OPTICAL CORRELATION PROCESSORS FOR HIGH-SPEED OBJECTS RECOGNITION AND LOCALIZATION

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Abstract. *In the article there are presented the mathematical and structural descriptions of the basic model of the optical correlation processor, of the processor using the matrixes of the lasers and filters. In order to decrease the processing time in the processors it is proposed to use the concept of the distribution of the operations of the objects recognition and localization and to realize there in the different channels. At the stage of the objects recognition it was proposed to use the filters generating the codified correlation functions consisting of a binary optical code which is analyzing in parallel with a high speed. There were elaborated new kinds of the optical correlation processors – with distributed targets detection and localization. There were given the analyses of the time expenditures in the different kinds of the processors.*

Keywords: *correlation, filter, localization, multichannel, object, optical, processor, recognition*

1. Introduction

In the signals and image analysis one of the basic operations represents the operation of correlation. In the optical correlation processor the function of correlation is calculated at a very high speed - of 10^{14} bytes/sec, which is compared with a super high computer's capabilities.

Unfortunately, the productivity of the optical processor decrease at the objects recognition and localization due to necessity to use a set of the filters. Also, the reliability of the targets detection can't satisfy the standards at using of the filters which generate a single correlation maxima.

The purpose of this article consists in the analysis of the basic model of the optical correlation processor, determination of the bottlenecks in the functioning, elaboration of the new structures of the optical processors characterizing by enhanced processing time and reliability of the objects recognition and localization.

In section 2 there are presented the mathematical and structural descriptions of the basic model of the optical correlation processor. It is stipulated that a disadvantage of this processor consists in the high processing time due to the necessity to input the different filters.

In section 3 it is described the optical processor based on the matrixes of the lasers and filters (PMLF) which permit to decrease the time of the targets detection. It was observed that the disadvantage of the basic model of the optical processor and the processor PMLF consists in the necessity to spend high time at the stage of the optical correlation functions scanning at the objects recognition and localization operations which are realized in one step.

To avoid this problem there were elaborated the processors in which the operations of the objects recognition and localization are realized in different channels (section 4).

In section 5 it was given the analyses of the time expenditures in the different kinds of processors. It was established that the processor using matrixes of the lasers and filters with distributed recognition and localization is characterized by a lowest processing time.

2. The basic model of the optical correlation processor

In signal and image analysis one of the basic operations represents the operation of correlation describing as:

$$CR_j(x,y) = P(x,y) * H_j(x,y), \tag{1}$$

where P(x,y) is the input signal (or image) and $H_j(x,y)$ is the filter, j=1÷J.

The operation of correlation can be described also as:

$$CR_j(\xi, \eta) = \iint_{-\infty}^{\infty} P(x,y) H_j^*(x-\xi, y-\eta) dxdy, \tag{2}$$

or, using Fourier transformation:

$$CR_j(\xi,\eta)=F^{-1}\{F\{P(x,y)\}F^*\{H_j(x,y)\}\}=F^{-1}\{P(u,v)H_j^*(u,v)\}=F^{-1}\{C_j(u,v)\} \tag{3}$$

where F and F^{-1} are the operations of the 2D Fourier transformation, direct and, respectively, inverse; the sign [*] is that of the complex conjugation; P(u,v), $H_j(u,v)$ are the Fourier transformations of the functions P(x,y) and respectively, $H_j(x,y)$; u, v – are the coordinates in the frequency space.

The structure of the basic model of the optical correlation processor (BMOP) realizing formula (3) is presented on figure 1. The input image P(x,y) is placed on the Space Light Modulator 1 (SLM1) in the P1 focus plane of the Fourier Lens 1 (FL1). When the image is illuminated by a laser L, in the P2 focus plane of the lens FL1 it is formed the Fourier transformation of the function P(x,y):

$$F\{P(x,y)\}=P(u,v)=\iint_{-\infty}^{\infty} P(x,y)\exp[-i2\pi(xu+yv)]dxdy. \tag{4}$$

In the plane P2, on the SLM2 is introduced the filter $H_j^*(u,v)$. As a result, at the output of the plane P2 will be formed the product $C_j(u,v)=P(u,v)H_j^*(u,v)$. After the realization of the Fourier transformation of the function $C_j(u,v)$ by the Fourier Lens FL2, in the P3 plane the optical distribution will be formed which will consists the correlation function $CR_j(\xi,\eta)$. This optical distribution will be scanned by the detector D and analyzed.

The time of the correlation functions calculation can be estimated by the formula:

$$T1=T_{SLM1}+ j(T_{SLM2} + T_{CO} + T_D), \tag{5}$$

where T_{SLM1}, T_{SLM2} represent the time of the data input on SLM1 (the function P(x,y)) and on SLM2 (the function $H_j^*(u,v)$) respectively; T_{CO} – the time of the correlation operation performing; T_D – the time of the optical correlation function scanning and analysis.

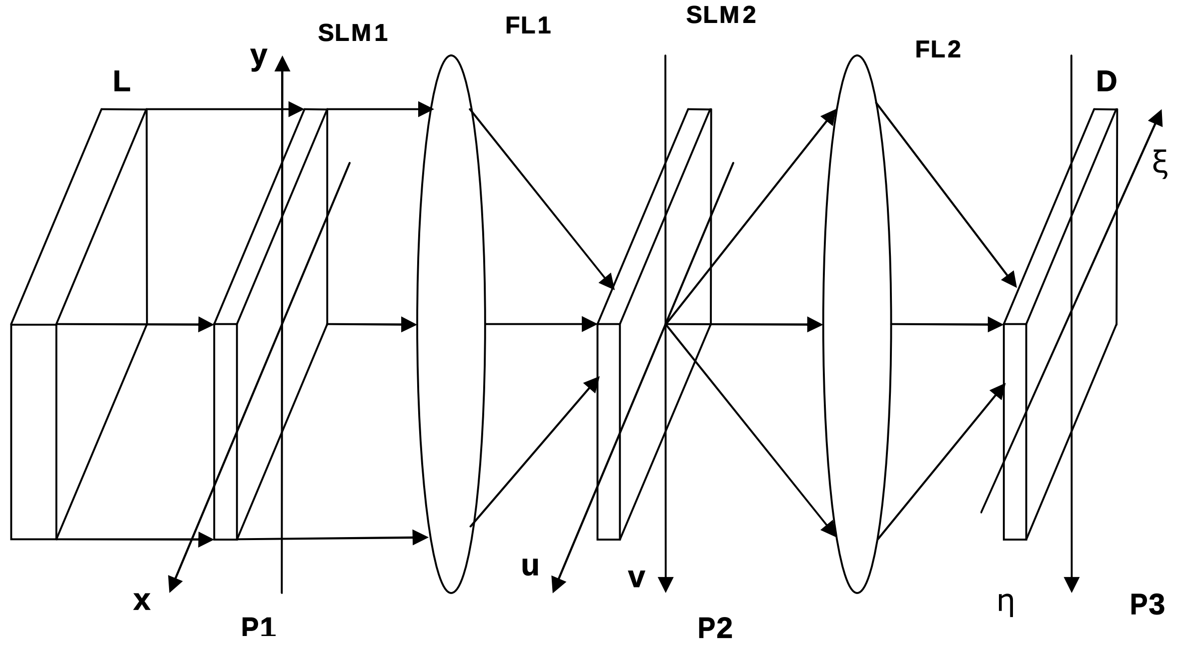

Figure 1. The structure of the basic model of the optical correlation processor

If the initial image P(x,y) contains, for example, 10^6 pixels, and the time of the correlation function performing is determined by the light beam time passing from laser L to detector D and equal to $T_{CO} = 10^{-8}$ sec, the productivity of the processor at the correlation function calculation will be very high, equal to 10^{14} bytes/sec.

Unfortunately, the productivity of the processor BMOP decrease at the objects recognition and localization due to necessity to use a set of the filters, to input the filters on the SLM2 (T_{SLM2} = 10ms), to scan the output optical correlation distribution by detector D (T_D = 10ms).

Also, the reliability of the targets detection can't satisfy the standards at using of the filters which generate a single correlation maxima.

2. The optical processor based on the matrixes of the lasers and filters

To decrease the processing time by avoiding of the first factor from mentioned above can be used the optical processor based on the matrixes of the lasers and filters (PMLF), presented in figure 2 [1].

The input image is fed to a modulator SLM1. The matrix of lasers ML represent the commutated matrix of the A1-GaAS diodes with radiation wave length 820nm, radiation capacity 5mW, width of radiation spectrum 4nm. The diode diameter is of 7 mm, emitter dimensions of 2x13μm, commutation time of 0.1mks.

The matrix of filters MF is a set of the computer generated holograms calculated in advance or in real time mode and placed on a modulator SLM2.

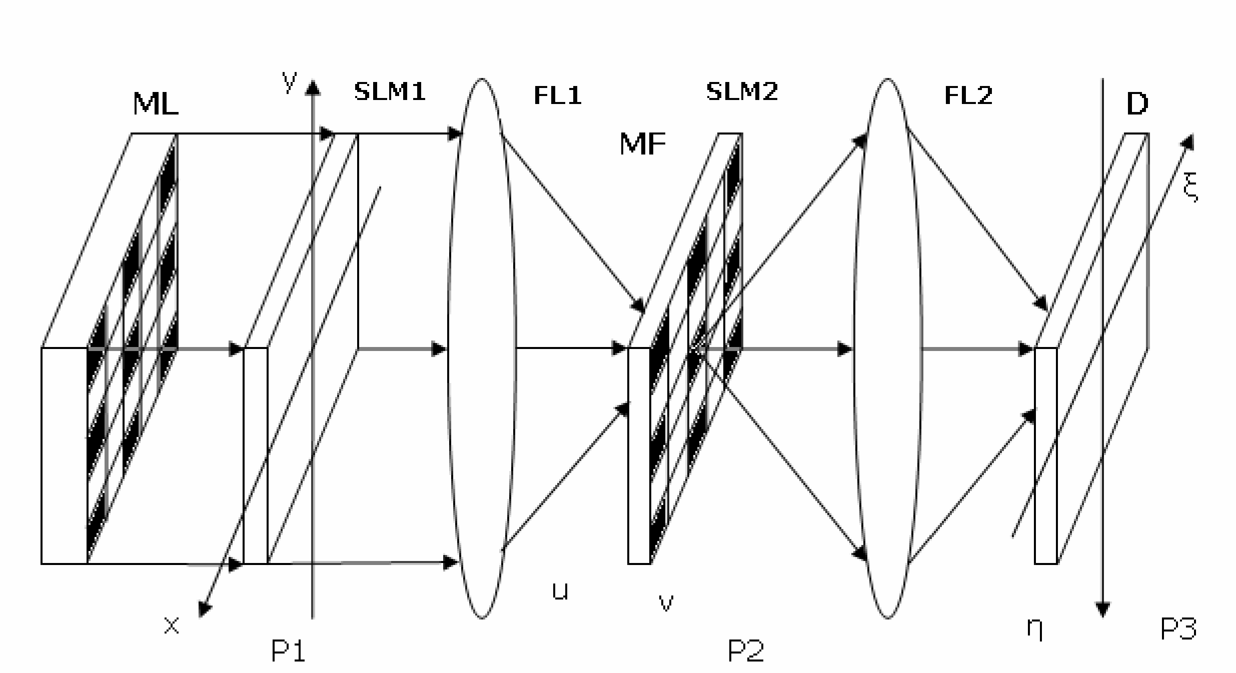

Figure 2. Optical processor based on the matrixes of the lasers and filters

The advantage of this processor consists in the significant reducing of the time at the filters input which in this case will be equal to the switching time T_s of a laser (T_s = 0.1mks).

The processing time in the processor PMLF can be estimated as:

$$T2=T_{SLM1}+d\cdot T_{SLM2}+j(T_s+T_{CO}+T_D) \quad (6)$$

were d=J/L; J is maximal number of the filters necessary to detect a target; L is the number of the lasers on the matrix ML.

4. The correlation processors with separate channels for objects' recognition and localization

The bottleneck of the processors BMOP and PMLF consists in the necessity to spend high time at the stage of the optical correlation functions scanning by detector D at the targets detection and localization operations which are realized in one step.

To avoid this problem we propose to divide the operations of the objects recognition and localization and to realize these operations in the different channels [2].

4.1. The processor PMLF with distributed functions of objects recognition and localization

To realize proposed approach there will be created two sets of the filters. The first set of the filters will be used for objects recognition, and the second set – for objects localization. The filters used for objects recognition will generate the codified correlation functions, which will consists the binary optical code from a K "units" [2]:

$$CR_{jd}(x,y) = P(x,y)*H_{jd}(x,y).$$

The filters response at the objects localization stage will consists of single correlation maxima, the coordinates' of which will permit to localize the objects:

$$CR_{jl}(x,y) = P(x,y)*H_{jl}(x,y).$$

The structure of the processor PMLF will be modified in the next mode (Fig.3). The optical distribution after the lens FL2 is divided by the semitransparent mirror SM into two channels.

In the first channel is realizing the operation of the objects recognition with a high speed. For this purpose it is used the device for the operative correlation field analysis (DOCFA). This device consists of the matrix of the threshold optrons 1, optical collector 2, the line of the threshold detectors 3, the voting logical elements 4 and 5, the elements NOT 6 and OR 7.

After the object will be recognized, on the modulator SLM2 (Fig.2) will be input a filter for localization of the object, it will be switched on the laser from the matrix ML, which will permit to realize the operation of correlation between the input function P(x,y) and the filter $H_{jl}^{*}(u,v)$ of the known object. This correlation function will consists a single correlation maxima which will be analyzed by detector D for determination of the correlation maxima coordinates which will permit to localize the object.

The processing time will be described as (at $T_{SLM1} = T_{SLM2}$):

$$\begin{aligned} T21 &= T_{SLM1} + d \cdot T_{SLM2} + j(T_s + T_{CO} + T_d) + [T_{SLM2} + T_s + T_{CO} + T_D] = \\ &= T_{SLM}(2+d) + j(T_s + T_{CO} + T_d) + (T_s + T_{CO} + T_D) \end{aligned} \quad (7)$$

were T_d is the time of the target detection, which is equal to the data time processing in the device DOCFA.

4.2. The processor BMOP with distributed recognition and localization

The structure of the processor described in section 2, can be modified in the same way as was described in section 4.1 with the purpose to divide the stages of the object's recognition and localization and to decrease the processing time, to increase the reliability of the objects recognition.

In this case the filters used at the targets detection will be input on SLM2 (fig.1) consequently until the object will be detected by the device DOCFA (fig.3). After this on SLM2 will be input the filter for object localization.

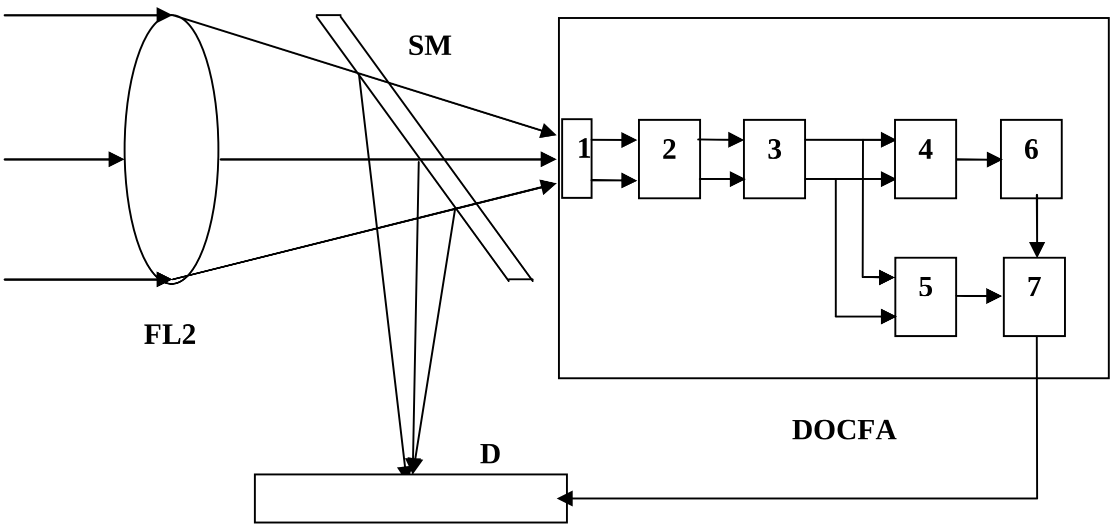

Figure 3. The channels for objects' recognition and localization.

The processing time in this kind of the processor will be estimated as:

$$T11=T_{SLM1}+j(T_{SLM2}+T_{CO}+T_d)+(T_{SLM2}+T_{CO}+T_D)=2T_{SLM1}+j(T_{SLM2}+T_{CO}+T_d)+(T_{CO}+T_D) \qquad (8)$$

5. The analyses of the time expenditures in the processors

There were calculated the processing time in the different types of the correlation processors using the formulas (5)-(8) for number of the filters j changed from 1 to 100, the time of the data input on SLM T_{SLM1} = T_{SLM2} = 10ms, the time of the correlation operation performing T_{CO} = 10ns, the time of the optical correlation function scanning and analysis T_D = 10ms, the number of the lasers in the matrix L=9, the switching time of a laser T_s = 0.1mks.

The results of the calculations there are presented at the Fig.4 were T1 is the processing time in the processor BMOP; T11 - in the processor BMOP with distributed stages of the recognition and localization of the objects (BMOP DRL); T2 – in the processor PMLF; T21 – in the processor PMLF with distributed recognition and localization (PMLF DRL)

Also, there were calculated the time relations T1/T11, T2/T21, T1/T21 and T11/T21 presented on fig.5.

The analyses of the data presented in fig.4 shows that the processors using matrixes of the lasers and filters with distributed recognition and localization is characterized by a lowest processing time changing from T21 = 0.04sec until 0.15sec at the changing of the number of the filters j from 1 to 100.

The processing times in the processors BMOP DRL - T11 and in the correlator PMLF - T2 are very closed and changed from 0.07sec to 1.13sec for the same diapason of the filters number j.

The correlator BMOP is characterized by a highest processing time changing from T1=0.11sec up to 2.01sec.

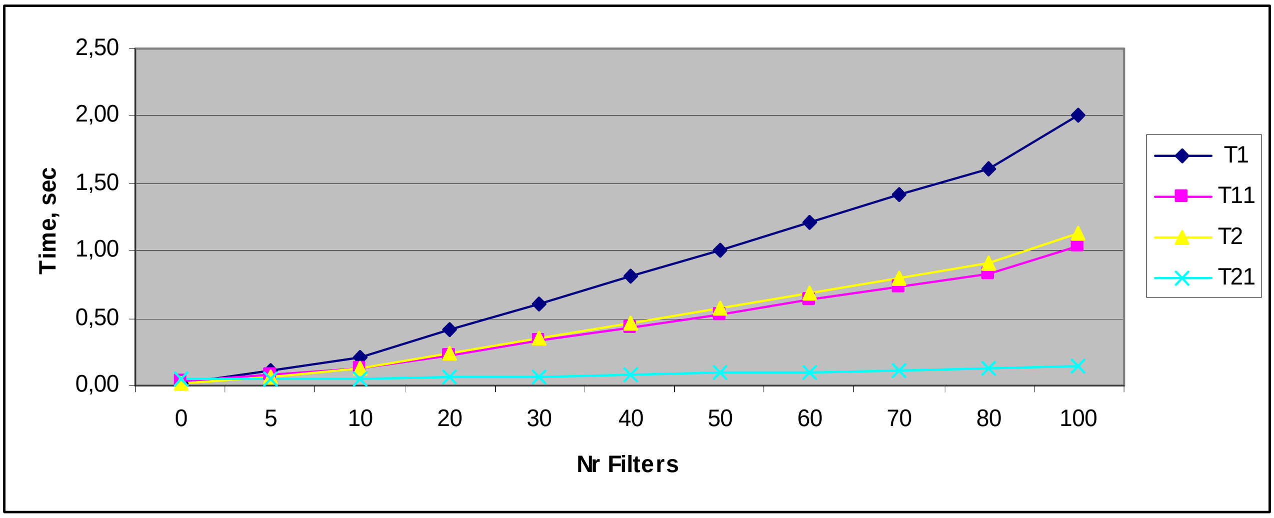

Figure 4. The processing time in the correlation processors

If the real time mode processing will be considered for the processing time less or equal to 0.5sec, this mode can be effectively realized in the processor PMLF DRL - for j<=100, in the processors PMLF and BMOP DRL - for j<=45, and in correlator BMOP - for j<=25.

The proposed approach of the recognition and localization operations distribution permit to decrease the processing time up to 2 times in the processors BMOP DRL, and up to 8 times in the processor PMLF DRL (Fig. 5).

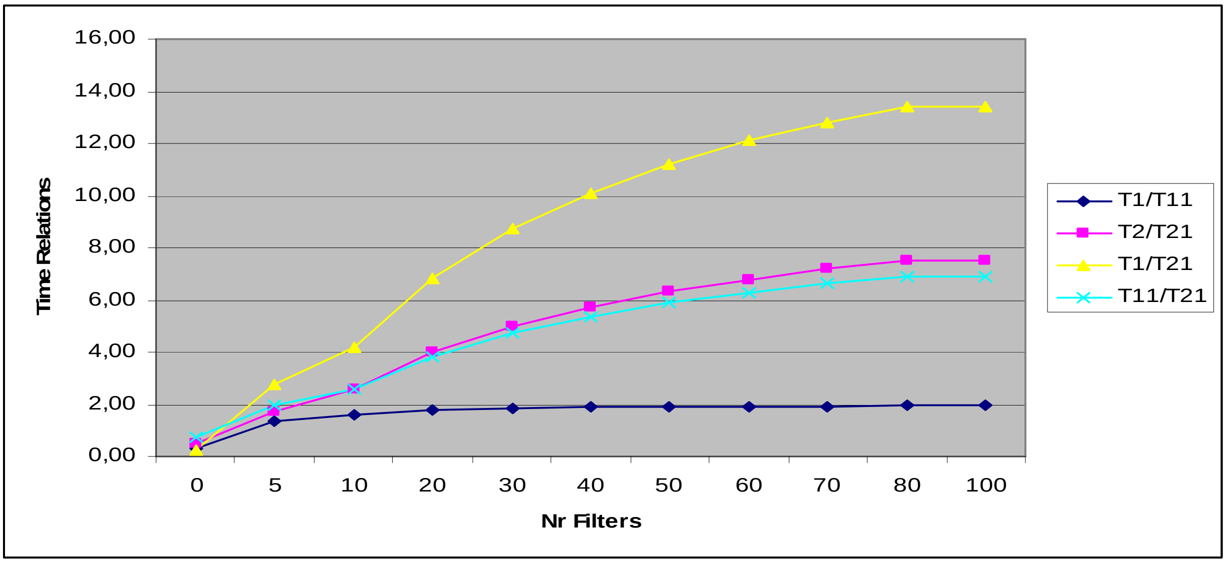

Figure 5. The processing time relations

6. Conclusion

The basic model of the optical correlation processor (BMOP) is characterized as a very high speed processor which can be compared with a super power computer system at the correlation function calculation stage. At the same time two factors influence negative on the optical processor final productivity: necessity to input the filters and to scan the output optical correlation distribution at the stage of the objects recognition and localization which are realized in one step.

To decrease the processing time there were proposed new structures of the optical correlation processors, based on using of the matrixes of the lasers and filters, organizing of the separate channels for objects recognition and localization and utilization of the filters with codified responses.

The optical processor based on the matrixes of the lasers and filters (PMLF) and processor BMOP with distributed detection and localization operations (BMOP DRL) permit to increase (up to 2 times) the speed of the objects recognition in comparison with a basic model of the optical correlation processor.

Much more effective is the processor PMLF with distributed recognition and localization operations which permit to decrease the processing time until 13 times.

It was established that the real time mode processing can be effectively realized in the processor PMLF DRL at number of the filters j<=100, in the correlators PMLF and BMOP DRL for j<=45, and in the correlator BMOP for j<=25.

The proposed approach of the operations of the recognition and localization distribution permit to decrease the processing time up to 2 times in the processor BMOP DDL and up to 8 times in the processor PMLF DRL.

From the point of the view of the processing time the correlator PMLF DRL is 7 times more effective than correlator BMOP DRL and on 13 times than correlator BMOP.

7. References

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