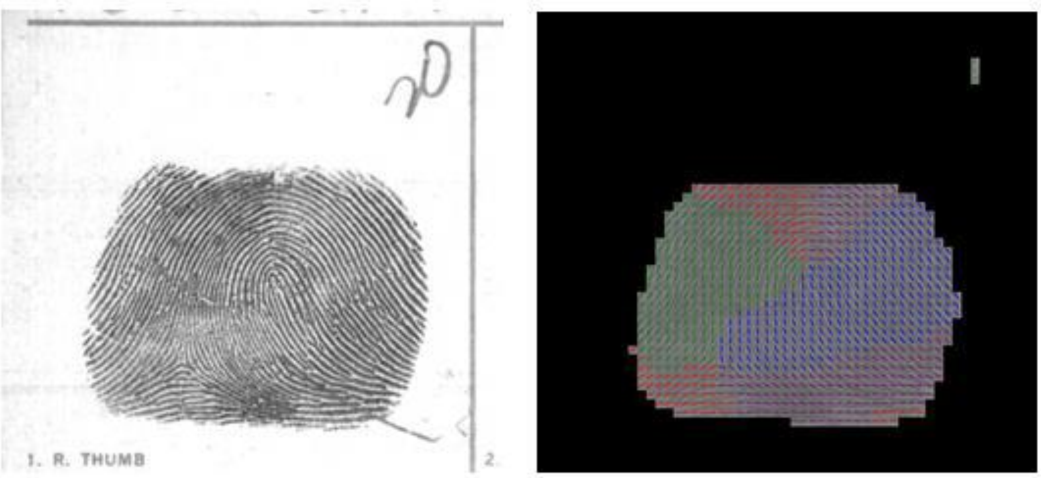


Figure 5. The result of the enhancement process for good quality fingerprint

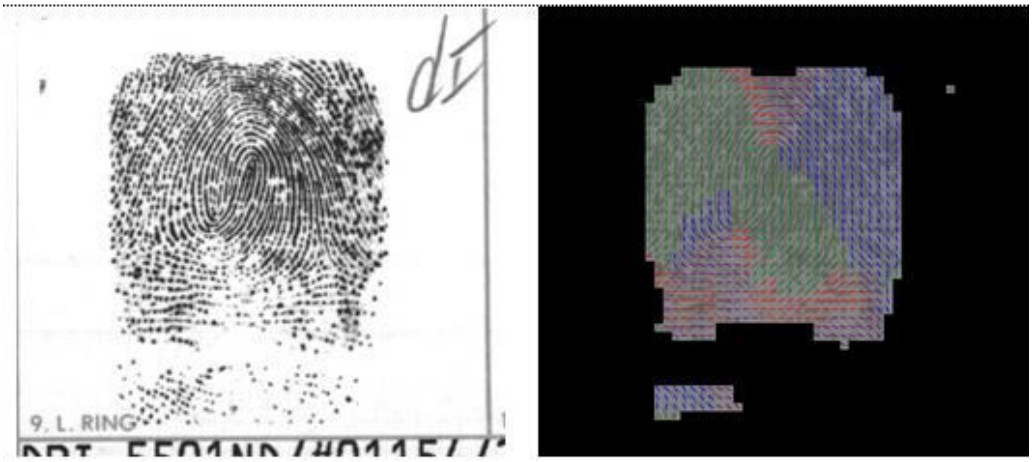


Figure 6. The result of the enhancement process for dry fingerprint

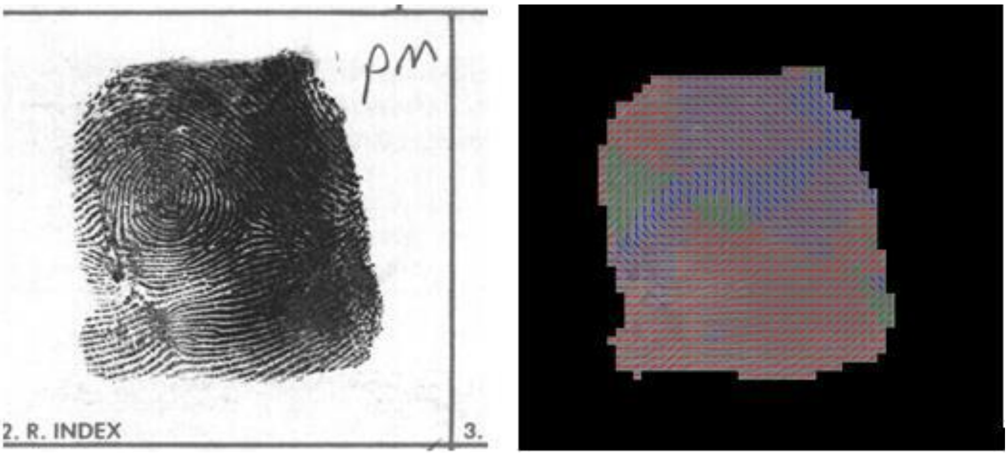


Figure 7. The result of the enhancement process for wet fingerprint

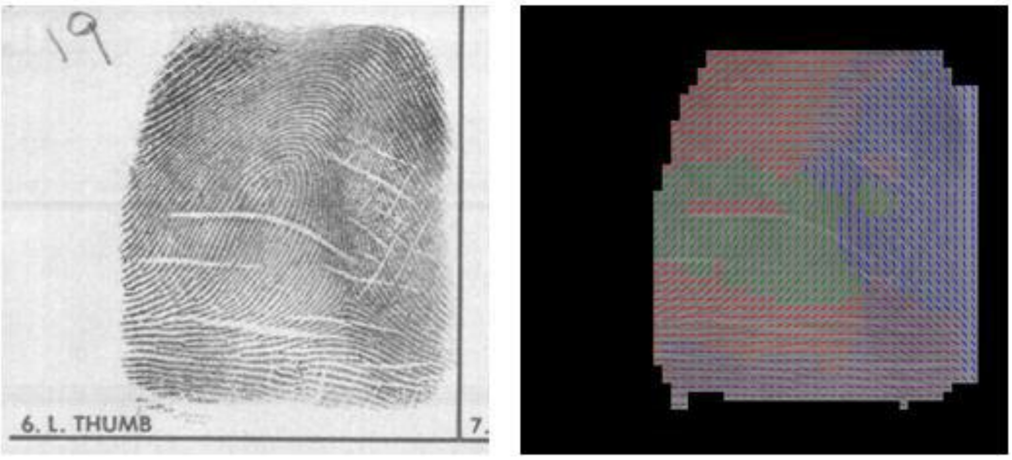


Figure 8. The result of the enhancement process for cuts fingerprint

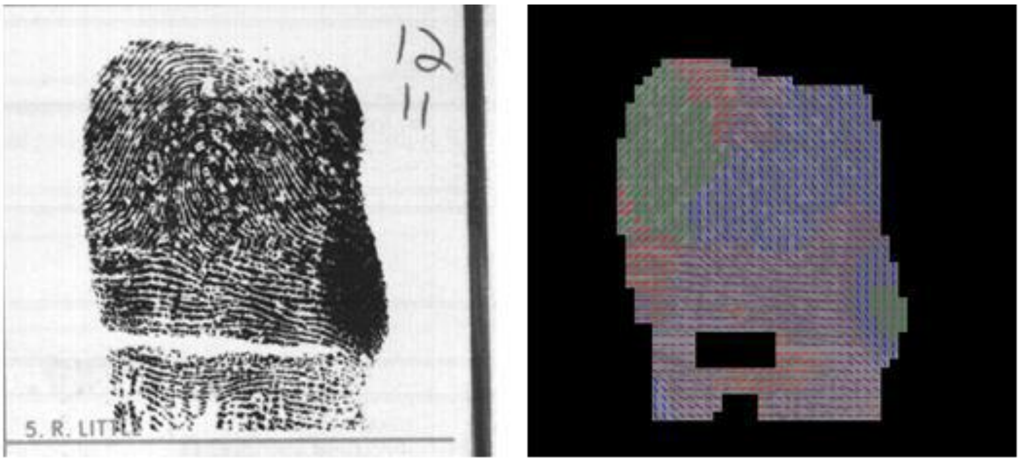


Figure 9. The result of the enhancement process for bruises fingerprint

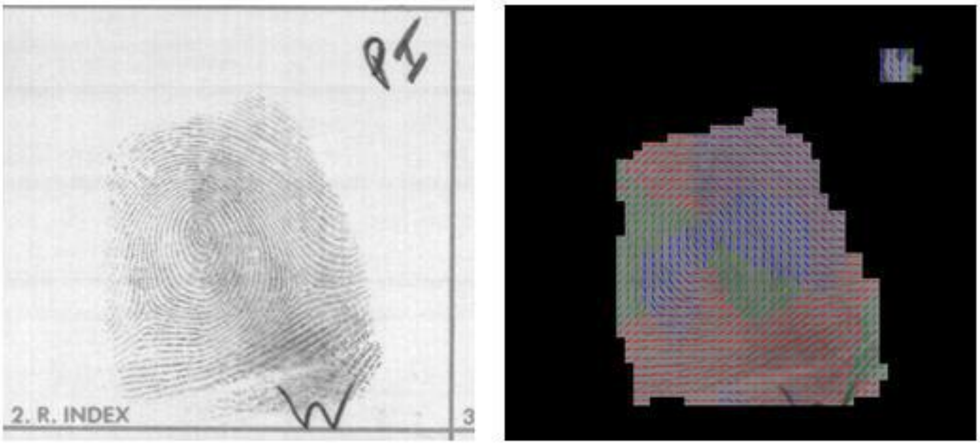
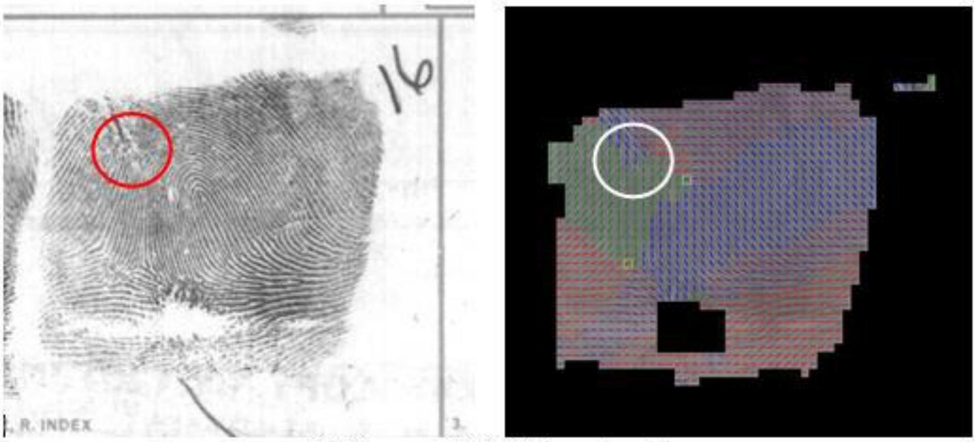
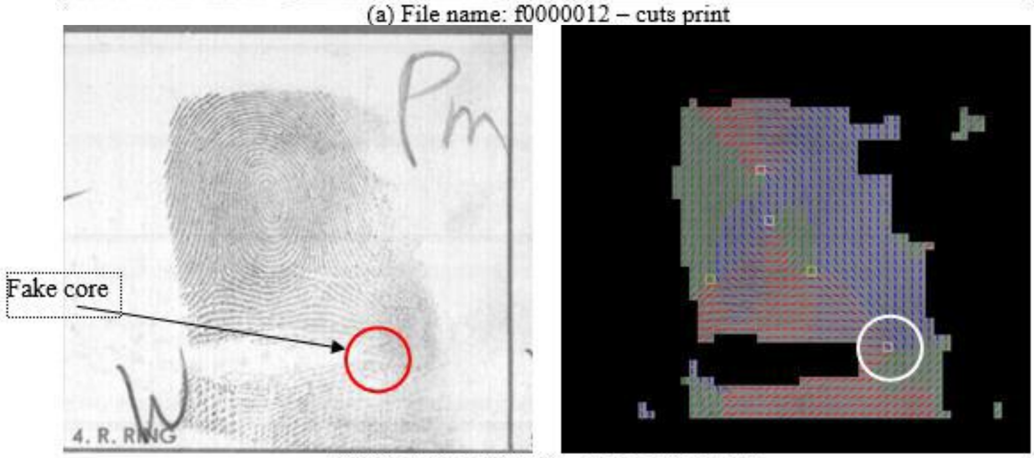


Figure 10. The result of the enhancement process for low contrast fingerprint

Overall, based on Figure 5 – 10 the performance of the proposed method is qualitatively satisfactory. Generally, orientation fields' structures are closely resemblance to the original ridge pattern especially surrounding the singular points' region, which is considered as a vital area for post-processing. Meanwhile, for certain cases such as wet, cuts and low contrast; the orientation fields structure sometimes does not reflect true gradient of ridges structure. However, this situation is acceptable if the effected area is beyond singular points' region. On the contrary, in some extreme cases whereby the estimated orientation fields' structure formed an artificial singular point region that leads to fake core or delta, are considered unacceptable (see Figure 11 (a),(b)). Thus, an additional tool is required to handle the situation.



(a) File name: f0000012 – cuts print



(b) File name: f0002084 – low contrast print

Figure 11. Artificial singular point regions

Furthermore, for the quantitative performance measurement, mean square error (MSE) is used for the evaluation [13][16]. The MSE represents cumulative squared error between the enhanced image and the original image. A lower value of MSE signifies a lesser error in the enhanced image, and vice versa.

In relation to that, Figure 12 provides a comprehensive comparative performance of enhancement methods between the proposed technique and Wang based on the MSE values [10], which is in accordance to the quantitative points of view. For this purpose, 100 fingerprint images of the NIST-DB14 Database i.e. f0000001 to f0000100 were used. Overall, the result has been revealed that MSE obtained by the proposed method is lower as compared to Wang. This implies that the performance of the proposed enhancement method is superior to Wang.

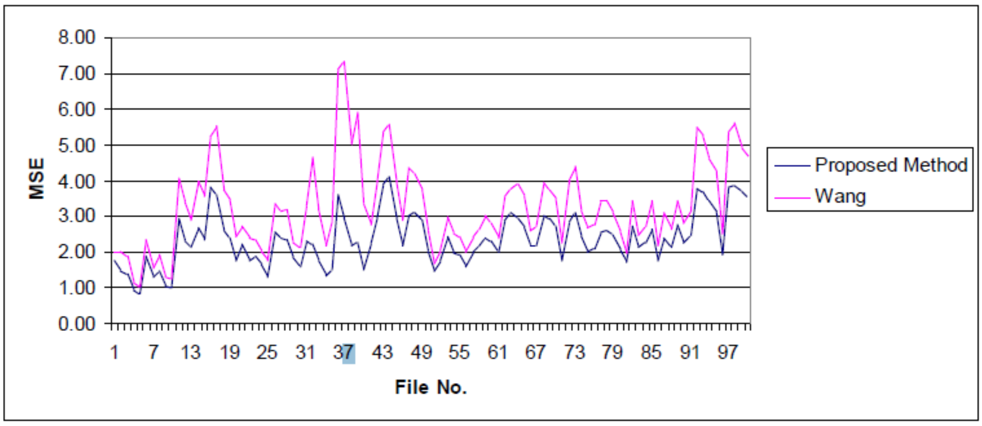


Figure 12. Mean square error results of both Wang and the proposed methods

5 CONCLUSION

On the base of gradient magnitude features, the new algorithm to the enhancement of fingerprint image for the estimation of orientation fields is proposed. This technique has successfully enhanced the ridges structure in the noise areas in foreground of the fingerprint image. Experiments show that our algorithm is improved compared to other method. Overall, the proposed enhancement technique has performed exceptionally well in most cases especially for good, dry, wet, and bruises prints.

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