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Optical-electronic systems for the fingerprints' recognition

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ABSTRACT

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: optical, electronic, system, fingerprints, recognition

1. INTRODUCTION

In the article[1], were presented, by authors, new methods of the fingerprints' recognition. In the presented paper are described the special purpose optical -electronic systems which realize the respective methods and the results of the investigation of these systems.

In Sec. 2 are described mono-channel and multi-channel optical-electronic systems. In Sec. 3 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.4, there are carried out 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. STRUCTURES OF THE OPTICAL -ELECTRONIC SYSTEMS FOR THE FINGERPRINTS' RECOGNITION

According to the proposed methods of fingerprints' identification[1], there were elaborated two special purpose systems: mono-channel and multi-channel optical-electronic systems.

2.1. Mono-channel optical-electronic system

The structure of mono-channel optical electronic system is presented in the figure 1. 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.

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2.2. 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.2), which contains a set of optical channels (processors). The additional optical processors are similar with that of the basic optical processor.

3. ORGANIZATION OF COMPUTING PROCESSES IN THE OPTICAL ELECTRONIC SYSTEMS

3.1. 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.

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 $P_{SB}(u,v)$.

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.

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:

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

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

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.

3.2. 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.

4. 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 :

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

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

$$T_{S1}=M\{2t_{SLM}+t_{D1}+t_{SG}+(t_{SLM}+t_{D2})N_e/m\}, \quad (1)$$

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

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

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:

$$T_{SDI}=M\{2t_{SLM}+t_{D1}+t_{SG}+ t_{GT}+(t_{SLM}+t_{D2})N_e/m\}, \quad (3)$$

$$T_{SD2}=M\{2t_{SLM}+t_{D1}+t_{SG}+ t_{GT}+(t_{SLM}+t_{D2})N_e/m\ k\ \}, \quad (4)$$

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

$$T_{IC}=M\{t_{SLM} + N_e(t_{SLM}+t_{D2})\}. \quad (5)$$

Systems' productivity at the fingerprints comparison step

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

$$P=mk/t_c, \quad (6)$$

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:

$$S=mS_{SLM}(1+a+b+c+d+e)+S_{SLM}(f+e+h(1+mn))=S_{SLM}[m(1+a+b+c+d+e)+(f+e+h(1+mn))], \quad (7)$$

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 are presented in figures 3÷9 and show the following.

1. The time of the algorithms „FSR" realization as of the algorithms „FSDR", does not differ so much (fig. 3). 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" (fig.4 and 5).

2. At the increase, the number m of optical processors from 1 to 10, the time of the ' recognition (fig.6) 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 (fig.7.) is increased till 30000 fingerprints/sec (at m=10), it is bigger with 10.6 times than the productivity of the system PRINTRAC (fig.8).

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 (fig.9), and is 39 times smaller than the price of the system "PRINTRAC"[4].

5. The analysis of the data presented in the fig.7, shows that the optimum number of the optical processors in the system is m=3.

The comparative data of the different systems for the persons' identification are presented in the fig.8.

CONCLUSION

1. It was elaborated a multi-processor optical - electronic system for the fingerprints' recognition.

2. 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").

3. 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).

4. 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.

5. 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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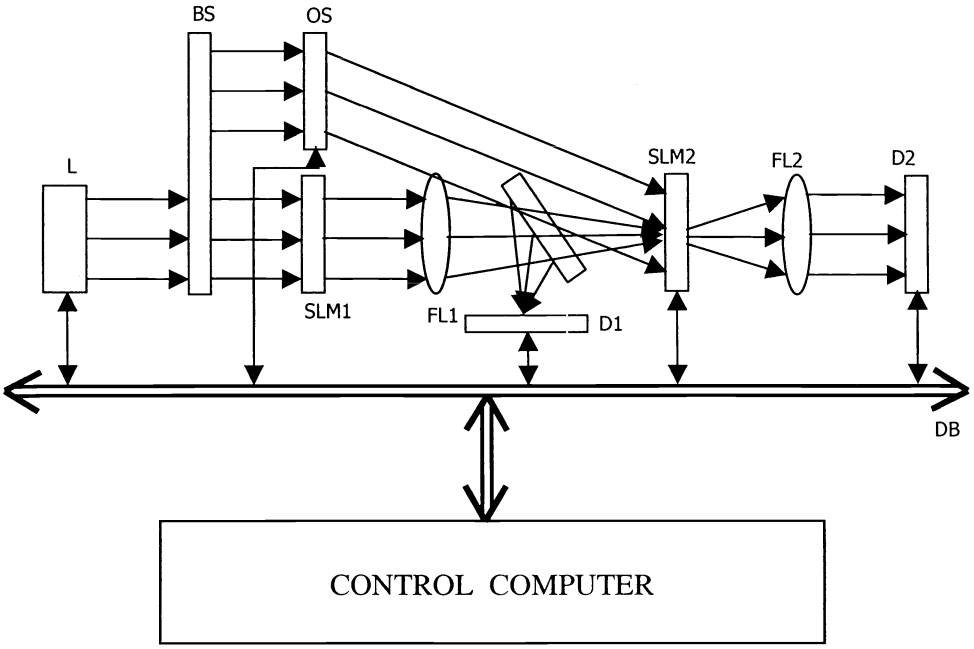

Fig.1. The mono-channel optical-electronic system

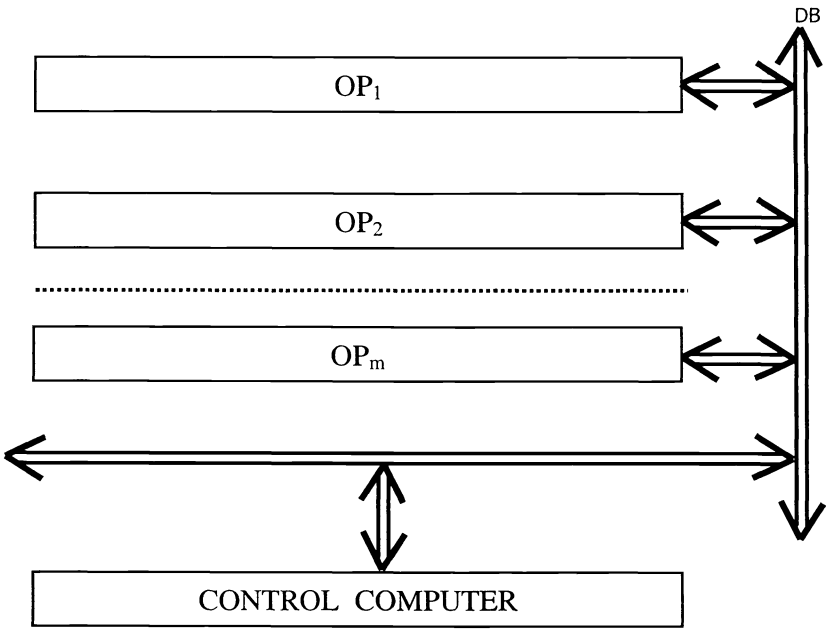

Fig.2. The multi-channel optical-electronic system

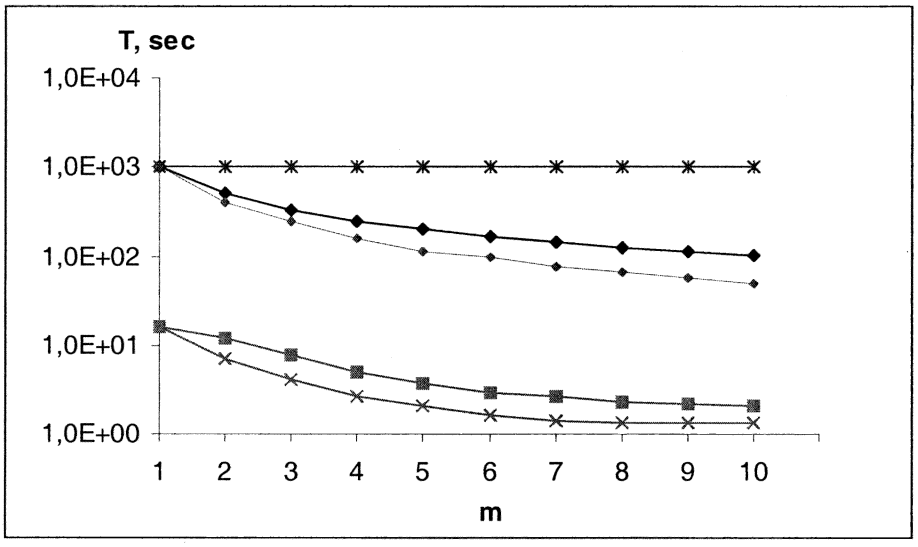

Fig.3. The time of the fingerprints' recognition in the optical-electronic system at a different number of optical processors m

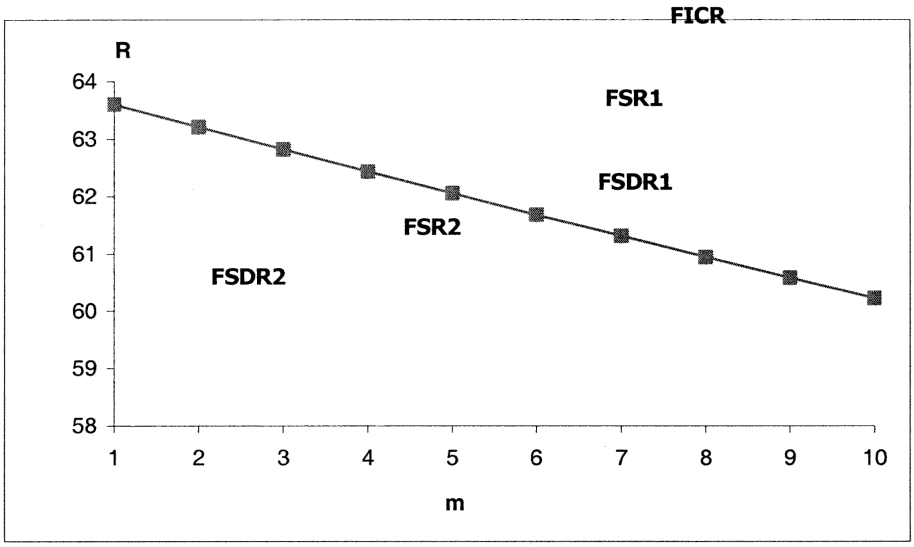

Fig.4. The time relation at the realization of the algorithms "FSR-1"and "FSR-2"

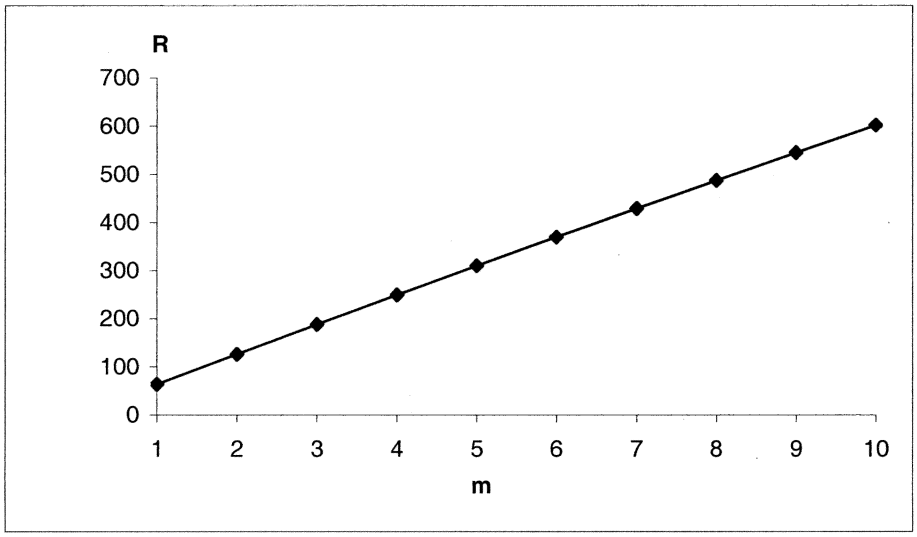

Fig.5. The time relation at the realization of the algorithms "FICR" and "FSR-2"

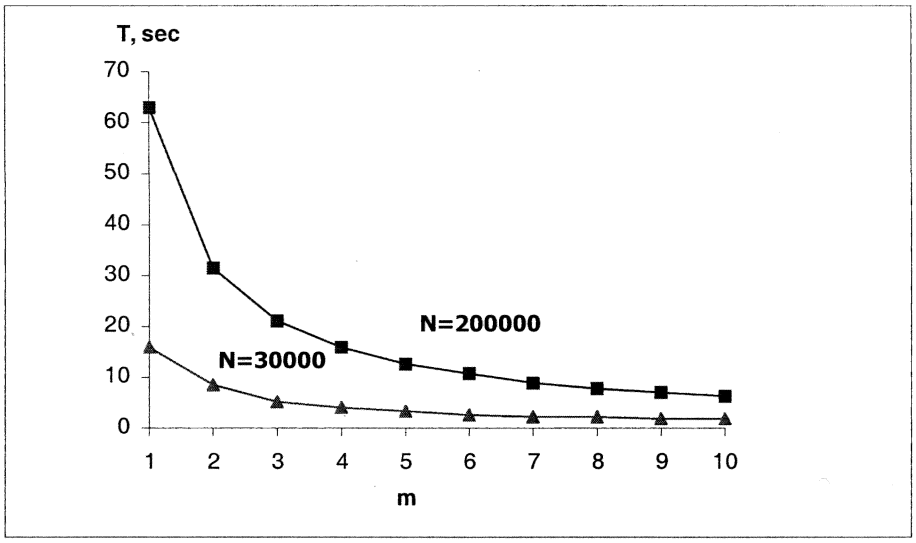

Fig.6. The time of the algorithm „FSR-2" realization at the different numbers N of standard fingerprints

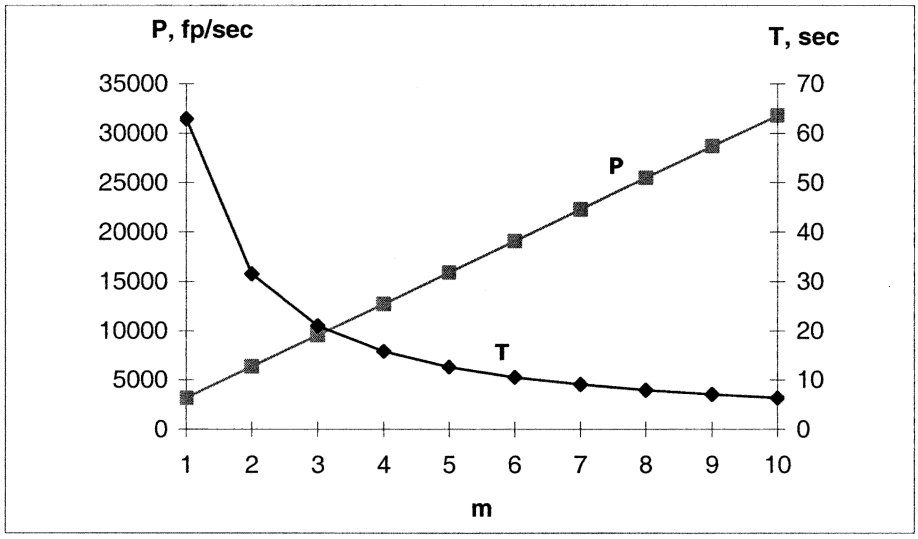

Fig.7. The productivity P at the fingerprints' comparison stage and the time T of the algorithm"FSR-2" realization

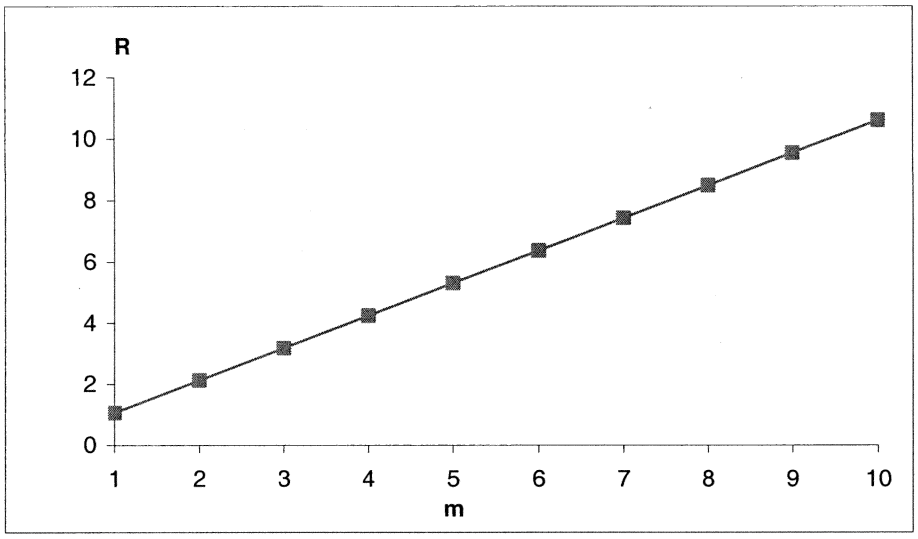

Fig.8. The productivity relation of the optical-electronic system (algorithm „FSDR") and the„Printrak" system

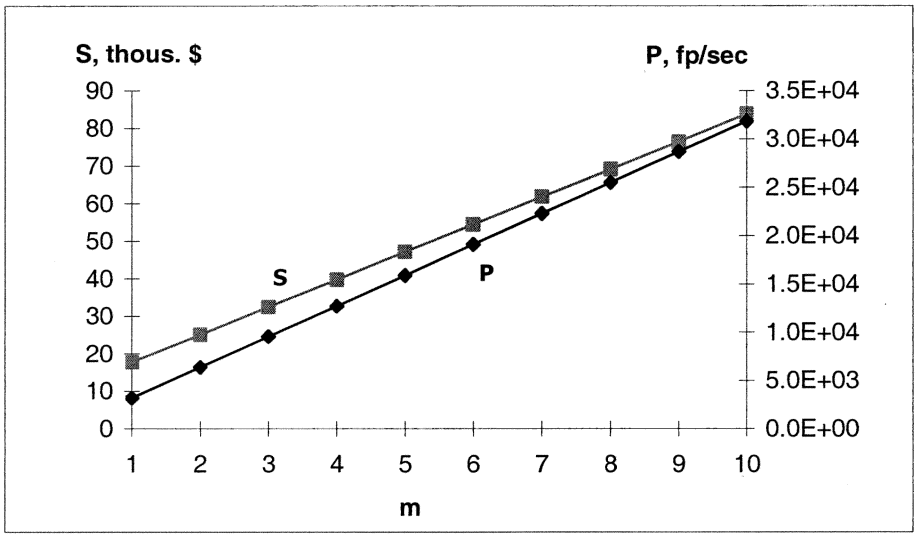

Fig.9. The price S and productivity P of the optical-electronic system