ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2011. No. 1(107)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 170 ELECTRONICS
ELEKTRONIKA

Robust Fingerprint Enhancement by Directional Filtering in Fourier Domain

B. M. Popovic
Academy of Criminalistic and Police Studies,
Cara Dušana 196, 11080 Belgrade, Serbia, phone: +381 11 3161444, e-mail: brankica.popovic@kpa.edu.rs
M. V. Bandjur, A. M. Raicevic
The Faculty of Technical Sciences, University of Priština,
Kneza Miloša 7, 38220 K. Mitrovica, Serbia, phone: +381 28 425320, e-mails: milos.bandjur@yahoo.com, andjraic@eunet.rs

Introduction

Reliable and accurate automatic personal authentication introduces biometric technology as a necessary component of any ID management system, both in government and civil sector. Amongst available biometrics, fingerprints are one of the most researched and used method of authentication [1, 2]. There were different realizations of automatic fingerprint identification systems (AFIS) in the last 50 years. We can either digitalize fingerprint image taken by ink or use inkless scanners to provide input image for AFIS. A number of operations are then applied in order to extract features (mostly minutiae) later used in matching process, so it is obvious that the AFIS accuracy relies heavily on the reliability of those extracted features. As Pankanti et al. [3] have shown detected spurious minutia can be more harmful to reliable AFIS performance than missed genuine one, so it is imperative to minimize the number of spurious minutia to maximal extent.

In order to utilize AFIS in law enforcement agencies first step was (is) to digitalize an archive of fingerprints obtained by ink method. Quality of those fingerprint images greatly depends on equipment and technique that is used, but there are also a number of factors (postnatal marks, occupational marks, creases, etc.) that contribute to large number of spurious minutiae detected. To minimize that number, enhancement is usually performed before feature extraction. When dealing with a particular fingerprint image, i.e. latent, we can apply any of many digital techniques and filters, even combining and adjusting them for that particular case. But in case of making an database of fingerprint templates for AFIS from an archive of cards of fingerprints taken by ink, the process of automatic minutia extraction is rarely intervened by human expert, so an enhancement method need to be robust and applicable to a wide range of input images. Due to the fact that in local area of fingerprint image, ridges and valleys have well-defined frequency and orientation, majority of proposed enhancement techniques utilize this contextual information. Several filters were proposed in spatial [4, 5] and frequency [6–9] domain.

In this paper, a robust enhancement algorithm in Fourier domain is presented. It is based first on amplifying the dominant frequencies by a factor of raised power spectrum (noise reduction) and then by appropriate filtering with Log-Gabor filter (directional enhancement). We extended our research [10] with fingerprint images taken by ink to images obtained by inkless scanners, and method proves to be effective for both cases.

Directional filtering in Fourier domain

When dealing with filtering in Fourier domain we have two different cases. First is when the filter is designed in spatial domain and filtering is performed in Fourier domain (instead of spatial convolution methods). Another approach is to design filter and perform filtering both in Fourier domain which was the case in our research. Filter designed in frequency domain is described with separable radial (H_r) and angular (H_a) components and is tuned specifically to the distribution of orientation and frequencies in the local region of the fingerprint image. Radial component depends only on local ridge spacing ($r=1/f$) and the angular depends only on local ridge orientation (ϕ), so overall filter function is described as

$$H(r,\phi)=H_r(r)\cdot H_a(\phi). \quad (1)$$

Positional dependence of filters requires defining and applying appropriate filter for each pixel which is computationally very expensive. Instead, a finite number of predefined filters are usually applied (regarding to finite number of discrete orientations, and fixed or average frequencies).

Band-pass Butterworth filter as radial component, and raised cosine filter as angular component proposed by Sherlock et al. [6], and adopted in [7, 8] are found to give very good results. Gabor based filtering [5], as the most popular method in fingerprint enhancement, can also be performed in frequency domain, but has some limitations (maximum bandwidth of a Gabor filter is limited to approximately one octave). To overcome that limitation and promote filtering in frequency domain, the Log-Gabor filter is proposed [9].

Log-Gabor functions have Gaussian transfer functions when viewed on the logarithmic frequency scale. 2D Log-Gabor filter is constructed in the frequency domain, with radial and angular component given by (2), where (r, ϕ) represents the polar coordinates, f_0 is the center frequency of the filter, ϕ_0 is the orientation angle of the filter, σ_r determines the scale bandwidth and σ_ϕ determines the angular bandwidth

$$\begin{cases} H_r(r) = \exp(-\frac{\left[\log(r/f_0)\right]^2}{2\sigma_r^2}), \\ H_a(\varphi) = \exp(-\frac{(\varphi-\varphi_0)^2}{2\sigma_\varphi^2}). \end{cases} \qquad (2)$$

Comparing with Gabor filters, Log-Gabor filters can be constructed with arbitrary bandwidth which can be optimized to have minimal spatial extent and are allowed to reduce the over-representation of low frequencies, which is the reason why we choose them for our enhancement method.

Proposed algorithm

In order to perform fingerprint enhancement in frequency domain proposed algorithm consists of following steps: local normalization, local orientation and frequency estimation and local filtering which are briefly described. Previously, input fingerprint image is divided into a number of $B\times B$ (16×16 in our experiment) square non-overlapping blocks since each of mentioned steps regards to a block.

Local normalization

First step is to normalize fingerprint image in each block separately to a constant mean and variance. The main purpose of normalization is to have input images with similar characteristics, to remove the effects of sensor noise and also to reduce the variation in gray-level values along the ridges and valleys (without changing the ridge and valley structures). If normalization is performed on the entire image as suggested in [5], then it cannot compensate for the intensity variations in different parts of the image due to the elastic nature of the finger. Separate normalization of each individual block alleviates this problem. Local normalization of input fingerprint image is done as proposed in [8].

Local orientation and frequency estimation

Reliable ridge orientation estimation is very important when directional filtering is employed. We utilized Gradient–based approach for orientation estimation [11]. Orientation image is seldom computed at full resolution. Instead, one (dominant) orientation is assigned for each non-overlapping block of size B×B of the image in following way: for each pixel (i,j) of the block, horizontal and vertical component of the gradient, G_x and G_y respectively, are calculated. We can use any gradient operator (mostly simple Sobel operator). Then, dominant local orientation $O(i,j)$ for the block is given by

$$O(i,j) = \frac{1}{2}\tan^{-1}\left(\frac{\sum_B 2G_xG_y}{\sum_B G_x^2 - G_y^2}\right) + \frac{\pi}{2}. \qquad (3)$$

Additional smoothing (low pass filtering) must be applied on the orientation values in order to eliminate inconsistencies in distorted and noisy regions containing creases and scars. It is done by converting orientation image into a continuous vector field and by performing vector averaging with some smoothening kernel [8].

The ridge frequency as a slowly varying property can be computed only once for each non-overlapping block of the image. We adopted method presented in [5], based on the projection sum taken along a line oriented orthogonal to the ridges which forms a sinusoidal signal, and the distance between any two peaks provides the inter-ridge distance K. The frequency f is computed as $f = 1/K$. The local frequency and orientation estimated above correspond to the center frequency f_0 and the orientation angle ϕ_0 of the Log-Gabor filter.

Local filtering

Firstly we transformed the original fingerprint image to frequency domain. To reduce the computational cost, the windowed Fourier transform (2D WFT) is applied to each non-overlapping block of size $B\times B$ in order to extract corresponding frequency spectrum. To eliminate the effects result from the block dividing of the image, the window size W should be larger than the block size B. This means that the neighboring windows will overlay each other with OV number of pixels. In order to meet the requirement for recovering the image from frequency domain, a raised cosine window is employed and defined as in [7]:

$$W(x,y) = \begin{cases} 1, & if\,(|x|,|y|) < B/2, \\ \frac{1}{2}\left(1+\cos\left(\frac{\pi(x-B/2)}{OV}\right)\right), & otherwise, \end{cases} \qquad (4)$$

where $(x,y) \in \left[-\frac{W}{2}, \frac{W}{2}\right]$.

To reach a compromise between performance and complexity, the window size $W\times W$ was set to 32×32. By moving the location of the window, the frequency spectrum corresponding to each block of the image can be obtained. Then the power spectrum is estimated, raised to a power α (0.5 was used) and multiplied by the spectrum elements ($F1 = F\bullet|F|^{\alpha}$). This has the effect of amplifying the dominant frequencies in the block, which, presumably, are those corresponding to the ridges, thereby increasing the ratio of ridge information to non-ridge noise and adapting to variations in ridge frequency from one block to the next. Then, each spectrum is filtered by a Log-Gabor filter tuned according to the orientation and frequency of the corresponding block ($E=F_l \bullet H_r \bullet H_a$). Apparently, the filter is constructed with the same size of the spectrum. Finally, the inverse Fourier transform of the filtered spectrums is computed ($B_{enh}=IFT(E)$), and its real part becomes the enhanced block.

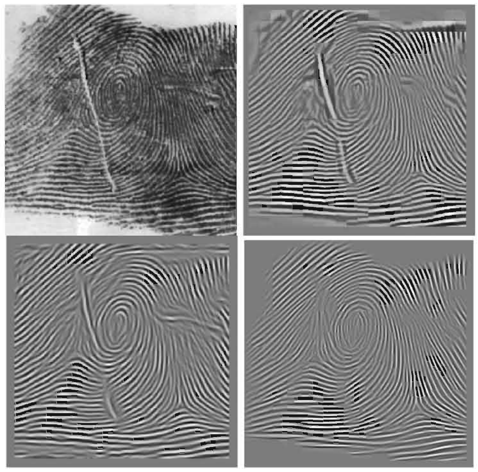
Experimental results

Our goal was to see if proposed enhancement algorithm is suitable to be implemented for various ranges of fingerprint images in process of creating AFIS template both for images obtained by ink and inkless scanners. Experiment was conducted on our own fingerprint database containing 100 fingerprint images (10 cards) taken by ink and then digitized with optical scanner using spatial resolution of 500 dpi and amplitude resolution of 8 bit per pixel. Second database [12] contains 168 fingerprint images obtained by optical scanner with same resolution (8 instances of 21 finger). Testing software was implemented using MATLAB® development environment (The Mathworks Inc., USA).

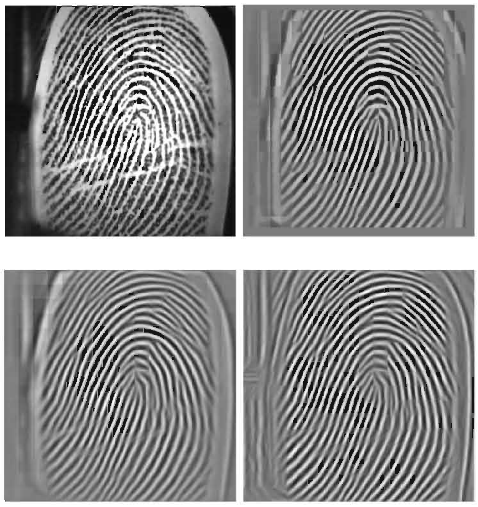
Result of proposed image enhancement method for test image from our database is shown in Fig. 1(a). We choose image containing scars (one quite wide) and smudgy regions in order to emphasize the enhancement results. For comparison the figure also shows two other images, enhanced with STFT method [7] (matlab code available from http://www.cubs.buffalo.edu/code.shtml) and with Gabor filter enhancement method [5] (Peter Kovesi's implementation code available at http://www.csse.uwa.edu.au/~pk/Research/MatlabFns/). Example demonstrates that proposed algorithm has preferable performance. Similar results were obtained for our entire database set with obviously enhanced ridge structure. In cases of images of relatively good quality all tested algorithms provide similar (comparable) results, as shown in Fig. 1(b) with sample fingerprint image taken from [12].

In order to quantify effect of enhancement, rather than to rely on subjective opinion (visual examination), we compared number of automatically extracted minutiae from original image and from enhanced one. Fingerprint Expert was previously asked to extract true minutiae from original fingerprint. We used algoritam presented in [13]. Results for image presented in Fig. 1 are compared in Table 1. E represents number of minutiae determined by the expert; A is the number of automatically extracted minutiae; P is the number of paired minutiae; M is number of missing minutiae and F is the number of false minutiae.

As result of proposed enhancement process there is significant decrease of number of automatically extracted minutiae and false minutiae (it goes up to 67% for some images from the database). Although directional filtering can reconnect ridges, some broad creases remains, resulting in false minutiae extraction. Rests of false minutiae are due to boundary effect and bad segmentation (especially for smudgy regions) and that will be the focus of our future work. Testing shall also be performed on larger fingerprint database (including public) in order to estimate more relevant statistical parameters for performance. Nevertheless, we can say that proposed method proves to be an adequate enhancement solution for AFIS since it provides significant reduction of extracted spurious minutiae.



(a) Original image from our database



(b) Original image taken from [12]

Fig. 1. Examples of enhanced images. From left to right: original image, image enhanced with STFT method, image enhanced with Gabor filter and proposed enhanced image

Table 1. Comparison of number of minutiae for various enhancement approaches

Enhancement method	Fig.	A	P	M	F	E
Without enhancement	1(a)	222	53	22	169	75
	1(b)	102	32	1	70	33
Gabor-based	1(a)	151	61	14	90	75
	1(b)	82	31	2	51	33
STFT	1(a)	138	63	12	75	75
	1(b)	60	33	0	27	33
Our proposed enhancement	1(a)	105	62	13	43	75
	1(b)	50	30	3	20	33

Conclusions

Fingerprint enhancement is a common and critical step in AFIS, and directional filtering technique, a general image-processing operation, is widely used for that purpose. Due to the characteristics of fingerprint image in frequency domain it seems natural to use directional band pass filter to enhance fingerprint image.

In this paper, method based first on amplifying the dominant frequencies by a factor of raised power spectrum (noise reduction) and then by appropriate filtering with Log-Gabor filter (directional enhancement), was found to produce preferable results for the fingerprints considered in this study. It is shown that filtering techniques work well in a broad range of cases, and is suitable for the quantity of fingerprints to be enhanced. As a result of enhancement process more reliable feature extraction is obtained, less spurious minutiae are extracted, improving the overall AFIS accuracy.

References

1. **Maltoni D., Maio D., Jain A. K., Prabhakar S.** Handbook of Fingerprint Recognition. – USA: Springer, 2003. –348 p.
2. **Ivanovas E., Navakauskas D.** Development of Biometric Systems for Person Recognition: Biometric Feature Systems, Traits and Acquisition // Electronics and Electrical Engineering. – Kaunas: Technologija. – 2010. – No. 5(101). – P. 87–90.
3. **Pankanti S., Prabhakar S., Jain A.** On the individuality of fingerprints // IEEE Trans Pattern Anal. Machine Intell, 2002. – Vol. 24. – No. 8. – P. 1010–1025.
4. **Gorman L. O' and Nickerson J. V.** An approach to fingerprint filter design // Pattern Recognition, 1989. – Vol. 22(1). – P. 29–38.
5. **Hong L., Wan Y., Jain A. K.** Fingerprint image enhancement: Algorithm and performance evaluation // IEEE Tran. Pattern Ana. Machine Intel, 1998. – Vol. 20, No. 8. – P. 777–789.
6. **Sherlock B. G., Monro D. M., and Millard K.** Fingerprint enhancement by directional Fourier filtering // Visual Image Signal Process, 1994. – Vol. 141. – P. 87–94.
7. **Chikkerur S., Cartwright A. N., and Govindaraju V.** Fingerprint enhancement using STFT analysis // Pattern Recognition, 2007. – Vol. 40. – No. 1. – P. 198–211.
8. **Raicevic A., Popovic B.** An Effective and Robust Fingerprint Enhancement by Adaptive Filtering in Frequency Domain // Facta Universitatis Series: Electronics and Energetics. – Niš, 2009. – Vol. 22. – No. 1. – P. 91–104.
9. **Wang W., Li J. W., Huang F. F., Feng H. L.** Design and implementation of Log–Gabor filter in fingerprint image enhancement // Pattern Recognition Letters, 2008. – Vol. 29. – P. 301–308.
10. **Popovic B.**, **Bandjur M., Raicevic A.,** Robust enhancement of fingerprint images obtained by ink method // Electronic Letters, 2010. – Vol. 46(20). – P. 1379–1380.
11. **Kass M., Witkin A.** Analyzing oriented patterns // Comput. Vision Graph. Image Processing, 1987. – Vol. 37. – P. 362–385.
12. **Biometric System Lab**., University of Bologna, Cesena Italy. Online: www.csr.unibo.it/research/biolab/.
13. **Popovic B.**, **Maskovic Lj**, **Bandjur M.**, Spurious Fingerprint Minutiae Detection Based on Multiscale Directional Information // Electronics and Electrical Engineering. – Kaunas: Technologija. – 2007. – No. 7(79). – P. 23–28.

Received 2010 07 05

B. M. Popovic, M. V. Bandjur, A. M. Raicevic. Robust Fingerprint Enhancement by Directional Filtering in Fourier Domain // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 1(107). – P. 37–40.

Reliable extraction of true minutiae in fingerprint image is critical to the performance of an automated fingerprint identification system (AFIS). In order to utilize AFIS in law enforcement agencies first step is to digitalize an archive of fingerprints obtained by ink method. For improving the quality of automatically extracted minutiae (both in number and type) enhancement is previously performed, but, nevertheless, quite a number of spurious minutiae (especially in blurry or regions containing scars and creases) are extracted. It is crucial for AFIS performance that number of extracted (and consequently saved in fingerprint template) spurious minutia is minimized to maximal extent. In order to do so, we propose directional Log-Gabor filtering in frequency domain. Results proved to be preferable for a wide range of input digitized fingerprint images. Ill. 1, bibl. 13, tabl. 1 (in English; abstracts in English and Lithuanian).

B. M. Popovic. M. V. Bandjur, A. M. Raicevic. Tiesioginio filtravimo taikymas Furjė transformacijose pirštų atspaudams atpažinti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 1(107). – P. 37–40.

Automatizuotose pirštų atspaudų sistemose labai svarbu patikimai išskirti individualius požymius. Norint panaudoti tokią sistemą, reikia surinkti atspaudus skaitmeniniu pavidalu taikant „rašalo“ metodą. Raukšlėtose ar randuotose vietose bandoma paryškinti ir išskirti individualius požymius. Maksimalų automatizuotos pirštų aspaudų sistemos našumą siekiama padidinti mažinant individualių požymių kiekį. Pasiūlytas Logo ir Gaboro dažnių filtravimo metodas. Gauti geresni rezultatai nei naudojant didelio skaičiaus pirštų atspaudų duomenų baze. Il. 1, bibl. 13, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).