Wavelet transform in biometrics

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ABSTRACT

The role of wavelet transform in biometric system of verification or identification is shown. Fingerprints as an example of popular biometric feature have been chosen for analysis and the influence of Gabor wavelet with various scales on the quality of output signal in optical recognition processor is presented.

Keywords: biometrics, wavelet transform, Gabon wavelet, optical correlator, fingerprints identification.

1. INTRODUCTION

During the past several years many efforts have been made to improve the performance of the recognition systems for security[1-5]. Biometric recognition systems for identification and verification are especially useful for institutions of civilian, police, military, commercial and financial domains. One of the ways of improving the performance of recognition processor is to use the preprocessing of pattern to be recognized based on the wavelet transform. A wavelet transform is an useful tool in various problems of signal and image processing[6,7] (for example in frequency analysis or feature extraction).
Recently one of the most popular and very efficient preprocessing method in biometric recognition is based on the Gabor wavelet[1,8-12]. We show in this paper the results of Gabor wavelet-based preprocessing on the performance of optical correlator adapted to fingerprints identification.

2. BACKGROUND

2.1. Gabor wavelet transform.

The wavelet transform WT_s can be expressed as a correlation between a signal $s(x,y)$ and a set of daughter wavelets $h_{a,b}(x,y)$:

$$WT_s(a_x,a_y,b_x,b_y) = \int\int s(x,y)h^*_{a,b}(x,y)dxdy = s(x,y)\otimes h_{a,b}(x,y) . \quad (1)$$

Daughter wavelets are generated from a mother wavelet $h(x,y)$ by dilation and translation:

$$h_{a,b}(x,y) = \frac{1}{(a_x a_y)^{1/2}} h\left(\frac{x-b_x}{a_x},\frac{y-b_x}{a_y}\right) . \quad (2)$$

In our analysis we use only dilated wavelets. The dilation is obtained by changing the scale of a wavelet (the parameter a in Eq.2). The product of a wavelet and a signal in a frequency domain results in a simple spatial filtering. This property combined with the ability of continuous changing the scale of the wavelets is very useful for pattern recognition because usually captures the characteristics of spatial localization and spatial frequency. Gabor wavelet (see Fig.1) defined by the equation

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$$G(x,y) = exp\left\{-\frac{x'^2 + y'^2}{2s^2}\right\} cos\left(\frac{\pi}{s}x'\right), \tag{3}$$

where: $x' = x\,sin\,\theta + y\,cos\,\theta$ and $y' = x\,cos\,\theta - y\,sin\,\theta$, and the parameter s denotes the scale of the wavelet, and theta is the orientation parameter, which captures additionally orientation characteristics.

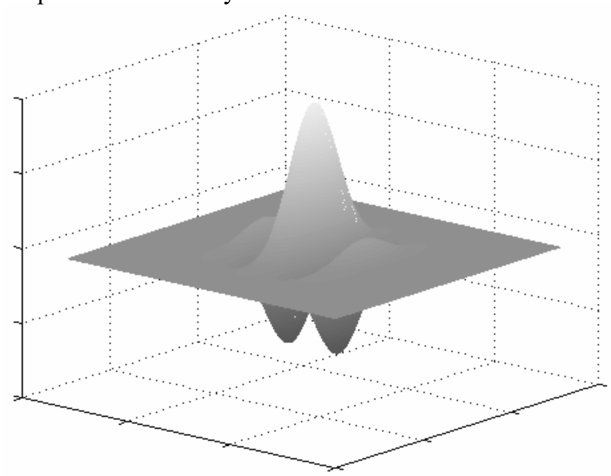
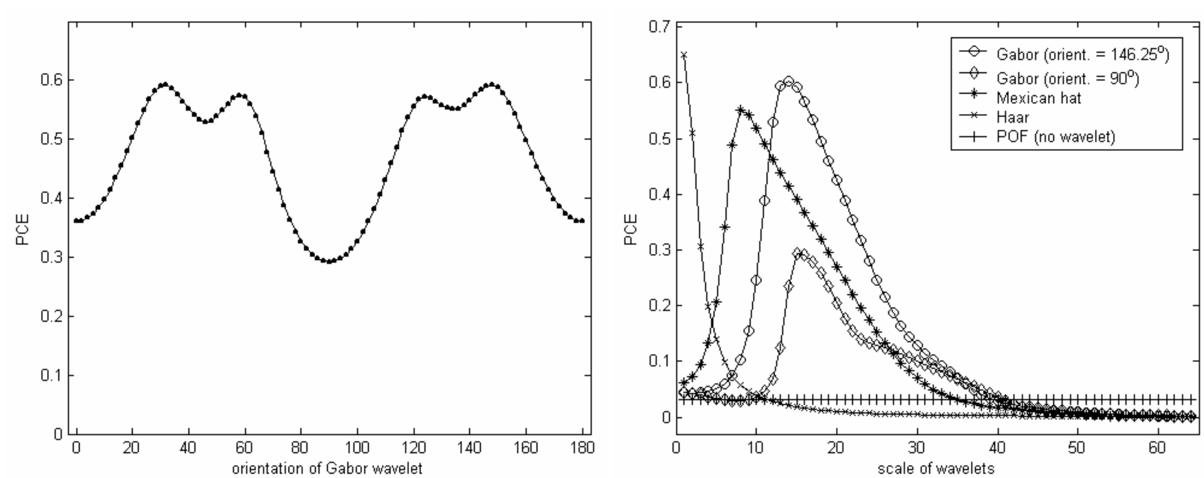


Fig. 1. Gabor wavelet.

In our previous paper[11] we have tested the influence of orientation and scale of Gabor wavelet on the quality of correlation peak in the case of face recognition. The criterion was the value of Peak to Correlation Energy (PCE) ratio[13,14]. Fig. 2a shows the influence of orientation of Gabor wavelet on the PCE value, and Fig. 2b shows the influence of the scale factor in the case of various wavelets.



a) b)

Fig. 2. Influence of wavelet parameters on the PCE value: a) influence of orientation of Gabor wavelet on PCE value, b) influence of scale of various wavelets on PCE value.

2.2. Gabor wavelet preprocessing.

Fig. 3 shows tested image of fingerprint and it's power spectrum. By applying a filter in the Fourier domain one can change the structure of spatial frequencies. This greatly affects the output plane distribution of the optical correlator, especially the height of the correlation peaks and the PCE value. In our analysis Gabor wavelet plays the role of spatial filter.

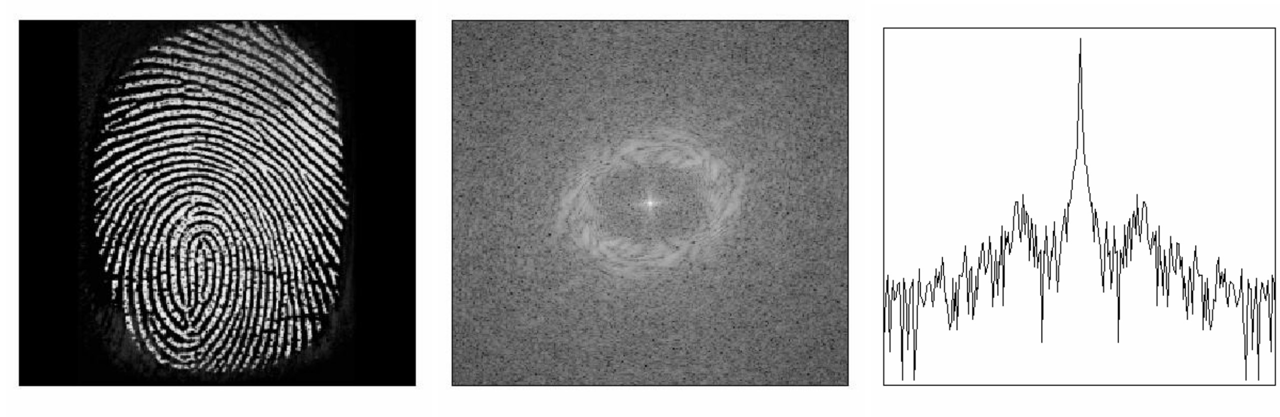


Fig. 3. Tested image and it’s power spectrum in 2D and 1D representation.

All samples of fingerprints were originally an 8-bit grayscale images. The preprocessing step was made by convolving the input image with the wavelet function (see Fig. 4). This can be simply obtained by multiplying the Fourier transforms of those two signals. Then after the inverse Fourier transform and the normalized intensity of preprocessed image has been calculated. Finally the intensity of the image was binarized by simple tresholding.

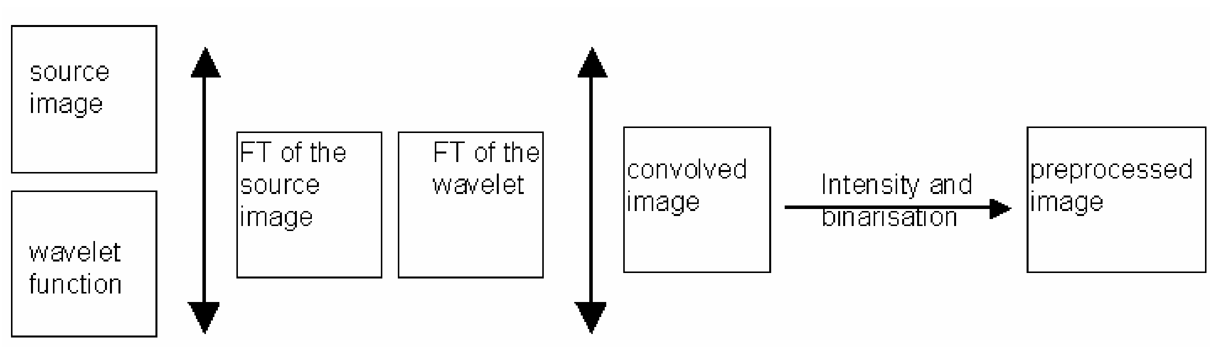


Fig. 4. Flowchart of the preprocessing step.

Wavelet function plays the role of additional band-pass filter in the Fourier domain of optical correlator with the transfer function depending on the scale factor. It is important to choose a proper scale of the wavelet adapted to the recognition

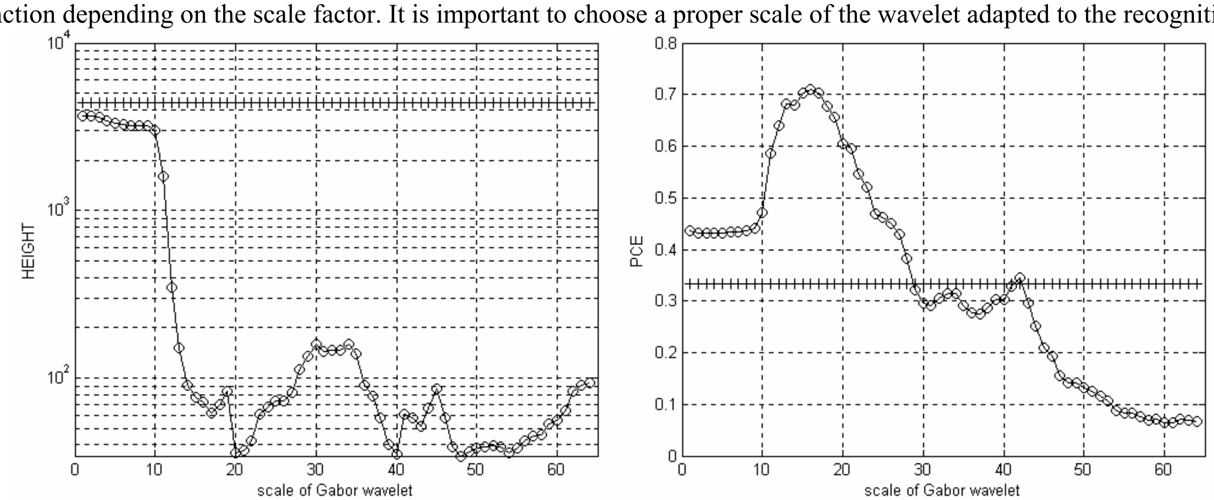


Fig.5. Gabon wavelet with various scales (height of autocorrelation peak and PCE criterion). Additionally horizontal „+” line represents value for phase only filtering (images without preprocessing step).

problem. To determine the influence of scale parameter on the quality of output signal we have used a Gabor wavelet for 64 different scales. The results presented in Fig. 5 show the influence of scale on the autocorrelation peak value and the value of PCE . The simulated correlation system was the 4f correlator with Phase Only Filtering (POF).

3. DATABASES OF FINGERPRINTS

In our simulation we have used two databases of fingerprints samples: from the internet[15] and "home made" samples. In the first case as a target, good quality sample of a fingerprint has been chosen (see Fig. 3). The tested set contained 50 samples. Six categories of distortion were composed digitally from the target affected by various deformations: *(a)* various occlusion (6 samples); *(b)* 4 geometric deformations (pinch, punch, 2x twirl); *(c)* shift (2 samples); *(d)* 6 samples with different intensities; *(e)* 5 different scale of samples; *(f)* orientation (10 various orientations). Two additional categories of samples were added: *(g)* real-life samples - 7 different scans of the same fingerprint (target) representing the real distortions, and *(h)* 9 non-targets. Examples of samples are presented in Fig. 6.

Fig. 6. Examples of fingerprints samples taken from Internet database: distorted target, nontarget, rotated target by 5 degrees, occluded target.

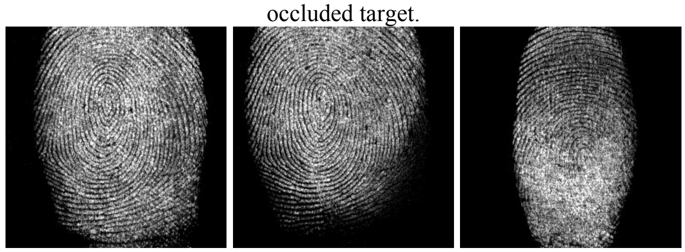


Fig. 7. Examples of poor quality fingerprints samples – „home made" ink scans: target, distorted target, nontarget.

Second database - "home made" samples, contains poor quality and low resolution images of fingerprints. They were obtained by scanning fingerprints captured with ink method. The scanning resolution was set to 300 DPI. All images in this database appear as blurred and defocused images with noisy background. We have used in our simulations 17 different scans of the same fingerprint. One of them was chosen as a target image (see Fig. 7). This kind of samples is very close to the real-life samples from the internet database.

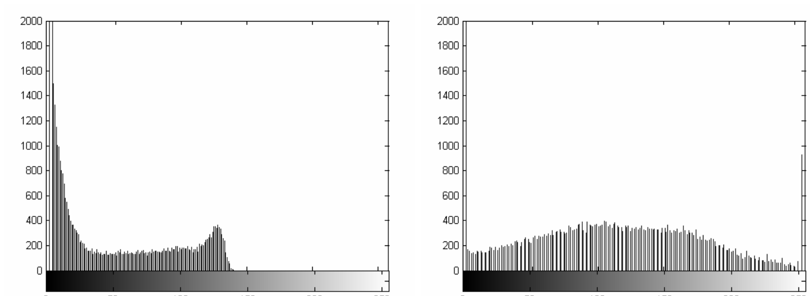


Fig. 8. Histograms of the target images from two databases. Left – internet database. Right – „home made" database.

Additionally a set of 16 different scans of four different fingers were used as a non-targets. In conclusion the whole second database can be treated as a real-life samples. Examples of samples from the second database are shown in Fig.7. Fig. 8 shows histograms typical for both databases.

4. CORRELATION METHODS

4.1. Vander Lugt architecture.

This correlation method simulated in our experiment is based on the Vander Lugt correlator architecture with Phase Only Filter (POF)[14]. Input scene contains a single object to be detected, and in the Fourier plane we obtain the distribution *FP(u,v)* described by the formula:

$$FP(u,v) = \frac{H^*(u,v)}{|H(u,v)|} S(u,v), \tag{4}$$

where *H(u,v)* and *S(u,v)* are the Fourier transforms of the target and the input scene, respectively, and *u,v* are spatial frequencies, asterix denotes the complex conjugation. We have also simulated Classical Matched Filtering (CMF)[14] in Vander Lugt system that can be described by very similar formula:

$$FP(u,v) = H^*(u,v)S(u,v). \tag{5}$$

All images used as target and input scene were previously preprocessed with Gabor wavelet according to formula described in the chapter 2.2. In both cases (POF and CMF) the results were obtained for low scale Gabor wavelet. As a criteria of performance we have used PCE ratio and correlation peak value. The best results were achieved by combining POF formula with Gabor wavelet.

4.2. Composite filters.

We have also tested a composite filters composed as a linear combination of five preprocessed images. Those images were obtained from target image by preprocessing by using Gabor wavelet of various scales and orientations. We have chosen two different scales of the Gabor wavelet for the preprocessing step according to the PCE criterion and correlation peak value. To simulate the composite filters, five images of the target have been prepared. As mentioned above they were obtained by convolving the target image (fig 3) with a Gabor wavelet. One image is the approximation of the target (it corresponds to low scale value), next four images are represented by details of the target oriented in four different directions (Fig. 9).

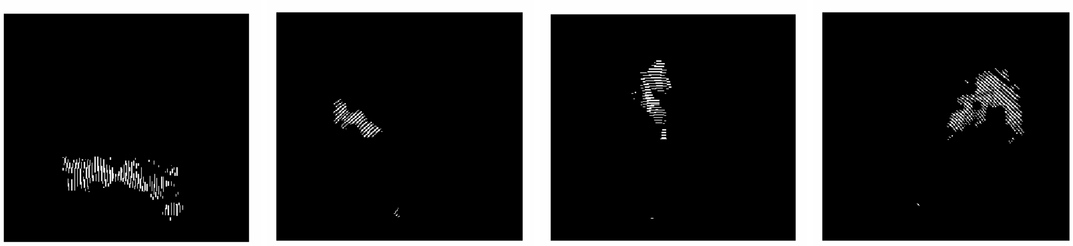


Fig. 9. Four images of target details. Theta parameter of Gabor wavelet was set to 0, 45, 90, 135 degrees.

This was obtained for various orientation of a Gabor wavelet with large scale factor. Composite filter is defined by linear combination of 5 representations of preprocessed sample and is defined by the formula:

$$H^*(u,v) = H_1^*(u,v) + H_2^*(u,v) + H_3^*(u,v) + H_4^*(u,v) + H_5^*(u,v), \tag{6}$$

where *H(u,v)* is the Fourier transform of the target and *u,v* are spatial frequencies. Lower indexes indicates five preprocessed images of the target and asterisk denotes the complex conjugate.

4.3. Joint Transform Correlator (JTC).

In the case of Joint Transform Correlator (JTC) architecture the Gabor wavelet preprocessing affects joint power spectrum according the formula:

$$FP(u,v) = H^*(u,v)S(u,v)|G(u,v)|^2, \tag{7}$$

where *G(u,v)* is the Fourier transform of a Gabor wavelet, *H(u,v)* and *S(u,v)* are the Fourier transform of the target and the input scene, respectively, and *u,v* are spatial frequencies, asterisk denotes the complex conjugate.

5. SUMMARY

All results presented in this section were obtained during computer simulations described previously in chapter 4. To compare the results of identification we have chosen a criterion based on a height of the correlation peak and the Peak to Correlation Energy (PCE) ratio[13,14]. PCE ratio can be described by the equation:

$$PCE = \frac{|c(0,0)|^2}{E_c}, \tag{8}$$

where *c(x,y)* is correlation function and:

$$E_c = \iint |c(x,y)|^2 \, dxdy \tag{9}$$

is the total energy in the correlation plane.
An example of results obtained in the Joint transform Correlation architecture are presented on Figure 10.

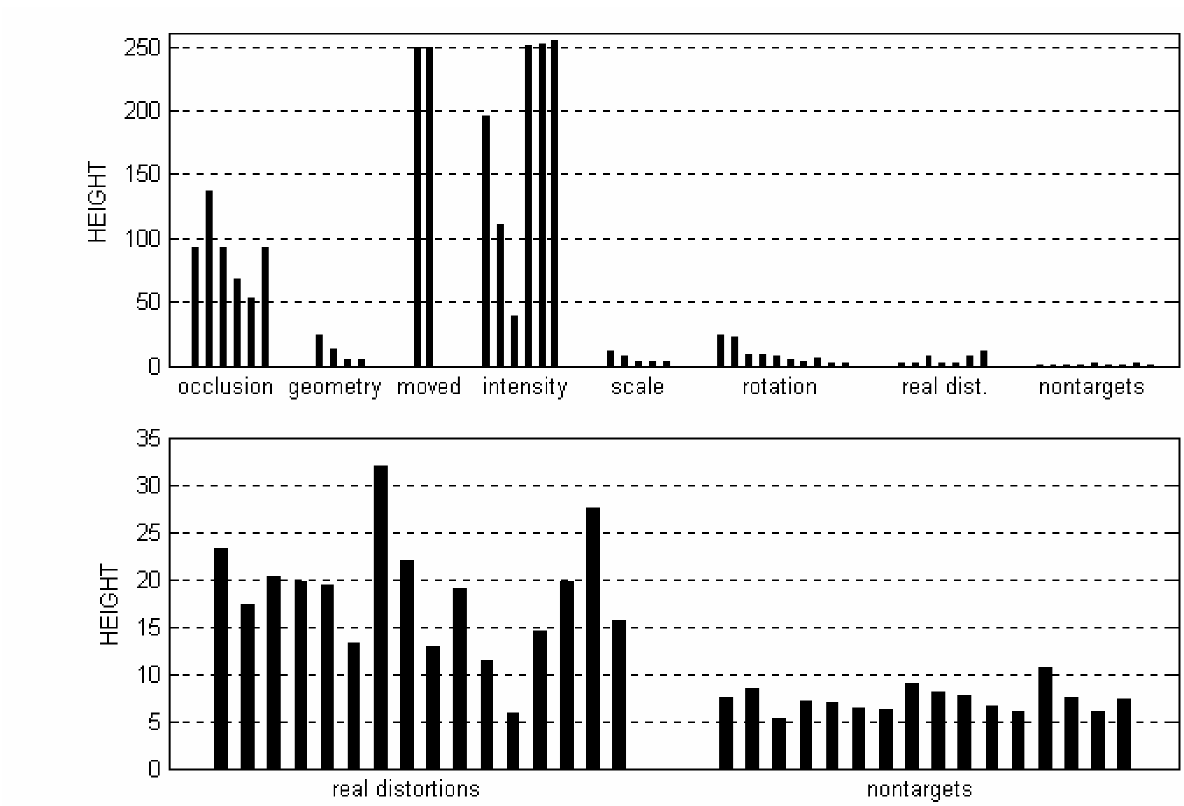


Fig. 10. Results of recognition obtained in the JTC architecture for two databases: internet database - above, "home made" - database below.

The summarized results are presented in tables 1 and 2 by using two criteria: table 1 contains results by using height of correlation peak, and table 2 – PCE ratio. The number of genuine accepts depends on the treshold level that was set in the correlation plane.

6. CONCLUSIONS

In this paper we show the influence of Gabor wavelet-based preprocessing on the recognition results of the fingerprints with various quality and various distortion. We have tested Vander Lugt correlator with simple and composite filters and also Joint Transform Correlator (JTC). We have used in our experiment two databases of fingerprints images with different quality. The crucial difficulties of proper classification are connected especially with the real-life samples of fingerprints. This problem needs further investigation.

samples (number)	CMF	POF	JTC+Gabor	CMF+Gabor	POF+Gabor	POF+Gabor(multi)
AVERAGE VALUES (HEIGHT) – INTERNET DATABASE						
autocorrel. (1)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
occlusion (6)	0.3523	0.3434	0.3582	0.3596	0.3385	0.3429
geometric (4)	0.6167	0.1003	0.0471	0.2528	0.0475	0.0603
shifted (2)	1.0000	1.0000	0.9999	1.0000	1.0000	1.0000
intensity (6)	1.3401	0.7212	0.7396	0.6760	0.3980	0.4224
scale (5)	0.5277	0.0839	0.0233	0.2341	0.0563	0.0660
rotation (10)	0.5709	0.0996	0.0366	0.2547	0.0546	0.0688
real (7)	0.7760	0.0815	0.0208	0.2041	0.0411	0.0507
nontargets (9)	0.9838	0.0047	0.0033	0.3333	0.0027	0.0032
AVERAGE VALUES (HEIGHT) – INK SCANS DATABASE						
autocorrel. (1)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
real (16)	0.7171	0.0096	0.0061	0.0918	0.0025	0.0026
nontargets (16)	0.3356	0.0015	0.0024	0.0089	0.0002	0.0003
NUMBER OF GENUINE ACCEPT						
Internet dtb.	3/40	40/40	40/40	5/40	39/40	39/40
Ink scans dtb.	9/16	15/16	15/16	12/16	14/16	14/16

Table 1. Results of simulations by using height of the correlation peak values as a criterion.

samples (number)	CMF	POF	JTC+Gabor	CMF+Gabor	POF+Gabor	POF+Gabor(multi)
AVERAGE VALUES (PCE) – INTERNET DATABASE						
autocorrel. (1)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
occlusion (6)	0.9440	0.5699	0.7584	0.8690	0.5515	0.5587
geometric (4)	0.6240	0.1104	0.1159	0.3090	0.0525	0.0668
shifted (2)	1.0000	1.0000	1.0011	1.0000	1.0000	1.0000
intensity (6)	1.0000	0.8853	0.7866	0.7424	0.4003	0.4376
scale (5)	0.5920	0.0975	0.0683	0.3133	0.0649	0.0761
rotation (10)	0.5920	0.1074	0.0823	0.2893	0.0584	0.0735
real (7)	0.3920	0.0521	0.0260	0.1463	0.0338	0.0421
nontargets (9)	0.3120	0.0018	0.0043	0.0699	0.0011	0.0015
AVERAGE VALUES (PCE) – INK SCANS DATABASE						
autocorrel. (1)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
real (16)	0.7347	0.0094	0.0099	0.0519	0.0020	0.0020
nontargets (16)	0.6735	0.0028	0.0066	0.0600	0.0009	0.0010
NUMBER OF GENUINE ACCEPT						
Internet dtb.	38/40	40/40	40/40	38/40	40/40	40/40
Ink scans dtb.	0/16	15/16	5/16	0/16	2/16	14/16

Table 2. Results of simulations by using PCE values as a criterion.

REFERENCES

1. D. Maltoni, D. Maio, A. K. Jain, S. Prabhakar, "Hanbook of fingerprint recognition" - Springer-Verlag, New York, 2003.
2. B. Javidi, J. Horner, "Special section on optical security" - Opt. Eng. 35, (1996), also 38, (1999).
3. K.Chalasinska-Macukow, R.Kotynski, "Correlation methods in optical encription and security" – pages: 197-203 in "Perspectives in Modern Optics and Optical Instrumentation", eds. by J.J.Joseph and K.Singh, Anita Publications, New Dehli (2002).
4. S.Prabhakar, S.Pankanti, A.K.Jain, "Biometric Recognition: Security and Privacy Concerns" - IEEE Security & Privacy, 1(2), 33-42 (2003).

5. B. V. K. Vijaya Kumar, Marios Savvides, Chunyan Xie, Krithika Venkataramani, Jason Thornton, Abhijit Mahalanobis, “Biometric verification with correlation filters” - Applied Optics, vol. 43, no. 2, 10 January 2004.
6. H.Schwarzer, S.Teiwes, “Diffractive elements for optical image processing” ch. 9 in “Diffractive Optics for Industrial and Commercial Applications”, J.Turunen and F.Wyrowski, Eds. - Academic Verlag, Berlin, 1997.
7. Y.Sheng, Y.O.Yang, “Transformation with Optics”, ch. 5 in “Introduction to Information Optics”, F.T.S.Yu, S.Jutamulia, and S.Yin, Eds. - Academic Press, San Diego 2001.
8. Ross, A. Jain, J. Reisman, “A hybrid fingerprint matcher” - Pattern Recognition, 36 (2003), 1661-1673.
9. M. Antkowiak, K. Chalasinska-Macukow, “Fingerprint identification by using artificial neural network with optical wavelet preprocessing” - Opto-Electronics Review, 11, no. 4, 2003.
10. M. Jedynski, K. Chalasinska-Macukow, “Wavelet transform for preprocessing in optical correlator with multilevel composite filter” - Optical Engineering, vol. 43 (2004), 1759–1766.
11. J. Strzelecki, K. Chalasinska-Macukow, “Face recognition by using optical correlator with wavelet preprocessing”, - Proc. SPIE 5566: “Systems of optical security” (2003), pages: 56-62.
12. John Daugman, “How iris recognition works” – IEEE Transactions on circuits and systems for video technology, vol. 14, no. 1, January 2004.
13. V.B.V.Kumar, L.Hassebrook, “Performance measure for correlation filters” - Appl. Opt. 29, 2997-3006 (1990).
14. J.Campos, F.Turon, L.P.Yaroslavsky, M.J.Yzuel, “Some filters for reliable recognition and localization of objects by optical correlator: a comparison” - Int. Journ. of Opt. Computing 2, 341-365 (1991).
15. Fingerprint Verification Competition - http://bias.csr.unibo.it/fvc2000/default.asp.