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Analysis of the Influence of Non-Directional Algorithms on Fingerprint Image Enhancement

M. Kocevar[1], S. Klampfer[1], A. Chowdhury[1,2,3], Z. Kacic[2]
[1]*Margento R&D d.o.o.,*
Gosposvetska cesta 84, 2000 Maribor, Slovenia
[2]*Faculty of Electrical Engineering and Computer Science,*
Smetanova 17, 2000 Maribor, Slovenia
[3]*Faculty of Energy Technology,*
Koroska cesta 62a, 3320 Velenje, Slovenia
marko.kocevar@margento.com

***Abstract*—Fingerprint image enhancement is of key importance for the efficiency of the automated fingerprint identification system. Before we can enhance a fingerprint image with contextual filters, we need to enhance fingerprint image contrast and readability with non-directional filters. This article provides an analysis of the influence of non-directional image enhancement techniques in the fingerprint image pre-processing step. To perform the analysis we used global normalization algorithm, local normalization algorithm, Wiener filter, histogram equalization algorithm and median filter. To evaluate the equal error rate in the experiments, done on a public database FVC_2004, we used Gabor filter and a state-of-the-art two-stage algorithm.**

***Index Terms*—Image processing, image enhancement, fingerprint recognition, Gabor filters.**

I. INTRODUCTION

In the spatial domain we can divide fingerprint image enhancement algorithms as follows: non-directional filtering, one-directional filtering and two-directional filtering. Non-directional filtering techniques, such as histogram equalization [1], normalization [2], Wiener filtering [3], and median filtering [1] are because of the non-stationary nature of the image efficient only in the pre-processing step and in particular enhance the image contrast and readability, but they do not change ridge structures which are deformed because of noise or other external factors.

That is, the fingerprint stays "the same" throughout one's life, but different factors may influence it: injuries, sensor noise, sweat, fingerprint wear due to old age, etc. The above mentioned factors may lead to a non-match of two same fingerprints, which consequently leads to an inefficient automated fingerprint identification system. Therefore it is necessary to enhance the image to the point where we can obtain a clearly defined structure of ridges and valleys on the basis of which we can correctly determine fingerprint features.

One-directional and two-directional filters differ from non-directional filters according to the mode of filtering; directional filters function on the principle of contextual filtering, where filter characteristics change according to the local context, which is in a fingerprint image often defined with local ridge frequency and orientation. Usually filter parameters are pre-calculated and then chosen for a particular image area.

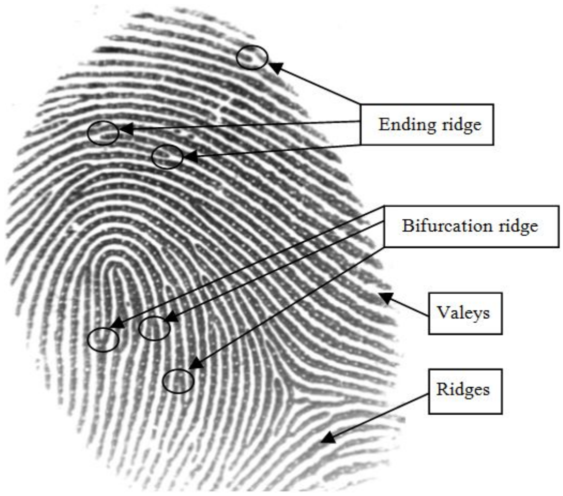

Fig. 1. Bifurcation and ending ridges.

A fingerprint consists of a structure of ridges and valleys (Fig. 1), the features or minutiae of which are most often used for determining a match between two fingerprints; minutiae where ridges end, and minutiae where ridges divide into two (Fig. 1). Because the efficiency of contextual filters highly depends on the fingerprint image contrast, fingerprint images need to be first enhanced with non-directional filters. This article presents an analysis of fingerprint image's contrast and readability enhancement with global normalization algorithms, local normalization, histogram equalization, Wiener filtering and median filtering.

The second section provides a review of certain non-directional pre-processing enhancement techniques, the third section describes fingerprint image enhancement with

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contextual Gabor filter, the fourth section describes fingerprint image enhancement with a two-stage algorithm, the fifth section presents experimental results, and the final section sums up the conclusions.

II. FINGERPRINT IMAGE PRE-PROCESSING

This section presents and briefly describes non-directional fingerprint image enhancement techniques.

A. Global Normalization

Normalization is a procedure with which we determine the greyscale levels' values of image elements in a fingerprint image.

With global normalization [2] we get a new intensity value for each individual pixel with the following equation

$$G(i,j)=\begin{cases} M_0+\sqrt{\dfrac{VAR_0(I(i,j)-M)^2}{VAR}} & P\ (i,j)>M, \\ M_0-\sqrt{\dfrac{VAR_0(I(i,j)-M)^2}{VAR}} & \text{otherwise.} \end{cases} \quad (1)$$

where M and VAR are the average and the variance of the fingerprint image respectively, and M_0 and VAR_0 are the desired mean value and variance, determined on the basis of empirical data ($M_0=0, VAR_0=100$).

B. Local Normalization

Local normalization [4] is performed for each individual pixel according to the local area of block $w \times w$ of the size $w=8$ pixels. Local normalization is more efficient than global normalization but the time needed for processing is significantly longer with local normalization.

C. Wiener Filtering

Wiener filtering [1] works on the basis of adaptive pixel-wise technique for removal of image noise. The filter determines the mean value and the standard deviation of fingerprint image pixels, using the neighbouring pixels of size 3×3.

$$w(n_1,n_2)=« +\frac{±^2-v^2}{±^2}\left(I\left(n_1-n_2\right)-«\right), \quad (2)$$

where v^2 is noise variance, $«$ is local mean value, and $±^2$ is the standard deviation of the greyscale image I in the area $n_1, n_2 \in «$.

D. Histogram Equalization

Histogram equalization [1] is a technique which enhances image contrast by equalizing greyscale image intensity. The greyscale image consists of 256 grey levels or tones. Image histogram is a graphic presentation of grey tones (x-axis) and the number of pixels for each tone (y-axis). Because grey levels are in the histogram figure unevenly distributed, we can enhance the image contrast with histogram equalization, so that we get a histogram which has a 5 equal distribution of all grey levels.

The function which equalizes the histogram is a cumulative histogram function, shown in (3).

$$s=f(r)=\int_0^r h_t(t)dt, \quad (3)$$

where h_t is the original image.

Equation (3) presents function's continuous form and (4) presents function's discrete form, used in digital imaging.

$$s=f(r)=\int_0^r \sum_{i=0}^{r} h_t(i). \quad (4)$$

E. Median Filter

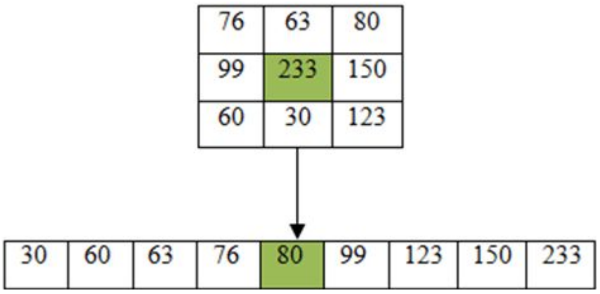


Fig. 2. Median filtering of an image with mask size 3 × 3.

Median filter [1] is used for elimination of picture noise and is based on neighbouring pixels. Figure 2 shows the functioning of a median filter with mask size 3×3 and the value of the centre pixel 233, which is replaced with value 80.

III. GABOR FILTER IMAGE ENHANCEMENT

Fingerprint image enhancement with Gabor filter was first presented in [2]. Gabor filter is contextually directed filter, which has both orientation and frequency characteristics, as well as optimal total resolution [5], [6]. In a fingerprint image context is presented with ridge frequency and orientation. Two-dimensional Gabor filter is defined with the following parameters ($f, ¯, ±_x, ±_y$)

$$h[x,y:¯,f]=\exp\left\{-\frac{1}{2}\left[\frac{x^2}{±_x^2}+\frac{y^2}{±_y^2}\right]\right\}\cos\left(2® \cdot f \cdot x_0\right), \quad (5)$$

where $x_0 = x\cos¯ + y\sin¯$, $y_0=-x\sin¯ + y\cos¯$, $¯$ is filter orientation, $[x_0, y_0]$ are newly obtained coordinates, rotated in Cartesian axis by angle $(90^{\circ} - ¯)$ anticlockwise. f is sinusoidal wave frequency and $±_x$ and $±_y$ are standard deviations of the Gaussian envelope along x and y axes.

IV. TWO-STAGE ENHANCEMENT ALGORITHM

In [4] authors presented a two-stage algorithm for low-quality fingerprint enhancement on the basis of image learning. The image is first enhanced in the first stage (in the spatial domain) with ridge compensation filter, which improves ridge structure. Then the image is enhanced in the second stage (in the frequency domain) on the basis of learning from the original image and from the image enhanced in the first stage. In [7]–[9] authors proved that band-pass frequency filters effectively enhance a fingerprint image. In the frequency domain filter $H(\circ, \ddot{\ })$ is expressed in polar coordinates $(\circ, \ddot{\ })$ with two separate functions; in the radial $H_{\circ}(\circ)$ and angular $H_{\ddot{\ }}(\ddot{\ })$ domains, and is defined as follows

$$H(\circ, \ddot{\ }) = H_{\circ}(\circ) + H_{\ddot{\ }}(\ddot{\ }). \qquad (6)$$

In the two-stage algorithm radial filter is expressed as an exponential filter as shown in the equation below

$$H_{\circ}(\circ) = \frac{1}{\sqrt{2®}\circ BW} \exp\left(-\frac{(\circ - \circ_c)^2}{2\circ BW}\right), \qquad (7)$$

where $\circ_c$ is the central frequency and $\circ BW$ is filter bandwidth, determined with the following equation

$$\circ BW = \frac{C \times \circ_c - C}{\circ_c}, \qquad (8)$$

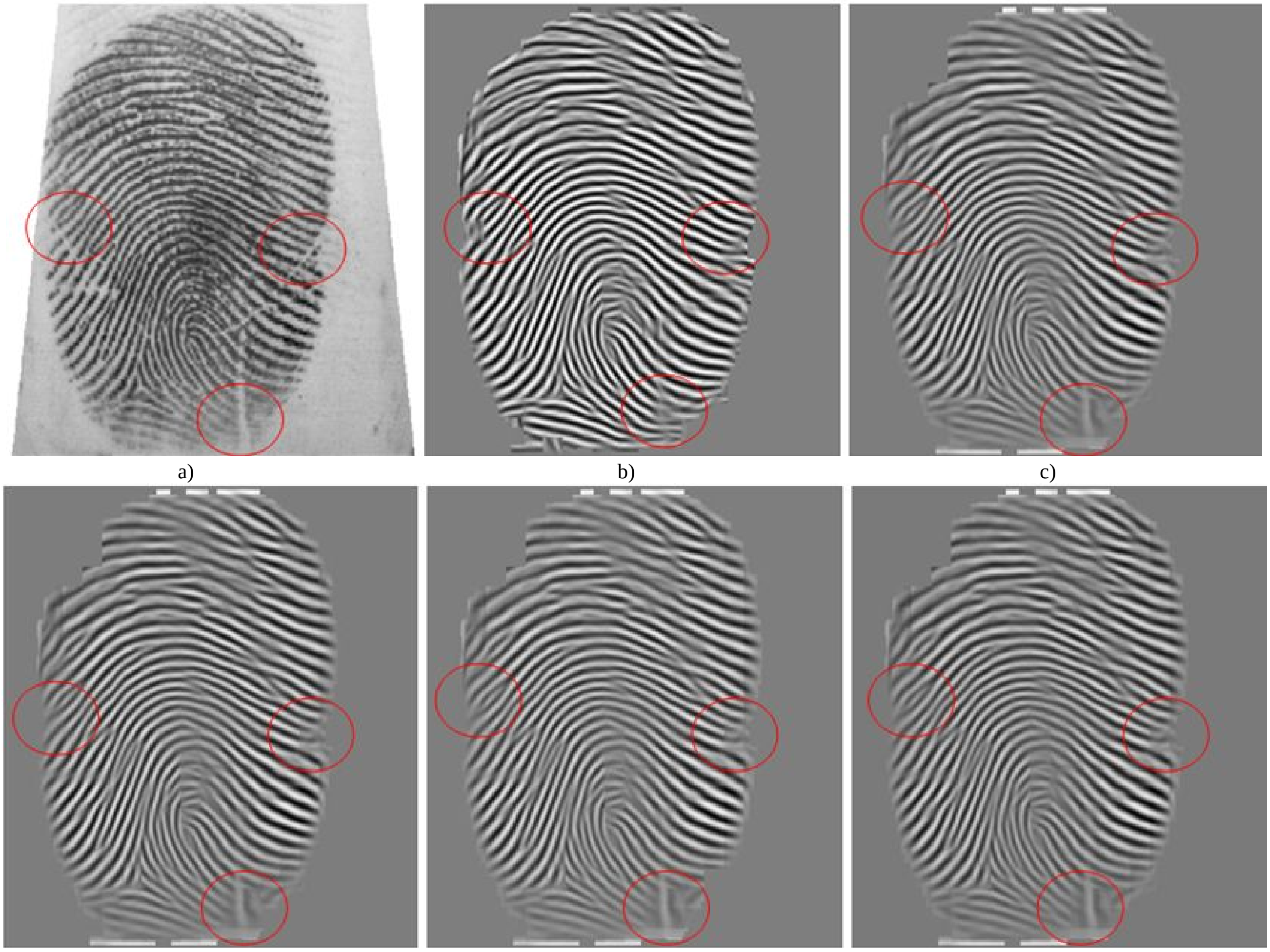
where C is the constant value. Exponential band-pass filter has in comparison with Buterworth filter faster and sharper suppression and is more efficient in removing noise [4]. Angular filter is an increased cosine filter (9), defined in the angular domain with centre orientation $\ddot{\ }_c$ and angular bandwidth $H_{\ddot{\ }}(\ddot{\ })$.

$$H_{\ddot{\ }}(\ddot{\ }) = \begin{cases} \cos^2 \frac{®}{2} \frac{(\ddot{\ } - \ddot{\ }_c)}{\ddot{\ }\mathrm{BW}}, & if\ |\ddot{\ }| < \ddot{\ } BW, \\ 0, & \text{otherwise}. \end{cases} \qquad (9)$$

V. EXPERIMENTAL RESULTS

Experiments were performed on database FVC_2004 [10] consisting of 4 sub-bases. DB1_A, DB2_A, DB3_A, DB4_A. Each sub-base includes 800 fingerprints, out of which 8 are of the same person. In sub-bases DB1_A and DB2_A fingerprint images were captured with an optic sensor, in sub-base DB3_A with a thermal sweeping sensor and in the sub-base DB4_A fingerprint images were artificially generated with SfinGe generator. For algorithm implementation we used the software MATLAB 2009 and a computer with the following characteristics:

– Processor: Intel (R) Core (TM) i7–2600K CPU @ 3,40 GHz 3.70 GHz
– RAM: 16 GB
– OS Type: 64-bit MS WINDOWS 7.



a) b) c) d) e) f)

Fig. 3. a) original image FVC_2004, DB2_A 2.4.tif; b) local normalization + Gabor; c) global normalization + Gabor; d) histogram equalization + Gabor; e) Wiener filter + Gabor; f) median filter + Gabor.

We assessed the efficiency of the verification system using FMR (False Match rate) and FNMR (False Non Match Rate) with the following equation:

$$FNMR = \frac{\text{Number of rejected genuine claims}}{\text{Total number of genuine accesses}} \times 100\%, \quad (10)$$

$$FMR = \frac{\text{Number of acepted imposter claims}}{\text{Total number of imposter accesses}} \times 100\%. \quad (11)$$

It needs to be noted that FMR is also known as FAR (false acceptance rates) and FNMR as FRR (false rejection rates). EER (Equal Error Rate) was used as a success rate indicator, marking the point where FNMR and FMR are equal [11]. The lower is the value of EER the more efficient is fingerprint image enhancement.

$$EER = \frac{\text{FMR} + \text{FNMR}}{2}, \text{ if } FMR = FNMR, \quad (12)$$

Figure 3 shows fingerprint image enhancement with non-directional enhancement techniques in combination with Gabor filter. Upon visual inspection of enhancement results (Fig. 3) we can notice substantial enhancement of ridge structures and image contrast with local normalization (Fig. 3(b)) in comparison with other non-directional filters. Red circle marks the influence of non-directional filters on the change of ridge structure and consequently on incorrectly determined features.

Figure 4 shows visual enhancement with non-directional filters in combination with a two-stage algorithm. In Fig. 4 we can notice that the visual image enhancement result with local normalization (Fig. 4(b)) is better than with other non-directional filters. The visual enhancement effect is especially noticeable in the image contrast (Fig. 4(b)) and in the fingerprint image area which cannot be corrected (red circle in Fig. 4(c)–Fig. (f).

Fingerprint image can be divided into good areas, correctable areas and non-correctable areas [2]. With experimental results we found that Wiener and median filters are inefficient in combination with contextual filters, as most structures of ridges and valleys falls into the non-correctable area, which is eliminated from the image. An example of such an enhancement effect is shown in Fig. 5, which presents a comparison between local normalization and Wiener filter.

a) b) c)

d) e) f)

Fig. 4. a) original image FVC_2004, DB2_A 2.4.tif; b) local normalization + two-stage algorithm; c) global normalization + two-stage algorithm d) histogram equalization + two-stage algorithm; e) median filter + two-stage algorithm, f) Wiener filter + two-stage algorithm.

a) b)

Fig. 5. a) Wiener filter + two-stage algorithm; b) two-stage algorithm with local normalization.

Wiener and median filter are used especially for image smoothing, which however results in inefficient contextual fingerprint image enhancement. As we wrote in the beginning, contextual filters function on the basis of determining ridge orientation. One of the most well-known and popular algorithms for determining ridge orientation is gradient procedure (e.g. Sobel algorithm). But gradient based determining of ridge orientation can also be inefficient because of inexpressive edges of ridges and valleys, since we smooth ridge and valley structures with smoothing filters in the pre-processing step.

Table I shows equal error rate evaluation for individual non-directional filtering techniques in combination with the popular Gabor filter and the state-of-the-art two-stage algorithm [4]. Because of a high number of deformed images in the public database FVC_2004 (Fig. 5(a)), we excluded equal error rate evaluation for Weiner and median filtering in connection with the two-stage algorithm. We need to also note that the two-stage algorithm uses the local normalization technique in the fingerprint image pre-processing step.

TABLE I. EQUAL ERROR RATE EER EVALUATION (%) ON A PUBLIC DATABASE FVC_2004 FOR NON-DIRECTIONAL ENHANCEMENT TECHNIQUES IN COMBINATION WITH GABOR FILTER [2] AND TWO-STAGE ALGORITHM [4].

FVC_2004	Compared algorithms	EER (%)	Processing time (s)
DB1_A	global normalization + Gabor	12.27 %	0.67 s
	local normalization + Gabor	10.89 %	16.13 s
	histogram equalization + Gabor	12.23 %	0.67 s
	Wiener filter + Gabor	12.48 %	0.74 s
	median filter + Gabor	13.54 %	0.65 s
	local normalization + two - stage	10.59 %	46.32 s
	global normalization + two - stage	24.68 %	32.53 s
DB2_A	global normalization + Gabor	11.17 %	0.37 s
	local normalization + Gabor	9.28 %	6.57 s
	histogram equalization + Gabor	11.59 %	0.40 s
	Wiener filter + Gabor	13.12 %	0.38 s
	median filter + Gabor	11.80 %	0.36 s
	local normalization + two - stage	8.33 %	17.86 s
	global normalization + two - stage	25.07 %	14.87 s
DB3_A	global normalization + Gabor	10.90 %	0.60 s
	local normalization + Gabor	9.48 %	8.35 s
	Histogram equalization + Gabor	12.14 %	0.47 s
	Wiener filter + Gabor	12.09 %	0.43 s
	median filter + Gabor	13.36 %	0.50 s
	local normalization + two-stage	9.54 %	34.25 s
	global normalization + two - stage	11.83%	15.32 s
DB4_A	global normalization + Gabor	13.39 %	0.41 s
	local normalization + Gabor	8.67 %	6.48 s
	histogram equalization + Gabor	13.40 %	0.36 s
	Wiener filter + Gabor	15.67 %	0.34 s
	median filter + Gabor	16.09 %	0.35 s
	local normalization + two - stage	10.90 %	25.96 s
	global normalization + two - stage	13.79 %	11.68 s

VI. CONCLUSIONS

This article presented an analysis of the influence of non-directional enhancement techniques in the fingerprint image pre-processing step. On the basis of experimental results we found that non-directional enhancement algorithms have a high influence on the efficiency of enhancement with contextual filters. Contrast enhancement algorithms, such as normalization and histogram equalization, are more efficient for fingerprint image enhancement in connection with a contextual filter, than Weiner or median filters, which are primarily intended for image smoothing and noise removal, such as "salt and pepper" noise removal. The best enhancement result with non-directional techniques is achieved with local normalization algorithm. Non-directional techniques, used for image smoothing, are inefficient in the fingerprint pre-processing step, especially because of inexpressive ridge edges, which are necessary for determining orientation of contextual filters.

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