R. N. Kvetniy, Dr. Sc. (Eng.), Prof.; O. Yu. Sofina

OPTIMIZATION OF THE METHOD OF INVERSE RESONANCE FILTRATION IN PROBLEMS OF OBJECTS RECOGNITION ON TEXTURE BACKGROUND

The paper considers new approach to the solutions of the problems of objects recognition on texture background. Filtration of textures is suggested to perform using inverse resonant filter (IRF).Filter synthesis is based on approximation of background surface by Fourier series, which compise proper natural 2D oscillations of the background.

Key words: *inverse filtration, discrete Fourier transform, natural oscillations.*

Objects recognition on the background of texture images – is one of the main problems in visual basing and videocontrol systems. Recognition is performed by means of background influence elimination and allocation of objects differing from it by statistical, structural or dynamic features. For this purpose the filter of corresponding type must be synthesized. Principle methods of textures analysis are given in surveys [1 - 5] .

Overwhelming majority of the methods intended for analysis of texture images work as classificators of certain statistical or spectral parameters. When the problem is to filter background with extraction of inhomogeneities, its realization by means of filters classificators is too complicated and bulky. For such problem solution the most efficient are methods based on autoregressive filters. but such methods are not able to reflect variation of constant component of image signal, since it correspond to variation of harmonics amplitude with zero frequency in spectral characteristic of model. It is known that autoregressive models reflect frequency properties of the signal and are not connected directly with amplitude spectrum [6]. Variation of constant component of the image is one of important features, since it can imply change of grey colour gradation or change of illumination intensity.

To make autoregression model more sensitive to variations of constant component, it is necessary to use its non – linear version having the components of the second and higher order [7 - 9]. The given approach was improved on the basis of texture filtrations by means of inverse resonant filter (IRF) [10, 11]. Filter synthesis is based on approximation of background surface by Fourier series, which constitutes principle natural 2D oscillations of background. In this case, unlike autoregressive models, amplitudes of harmonics are taken into consideration. As numerous experiments aimed at method testing, showed, the analysis of complex background images, for instance, quasiregular, dynamic, requires synthesis of high order IRF – at least 64 * 64.

For synthesis of such filter it is necessary to define 32 pairs of complex matching resonance oscillations per each of space coordinates, whereas their real number can be fewer. Realization of IRF applying the operation of 2D convolution requires a great volume of computations.

Hence, the paper considers the problem of high order IRF synthesis solution and its efficient realization using fast discrete Fourier transforms (DFT).

The goal of the given paper is enhancement of filtration efficiency as a result of elaboration of DFT – based fast filtration algorithm in the basis of functions, corresponding to resonance oscillations of background surface.

Operator of 1 D DTF can be presented in matrix form as

$$\mathbf{F}_N(k,x) = \left[\exp - \imath 2\pi \left(kx/N\right)\right]_{k,x=0\ldots N-1} \qquad (1)$$

If $N = m^n$, where m,n – random constants, them matrix (1) can be factorized – present as the product of simpler matrices. Factorized presentation products algorithm of fast Fourier transform (FFT) [12]. We will write in the following form [13]

$$\mathbf{F}_N(k,x)=\prod_{i=1}^{n}\mathbf{W}_i(k,x)=\prod_{i=1}^{n}\left(\mathbf{V}_m(v_i)\otimes\mathbf{I}_{m^{n-i}}\left(k^i,x^i\right)\otimes\Omega_m\left(m^{i-1}k^i,v_i,u_i\right)\otimes\mathbf{I}_{m^{i-1}}\right) \tag{2}$$

$$k=k^i+\sum_{j=1}^{i}v_j m^{n-j};\quad x=m^i x^i+\sum_{j=1}^{i}u_j m^{j-1}$$

where $\otimes$ – operation of direct or tensor multiplication [12], $\mathbf{I}_{m^{n-i}}\left(k^i,x^i\right)$ – single diagonal matrix, index indicates its size, number of lines and columns k^i, $x^i=0,1,\ldots,N/m^i-1$, indices $u_i=0,1,\ldots,m-1$ together with x^i indicate the number of elements, data vectors which are multiplied by phase – rotating matrix

$$\Omega_m\left(k^i,v_i,u_i\right)=\left[\exp\left(-\imath\frac{2\pi}{N}\left(k^i+v_i\frac{N}{m}\right)u_i\right)\right]_{v_i,u_i=0,\ldots,m-1} \tag{3}$$

where indices $v_i=0,1,\ldots,m-1$ together with k^i indicate the elements of product vector. Expression (2) can be generalized, in case, when, N is the product of random integers [13]. Let $N=pm^{n-1}$ and matrix (3) for $i=1$ have the following form:

$$\Omega_p\left(k^1,v_1,u_1\right)=\left[\exp\left(-\imath\frac{2\pi\ k^1u_1}{N}\right)\exp\left(-\imath\frac{2\pi\ v_1u_1}{p}\right)\right]_{v_1,u_1=0,\ldots,p-1} \tag{4}$$

The first multiplier defines frequency series k^1/N. The second multiplier in (4) forms elements of DTF operator, when $N=p$. We substitute frequency series by resonance frequencies and we obtain the following expression:

$$\Omega_p\left(k^1,v_1,u_1\right)=\left[\exp\left(-\imath\frac{2\pi k^1u_1}{N}\right)\exp\left(-\imath 2\pi\ v_1 f_{u_1+1}\right)\right]_{v_1,u_1=0,\ldots,p-1} \tag{5}$$

Matrix (5) is substituted in expression for DFT (2) and we will obtain the operator, denoted as operator of discrete Fourier transform with own nucleus (DFTON) relatively certain signal, characterized by a number of resonance frequencies $f_1\ldots f_p$. Let us write the given transform in factorized form

$$\mathbf{F}_N^{'}(k,x)=\left(\mathbf{V}_p(v_1)\otimes\mathbf{I}_{m^{n-1}}\left(k^1,x^1\right)\otimes\Omega_p\left(k^1,v_1,u_1\right)\right)\prod_{i=2}^{n}\mathbf{W}_i^{'}(k,x) \tag{6}$$

$$\begin{cases} i=1:\ \ k=k^1+v_1m^{n-1};\ \ x=px^1+u_1. \\ i>1:\ \ k=k^i+\sum\limits_{j=1}^{i}v_j\,pm^{n-j-1};\ \ x=pm^{i-1}x^i+\sum\limits_{j=1}^{i}u_j\,pm^{j-2} \end{cases}$$

where $\mathbf{W}_i^{'}(k,x)=\prod_{i=1}^{n}\left(\mathbf{V}_m(v_i)\otimes\mathbf{I}_{m^{n-i}}\left(k^i,x^i\right)\otimes\Omega_m\left(pm^{i-2}k^i,v_i,u_i\right)\otimes\mathbf{I}_{pm^{i-2}}\right)$.

Analog transform $\mathbf{F}_N^{'-1}(k,x)$ which is characterized by complex conjugate values of matrices (3) elements and matrix (5) is inverse to transform (6),

$$\Omega_p^{-1}\left(k^1,v_1,u_1\right)=\left[\exp\left(\imath\frac{2\pi k^1u_1}{N}\right)\varphi_{v_1u_1}\right]_{v_1,u_1=0,\ldots,p-1}$$

where $\varphi_{v_1u_1}$ – elements of matrix, inverse to matrix with elements $\exp\left(-\iota 2\pi\ v_1 f_{u_1+1}\right)$.

For definition of the filter, sized $N_x \times N_y$, where $N_x = Pm_x^{n_x-1}$ and $N_y = Qm_y^{n_y-1}$, we can synthesize DFTON (6) with $p = P$, $m = m_x$ and $p = Q$, $m = m_y$.

Representation of surface matrix of basic region $\mathbf{U}_b$ by means of DFTON can be written as

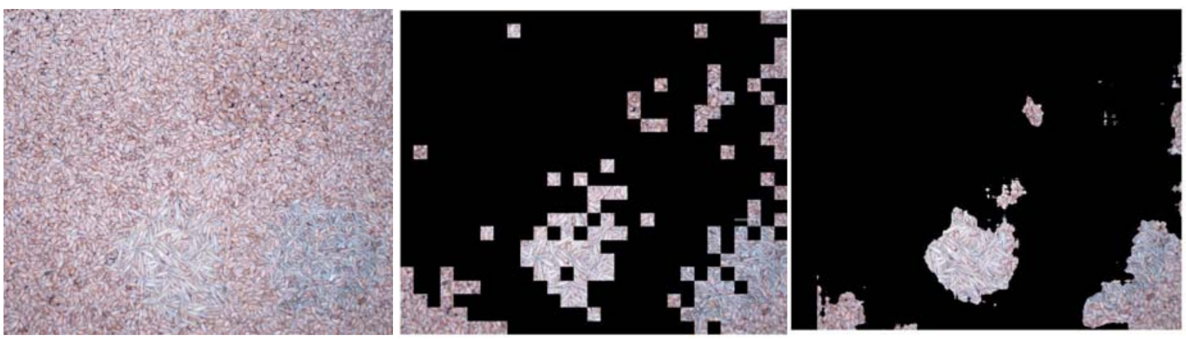
$$\mathbf{U}_b \cong \mathbf{F}'_{Nx}\mathbf{A}\mathbf{F}'^{T}_{Ny} \tag{7}$$

Matrix elements of pulse – transient characteristic in spectral region have the form $H_{m,n} = E_{m,n}A^{-1}_{m,n}$, where $A_{m,n}$ – elements of spectral matrix in (7), $E_{m,n} = \sum\limits_{i,k=0}^{N_x-1,N_y-1} z^i_{xm} z^k_{yn}$, $z^i_{x(y)m}$ – basis function. Filtration in spectral region of surface fragments can be written as matrix operations sequence

$$\Xi = \mathbf{F}'_{Nx}\mathbf{H}\left(\mathbf{F}'^{-1}_{Nx}\mathbf{U}\mathbf{F}'^{-1^T}_{Ny}\right)\mathbf{F}'^{T}_{Ny} \tag{8}$$

where Ξ – matrix of divergence signal. Statistic analysis of the given signal allows to allocate inhomogeneities. For filtration in spatial region matrix of pulse – transient characteristic of IRF can be defined as

$$\mathbf{h} = \mathbf{F}'^{-1}_{Nx}\mathbf{H}\ \mathbf{F}'^{-1^T}_{Ny} \tag{9}$$



a) b) c)

Рис. 1. a) original image; б) objects definition on textured background by means of filtration in spectral region б) objects definition on textured background by means of filtration in spatial region

Filtration in spatial region is performed by means of 2D surface signal convolution with transient characteristics (9). Filtration in spectral region can be performed in full scale by means convolution operation (8) with serial shift of $\mathbf{U}$ matrix elements or by means of express – analysis of fragments $N_x \times N_y$ sequence. From the point of view of minimization of operations number it is expedient to perform filtration in two stages. At the first stage express – analysis is to be performed, at the second stage – more accurate analysis of allocated fragments by means of convolution operation in spectral or spatial areas is to be performed. Methods of filtration were investigated by means of image test example of 2048×2048 pixels, shown in Fig 1. On textured background – grains of wheat, there are three types inhomogeneity – wet grain, grains of oat and rye. The order of filter is 96×96. For synthesis of filter basis of DFTON on the set of samples $N_{x(y)} = 6 \cdot 2^4$ is formed. The results of express- analysis in spectral region are shown in Fig 1b, results filtration in spatial region – are shown in Fig 1c. Analogous results were obtained using functions basis, formed with the help of resonance frequencies. Hence, the approach based on DFTON gave equivalent by quality result of filtration at considerably less number of operations due to the usage of fast DFT. Let us evaluate the gain in number of operations. For realization of filtration in spatial region $96 \times 96 = 9216$ operations of multiplication and addition per one pixel. Transformation (8) without using fast algorithm requires 2305 analogous operation per pixel.

One operation of fast DFTON requires $(16 \times 4 \times 6 + 6 \times 6 \times 16) \times 6 = 5720$ operations. 2D DFT in (8) is performed for 96+96 columns and line twice – direct inverse. Totally – 241 operations per pixel of the fragment 96×96, i.e., almost 24 times less as compared with filtration in spatial region and almost 10 times less as compared with conventional basis DFT. Naturally, quality of filtration is less, but allocated fragments and those , adjacent to them, can be filtrated more accurately. as a result we obtain image of type, shown in Fig 1b.

The paper considers the realization of IRF, intended for filtration of inhomogeneities of texture images. New type of functions basis for express – analysis of image in spectral area is suggested. Basis sets take into consideration resonance properties of the image and have the structure of fast transforms enabling to reduce considerably the number of operations. Unlike known basis sets [12,13] basis sets of DFTON are not orthogonal and partially multiplicative.

REFERENCES

1. Tuceryan M., Anil K. J. Texture analysis. Handbook of pattern recognition & computer vision. – World Scientific Publishing Co., Inc, River Edge, NJ. – 1993. – 643 p.
2. Reed T. R., Hans du Buf J. M. A review of recent texture segmentation and feature extraction techniques // CVGIP: Image Understanding. – 1993. – V.57. – P. 359-372.
3. Conners R.W., Harlow C.A. A Theoretical Comparison of Texture Algorithms // IEEE Trans. Pattern Analysis and Machine Intelligence. – 1980. – V. 2. – № 3. – P. 204-221.
4. S. Soatto, G. Doretto, Y. N. Wu. Dynamic Textures // International Journal of Computer Vision. – 2003. – №. 2. – P. 91-109.
5. Randen T., Husoy J.H. Filtering for Texture Classification: A Comparative Study // IEEE Trans. Pattern Analysis and Machine Intelligence. – 1999. – V. 21. – № 4. – P. 291-310.
6. Буняк Ю.А. Операторная модель авторегрессии и скользящего среднего // Радиоэлектроника. – 1998. – Т. 41. – №9. – С. 53-60.
7. Квєтний Р.Н, Буняк О.Ю. Використання моделей двохвимірного передбачення з квадратичною нелінійністю для розпізнавання об’єктів на динамічному фоні // Вимірювальна та обчислювальна техніка в технологічних процесах. – 2006. – №1. – С. 156-159.
8. Квєтний Р.Н, Буняк О.Ю. Розпізнавання об’єктів на динамічному фоні за допомогою моделей двохвимірного нелінійного передбачення // Інформаційні технології та комп’ютерна інженерія. – 2007. – №1. – С. 189-192.
9. Kvetny R., Bunyak O. Objects recognition on dynamic background using two-dimensional prediction models with quadratic nonlinearity // Наукові праці Вінницького національного технічного університету. – 2007. – №1. – 4 с.
10. Квєтний Р.Н, Буняк Ю.А, Буняк О.Ю. Моделі динамічного фону в задачах розпізнавання об’єктів // Радіоелектронні і комп’ютерні системи. – 2007. – №7 (26). – С. 227-232.
11. Bunyak O. Object recognition in image-based systems using resonance inverse filtering // Вісник Черкаського державного технологічного університету. – Спецвипуск, 2007. – С. 63-66.
12. Трахтман А.М., Трахтман В.А. Основы теории дискретных сигналов на конечных интервалах. – М.: Сов. радио, 1975. – 208 с.
13. Буняк Ю.А. Класс дискретных ортогональных систем субэкспоненциальных функций // Изв. АН СССР. Радиотехника и электроника. – 1989. – Т. 34. – №6. – С. 1300-1303.

Kvetniy Roman – Dr. Sc. (Eng), Professor, Head of the Chair of automation and information – measuring devices.

Sofina Olga – Post - Graduate of the Chair of automation and information measuring devices.
Vinnytsia National Technical University