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A Technique to Improve Ridge Flows of Fingerprint Orientation Fields Estimation

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Abstract

An accurate estimated fingerprint orientation fields is a significant step for detection of singular points. Gradient-based methods are frequently used for estimating orientation fields but those methods are sensitive to noise. Fingerprints that perfect quality are seldom. They may be corrupted and degraded due to impression conditions or variations on skin. Enhancement of ridge flows improved the structure of orientation fields and hence increased the number of true singular points thereby conducting the overall performance of the classification process. In this paper, we provided discussion on the technique and implementation to improve local ridge flows of fingerprint orientation fields. That main technique have four steps; firstly, fingerprint segmentation; secondly, identification of noise areas and marking; thirdly, estimation of fingerprint orientation fields, and finally, enhancement of ridge flows using minimum variance of the cross centre block direction in squared gradients. A standard fingerprint database is used for testing of proposed technique to verify the tier of effectivity of algorithm. The experimental results suggest that our enhanced algorithm achieves visibly better ridge flows compare to other methods.

Keywords*: orientation fields, enhancement of ridge flows, cross centre block (CCB)*

1. Introduction

The skin on fingers shows a flow like pattern of ridges. This pattern of ridges on each finger is unique, permanent and immutable. The structural features of these ridges, such as the overall global pattern of ridges, singularity regions i.e. core and delta, ridge shape, width, minutiae i.e. ridge ending and bifurcation and sweat pores are used as characteristics of classification and identification to distinguish between two fingerprints or find out the similarity between them.

Topologically, fingerprint image often viewed as oriented textures by assuming local ridge flow. There are two types of ridge flows i.e. the pseudo-parallel ridge flows and high-curvature ridge flows. The pseudo-parallel ridge structures are coarsely determined by estimating of orientation fields and high-curvature ridge flows, which are located around the singular points. The orientation fields belong to the set of features that can be detected at the global feature, which describes one of the basic structures of a fingerprint image. Orientation fields contain information about the local average directions of fingerprint ridges.

Most of the existing fingerprint classification methods make use of the orientation fields [1]. The accuracy of orientation field estimation is crucial to fingerprint classification, which is an essential step toward large-scale fingerprint related system [2]. However, fake orientation fields are inevitable due to skin or impression conditions, etc. Low-quality regions pose a great threat to both feature extraction and fingerprint classification, as their positions and size are unpredictable.

Excellent quality of fingerprint 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

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fingerprint image, enhancement of ridge flows is needed to improve the clarity and continuity of the ridge structures.

This paper presents a new method for enhancement of ridge direction in order to estimate fingerprint orientation fields. The process involved four main parts namely, segmentation foreground and background, identification of noise areas and marking using gradient coherence, orientation field estimation using gradient-based approach, and enhancement of ridge direction using proposed method. The rest of the paper is organized into sections. Section 2 is the related work of the study, which is followed by proposed method in section 3, while the results of the experiments are explained in detail in section 4. The summary and concluding remarks are given in section 5.

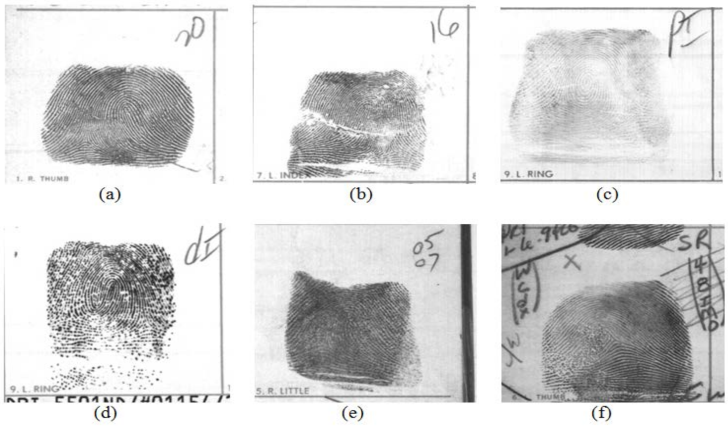


Figure 1. Quality of fingerprint image: (a) Good, (b) Broken/cut, (c) Low contrast, (d) Dry, e) Wet, and (f) Stain

2. Related work

The orientation field can be used for a variety of purposes, such as singular points detection and others feature extraction. Varieties of the methods for orientation field estimation are known from literatures, which include gradient-based approaches, filter-bank based approaches, and model-based approaches. Compared with the other two kind methods, gradient-based methods are more accurate and subtle [3].

However, the gradient-based methods also have their drawbacks. Since gradient is usually computed on a pixel level, the method is quite sensitive to noise. Therefore, post processing techniques, such as smoothing and blurring, are needed for enhancement ridge direction [4]. Up to now, various methods have been proposed for enhancement ridge direction, and can be classified as filtering-based approaches and diffusion-based approaches [2].

2.1. Orientation Field Estimation using Gradient Based Approach

The purpose of the orientation field estimation is to determine the global structure and direction of the ridges in the fingerprint image. Instead of computing local ridge orientation at each pixel, most of the fingerprint processes estimate the local ridge orientation at discrete positions based on block of pixels. This obviously reduces computational efforts and complexity. The simplest and efficient way to extract the ridge orientation is by computing the gradient of each block of pixels of the fingerprint image [5].

The orientation of the fingerprint image is computed in non-overlapping blocks by examining the gradients of each pixel intensities in the x and y directions within the block. The ridge flow direction at every pixel (i, j) consists of angle $\theta_{xy}(i, j)$ indicating the direction of flow with respect to the horizontal axis. Since opposite ridge flow directions are equivalent, $\theta_{xy}(i, j)$ is uniquely determined only in $[0, \pi]$.

The gradient is two-dimensionally equivalent to the first derivative and is defined as the vector.

$$G[F_{xy}(i,j)] = \begin{bmatrix} G_x(i,j) \\ G_y(i,j) \end{bmatrix}, \quad (1)$$

Where $G_x(i,j) = \partial f / \partial x$ and $G_y(i,j) = \partial f / \partial y$ components are the derivatives of F in $[x_i, y_j]$ with respect to the x and y directions in the Cartesian system, respectively. It is well known that the gradient phase angle denotes the direction of the maximum pixel-intensity change and magnitude of the gradient is defined as the square root of the number of gradient direction with respect to the x and y directions. Gradient component derivatives are approximated through many operator, one of which is the most commonly used Sobel operator [6].

The above method, although simple and efficient, has some disadvantages. First, using the Sobel operator to estimate component $G_x(i,j)$ and $G_y(i,j)$. Furthermore, computing $\theta_{xy}(i,j)$ as the arctangent of the $G_y(i,j)/G_x(i,j)$ ratio, presents problems due to the non-linearity and discontinuity at 90^o. Second, single orientation estimation reflects the ridge-valley direction at too-fine-scale and is generally very sensitive to the noise.

The above problems can be reduced by doubling the gradient angles and performing average separately on the cosine and sine phases [5]. For the purpose of doubling the angles and squaring the length, the gradient vector is converted into the polar system, which is given by $G_x(i,j) = r\cos\theta_{xy}(i,j)$ and $G_y(i,j) = r\sin\theta_{xy}(i,j)$ where $-\frac{1}{2}\pi < \theta_{xy} \le \frac{1}{2}\pi$. Thus, Equation (1) can be written as:

$$G[F_{xy}(i,j)] = \begin{bmatrix} r\sin 2\theta_{xy}(i,j) \\ r\cos 2\theta_{xy}(i,j) \end{bmatrix}. \quad (2)$$

Ratta, *et al.,* in [7] obtained dominant direction in a 16×16 block using the following equation.

$$\theta_d = \frac{1}{2}\tan^{-1}\left(\frac{\sum_{i=1}^{16}\sum_{j=1}^{16} 2G_x(i,j)G_y(i,j)}{\sum_{i=1}^{16}\sum_{j=1}^{16} (G_x(i,j)^2 - G_y(i,j)^2)} \right), \quad (3)$$

Where $G_x(i,j) \neq 0$ and $G_y(i,j) \neq 0$. The angle θ_d is only quantized into 16 directions. Wang, *et al.,* used overlapping block and weighted averaging schemes to have improved the performance of a gradient-based method [8].

Bazen and Gerez in [9] have shown that the squared based method is equivalent to principal component analysis of the autocorrelation matrix of the gradient vector. Furthermore, they have designed a method to estimate the orientation field of fingerprint based on the principal component analysis. The method for extracting local ridge orientation is based on averaging squared gradient. Average gradient direction is $\theta_{xy}(i,j)$, with $-\frac{1}{2}\pi < \theta_{xy}(i,j) \le \frac{1}{2}\pi$.

2.2. Enhancement of Ridge Direction

Hong, *et al*., in [10] 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 $l \times w\,(32 \times 16)$ 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.

Liu, *et al*., in [11] used an orientation consistency that describes how well the orientations over a neighbourhood are consistent with the dominant orientation to smooth the orientation and reference-point localization. They claimed that adaptive smoothing method could not only attenuate well on the heavy noise but also maintain the orientation localization of high curvature area. The location of reference point and reference orientation of each fingerprint in data experiment is determined manually by researcher, so it can not be trusted for its accuracy.

Chikkerur, *et al.,* in [12] used a Gaussian kernel of size 3×3 to smooth the orientation image and smoothening kernel of size 3×3 applied repeatedly provides a better smoothening result than using a larger kernel of size 5×5 or 7×7. Results achieved for the matching accuracy for prints of poor quality is still not satisfactory.

Kass and Witkin in [5] pioneered the idea of filter-bank approach for orientation estimation although in implementation their method is quite different from the filter-bank one. In this method, the directional derivative is regarded as a random variable and the most reliable 'gradient' is estimated as the greatest variance of the directional derivative with solution as follows:

$$\theta_{KW} = \frac{1}{2}\tan^{-1}\left(\frac{W \otimes 2I_x I_y}{W \otimes (I_x^2 - I_y^2)}\right), \tag{4}$$

Where $W(x, y)$ represents a Gaussian filter, and $\otimes$ stands for convolution.

Wu, *et al.,* in [13] proposed fingerprint enhancement method based on integration of anisotropic filter and Directional Median Filter (DMF). The fingerprint images are first convolved with anisotropic filter then filtered by DMF. Eight DMF templates, with suitably pre-selected windows size W, 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.,* in [14] 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. The basic idea is to conduct redundant estimation over four overlapping neighbourhoods for each target block V. The concept is similar to Kuwahara filter [15]. For each of the four overlapping block marked $\mathrm{D}_1, \mathrm{D}_2, \mathrm{D}_3, \text{and } \mathrm{D}_4$ is determined coherence values $\mathrm{C}_1, \mathrm{C}_2, \mathrm{C}_3, \text{and } \mathrm{C}_4$. Then find the maximum value of coherences and assign the corresponding orientation angle to the target block.

Zhang and Yan in [2] proposed a constrained Delaunay triangulation (CDT) based orientation interpolation method. The focus is on the representation of the fingerprint images to reflect the randomness and irregularity of corrupted regions in fingerprint images.

3. Proposed Method

Basically, a new scheme of enhanced fingerprint orientation fields is proposed based on minimum variance of squared gradients. With regard to this, there are four processes, which include: foreground extraction, identification and marking of noise areas, estimation of orientation fields, and enhancement of ridge direction in the noise areas. The basic idea of the ridge direction enhancement method is to find the minimum variance among the four directions of squared gradients. Furthermore, replacing the gradient values at the center block with the mean value for which variance attains its minimum value.

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. The proposed extraction begins with normalization of the fingerprint's intensity values by adopting normalization approach in [16]. 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. Let $I(m,n)$ denote the grey-level or intensity value of the pixel at the *m*-th row and *n*-th column of $W \times H$ pixels of fingerprint image size. Let Mg and Vg denote the global mean and global variance values of fingerprint image, respectively. Calculate the normalized grey-level value $N(m,n)$ at pixel (m,n) of fingerprint image.

Once the normalised grey-level values of the fingerprint image are obtained, the next process is to extract the foreground from the fingerprint image used method is proposed in [17]. A segmentation approach which combines local mean value of the normalised grey-level and local variance value of the gradient magnitude. 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. denoted by $Vgr(i,j)$) and threshold (i.e. G_{th} 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.

3.2. Noise Areas Identification and Marking Using Gradient Coherence

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 method used to identify noise areas and marking using gradient coherence is adopted from [18] and modified by the method in [8].

The larger value of gradient coherence 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 has 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 $B = 16$. 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. Next, gradient coherence $Coh(i,j)$ of each block at pixel (i,j) is calculated. An example of the resultant image after undergone the above process is given in Figure 2. In this case, $Coh(i,j) <= 0.5$.

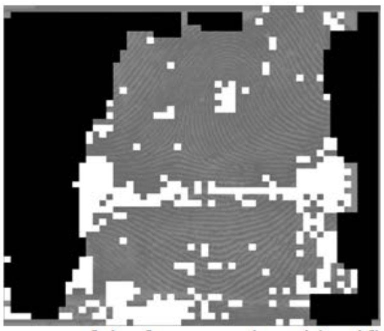


Figure 2. Noise areas of the foreground are identified and labeled;
The white coloured blocks indicate the noise areas

3.3. Orientation Fields Estimation

The purpose of the orientation field estimation is to determine the global structure and direction of the ridges in the fingerprint image. Instead of computing local ridge orientation at each pixel, most of the fingerprint processes estimate the local ridge orientation at discrete positions based on block of pixels. This obviously reduces computational efforts and complexity. The simplest and efficient way to extract the ridge orientation is by computing the gradient of each block of pixels of the fingerprint image. The accuracy of the orientation field is greatly relied on image quality and size of the block. The method used for orientation field estimation is adopted from [19], and also as follows.

1. Partition the foreground image into P blocks of $B \times B$ pixels.
2. Calculate $V_x(i,j)$ and $V_y(i,j)$ for each block using the equation.

$$V_x(i,j) = \sum_{u=i}^{i+B-1} \sum_{v=j}^{j+B-1} (G_x^2(u,v) - G_y^2(u,v)), \tag{5}$$

$$V_y(i,j) = \sum_{u=i}^{i+B-1} \sum_{v=j}^{j+B-1} 2G_x(u,v)G_y(u,v), \tag{6}$$

Where $G_x(u,v)$ 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 $B \times B$.

3. Calculate gradient angle $\theta(i,j)$ using the equation.

$$\theta(i,j) = \frac{1}{2}\arctan\left(\frac{V_x(i,j)}{V_y(i,j)}\right). \tag{7}$$

Then, the normalised form of $\theta(i,j)$ (i.e. angle beyond 180 degree is set to $0^o - 180^o$ accordingly) is given by:

$$\theta'(i,j) = \begin{cases} \theta(i,j) & \text{if} \quad V_x(i,j) > 0 \text{ and } V_y(i,j) \ge 0 \\ \theta(i,j) + \pi/2 & \text{if} \quad V_x(i,j) < 0 \text{ and } V_y(i,j) \ge 0 \\ \theta(i,j) + \pi/2 & \text{if} \quad V_x(i,j) < 0 \text{ and } V_y(i,j) \le 0 \\ \theta(i,j) + \pi & \text{if} \quad V_x(i,j) > 0 \text{ and } V_y(i,j) \le 0 \end{cases}. \tag{8}$$

4. Calculate smoothed orientation field using Gaussian filtering operator mask $Gs(p,q)$ (with $\sigma = 1.4$) as follows:

$$\theta''(i,j) = \frac{1}{2}\arctan\left(\frac{\sum_{p=-1}^{1}\sum_{q=-1}^{1} Gs(p,q) \times \cos(2(\theta'(i+p, j+q),}{\sum_{p=-1}^{1}\sum_{q=-1}^{1} Gs(p,q) \times \sin(2(\theta'(i+p, j+q).}\right). \tag{9}$$

5. Separate the orientation field into four regions that consist of ranges $0^o \le \theta''(i,j) < 45^o$ that is marked with red colour, $45^o \le \theta''(i,j) < 90^o$ yellow colour, $90^o \le \theta''(i,j) < 135^o$ blue colour, and $135^o \le \theta''(i,j) \le 180^o$ purple colour.

Normally, after the orientation field estimation, there are still remaining orientation fields that do not perfectly align with true ridges direction. This is due to the persistence of the noises. Therefore, an improved method is proposed. The proposed method is inspired by [8, 14] This method only focuses on the noise regions without encroaching rest of clean area of the fingerprint. Briefly process is referred in [20] and detailed process is as follows.

1. Input: noise areas obtained from section 3.2.
2. Let orientation field $\theta''(i,j)$ obtained from equation (9).
3. Create an array of one dimension $Q=\{\varphi_0,\varphi_1,\varphi_2,...,\varphi_{H^2-1}\}$, whose elements represent the values of orientation field $\theta''(i,j)$ for each pixel in CCB. Define $Q_1,\ Q_2,\ Q_3,$ and Q_4 as subsets of Q as in equation below.

$$\left.\begin{array}{r} Q_1=\{\varphi_k\in Q\,|\,k=(u-1)(H+1)\},\\ Q_2=\{\varphi_k\in Q\,|\,k=\dfrac{(H-1)}{2}+(u-1)H\},\\ Q_3=\{\varphi_k\in Q\,|\,k=(H-1)u\},\\ Q_4=\{\varphi_k\in Q\,|\ k=\dfrac{H(H-1)}{2}+(u-1)\},\end{array}\right\}, \quad (10)$$

Where $u=1,2,3,...,H$.

4. In this case, $H=3$. Figure 3 shows subsets $Q_1=\{\varphi_0,\varphi_4,\varphi_8\}$, $Q_2=\{\varphi_1,\varphi_4,\varphi_7\}$, $Q_3=\{\varphi_2,\varphi_4,\varphi_6\}$, and $Q_4=\{\varphi_3,\varphi_4,\varphi_5\}$ in the CCB of size 3×3.

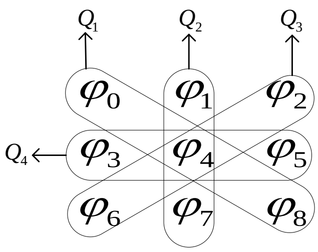


Figure 3. A 3×3 CCB of orientation field

5. Calculate mean and variance of orientation fields $Ma|Q_l$ and $Va|Q_l$ for $l=1,2,3,4$ of orientation fields in each CCB using the following equations:

$$Ma|Q_l=\frac{\sum_{u=1}^{H}\varphi_k|Q_l}{H}, \quad (11)$$

$$Va|Q_l=\frac{\sum_{u=1}^{H}(\varphi_k|Q_l-Ma|Q_l)^2}{H}. \quad (12)$$

6. Replace orientation field at the centre block $\varphi_{\frac{(H-1)(H+1)}{2}}$ with $Ma|Q_l$ for which $Va|Q_l$ attains its minimum value. So that mathematically,

$$\varphi_{\frac{(H-1)(H+1)}{2}}=Ma|Q_l,\ \text{if}\ \min_{l=1,2,3,4}(Va|Q_l) \quad (13)$$

7. Calculate smoothed orientation image, $V_x^{'''}(i,j)$ and $V_y^{'''}(i,j)$, using Gaussian filtering operator mask with a $\sigma = 1.4$.

$$V_x'''(i,j) = \sum_{p=-1}^{1} \sum_{q=-1}^{1} Gs(p,q) \times V_x''(i+p, j+q), \tag{14}$$

$$V_y'''(i,j) = \sum_{p=-1}^{1} \sum_{q=-1}^{1} Gs(p,q) \times V_y''(i+p, j+q). \tag{15}$$

8. The final smoothed orientation field $\theta^{'''}(i,j)$ at each block of fingerprint image is defined as:

$$\theta'''(i,j) = \frac{1}{2}\arctan\left(\frac{V_y^{'''}(i,j)}{V_x^{'''}(i,j)}\right). \tag{16}$$

Figure 4(a)-(c) shows the fingerprint image that original, before enhancement and after enhancement using minimum variance of orientation fields, respectively. In the Figure 4(b), there are many false singular points, while in Figure 4(c), core and delta can be detected correctly.

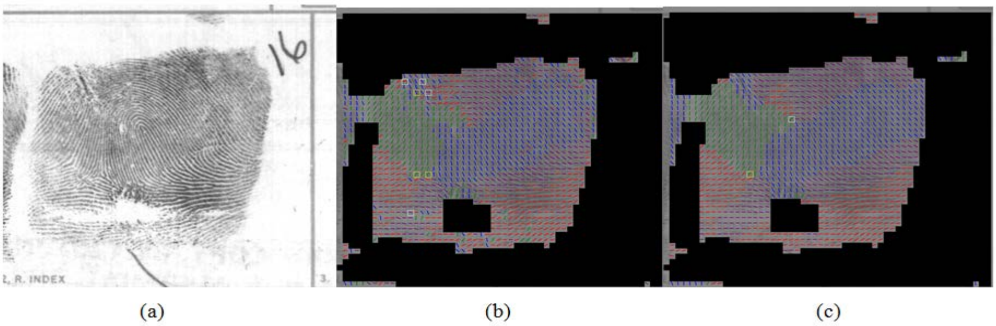


Figure 4. Result of the enhancement process in the noise areas (a) Original image, (b) Orientation image before enhancement, (c) Orientation image after enhancement

4. Results and Analysis

An enhancement of ridge flows 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 [1]. Evaluation for the ridge enhancement process can be done either qualitatively or quantitatively, by evaluating the performance measurement of orientation field [3] or minutiae detection [4, 16]. 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.

Since no ground truth exits for the evaluation of estimating fingerprint orientation fields, the measurement of objective error cannot be easily constructed [7, 8]. Therefore, the noise resistance is often evaluated by manual observation for fingerprint orientation estimates.

We have used standard fingerprint database NIST Database 14 for testing of proposed algorithm to verify the degree of efficiency of algorithm. Figure 5 to Figure 10 show some results of the ridge enhancement process in terms of orientation fields' structure points of view.

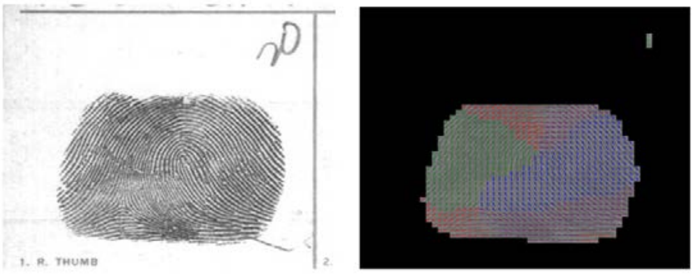


Figure 5. The result of the enhancement process for good quality fingerprint

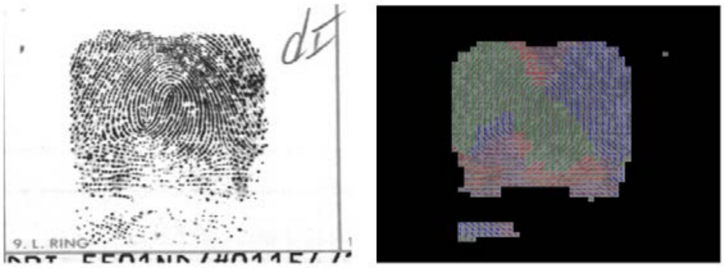


Figure 6. The result of the enhancement process for dry fingerprint

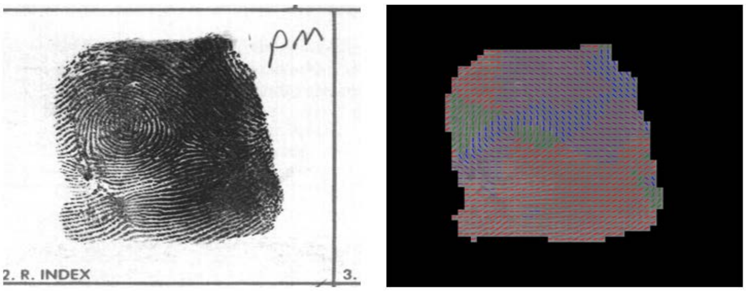


Figure 7. The result of the enhancement process for wet fingerprint

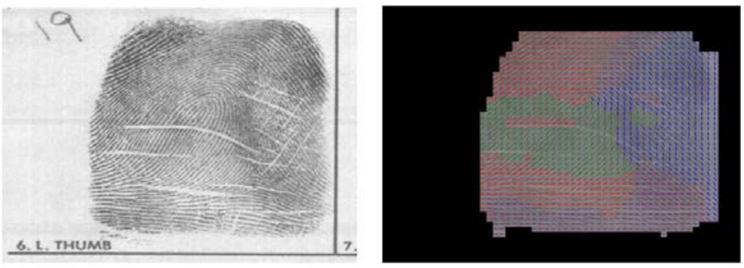


Figure 8. The result of the enhancement process for cuts fingerprint

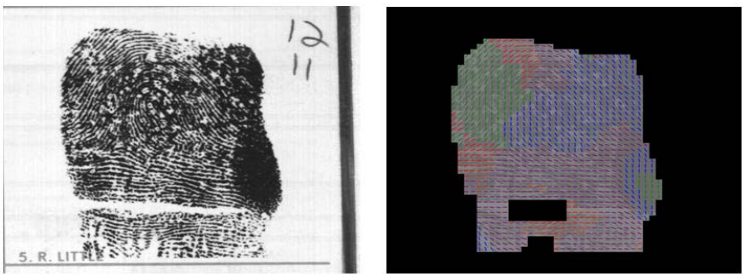


Figure 9. The result of the enhancement process for bruises fingerprint

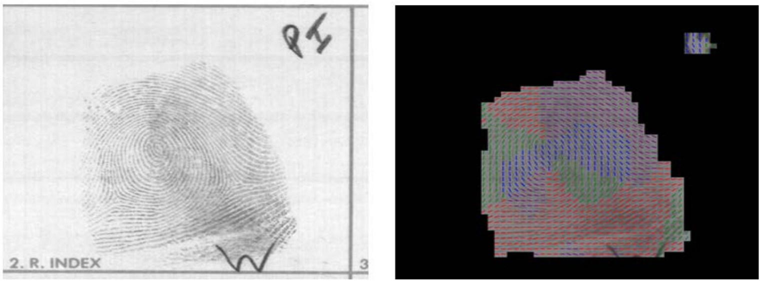
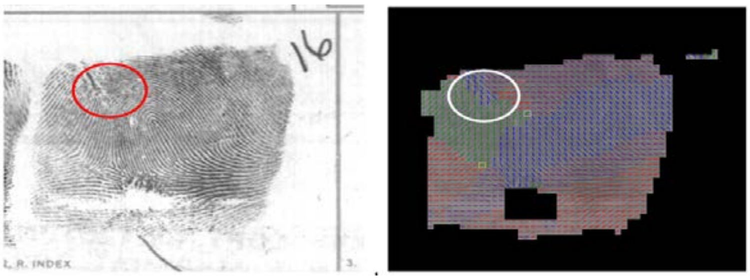
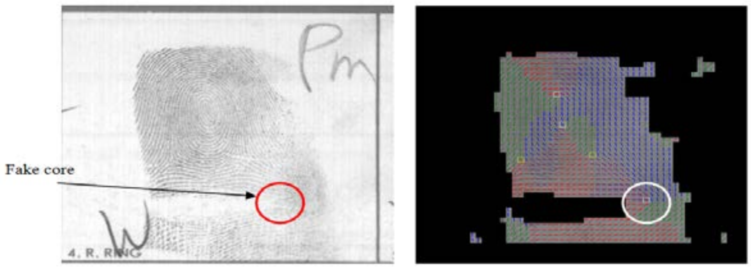


Figure 10**.** The result of the enhancement process for low contrast fingerprint

Overall, based on Figure 5-10 the performance of the proposed method is qualitatively satisfactory. Generally, orientation fields' structures are closely resembled 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 field 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 [21, 22]. 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, *et al.,* in [8, 13] based on the MSE values, which is in accordance to the quantitative points of view. For this purpose, 100 fingerprint images i.e. f0000001 to f0000100 were used. Overall, the result has revealed that MSE obtained by the proposed method is lower as compared to Wang, *et al*. This translates that the performance of the proposed enhancement method is superior to Wang, *et al*.

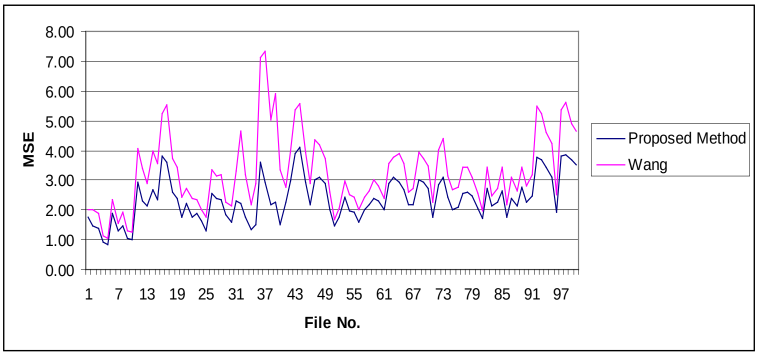


Figure 12. Mean square error results of both Wang, *et al*., and the proposed methods

As for the quantitative performance evaluation, the same assessment criteria that have been used in the singular point detection are also applied here [18]. In addition, for the sake of benchmarking, the method of singular points detection in [19] with preceded proposed method is compared with the lone Poincarè index approach with preceded Wang method [8, 13] that has been employed by the majority in this field.

Table 1. Comparison results of singular points detection

Methods	MC (%)	MD (%)	FC (%)	FD (%)
Poincaré index method with preceded Wang method in [8, 13]	4.96	9.47	27.37	20.90
Method in [19] with preceded proposed method	4.81	16.39	5.86	2.11

Where MC: Miss Rate of Cores (i.e. discarded true cores), MD: Miss Rate of Deltas (i.e. discarded true deltas), FC: False alarm rate of Cores (i.e. falsely accepted cores), and FD: False alarm rate of Deltas (i.e. falsely accepted deltas).

In order to accomplish the task, an experiment was conducted using 500 fingerprints viz. f0000001 to f0000500 and the results are compiled in Table 1. The results have shown that the proposed method has outperformed the Wang method in term of False alarm rate on both core and delta. However, the MD is worsened, and this is due to the fact that in most cases, deltas are situated close to the border of the foregrounds. In other words, the area could not be reached by the algorithm when seeking for the singular point.

5. Conclusion

On the base of variance of squared gradient magnitude, the new algorithm for the enhancement of ridge direction 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 the proposed algorithm can improve the acquisition of true singular points and eliminate fake singular points. Overall, the proposed enhancement technique has performed exceptionally well in most cases especially for good, dry, wet, and bruises prints.

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