

PERFORMANCE EVALUATION OF FIELD SMOOTHING FILTERS

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ABSTRACT

In this paper, we propose a performance evaluation of orientation field smoothing according to the application of two different filters; average filter and Gaussian filters. Each is investigated at different sizes. The finding is that by applying the filters size of 2-4 times of ridges spacing, the orientation field can be smoothed with less distortion. Gaussian filter seems to offer slightly better performance compared to an average one. Success in core point detection using Poincare technique is used to measure the filtering performance.

Keyword: Fingerprint, type of filter, field smoothing, enhancement, core point detection.

1. INTRODUCTION

Fingerprint is one of the most important biometric technologies. This is because it holds many desirable features such as universality, permanence, collectability, and distinctiveness. Personal identification based on fingerprint matching is now popular in wide range of applications. Most automatic fingerprint identification systems are based in minutiae matching [1, 2, 3]. Frequency domain content also applicable in such a purpose [4].

A fingerprint is the pattern of ridges and valleys on the surface of a fingerprint. Minutiae are local discontinuities in the fingerprint pattern. The most important ones are ridge ending and ridge bifurcation. Spurious ridge structure may change the individuality of input fingerprints. Ridges and valleys in a local neighborhood form a sinusoidal-shaped plane wave, which has a well-defined frequency and orientation. The core point has played important roles in many fingerprints identify techniques. The success of the identification (or matching) process is very much relied on the image quality. In many cases, fingerprints are with numerous discontinuous ridges (dry, wet, damped, scars and smudges). The main difficulty for feature extraction is that fingerprint quality is often too low, thus noise and contrast deficiency can produce false minutiae or hide

valid ones. Even high quality images can also yield false minutiae, for example, when the person has cuts or scars in his/her fingers.

There appear many algorithms and techniques proposed and applied to fingerprint image enhancement: using Fourier transform [5], Gabor filters [2], Wavelet transform [6], and minutiae filtering, applied to binary [7] or gray-scale images [8]. The goal of an enhancement algorithm is to improve the clarity of ridge structures of fingerprint images in recoverable regions and to remove the unrecoverable regions.

Core point and delta point are ones of fingerprints' features that commonly used in fingerprint classification [9,10,11,12]. Classification process is of more importance when one wants to search a particular pattern in a large database. There are also many techniques used in searching for the corepoint; for instance, direction of curvature (DC), geometry region (GR), and poincare method. Among these, poincare technique can also detect a delta point. The Poincare technique accomplishes its task by checking the field orientation around the considering point. The success of point identification is solely depended on the correctness of the field orientation. In many cases, fields are distorted by the discontinuity of the ridges. Smoothing the field is then helpful when one tries to eliminate the alias points created according to field distortion.

The orientation field can be reliably estimated using 2-D low pass filter, gradient based approach and filter based approaches [4]. The filter based approaches are good as accurate as gradient based because of number of filters window size is so large and the local ridge orientation (field smoothing) varies slowly in a local neighborhood where no core point appears. The discontinuity of ridge and valley due to noise and blur an image can be removing by applying a Gaussian low pass filter. The Average (mean) filter smooth fingerprint image data, thus eliminating noise. This filter performs spatial filtering on each individual pixel in an image using the grey level values in a square or rectangular window surrounding each pixel.

Gabor filter, on the other hands, depends very much on the orientation and ridge frequency. Because the local

orientation changes very rapidly in the core point area, we almost cannot make it accurate. So, the result of enhancement in the core point is fairly poor. There comes the need of prior field smoothing. Hence, there have been many methods attempt to solve this problem. In particular case, Hong et al. [4] proposed a decomposition method to estimate the orientation field from a set of filtered images obtained by applying a bank of Gabor filters on the input fingerprint images.

In this paper, we propose core point detect method where the field smoothing enhancement is needed in prior. In section 2, we review fingerprint enhancement steps as follows: normalization, type of filter, orientation field, ridge frequency and direction filter. In section 3, we review an algorithm used for core point detection, a Poincare technique. In section 4, we compare the obtained results indicating the performance of applying the local enhancement, and finally we concluded the paper in section 5.

2. FINGERPRINT ENHANCEMENT

Many acquired fingerprint images may accompany noises, and also may be are of low quality such as dry, wet, damped, scars, smudges and so on. In most case, the degradation occurs in part. Without any attempts, it is hard to identify the core point and minutiae of such images with those degradations.

2.1 Normalization

Let, $I(i, j)$ denote the gray-level value at pixel (i, j) , M and Var denote the estimated mean and variance of image I , respectively, and $N(i, j)$ denote the normalized gray-level value at pixel (i, j) . The normalized image is defined as [12]:

$$N(i, j) = \begin{cases} M_0 + \sqrt{\frac{Var_0(I(i, j) - M_i)^2}{V_i}} & \text{if } I(i, j) > M \\ M_0 - \sqrt{\frac{Var_0(I(i, j) - M_i)^2}{V_i}} & \text{otherwise} \end{cases} \quad (1)$$

Where, M_0 and Var_0 are the desired mean and variance values, respectively. In this work, we set values mean $M_0 = 0.5$ and variance $Var_0 = 1$. The mean and variant of a gray-level fingerprint image with the dimension of $M \times N$ pixels, are defined respectively as:

2.2 Type of Filters

Orientation field tends to be broken for the disconnected ridge. Spurious may also well observed for the fairly dry image. These are considered as noise. These noises can be removed by applying a low pass filter. At this state we are considering average filter and Gaussian filter to tune up the field orientation.

2.2.1 Average Filter

The average filtering is simply to replace each pixel value in an image with the average (mean) value of its

neighbors, including itself. This has the effect of eliminating pixel values which are unrepresentative of their surroundings. Average filtering is usually thought of as a convolution filter. Like other convolutions it is based around a kernel, which represents the shape and size of the neighborhood to be sampled when calculating the average. All element of the matrix *i.e.* a_{ij} is 1.

$$G(x, y) = \left(\frac{1}{m}\right)^2 \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \quad (2)$$

2.2.2 Gaussian Filter

The Gaussian filter is used as a low pass filter to blur an image. The Gaussian filter is to use this 2-D distribution as a point-spread function, and this is achieved by convolution. Since the image is stored as a collection of discrete pixels we need to produce a discrete approximation to the Gaussian function before we can perform the convolution. In theory, the Gaussian distribution is non-zero everywhere, which would require an infinitely large convolution kernel, but in practice it is effectively zero more than about three standard deviations from the mean, and so we can truncate the kernel at this point. σ

$$G(x, y) = \left(\frac{1}{2\pi\sigma}\right)^2 \exp\left\{-\frac{(x^2 + y^2)}{2\sigma^2}\right\} \quad (3)$$

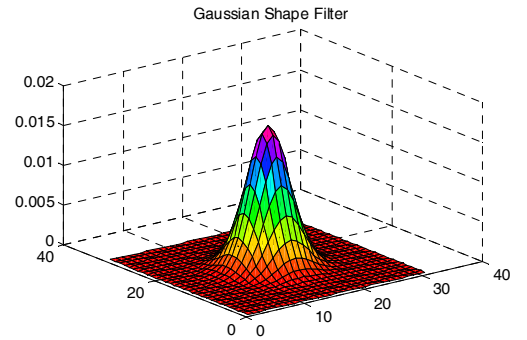


Figure 1. Gaussian filter

2.3 Orientation Field

The ridge's orientation is an intrinsic character of the fingerprint image and the pixel, an orientation image, θ , where $\theta'(i, j)$ represents the local ridge orientation at pixel (i, j) . Local ridge orientation is usually specified for a block rather than at every pixel; an image is divided into a set of $w \times w$ non-overlapping blocks and a single local ridge orientation is defined for each block. Note that in a fingerprint image, there is no difference between a local ridge orientation of $\pi/2$ and $3\pi/2$, since the ridges oriented at $\pi/2$ and the ridges oriented at

$3\pi/2$ in a local neighborhood cannot be differentiated from each other.

2.3.1 Field Estimation

A number of methods for orientation field estimation have been proposed [2] to estimate the orientation of fingerprint. In this paper, the smoothed orientation field based on least mean square algorithm is summarized as follows:

Divide the input image I into consecutive (non-overlapping) blocks with size $w \times w$.

Compute the x and y magnitude of the gradients $[(V_x(i, j)$ and $V_y(i, j)]$, at each pixel $\partial_x(u, v)$ and $\partial_y(u, v)$ in x and y directions respectively

Apply the 2D Low Pass Weiner filter, to reduce noise from the fingerprint image, on the x and y gradients.

$$V_x(i, j) = \sum_{u=i-w/2}^{i+w/2} \sum_{v=j-w/2}^{j+w/2} 2\partial_x(u, v)\partial_y(u, v), \quad (4)$$

$$V_y(i, j) = \sum_{u=i-w/2}^{i+w/2} \sum_{v=j-w/2}^{j+w/2} 2\partial_x^2(u, v)\partial_y^2(u, v), \quad (5)$$

Estimate the local orientation of each block centered at pixel (i, j) using the following equations.

$$\theta(i, j) = \frac{1}{2} \tan^{-1} \left\{ \frac{V_y(i, j)}{V_x(i, j)} \right\} \quad (6)$$

Where, $\theta(i, j)$ is the least square estimate of the local ridge orientation of the block centered at pixel (i, j) .

2.2.2 Field Smoothing

At this state, the local ridge orientation (field smoothing) varies slowly in a local neighborhood where no core point appears. The discontinuity of ridge and valley due to noise can be softening by applying a low pass filter.

Apply a 2-D Gaussian low pass filter the orientation image must be converted to a continuous vector field, which defined as bellows:

$$\Phi_x(i, j) = \cos\{2\theta(i, j)\}, \text{ and } \Phi_y(i, j) = \sin\{2\theta(i, j)\}, \quad (7)$$

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

With the resulted vector field, the filters can be performed.

$$\Phi'_x(i, j) = \sum_{u=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} \sum_{v=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} G(u, v) \cdot \Phi_x(i - uw, j - vw), \quad (8)$$

$$\Phi'_y(i, j) = \sum_{u=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} \sum_{v=-\frac{w_\Phi}{2}}^{\frac{w_\Phi}{2}} G(u, v) \cdot \Phi_y(i - uw, j - vw), \quad (9)$$

here $G(u, v)$ is a two dimension specified filter of the size $w_\Phi \times w_\Phi$.

The smoothed orientation field (local ridge orientation at (i, j)) can then be computed as follows:

$$\theta(i, j) = \frac{1}{2} \tan^{-1} \left(\frac{\Phi'_y(i, j)}{\Phi'_x(i, j)} \right) \quad (10)$$

2.3.3 Ridge Frequency

In the gray-level fingerprint image, a long ridge and valley can be model as a sinusoidal-shaped wave along the direction perpendicular to the local ridge orientation. Let $N(i, j)$ be the normalized image and $\theta'(i, j)$ be the smoothed orientation field image, and then the steps involved in local ridge frequency estimation are as follows.

Divide image $N(i, j)$ into blocks of size $w \times w$, 5×5 , centered at pixel (i, j) .

For each block centered at the pixel (i, j) , compute an oriented window of size $l \times w$ (32×5).

For each block centered at pixel (i, j) , compute the x -signature, $X[0], X[1], \dots, X[l-1]$ of the ridges and valleys with the oriented window, where

$$X[k] = \frac{1}{w} \sum_{d=0}^{w-1} N(u, v), \quad 0 \leq k \leq l-1 \quad (11)$$

and the co-ordinates,

$$u = i + (d - \frac{w}{2}) \cos \theta'(i, j) + (k + \frac{1}{2}) \sin \theta'(i, j) \quad (12)$$

$$v = j + (d - \frac{w}{2}) \sin \theta'(i, j) - (k - \frac{1}{2}) \cos \theta'(i, j) \quad (13)$$

If there are no minutiae and core points in the local oriented window, the x -signature forms a sinusoidal-shape wave, which has the same frequency as that of the ridges and valleys in the oriented window x -signature. Let $T(i, j)$ be the average number of pixels between two consecutive peaks in the x -signature, then the frequency, $f(i, j)$, is computed as:

$$f(i, j) = \frac{1}{T(i, j)} \quad (14)$$

If no consecutive peaks can be detected from the x -signature, then the frequency is assigned a value of -1 to differentiate it from the valid frequency values.

For the FBI scanning standard of 500 dpi, this ranges is 1/3 to 1/25. Therefore, if the estimated value of the frequency is out of this range, then the frequency is assigned a value of -1 to indicate that a valid frequency cannot be obtained.

If the x -signature does not form a well-defined sinusoidal wave, the estimated frequency of the block is rejected. If there are not too many of these blocks, their

local frequencies can be interpolated from the frequencies of the neighboring blocks.

2.4 Directional Filtering

In normal fingerprint image, the sinusoidal-shaped waves of ridges and valleys vary slowly in a local constant orientation. Therefore, a band-pass filter that is tuned to the corresponding frequency and orientation can efficiently remove the undesired noise while preserving the true ridge and valley structures. The Gabor filter have both frequency-selective and orientation-selective properties and have optimal joint resolution in both spatial and frequency domains.

$$h(x, y : \phi, f) = \exp\left[-\frac{1}{2}\left(\frac{x_\phi^2 + y_\phi^2}{\delta_x^2 + \delta_y^2}\right)\right] \cos(2\pi f x_\phi) \quad (15)$$

where

$$x_\phi = x \cos \phi + y \sin \phi \quad (16)$$

$$y_\phi = -x \sin \phi + y \cos \phi \quad (17)$$

Where, ϕ is the orientation of the Gabor filter, f is the frequency of a sinusoidal plane wave, δ_x and δ_y are the standard deviations of the Gaussian envelope along x and y axes, respectively.

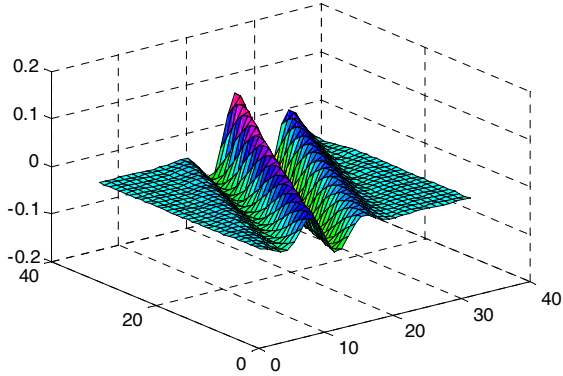


Figure 2. Gabor filter

2.5 Segmentation

The process is employed to extract the printed image from its background. The consecutive block of 15×15 pixels was designed in this study.

3. CORE POINT DETECTION TECHNIQUES

The core point is generally recognized as the top-most point that the ridges making turns. In order to detect the fingerprint center point area, we first locate the core point corresponding to the uppermost point contained in the inner-most ridge line. There exist several techniques for core point detection. They are; for instance; Poincare index (PC), Direction of curvature (DC), and Geometry region (GR). Each holds its individual complexity and performance.

3.1 Poincare Index Technique (PC)

The Poincare index technique is fairly simple and suitable for both core point and delta point identification. Upon the availability of estimated orientation field $\theta'(i, j)$ given above, for the pixel in the sub block centered at (i, j) we can compute Poincare index, $PC(i, j)$, for particular number of point N_p .

$$PC(i, j) = \frac{1}{2\pi} \sum_{k=0}^{N_p} \Delta(k) \quad (18)$$

$$\Delta(k) = \begin{cases} \delta(k) & \text{if } |\delta(k)| < \pi/2 \\ \pi + \delta(k) & \text{if } |\delta(k)| < -\pi/2 \\ 0 & \text{otherwise} \end{cases} \quad (19)$$

and,

$$\delta(k) = \xi(x_{(k+1) \bmod N_p}, y_{(k+1) \bmod N_p}) - \xi(x_k, y_k), \quad (20)$$

The number of points used in our experiment is 8. The core point should yield the Poincare index 0.5. If the Poincare index is less than -0.5 then such a block is the delta block.

4. EXPERIMENT & RESULTS

We used the downloaded DB1_A of FVC-2004 as our database in this study. Captured with optical sensor, "V300" by CrossMatch, an image size is of 640×480 pixels with 500 dpi resolutions. In our experiment we randomly chose 104 fingerprint images; all are with core point. In the process of field smoothing, two types of filter, namely, average filter and Gaussian filter were investigated; each at different window size, from 3×3 to 45×45 pixels. Gabor filter is used in the directional filtering process. The performance if the filter is measured by the success in core point locating. Illustrated in Fig. 3, we can see that the field smoothing could have a vital impact on field orientation rectifying.

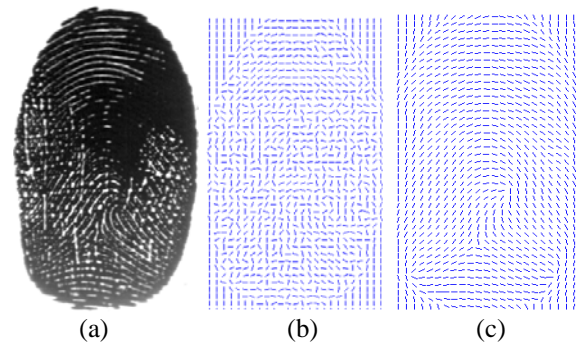


Figure 3. Filtering effects (a) original image (b) corresponding orientation field, and (c) orientation field after the application of Gabor filtering

Core point detection results of the fingerprints image with already at high quality is shown in Fig. 4. In Fig. 4

(a) and (b), are the resulted core point detection of no-enhancement images whilst (c) and (d), are the corresponding images but with directional filtering enhancement. It is clear that the enhancement is not so helpful in this case. This is because the images are already at high quality.

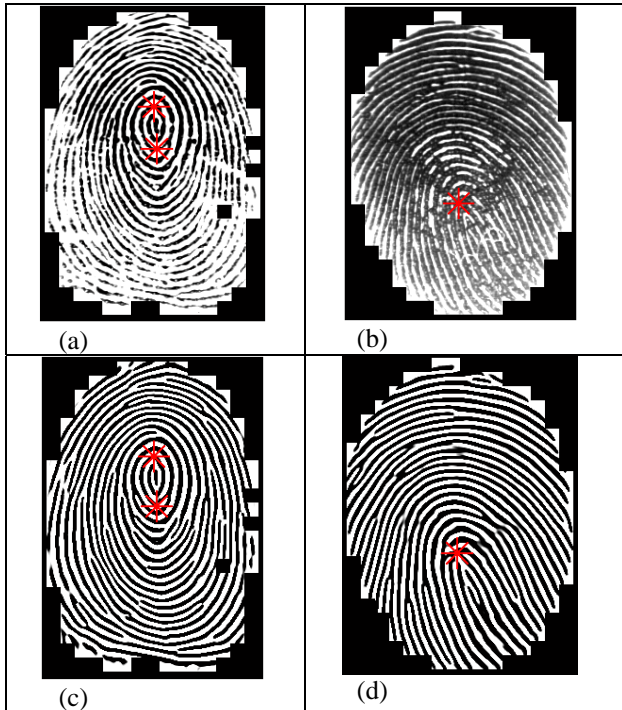


Figure 4. Core point detection results of high quality fingerprints image; (a) without enhancement and (b) with enhancement.

In contrast when the images are of low quality, the enhancement by directional filter is essentially useful. This is illustrated in Fig. 5. Shown in (a) and (b), the algorithm has detected many wrong core points when the images are not filtered. However those alias points can be reduced dramatically when the same images are enhanced. These are shown in Fig. 5; (c) and (d). In this particular case, Gaussian filter with the window size of 31×31 pixels was applied in the field smoothing process.

Further investigation to those 104 images, 40 images hold 2 core points (dual core) and 64 images hold single core point (many of them in this group hold left-loop and right-loop patterns). To investigate the proper window size of the filter, we counted the number of alias core points while changing the filter size. Results taken upon dual core group and single core group are shown in Fig. 6 and Fig. 7 respectively.

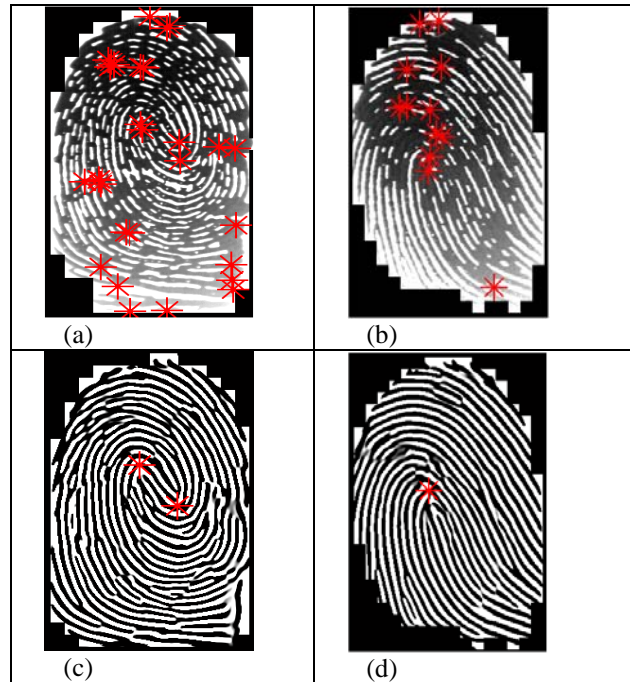


Figure 5. Core points detection results of some fingerprints image: Shown in the first row, (a) and (b) are images with no enhancement. Shown in the second row; (c) and (d) are the corresponding images, but with the application of orientation field smoothing and directional enhancement.

In both cases, Gaussian filter is slightly better than average filter. The filtering effect of both types did not shown much improvement when the window size is over 31×31 pixels. However, we have noticed that when the filter window size is too large (more than 45×45 pixels), the filtered image is deteriorated as the detected core point seems to drift apart (for the dual core images).

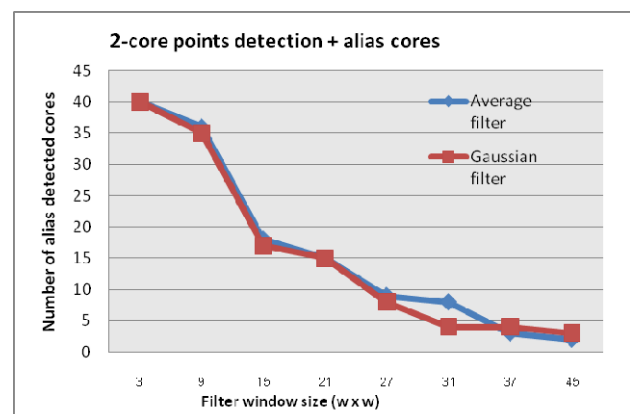


Figure 6. Alias core points versus filter window size. Images are 2-core point fingerprint pattern (Whorl). Total is 40 images.

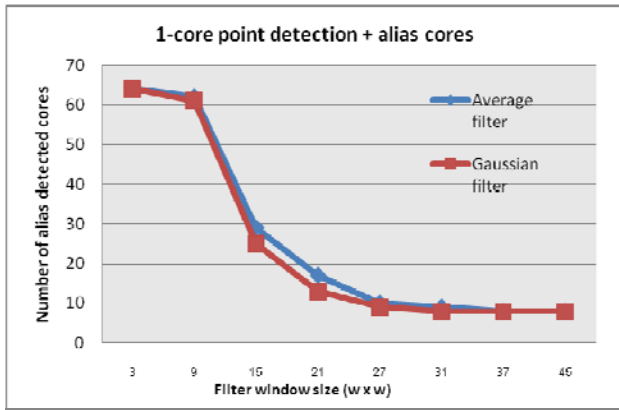


Figure 7. Alias core points versus filter window size. Images are single-core point fingerprint pattern (left-loop or right-loop). Total is 64 images.

One may also notice that we cannot get the number of alias core point down to zero, and even worse we also got a number of wrong located core points in our experiment. This is true. The main reason is that some images are of so poor quality. They are beyond the performance of the enhancement process. The cases are shown in Fig. 8. We still need more procedure to eliminate these alias points.

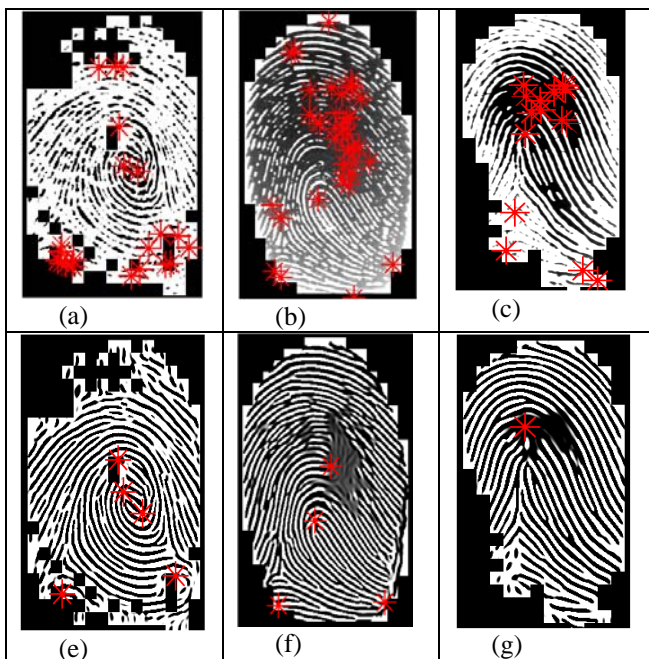


Figure 8. Example of very poor quality images. Shown in the first row, (a), (b) and (c) are images with no enhancement and the second row are those with the application of enhancement.

5. CONCLUSION

Average filtering and Gaussian filtering for field smoothing are investigated in this work. A Gaussian filter is slightly superior compared to an average filter at all window size. Filtering effect becomes stable when the window size is greater than 31×31 pixels. The smaller

window size cannot rectify well the noisy field. As a result many alias core points still left. The too large window size is also not desirable as the filter ridge seems to separate apart. The right core point detection together with directional filtering are useful in fingerprint matching in the frequency domain. Both core point and delta point detection are useful in fingerprint classification.

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REFERENCES

- [1] A. Jain, L. Hong, and R. Bolle, "On-line fingerprint verification," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 19(4):302–313, April 1997.
- [2] L. Hong, Y. Wan, and A. Jain. "Fingerprint image enhancement: Algorithm and performance evaluation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 20(8):777–789, August 1998.
- [3] Y. He, J. Tang, X. Luo, and T. Zhang, "Image enhancement and minutiae matching in fingerprint verification," *Pattern Recognition Letters*, 24, 2003.
- [4] A.K. Jain S. Prabhakar L. Hong and S. Pankanti, "Filterbank-Based Fingerprint Matching," *IEEE Trans. Image Processing*, vol. 9, no. 5, pp. 846-859, 2000.
- [5] B. G. Sherlock, D. M. Monroe, and K. Millard. "Fingerprint enhancement by directional Fourier Filtering," *IEEE Proceedings in Visual Image Signal Processing*, 141(2):87–94, April 1994.
- [6] M. Tico, P. Kuosmanen, and J. Saarinen "Wavelet Domain Features for Fingerprint Recognition," *Electronic Letter*, Vol.37, No.1, Jan. 2001.
- [7] A. Farina, Z.M. Kovacs-Vajna, and A. Leone, "Fingerprint minutiae extraction from skeletonized binary images," *Pattern Recognition*, 32(5):877–889, 1999.
- [8] D. Maio, D. Maltoni, "Direct Gray-Scale Minutiae Detection in Fingerprints," *IEEE Trans. Pattern Anal. Machine Intell.*, Vol. 19, No. 1, pp. 27-40, 1997.
- [9] A. K. Jain, S. Prabhakar and L. Hong, "A Multichannel Approach to Fingerprint Classification," *IEEE Trans. on PAMI*, Vol.21, No.4, pp. 348-359, April 1999.
- [10] Sen Wang, Wei Wei Zhang, Yang Sheng Wang, "Fingerprint Classification by Directional Fields", *Proc. 4th IEEE Int. Conf. on Multimodal Interfaces (ICMI'02)*, 2002.
- [11] A. Julasayvake and S. Choomchuay, "A Combined Technique in Fingerprint Core Point detection," *Proc. Of Int. Workshop on Advanced Image Technology 2007*, Thailand, January 2007, pp. 556-560
- [12] A. Julasayvake and S. Choomchuay, "An Algorithm for Fingerprint Core Point detection," *Proc. of Int. Symp. on Signal Processing and its Applications 2007 (ISSPA-2007)*, United Arab Emirates, February 2007.

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