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Perspective optical-electronic technologies for persons identification and verification on the bases of the fingerprints

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ABSTRACT

There are presented the results of the investigations of the fingerprints' images correlation recognition in conditions of different distortions – scale, angular orientation change, image's surface reducing, noises' influence. There are examined possibilities of the persons' identification and their verification. There are proposed and investigated the method of the fingerprints' semi-spectrums recognition and the method of the fingerprints' space-dependent recognition. There are presented the structures of the special purpose mono-channel and multi-channel optical-electronic systems and are described computing processes in the systems at the realization of the different fingerprints recognition algorithms: „FSR-1", „FSR-2", „FSDR-1", „FSDR-2", „FICR". Also, there are presented the results of systems investigations: fingerprints time recognition, systems productivity at the fingerprints comparison step, systems prices.

Keywords: correlation, identification, fingerprints, optical electronic, person, recognition, system, verification

1. INTRODUCTION

The persons' verification and identification, on the bases of the fingerprints, represent a very important problem, the effective solution of which is necessary in different applications – in criminology, access systems etc. Between different requirements to the systems can be selected the most important – speed of fingerprints' recognition, discrimination possibility (or reliability), complexity and others.

The correlation method, being realized in optical processors, allows the images recognition with a very high speed, until 10^{14}bits/sec. At the same time, the construction of the optical processor is not very complex and it can possess small-weight and dimensions characteristics (around $13cm^2$).

Optical processors can be used successfully for the fingerprints' images recognition, invariant to displacements. Unfortunately, the standard correlation method wasn't, profoundly, investigated from the point of view of fingerprints' recognition stability in the conditions of the change of the scale, of the angular orientation, of the image's surface reducing, of the noises influence, etc. Such fingerprints' images distortions are typical in criminology.

Taking into account this fact, the experimental investigations were executed with the purpose to establish the possibility of utilization of the correlation method for the fingerprints' images recognition in conditions of influence of the indicated above distortions and resolving of the persons' identification and verification problems(Sec.2).

The carried out investigations permitted to establish the negative influence of the noise on the recognition of the fingerprints' images with a reduced surface. In criminology, it appears frequently the necessity of the analysis of such types

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of fingerprints - with the reduced surface and which contain a noisy background. Taking into consideration this fact, it was proposed and investigated the method of the fingerprints' semi-spectrums recognition (Sec.3). It was shown that this method is characterized by stability to the reduction of the surface of the input fingerprints images and to the noise. At the stage of comparison with standards, this method is characterized by a reduced volume of information, which allows the decrease of the processing time and the volume of information necessary for storing of the standard images. The method is proved to be efficient for the person's verification on the base of the fingerprints and for the persons' identification in conditions of a strict observance of the requirements regarding the angular position and the scale of images.

For an effective resolving of the persons' verification and identification problems, it was proposed the method of the fingerprints' space-dependent recognition, which represents the extension of the previous method (Sec. 4). The proposed method allows the fingerprints' recognition independent from displacements, rotation and scaling.

Are described the special purpose optical -electronic systems which realize the respective methods and the results of the investigation of these systems.

In Sec. 5 are described mono-channel and multi-channel optical-electronic systems. In Sec. 6 are presented computing processes which realize the methods: of the fingerprints' semi-spectrum recognition method, of the fingerprints' spatial-dependente recognition and of the fingerprints' images correlation recognition. In Sec.7, there are described the estimation of the recognition time at the realization of the different fingerprints recognition algorithms ("FSR-1", „FSR-2", „FSDR-1", „FSDR-2", „FICR") and of the systems productivity at the fingerprints comparison step and price of optical-electronic systems

2. FINGERPRINTS' IMAGES CORRELATION RECOGNITION

The method of the fingerprints' images correlation recognition (FICR) is based on the calculation of the correlation function between the image of the unknown fingerprint and one of its standard images. In general, the correlation function is expressed by the following formula:

$$C(\xi, \eta) = \iint_{-\infty}^{\infty} P(x,y)H^*(x-\xi,y-\eta)dxdy, \quad (1)$$

where P(x,y) describes the unknown image and H(x,y) is the standard one.

One of the most efficient methods of the correlation function calculation is based on the utilization of the bi-dimensional Fourier transformation. In this case, the function of correlation takes the following form:

$$C(\xi,\eta)=F^{-1}\{F\{P(x,y)\}F^*\{H(x,y)\}\}=F^{-1}\{P(u,v)H^*(u,v)\}=F^{-1}\{C(u,v)\}, \quad (2)$$

where F and F^{-1} are the operations of the bi-dimensional Fourier transformation, direct and, respectively, inverse; the sign * is that of the complex conjugation; P(u,v), H*(u,v) are the Fourier transformations of the functions P(x,y) and respectively, H(x,y); u, v - the coordinates in the frequency space.

For an efficient calculation of the correlation function, described by the formula (2), can be used the optical processor, the structure of which is presented in the figure 1. The image P(x,y) is placed in the P1 focus plane of the Fourier lens LF1. When the image is illuminated by a laser, in the P2 focus plane of the lens LF1 it is formed the Fourier transformation of the image P(x,y):

$$F\{P(x,y)\}=P(u,v)=\iint_{-\infty}^{\infty}P(x,y)\exp[-j2\pi(xu+yv)]dxdy. \quad (3)$$

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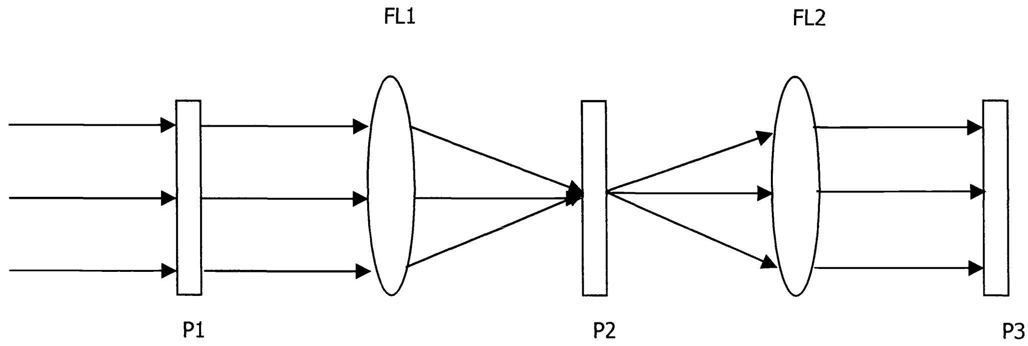

Fig. 1. The structure of the optical processor

Also, in the P2 plane is placed the holographic filter H*(u,v). As a result, in the P2 plane appears the formula C(u,v)=F(u,v)H*(u,v). After the realization of the Fourier transformation of the function C(u,v) by the help of the lens LF2, in the P3 plane the correlation function C(ξ, n) will be formed.

If the initial image contains, for example, 10^6 pixels, and the time of performing the correlation operation is determined by the light beam time passing in the processor and is equal to 10^{-8} sec, the productivity of the processor will be very high, equal to 10^{14} bits/sec. At the same time, the construction of the optical processor is not very complex and it can possess small weight and dimensions characteristics (around $13cm^2$).

Optical processors can be used successfully for the fingerprints' images recognition, invariant to displacements. Unfortunately, the standard correlation method wasn't, profoundly, investigated from the point of view of fingerprints recognition stability in the conditions of change of the scale, of the angular orientation, of the image's surface reducing, of the noises influence, etc. Such fingerprints' images distortions are typical in criminology.

Taking into account this fact, a lot of experimental investigations were executed with the aim to establish the possibility of utilization of the correlation method to the resolving of the invariant fingerprints' recognition, for resolving of the persons' identification and verification problems. These investigations were carried out using the special software "IPS-1"[1].

There were been made investigations related to the influence of the change of the fingerprints' image angular orientation, of the scale, of the image's surface reduction and the influence of the noise on the C_M - the maximal value of the correlation function: $C_M = \max\{[C(\xi\eta)]^2\}$. The parameter K was used in investigations, calculated as the relation of the C_M values of the cross-correlation function (this in the case of the image distortions) and of the auto-correlation function.

Investigation of the influence of the fingerprints' image angular orientation on the C_M value

There are carried out the investigation of the parameter $K_U = C_{MU}/C_M$, were C_{MU} is the values of the correlation function in the $\Theta \neq 0$ angular positions of the fingerprints' images, and C_M is the value of the correlation function at $\Theta=0$, for different values of the images resolution R.

The results of the investigation shows that in the case of the fingerprints, the correlation function is very sensitive to the angular position of the image. For the threshold value $K_U=0.7$ (which corresponds to that given in practical problems), the accepted differences in the angular orientation of the input and standard fingerprints' images are those of $\Theta_A=1°$ for $R=128^2$ and $\Theta_A=0.8°$ for $R=64^2$.

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Investigation of the influence of the scale change of the fingerprints' images on the C_M value

There are carried out the investigation of the parameter $K_S = C_{MS}/C_M$, were C_{MS} is the maximal values of the fingerprints images cross-correlation functions at the scale $S \neq 1$, and C_M is the maximal value of the auto-correlation function (at $S=1$), for different values of the images' resolution R. The analysis shows that the correlation function is very sensitive to the change of the scale of the fingerprints. For the $K_S=0.7$ threshold value, the accepted difference in the scale change of the input and standard fingerprints' images is of $S_A=5\%$ for $R=128^2$ and $S_A=3\%$ for $R=64^2$.

Investigation of the influence of the surface change of the of the fingerprints images on the C_M value

There are carried out the investigation of the parameter $K_{SP}=C_{MP}/C_M$, were C_{MSP} is the values of the cross-correlation functions for the input fingerprints with the surface coefficient $SP \leq 1$, and C_M is the value of the auto-correlation function (at $SP=1$), for different values of the image resolution R. The results of the investigation shows, that the correlation function is stable to the reduction of the surface of the fingerprints' images. The C_M value decreases to 30% for the parameter $SP=0.5$ ($R=64^2$).

Investigation of the noise's influence in the fingerprints' input image on the C_M value

There are carried out the investigations of the noise's influence in the fingerprints' input image on the C_M maximal value of the correlation function, for different values of the resolution R of the images, angular orientation, scale and the fingerprints' surface, at the different probability N of the additive noise introduction in to image.

The results of the investigations demonstrated the followings: in the case of the rotation or of the scale changes of the fingerprints' images, the introduction of the noise, in fact, doesn't influence on the C_M maximal value of the correlation function.The noise influences on the C_M in case of change of the fingerprints' surface or resolution. At N=0.02, the accepted value of the fingerprints' surface reduction is until 15% for R=256.

Investigation of the discrimination possibility

Pursuing the purpose of investigating the discrimination possibility of the correlation recognition method, there were been calculated correlation functions between different fingerprints' images and calculated the relations: $K_{Di}= C_{Mii}/C_{Mij}$, where C_{Mii}, C_{Mij} are functions of auto-correlation and, respectively, of cross-correlation. The results of the investigations show that the K_D values depend on the images' resolution R. At the reduction of R until $R=64^2$, the value of K_D reduces, but it remains sufficient for the correct fingerprints recognition.

The results of the investigations of the method of correlation recognition of the fingerprints' image (CRFI) demonstrated the followings.

1. This method is very sensitive to the non-correspondence of the angular orientation, of the scale of the fingerprints' input image to the standard one. A difference only of 0.8° in the angular position or of 3% in the scale causes the reduction, until the critic value, of the maximum of the correlation function;

2. The method FICR isn't so influenced by the surface reduction of the fingerprints' images submitted to recognition; the fingerprints' surface could be decreased until 50%;

In case of rotation or scaling change of the fingerprints' image, the noise, in fact, doesn't influence on the maximal value of the correlation function, but influences it in case of change of the fingerprints' surface and of the image's resolution. The accepted value for the fingerprints' surface reducing is till 30% (at N=0.02).

3. The method is characterized by a high discrimination possibility (DP) regarding the fingerprints' recognition. Concomitantly, the DP of this method depends on the images' resolution;

4. The method FICR is considered to be efficient both to the resolving of the verification and identification of the persons on the base of the fingerprints, in conditions of a strict observance of the requirements to the angular position, scale, surface of the fingerprints' images and absence of the noise in images.

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3. FINGERPRINTS' SEMI-SPECTRUMS RECOGNITION

3.1 Method of the fingerprints' semi-spectrums recognition

The results of the investigations, presented in Sec.2, indicate the negative influence of the noise in the recognition of fingerprints' images with a reduced surface. In criminology, it appears frequently the necessity of the analysis of such types of fingerprints - with the reduced surface and which contain a noisy background.

For an efficient recognition of the fingerprints' images we propose a new method - the fingerprints' semi-spectrums recognition (FSR). At the basis of this method, it is used the property of concordance between the objects' images and their Fourier spectrums. As it is described in [1], the Fourier spectrum of the image is symmetrical and repeats to 180°. At the image rotation, the Fourier spectrum rotates with an equal angle. To the image scaling, the Fourier spectrum's dimensions change in an inverse proportion. So, the Fourier spectrum represents the object's initial image. Moreover, the proposed method bases on the fact that the noise of additive type, present in image, is characterized by low frequencies in the Fourier space.

The elaborated method consists in the followings.

1. In the first stage, there is formed the Fourier spectrum of the input image P(x,y):

$$P(x,y) \rightarrow P_S(u,v) = |F\{P(x,y)\}|^2.$$

2. The image $P_S(u,v)$ is segmented on the base of brightness criterion, which allows to avoid the influence of the noise's frequencies: $P_S(u,v) \rightarrow P_{SB}(u,v)$.

3. Considering the symmetry property of the Fourier spectrum, from the image $P_{SB}(u,v)$ is forming another one, which represents only a half of this image and which is called "semi-spectrum": $P_{SB}(u,v) \rightarrow P_{SBN}(u,v)$.

This allows to reduce the volume of the information necessary for the storing of the standard image and of the volume of calculations necessary for the fingerprints' recognition.

4. It is realized the operation of recognition of the $P_{SBN}(u, v)$ image by the calculation of the correlation function with different standards:

$$C_j(\xi,\eta)=\max_{\Omega}\max_{j}\{\iint_{-\infty}^{\infty} P_{SBN}(u,v)\sum_{j=1}^{L} H^*_{SBN}(u-\xi,v-\eta)dudv, \quad (4)$$

where Ω- the correlation field, L-the number of standard images.

The proposed method permits the recognition of the fingerprints with the reduced surface in comparison with the standard image, if even the first one could be distorted by noise. At the same extent, this method is characterized by the reduced volume of information in the phase of comparison with the standards which permit to reduce the processing time and the volume of information necessary for the storing of the standard images.

3.2. Investigation of the fingerprints' semi-spectrums recognition method

For proposed in Sec. 3.1. method, it was investigated the influence on the C_M-maximal value of the correlation function, of the noise in the input fingerprints' image, of a different surface of the fingerprints, of the resolution, of the angular orientation, of the scale, of the discrimination possibilities.

On the bases of the obtained results of the investigations it is possible to conclude the following.

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1. The noise in the input image doesn't, practically, influence the value C_M;

2. This method is very sensitive to the non correspondence of the fingerprints' image to the standard one, from point of view of angular position and scale. The difference only of 0.5° in the angular position or of 4% in scale causes a critic reduction of the maxim of the correlation function;

3. The method is stable to the reducing of the surface of the fingerprints' image. The fingerprints' surface could be reduced until 40%;

4. The method is characterized by a high discriminatory possibility in what regards the recognition of the fingerprints' images;

5. The method is efficient in the persons identification and verification on the bases of the fingerprints in conditions of a strict observance of the requirements in what concerns the angular position and the scale.

4. FINGERPRINTS' SPACE-DEPENDENT RECOGNITION

4.1 The method of fingerprints' space-dependent recognition

The disadvantage of the methods FICR and FSR consists in the necessity of a strict observance of the requirements regarding the angular position and the scale of the fingerprints' images. In connection with this, it was elaborated another method which could offer the possibility of recognizing the fingerprints indifferent of the indicated distortions. The proposed method is based on the formation of the fingerprints' images semi-spectrums and their presentation in the polar-logarithm system of coordinates.

The method of the fingerprints space-dependent recognition (FSDR) includes the following stages.

1. There forms the Fourier spectrum of the input image P(x, y), that allows the centering of the fingerprints:

$$P(x,y) \rightarrow P_S(u,v) = |F\{P(x,y)\}|^2.$$

2. The operation of $P_S(u, v)$ image segmentation brightness is realized with the aim of noise removing:

$$P_S(u,v) \rightarrow P_{SB}(u,v).$$

3. There forms the spectrum of the image $P_{SB}(u,v)$:

$$P_{SB}(u,v) \rightarrow P_{SBN}(u,v).$$

4. There takes place the operation of image $P_{SBN}(u, v)$ transformation in the coordinate system (u_1,v_1):

$$P_{SBN}(u,v) \rightarrow P_{SBN}(u_1,v_1),$$

where $u_1 = \mathrm{arctg}(v/u)$, $v_1=\ln\{(u^2+v^2)^{1/2}\}$.

This transformation allows to reduce the influence of rotation and scaling in the image $P_{SBN}(u,v)$ to displacements on the u_1 and v_1 axes, and, respectively, to utilize the property of the correlation algorithms concerning the shifts.

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5. The realization of the operation of image $P_{SBN}(u_1 v_1)$ recognition:

$$C_j(\xi, \eta) = \max_{\Omega} \max_{j} \{\iint_{-\infty}^{\infty} P_{SBN}(u_1,v_1)\sum_{j=1}^{L} H^*_{SBNj}(u_1-\xi,v_1-\eta)du_1dv_1. \quad (5)$$

So, the described method contains a supplementary stage in comparison with the precedent one, which allows to recognize the fingerprints' independent from displacements, rotation and scaling.

4.2. Investigation of the method of fingerprints' space-dependent recognition

The elaborated method of the fingerprints' rècognition was studied from the point of view of the influence of the angular position, of the scale, of the noise in the input image on the C_M value of the correlation function. Also, was investigated the discrimination possibility.

The results of the investigations show the followings.

1. The method is stable to the change of the angular position and scale of the fingerprints. At the change of indicated parameters, the maximums of the correlation function decrease insufficiently. The discrimination possibilities are high.

2. The FSDR method could be used for resolving of the problems of identification and verification of the persons on the base of the fingerprints.

5. STRUCTURES OF THE OPTICAL -ELECTRONIC SYSTEMS FOR THE FINGERPRINTS' RECOGNITION

According to the proposed methods of fingerprints' identification (sec.3,4), there were elaborated two special purpose systems: mono-channel and multi-channel optical-electronic systems.

5.1. Mono-channel optical-electronic system

The structure of mono-channel optical electronic system is presented in the figure 2. There are two basic modules in this system – an optical module and an electronic one.

The optical module contains the laser L, the optical beam splitter BS, the optic switch OS, the spatial light modulators SLM 1 and SLM2, the Fourier lenses FL1 and FL2, the semitransparent mirror SM, the detectors D1 and D2. The laser, the optical switch, the spatial light modulators and the detectors are connected with the electronic module (personal computer) by a data buss. The PC executed the functions of computing processes control in the system, of image processing and others.

5.2. Multi-channel optical electronic system

In order to increase the speed of the fingerprints' identification, it was elaborated a multi-channel optical electronic system (Fig.3), which contains a set of optical channels (processors). The additional optical processors are similar with that of the basic optical processor.

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6. ORGANIZATION OF COMPUTING PROCESSES IN THE OPTICAL ELECTRONIC SYSTEMS

6.1. Computing processes in the mono-channel optical electronic system

Organization of computing process at the realization of the fingerprints semi-spectrum recognition method

There were elaborated two algorithms of computing processes organization: "FSR-1"and „FSR-2". According to the algorithm „FSR-1", the correlation functions are calculated on the bases of standard images filters, which were preliminary calculated and stored in the computer memory. At the realization of the algorithm „FSR-2", the standards are preserved in the form of images, but the filters are formed from the input fingerprints' images.

Algorithm of computing processes organization „FSR-1"

1. The initial image of the fingerprints – the function P(x,y) is extracted from the computer and is recorded on the spatial light modulator SLM1.

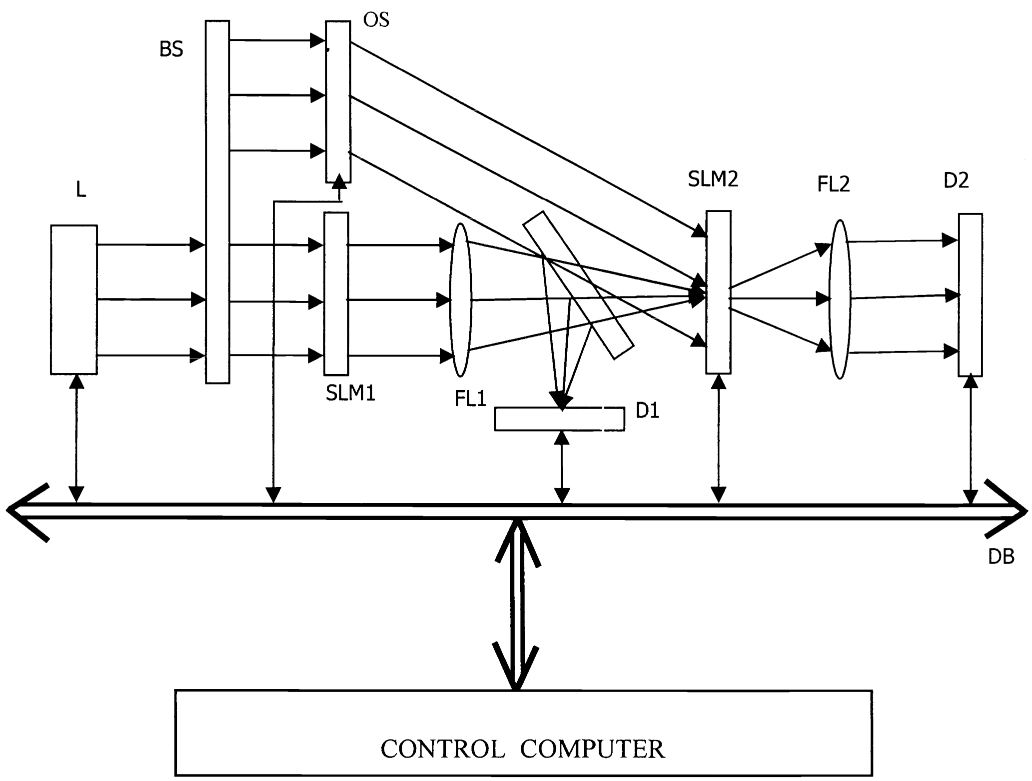

Fig.2. The mono-channel optical-electronic system

2. A coherent optical light beam, formed by the laser L, passes through the optical beam splitter BS to the spatial light modulator SLM1, it is modulated by the image P(x,y), later passes through the lens LF1 and as a result, in the input plan of the detector is formed the Fourier transformation of the function P(x,y), which is scanned by this detector and represents the Fourier spectrum $P_S(u,v)=|F\{P(x,y)\}|^2$.
3. The signals which describe the function $P_S(u,v)$, from the detector D1 are introduced in the computer.

4. In computer, the digital image $P_S(u,v)$ is segmented in order to avoid the influence of the noise's frequencies: is formed the function $P_{SB}(u,v)$.

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5. On the bases of the image $P_{SB}(u,v)$ is formed the semi-spectrum $P_{SBN}(u,v)^1$.

6. The image $P_{SBN}(u,v)$ is extracted from the computer and is recorded on the spatial light modulator SLM1.

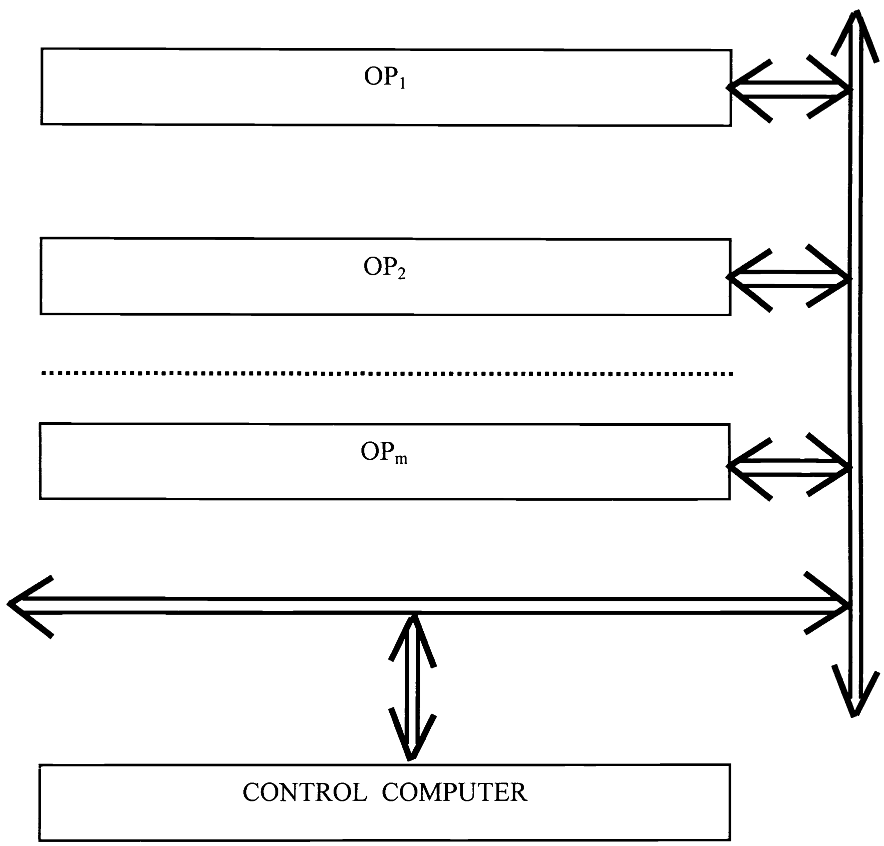

Fig.3. The multi-channel optical-electronic system

7. The standard image is also extracted from the computer and is recorded on the spatial light modulator SLM2. It has the form of the conjugated Fourier transformation: $H^*_{SBNj}(p,q)=F^*\{H_{SBNj}(u,v)\}$.

8. It is formed the Fourier transformation of the image $P_{SBN}(u,v)$ with the help of the lens LF1: $F\{P_{SBN}(u,v)\}=P_{SBN}(p,q)$.
9. The $P_{SBN}(p,q)$ and $H^*_{SBNj}(p,q)$ functions are multiplied at the spatial light modulator SLM2: $P_{SBN}(p,q)H^*_{SBNj}(p,q)$.

10. With the help of the lens LF2 it is formed the Fourier transformation of the $\{P_{SBN}(p,q)H^*_{SBNj}(p,q)\}$ product and as a result, at the detector D2 it will be obtained the correlation function, which will have a bi-dimensional optical distribution form:

$$C_j(\xi,\eta) = F\{P_{SBNj}(p,q)H^*_{SBNj}(p,q)\}.$$

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11. The detector D2 scans the optical field which contains the function $C_j(\xi,\eta)$. In the case if the function $H_{SBNj}(p,q)$ is identical to function $P_{SBN}(p,q)$, the function $C_j(\xi,\eta) = F\{|P_{SBN}(p,q)|^2\}$ will be the auto-correlation function, whose maximum will be recorded by the detector D2. The respective signal is introduced in the computer, it fixes the number j which identifies the fingerprint. If the $H_{SBNj}(p,q)$ and $P_{SBN}(p,q)$ functions do not coincide, the stages 7-10 will be repeated.

Algorithm of computing processes organization „FSR-2"

The 1-6 steps of the algorithm „FSR-2" coincide with the respective steps of the algorithm „FSR-1".

7. The optical beam, generated by the laser L, passes through the spatial light modulator SLM1, it is modulated by the $P_{SBN}(u,v)$ and then passes through the lens LF1.

8. The optical switch OS openes and at the spatial light modulator SLM2 it is formed the conjugated Fourier transformation of the function $P_{SBN}(u,v)$: $P_{SBN}(u,v) \rightarrow P^*_{SBN}(p,q)$ at the interaction of the optical beams passes through the lens FL1 and the beam splitter BS.

9. The standard image $H_{SBNj}(u,v)$ is extracted from the computer and is recorded on the spatial light modulator SLM1.The standard image can contain a set of standard fingerprints, which will permit to reduce the total time of recognition and to increase the system's productivity.

10. With the help of the lens LF1, it is formed the Fourier transformation of the function $H_{SBNj}(u,v)$: $F\{ H_{SBNj}(u,v)\}= H_{SBNj}(p,q)$. This function is multiplied with the function $P^*_{SBN}(p,q)$.

11. With the help of the lens LF2, it is realized the Fourier transformation of the product $\{H_{SBNj}(p,q)P^*_{SBN}(p,q)\}$. It is formed the correlation function in the plan of the detector D2:

$$C_j(\xi,\eta) = F\{H_{SBNj}(p,q)P^*_{SBN}(p,q)\}$$

12. The detector D2 scans the optic distribution $C_j(\xi,\eta)$. If the function $C_j(\xi,\eta)$ will be a autocorrelation one, then the fingerprints image will be identified. Otherwise, the steps 9-12 will be repeated.

Taking into consideration that at the recognition stage the correlation function can be calculated on the basis of the set of standard fingerprints and the unknown image filter, the algorithm „FSR-2" privides a faster identification of the fingerprints than the algorithm „FSR-1".

Organization of computing processes at the realization of the fingerprints' spatial-dependente recognition method

At the realization of the fingerprints spatial-dependente recognition method, in the optical-electronic system can be implemented two algorithms of computing processes organization, named as the "FSDR-1" and "FSDR-2".

Algorithm of computing processes organization „FSDR-1"

This algorithm is identical with that of „FSR-1" and calculates the correlation function on the basis of the standard images filters. The diferences between these algorithms are in the steps 3-11. At the step 3, the image of the semispectrum $P_{SBN}(u,v)$ is transformed supplementary in the logarithmic polar system of coordinates:

$P_{SBN}(u,v) \rightarrow P_{SBN}(u_1,v_1)$, were u_1=arctg(v/u), $v_1=\ln\{(u^2+ v^2)^{1/2}\}$.

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The images which were presented in the system of coordinates (u_1, v_1) are processed at the steps 6-11.

Algorithm of computing processes organization „FSDR-2"

The algorithm is identical with the „FSR-2" one and is basesd on the formation of the standard fingeprints' image filter. The diference between these algorithms is in the step 3. At this step, the image of the semispectrum $P_{SBN}(u,v)$ is transformed supplementary in the logarithmic polar system of coordinates: $P_{SBN}(u,v) \rightarrow P_{SBN}(u_1,v_1)$. At the stages 6-12, there are processed the images presented in the system of coordinates (u_1,v_1).

The algorithm of the fingerprints' images correlation recognition

This algorithm contains the following steps.

1. The initial image P(x,y) is extracted from the computer and is recorded on the spatial light modulator SLM1.

2. The standard image is also extracted and recorded on the spatial light modulator SLM2. It has the form of the conjugated Fourier transformation: $H^*_j(u,v)=F^*\{H_j(x,y)\}$.

3. It is formed the Fourier transformation of the image P(x,y) with the help of the lens LF1:

$F\{P(x,y)\}=P(u,v)$.

4.The functions P(u,v) and $H^*_j(u,v)$ are multiplied at the spatial light modulator SLM2: $Q(u,v) = P(u,v)H^*_j(u,v)$.

5.With the help of the lens LF2 it is formed the Fourier transformation of the $\{P(u,v)H^*_j(u,v)\}$ product and, as a result, in the plan of the detector D2, it will be obtained the correlation function:

$C_j(\xi,\eta) = F\{P(u,v)H^*_j(u,v)\}$.

6. The detector D2 scans the optical function $C_j(\xi,\eta)$. If this function will be a auto-correlation one, then its maximum will be recorded by the detector D2. The respective signal is introduced in the computer and it fixes the number j which identifies the fingerprint. Otherwise, the steps 2-6 will be repeated.

6.2. Computing processes in the multi-channel optical-electronic system

The computing processes in the multi-channel optical-electronic system are organized in the same way as those from the mono-channel optical-electronic system, which were used in order to realize different methods. The standard images are introduced in parallel in all optical channels at the stage 6 of the algorithms "FSR-1" and "FSR-2", at the stage 9 of the algorithms "FSDR-1" and "FSDR-2". This permits to increase the speed of the fingerprints' recognition.

7. ESTIMATION OF THE OPTICAL-ELECTRONIC SYSTEM CHARACTERISTICS

There was estimated the productivity of the system during the realization of different algorithms of computing processes organization.

Estimation of the recognition time at the realization of the algorithm "FSR-1"

The recognition time can be estimated in the following way :

$$T_{S1} = M\{\sum_{i=1}^{6} t_i + [N_e/m] \sum_{i=7}^{11} t_i\},$$

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where M – the number of the fingerprints; N_e – the number of standards; m – the number of optical channels in the system; t_i- the processing time at the stage i.

The t_i values can be described in the following way: $t_1=t_{SLM}$; $t_2=t_{D1}$; $t_3=0$ (the step 3 can be realized in parallel with the step 2); $t_4=t_{GS}$; $t_5=0$ (the step 5 can be realized in parallel with the step 4), $t_6=t_7=t_{SLM}$; $t_8=t_9=t_{10}=0$, these operations are realized optically; $t_{11}=t_{D2}$. So we will have

$$T_{S1}=M\{2t_{SLM}+t_{D1}+t_{SG}+(t_{SLM}+t_{D2})N_e/m\}, \quad (6)$$

where t_{SLM} - the time for image extraction from the computer and recording on the spatial light modulator SLM1; t_D – the functioning detector time; t_{SG} – the image segmentation time.

Estimation of the recognition time at the realization of the algorithm "FSR-2"

The time of the fingerprints' recognition can be estimated in the following way:

$$T_{S2} = M\{\sum_{i=1}^{8} t_i + [\sum_{i=9}^{12} t_i]N_e/mk\},$$

where k – the number of the fingerprints in the standard image.

The t_i values can be described as: $t_1=t_{SLM}$; $t_2=t_{D1}$; $t_3=0$ (the step 3 is realized in parallel with the step 2); $t_4=t_{SG}$; $t_5=0$ (the step 5 can be realized in parallel with the step 4), $t_6= t_{SLM}$; $t_7= t_8=0$, these operations are realized optically; $t_9=t_{SLM}$; $t_{10}=t_{12}=0$; $t_{11}=t_{D2}$. So we will have

$$T_{S2}=M\{2t_{SLM}+t_{D1}+t_{SG}+(t_{SLM}+t_{D2})N_e/mk\}, \quad (7)$$

Estimation of the recognition time at the realization of the algorithms "FSDR-1" and "FSDR-2"

The algorithms "FSDR" differ from the algorithms "FSR" in the additional operation of image transformation in the logarithmic polar system of coordinates. Taking into consideration this fact, the functioning time of the algorithms "FSDR-1" and "FSDR-2" can be estimated as follows:

$$T_{SDI}=M\{2t_{SLM}+t_{D1}+t_{SG}+ t_{GT}+(t_{SLM}+t_{D2})N_e/m\}, \quad (8)$$

$$T_{SD2}=M\{2t_{SLM}+t_{D1}+t_{SG}+t_{GT}+(t_{SLM}+t_{D2})N_e/mk\}, \quad (9)$$

where t_{GT} - the time for geometrical transformation of the image.

Estimation of the recognition time at the realization of the algorithm "FICR"

According to this algorithm, the time for the fingerprints' recognition can be estimated as follows:

$$T_{IC}=M\{t_1 + N_e\sum_{i=2}^{6} t_i\},$$

The t_i values can be described as: $t_1=t_2=t_{SLM}$; $t_3=t_4=t_5=0$, the operation on the stages 3, 4, 5 are realized optically; $t_6=t_{D2}$. So we will have

$$T_{IC}=M\{t_{SLM} + N_e(t_{SLM}+t_{D2})\}. \quad (10)$$

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Systems' productivity at the fingerprints comparison step

The system's productivity at this step can be estimated in the following way:

$$P=mk/t_c, \tag{11}$$

were m - the number of the optic channels in the system; k - the number of the fingerprints' images, which are compared in one channel; t_c – the time of fingerprints comparison; $t_c=t_{SLM}+t_{D2}$.

Price of the optical-electronic system

The price of the optical-electronic system can be estimated, approximately, as:

$$S=m[S_L+S_{BS}+S_{OS}+2S_{SLM}+2S_{FL}+S_{D2}]+S_{SM}+S_{D1}+S_C(1+mn),$$

where m - the number of the optical processors; S_L - the laser price; S_{BS} - the price of the optic beam splitter; S_{OS} - the optical switch price; S_{SLM} - the price of the spatial light modulator; S_{FL} -the Fourier lens' price; S_D - the detector price; S_{SM} - the price of the semitransparent mirror; S_C -the computer's price.

At the using of the SLM price as a basic one, the prices of other devices can be estimated as: $S_L= aS_{SLM}$, $S_{BS}=bS_{SLM}$, $S_{OS} = cS_{SLM}$, $S_{FL} = dS_{SLM}$, $S_D = eS_{SLM}$, $S_{SM} = fS_{SLM}$, $S_C = hS_{SLM}$. In this case, the price of the system can be described as:

$$S=mS_{SLM}(1+a+b+c+d+e)+S_{SLM}(f+e+h(1+mn))=S_{SLM}[m(1+a+b+c+d+e)+(f+e+h(1+mn))], \tag{12}$$

The coefficients values are as follows: a=0.2; b=0.01; c=0.03; d=0.1; e=0.1; f=0.001; h=3; n=0.13.

Estimation of the systems parameters

There were estimated the time of the fingerprints recognition algorithms, the system productivity P at the fingerprints comparison with standards stage, the system price S, in conditions of t_{SLM}=20ms, t_D=1ms, t_{SG}=20ms, t_{GT}=20ms, m=1÷10, M=1, N=30000÷200000, k=1÷64. The results of these estimations show the following.

1. The time of the algorithms „FSR" realization as of the algorithms „FSDR", does not differ so much. The time algorithms "FSR-2" and "FSDR-2" realization is much shorter than the time of the algorithms "FSR-1" and "FSDR-1" realization.The algorithm „FSDR-2" is with 62 times more efficient than the algorithm „FSDR-1" and in 270 times is more efficient in comparison with the algorithm "FICR".

2. At the increase, the number m of optical processors from 1 to 10, the time of the ' recognition at the realization the algorithm „FSDR-2" will decrease from 13.8 sec till 1.32 sec (at N=30000 of fingerprints) and from 62.9sec till 6.4sec (at N=200000 of fingerprints).

3. For algorithm "FSDR-2" the system productivity at the fingerprints comparison step is increased till 30000 fingerprints/sec (at m=10), it is bigger with 10.6 times than the productivity of the system PRINTRAC.

4. The price of optical-electronic system is increased from 17.7 thousands dollars till 83.8 thousands dollars, at the increase of the optical processors number m from 1 to 10, and is 39 times smaller than the price of the system "PRINTRAC"[4].

5. The analysis shows that the optimum number of the optical processors in the system is m=3.

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8. CONCLUSIONS

1. The carried out investigations of the fingerprints' images correlation recognition method permitted to establish the fact this method is very sensitive to the non-correspondence in the angular orientation and in the scale of the input and standard fingerprints' images. The discussed method is stable to the surface fingerprints reduction; the noise doesn't, practically, influence on the maximal value of the correlation function in case of rotation or of scaling of the fingerprints' images, but, this happens when the fingerprints' surface and the image's resolution are changing; the recognition discrimination possibility depends on the images' resolution. The FICR method could be efficiently used especially for verification of the persons on the base of the fingerprints. The persons' identification can be made in conditions of a strict observance of the requirements concerning the angular position, the scale, the surface of the fingerprints' images and the absence of the noise in image.
2. It was elaborated the method of fingerprints' semi-spectrums recognition, characterized by stability to the reduction of the surface of the input fingerprints images and to the noise. At the stage of comparison with standards, this method is characterized by a reduced volume of information, which allows the decrease of the processing time and of the volume of information necessary for the storing of the standard images. This method is proved to be efficient for the person's verification on the base of the fingerprints and for the persons' identification in conditions of a strict observance of the requirements regarding the angular position and the scale of images.
3. There was presented the method of the fingerprints' space-dependent recognition. It allows the fingerprints' recognition independent from displacements, rotation and scaling. This method could be successfully used to the resolving of the problems of the persons' verification and identification.
4. It was elaborated a multi-processor optical - electronic system for the fingerprints' recognition.
5. There were elaborated and investigated 4 algorithms of computing processes organization in the optical-electronic system, which calculates the correlation functions on the basis of the filters of the standard images (algorithms "FSR-1" and "FSDR-1") and, directly, on the basis of the standard images (algorithms "FSR-2" and "FSDR-2").
6. The second group of algorithms ("FSR-2" and "FSDR-2") are with 62 times more efficient than the algorithms of the first group ("FSR-1" and "FSDR-1") and 270 times than the algorithm "FICR" (standard correlation recognition algorithm).
7. The system productivity, at the fingerprints comparison stage, is 30000 fingerprints/sec at number of optical processor m=10, and is with 10.6 times bigger than the productivity of the electronic system PRINTRAC.
8. The price of the elaborated optical-electronic system is 83.8 thousand dollars (at the m=10), and is with 39 times smaller than the PRINTRAC system.

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