Computer Science Journal of Moldova, vol.5, no.1(13), 1997

The methods and computer structures for adaptive Fourier descriptive image analysis

V.Perzhu A.Gurau

Abstract

New architectures of image processing computer systems, based on the algorithms of Fourier — descriptive (FD) analysis have been developed. A new computing processes organisation method on the basis of FD image features has been proposed. The structures of two problem-oriented optical-electronic computer systems have been developed. The estimation of time expenditures in the systems have been carried out.

1 Introduction

A perspective trend in development of highly productive computer means for invariant image processing is the elaboration of the problem-oriented computer systems on the basis of Fourier - descriptive analysis (FDA) algorithms [1]. These systems are characterized by their relative simplicity and the possibility of combination between electronic and optical processing means. However, in the known structures [1,2] the main volume of calculations is implemented in electronic devices, that predefines essential time expenditures. Besides, in these systems there is no possibility to define object parameters, such as their angle orientation, scale, location. Indicated lacks restrict essentially the sphere of their application.

In this article new architectures of image processing computer systems that use FDA algorithms have been developed. The suggested systems are based on the construction principle of computing means which are controlled by input images parameters [3]. A new method of Fourier-descriptive Image Features (FDIF) forming is presented in section 2. In section 3 a new method of computing processes organisation based on the FDIF have been described. The structures of two problem-oriented optical-electronic computer systems have been elaborated on the basis of the proposed method of computing processes organisation and method of the FDIF forming (section 4). Evaluation of time expenditures during identification step and total time expenditures in the systems have been done.

2 Fourier-descriptive image features formation methods

The Fourier discriptive image features represents a set of features which are invariant to angle orientation, scale changing, location of the input image [1]. The formation of FDIF consists of the following. Let $P(u,v)$ be the squared absolute value of Fourier-transformation of image $P(x',y') = P(x+e_3, y+e_4, e_1, e_2)$. As it is known, the function P(u,v) is invariant to shiftings (the parameters e_3, e_4) of the initial function $P(x',y')$. By the threshold limitation method we create the function $P_{kp}(u,v)$ that represents the closed external contour of image Fourier - spectrum from the function P(u,v) (Fig. 1).

In the spatial frequences plane (u,v) the contour line $P_{kp}(u,v)$ can be described by angle function $\Phi(\alpha)$ of the tangents to $P_{kp}(u,v)$ and axis U. According to the known method of the FDIF forming, the function $P_{kp}(u,v)$ is sampled at the M_k points, the parameters $l_p, \Delta\Phi_p, L$, are determined, where l_p is the distance between the points p and $(p{+}1)$; $\Delta\Phi_p$ denotes the angle of the tangents to the points $(p-1)$ and p; L is the total length of the contour line.

Then FDIF are calculated by the formula:

$$A_k = \sqrt{a_k^2 + b_k^2}, \tag{1}$$

where

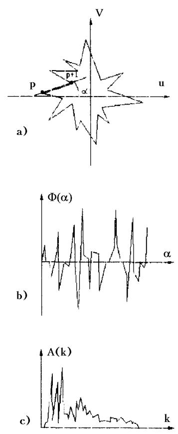

Fig. 1. Contouread Fourier-spectrum image - (a);
angle function $\Phi(\alpha)$ - (b); Fourier-descreptive image features - (c)

$$a_k = -\frac{\sum_{p=1}^{M} \triangle\Phi_p cos\frac{2\pi l_p k}{L}}{k}, \quad (2)$$

$$b_k = -\frac{\sum_{p=1}^{M} \triangle\Phi_p sin\frac{2\pi l_p k}{L}}{k}, \quad (3)$$

The parameters a_k and b_k represent the coefficients of Fourier series of the function $\Phi(\alpha)$. The values of A_k will be invariant to the rotation and scale changing of the image.

Thus the presented method of image FDIF forming consists in the following.

1) Forming of input image Fourier-spectrum.
2) Picking out the external Fourier-spectrum contour.
3) Calculation of the parameters: $l_p, \triangle\Phi_P, L$.
4) Calculation of the parameters: a_k, b_k, A_k according to the expressions (1)-(3).

The analysis shows that the steps 1,2 can be implemented by electronic or optical means. The steps 3,4 are implemented only by electronic means, that require substantial time expenditures.

A new method of the FDIF forming have been developed. The difference between this method and the known one is in the fact that after forming the external contour of image Fourier-spectrum, the function $\Phi(\alpha)$ is calculated. Then the squared absolute value of Fourier transformation (FT) of the function $\Phi(\alpha)$ is made up, i.e. calculation of $\mid FT\{\Phi(\alpha)\} \mid^2$, which represents the values of parameters A_k, that is the set of required FDIF.

In this method of the FDIF formation the necessity of electronic processing exists only at the step of computing of the function $\Phi(\alpha)$ All the following operations can be implemented optically that allows to reduce essentialy the total time expenditures.

3 Method of computung processes organisation on the basis of the FDIF

The proposed method of computing processes organisation consists in the following. At the first step the input image $P(x', y')$ or its fragment is subjected to preprocessing with the purpose of noise elimination: $P(x', y') \longrightarrow P_1(x', y')$. Then image $P_1(x', y')$ is set in to two information processing channels.

Image shifting parameters e_3, e_4 on a plane are determined in the first channel. The image $P_1(x', y')$ is contoured in the second channel: $P_1(x', y') \longrightarrow K\{P_1(x', y')\} = P_k(x', y')$. This operation will permit to avoid the background influence, dissimilarities of the function intensity of $P_1(x', y')$ at the step of threshold limitation of its Fourier-spectrum.

At the next step the Fourier-spectrum of image $P_k(x', y')$ is computed:

$$P_k(x', y') \longrightarrow \mid FT\{P_k(x', y')\} \mid^2 = P_k(u, v)$$

and by means of the threshold limitation method the function $P_{kp}(u, v)$ is made up, representing contour image of Fourier-spectrum at a certain level of intensity. Further the image $P_{kp}(u, v)$ is set into the third, the fourth and the fifth processing channels.

The complexity [3] SL of the image $P_k(u, v)$ and the maximum freqwuency f_m of Fourier-spectrum are computed in the third channel. Information about parameters SL, f_m is set into the fourth and the fifth channels.

In the fourth channel the necessary number of points M of the function $P_{kp}(u, v)$ sampling is defined in correspondence with the image complexity SL and the values of a_k, b_k, A_k are calculated. On the basis of A_k parameters the object classification is carried out. This procedure can be implemented using different methods, for example, Fisher's method, Karunen-Loev method or others.

Basing on the object classification results and on the value of f_m the object scale changes is determined (the parameter e_1). Further, information about e_1 is transmitted int the fifth processing channel, where the function $P_{kp}(u, v)$ is normalized with respect to e_1 and is transformed to a polar coordinate system: $P_{kp}(u,v) \longrightarrow P_{kh}(u_1,v_1) = P_{kh}[u_1 + u_0(e_2), v_1]$.

Then the value of e_2, the object angle orientation is determined using the method of the phase component extraction.

Thus the peculiarities of the suggested computing processes organisation method consists of the following.

1) By the input image contouring operation introducing the accuracy of object identification is increasing owing to more accurate formation of the function $P_{kp}(u,v)$. This is conditioned by the fact that the value of intensity threshold, on which $P_{kp}(u,v)$ is formed, will not depend on the input image intensity variations.

2) This method allows to identify the objects, and also to calculate their parameters, namely: location, angle orientation and scale.

3) The preliminary image complexity SL calculation allows to determine the accurate value of the number of sampling points M of the function $P_{kp}(u,v)$. This gives the possibility to increase the accuracy and to decrease time expenditures at the identification step. Besides, the value of SL parameter is used during the image coordinates transformation for the computing process adaptive control, that allows to reduce substantially the time expenditures.

4 Image processing computer systems

In accordance with the suggested computing processes organisation method and the methods of FDIF forming the structures of two optical-electronic computer systems (OECS) have been developed.

The structure of the first computer system (OECS1) is represented in Fig. 2. The system contains the laser 1; the block of image input 2; the processors for preliminary image processing 3,4; the optical multipliers 5,6; the processors of object parameters calculations 7,8; the Fourier processor 9; the digital processor 10; the processor of image complexity calculation 11; the processor for image coordinates

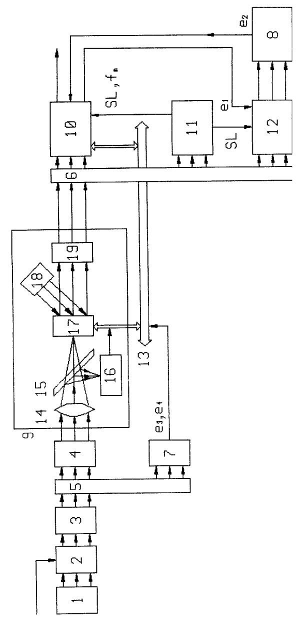

Fig.2. The structure of the image processing computer system

transformation 12; control and data bus 13. The Fourier processor 9 contains the Fourier lens 14, the semitransparent mirror 15, the photo-receiver 16, the optical transparency 17, the supplementary laser 18, the matrix of threshold optrons (MTO) 19.

The processor 3 is used for image noises elimination, the processor 4 implements the operation of image contouring. The processor 7 is used to determine the object location on the plane, i.e. the parameters e_3, e_4. The processor 8 is applied for calculation of the object angle orientation (the parameter e_2). The objects classification and their scale calculation (the parameter e_1) are carried out in the processor 10. Besides, this processor carries out the control functions in the system.

In the processor 9 with the help of the lens 14 the image Fourier-spectrum is made up and is recorded in the transparency 17. By means of the semitransparent mirror 15 Fourier-spectrum is also formed in the plane of photo-receiver 16, were the light intensity maximum value is determined and electrical signal of threshold limitation is transmitted to the MTO 19. By the laser 18 the Fourier-spectrum image is read from the transparency 17 in the reflection mode and passes through the MTO 19, where it is limited in intensity and further is transmitted to the processor 9 output.

The difference of another image processing computer system (OECS2) from OECS1 consists of the presence of suplementary devices: the module of electro - optical transformer, the semitransparent mirror. Besides, in this system the values of parameters a_k, b_k, A_k are calculated optically, that allow to reduce essentially the time expenditures during the input image Fourier-descriptors formation.

The total time expenditures in the elaborated systems are estimated as:

$$\begin{aligned} T_1 \quad = \quad & \alpha_c^2 N_n^2 [t_{ex} + 4\alpha_c \nu \frac{4t_m + t_s + t_f + t_r}{N_n}] + 4\alpha_c \nu N_n [8\alpha_c \nu N_n (4t_m + \\ & + t_f) + (m_k - 1)(t_m + t_s) + 7t_m + 4t_s + 2t_r + t_f] + (m_k - 1) \\ & (t_{cp} - t_s) + N_n(0.8N_n + 5.15) + 131.1, \qquad \mu s, \end{aligned} \tag{4}$$

$$T_2 = \alpha_c^2 N_n^2[t_{ex} + 4\alpha_c\nu\frac{4t_m + t_s + t_f + t_r}{N_n}] + 4\alpha_c\nu N_n(t_s + t_d + t_f) + +(m_k - 1)\cdot[4\alpha_c\nu N_n(t_m + t_s) + t_{cp} - t_s] + \nu N_n(0.8N_n + +5.15) + 241.1, \quad \mu s, \qquad (5)$$

where α_c is the parameter which is defined by the contour complexity; N_n is the number of sampling elements; $t_{ex}, t_{tr}-$ the pixel extraction time and the time of its coordinates transformation; ν is the parameter which is defined by the contour length; t_m, t_s are the times of two operands multiplication and addition respectively; t_f is the trigonometric function calculation time; t_r is the square root calculation time; m_k is the number of object classes.

One of the considerable differencies of the elaborated computer systems from the known one is the possibility to define the object parameters, namely: location, angle orientation and scale. That is why it is expediently to compare the given system with the known one by the time expenditures only at the object identification step, which will be the following:

$$t_{id1} = 4\alpha_c\nu N_n[8\alpha_c\nu N_n(4t_m + t_f) + (m_k - 1)(t_m + t_s) + 7t_m + +4t_s + 2t_r + t_f] + (m_k - 1)(t_{cp} - t_s) + 104.9, \quad \mu s, \qquad (6)$$

$$t_{id2} = 4\alpha_c\nu N_n(t_s + t_m + t_f) + (m_k - 1)[4\alpha_c\nu N_n(t_m + t_s) + t_{cp} - -t_s] + 215.2, 7, \quad \mu s, \qquad (7)$$

The time expenditures at this step in the known system [1,2] are defined in the following way:

$$t_{id} = 4\nu N_n[8\nu N_n(4t_m + t_f) + (m_k - 1)(t_m + t_s) + +7t_m + 4t_s + +2t_r + t_f] + (m_k - 1)(t_{cp} - t_s) + 100.3, \quad \mu s, \qquad (8)$$

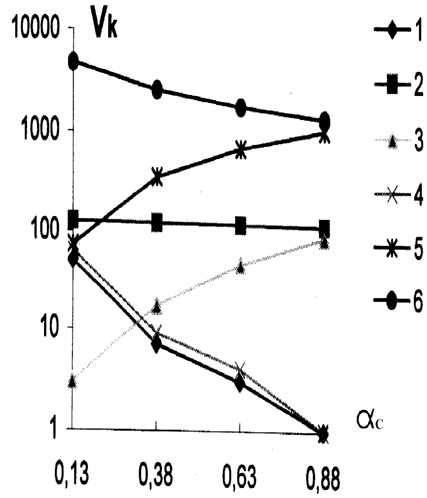

Fig.3. Advantage in speed of objects identification at $m_k = 2, N_n = 64$: in the OECS1 in comparision with the OECS2 - 1; in the OECS1-2; OECS2-5; at $m_k = 10, N_n = 512$: in the OECS1-3, in the OECS1 in comparison with OECS2-4; in the OECS2-6;

Basing on the relations (4)-(8) have been made the estimation of the total time expenditures in the elaborated systems and of the time expenditures at the step of identification in these and in the known systems and also the advantage in speed: $V_{k1} = t_{id}/t_{id1}$, $V_{k2} = t_{id}/t_{id2}$, $V_{k3} = t_{id1}/t_{id2}$.

The estimation took place with the following values of parameters: $\alpha_c = 0.125 \div 1; \nu = 0.5 \div 2; N_n = 64 \div 512; m_k = 2 \div 10; t_m = 0.04 \mu s; t_s = t_{cp} = 0.02 \mu s; t_r = t_f = 0.05 \mu s; t_{ex} = 0.015 \mu s$.

The results of calculations showed that while varying the parameters α_c from 0.125 to 0.875, N_n from 64 to 512 and m_k from 2 to 10 the time expenditures t_{id} are increasing during the identification step in the first system from 0.55ms to 1.35sec, in the second system from 0.22ms to 1.38ms and in the known one from 28ms to 1.76sec. The value of t_{id} in the first system depends unimportantly on the classes number m_k of identificating objects, but on increasing the parameters α_c, N_n its growing is sufficiently abrupt. The value of t_{id} in the second system starts to enlarge more considerably while increasing the parameters m_k, α_c when $N_n \geq 128$. The speed advantage in both systems depends on the parameters α_c, m_k, N_n (Fig.3).

When $\alpha_c = 0.125, m_k = 2, N_n = 64$ the values $V_{k1} = 50, V_{k2} = 126$, but when $m_k = 10, N_n = 512$ they are a.f.: $V_{k1} = 63, V_{k2} = 4622$.

On increasing α_c, m_k, N_n inside the indicated limits the value of parameter V_{k3} is growing up from 3 to 979 times. Thus the calculation of Fourier-descriptive image features is more effective in the elaborated systems. The FDIF are calculated in the second system with the less time expenditures than in the first one. On incresing the parameters α_c, m_k, N_n the total time expenditures are also increased: in the first system from 4 ms to 1.57 sec and in the second one from 4 ms to 217 ms. The following dependence also can be observed: at the increase of the parameters α_c, N_n the efficiency of the second system is growing with respect to the first one (Fig.4).

The analysis showed that owing to the preliminary calculation of the image complexity and the respective computing processing organisation in the elaborated systems there exists the possibility to decrease considerably the image processing time expenditures. Thus, the time

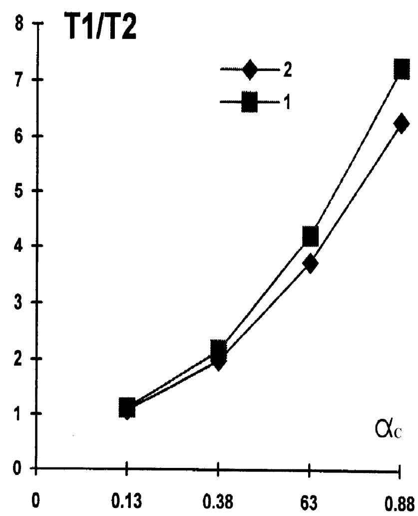

Fig.4. The efficiency of the OECS2 respective to OECS1: 1 - at $m_k = 2, N_n = 64; 2 - atm_k = 10, N_n = 512$

expenditures at the identification step can be decreased more than 30 times in OECS1 and 28 times in OECS2. The total time expenditures can be decreased on the average 6.5 times.

5 Conclusion

The new method of Fourier-descriptive image features FDIF calculation have been proposed, which allows to implement optically the greater part of calculations and gives the possibility to increase the processing speed.

The new method of the computing processes organisation is elaborated on the basis of Fourier-descriptive analysis of images. The peculiarities of the method are the following. By introducing the operation of the input image contouring, the object identification accuracy is increased due to more accurate FDIF forming. This method allows not only to identify the objects, but to calculate their parameters, such as location, angle orientation, scale. One of the method steps is the image complexity calculation, that gives the possibility to decline time expenditures at the identification step and to increase the calculation results accuracy.

On the basis of the proposed method of the computing processes organisation and the method of FDIF forming there have been elaborated the structures of two optical-electronic computer systems. It is shown that the speed of both systems during the identification step exceeds considerably the known system.

Due to the introduction of the operation of image complexity preliminary calculation there appears the possibility to reduce the time expenditures up to 30 times during the identification step and the total time expenditures in the systems up to 6.5 times.

References

[1] Duvernoy J. Extraction of invariant directional signatures of terrain textures from Fourier spectra // Optics communication. N2, Vol 48. -1983. pp.80-84.

[2] Duvernoy J. Optical-digital processing of directional terrain textures invariant under translation, rotation and change of scale// Applied Optics. -N6, Vol 23. -1984. - pp.828-837.

[3] Perzhu V.L. The construction of adaptive computing means for image processing// Proc. of International conf. on microelectronics and computer science ICMSC-92. -21-23 Oct. -Chisinau, 1992. - pp.71-76.

Veacheslav L. Perzhu, Adrian V. Gurau,
Tehnical University of Moldova
Bd. Shtefan Mare, 168, Kisinau
MD-2004, Republic of Moldova
phone: (3732)497016
Fax: (3732)237509

Received 27 November, 1996