METHOD OF DISCRETE WAVELET ANALYSIS OF EDGES ON THE RANDOM BACKGROUND

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ABSTRACT

Currently known algorithms suppose preliminary image filtering with consecutive solving of edges extraction problem. In the process of development of image filtering algorithms the a priori knowledge of distortion interference characteristics is also required. In practice in most of the cases such information is not available or is approximate. A new method of objects' edges extraction in the images was developed, in the presence of distortion, by applying direct and inverse wavelet transformation. The results of mathematical modeling are provided. The proposed approach may be used in the course of development of digital picture processing systems, self-contained robots engineering, and under the surveillance conditions which complicate the registration process in the absence of a priori data about the background noise type.

Keywords

Edge detection, image analysis, wavelet-transformation.

1. INTRODUCTION

In recent times the systems of different objects identification are actively developed. Thereat the volume of stored information and its fidelity show notable growth. At the same time the problem arises of in-line data processing and valid data retrieval from large scale arrays of images. Such problems arise in quite a few brunches of knowledge: healthcare, radiolocation, space studies and Earth exploration, television, etc. For example, diagnostics by analysis of human innards image, forest fire detection, navigation objectives, synthetic vision for special systems, etc.

One of development trends of modern IT-technologies is the development of methods and algorithms of analysis of signals (measurement results) and their derivatives against the registration noises background. Such problems arise at mathematical simulation of different dynamic processes and objects, described by differential equations in the course of control automation of given processes, and in the course of image processing in edge extraction problem.

Without the skill and knowledge of efficient solution of such type of problems, there is no sense to discuss elaboration of the corresponding systems of signals and images processing [Gon01a, Kra01a]. One common point of all the above problems is that a calculation of derivatives of different orders (as a rule, the first and the second) against the noise background is required for the automated processing of measurement results. The problem of signal differentiation is incorrect, that is why basing on traditional analogous differentiating circuits and amplifiers, it turns out that it is impossible to create an ideal differentiator or a differentiator, which is sufficiently close to it.

Solution of the edge extraction problem is used in industrial applications for engineering of self-contained robots, as well as the systems of image analysis under adverse surveillance conditions, various hindering factors, complicating the process of image registration in the absence of a priori data about the background noise type. It means that the methods and algorithms of data processing from the image detectors shall take into account the presence of noises of different nature, related to images and signals registration in actual systems. The above makes it absolutely apparent the significance of analysis of existing and development of new methods of digital differentiating of signals and images, registered at the noise background, and selection of such a single or several of them, which are best suited for implementation with the use of modern microprocessor engineering and providing for the needed characteristics, and not requiring the information about a priori characteristics of interference and background noises.

Hence, today the scientific task of development of the automated analysis methods for the results of measurements for objects' edge extraction in images in the presence of background noise currently is not properly solved, and is important.

2. PROBLEM SOLUTION

Let us examine in greater detail the algorithms of wavelet differentiation with the use of MHAT, DOG, WAVE wavelets, obtained on the basis of the earlier developed method of wavelet differentiation [Bez01a - Bez03a].

In order to find the edge it is necessary to calculate the gradient [Gon01a, Kra01a].

In general terms the derivatives of a row and a column of images may be expressed as follows:

$$\frac{\partial S(j)_i}{\partial x} = S1(j)_i = C_\psi \sum_{m=1}^{NK}\sum_{n=0}^{N-1} CTWSS(m,n,i)\frac{\partial \varphi(x_j)}{x}, \quad (1)$$

$$\frac{\partial S(i)_j}{\partial y} = S1(i)_j = C_\psi \sum_{m=1}^{NK}\sum_{n=0}^{N-1} CTWSC(m,n,j)\frac{d\varphi(y_i)}{dy}, \quad (2)$$

$$i = 0...N, \quad j = 0...N,$$

where $CTWSS(m,n,i)$ and $CTWSC(m,n,j)$ are correspondingly the coefficients of direct discrete wavelet transformation by the rows and columns of image matrix $S(i,j)$.

$$CTWSS(m,n,i) = \sum_{j=0}^{N-1}\varphi_{m,n}(x_j)S(i,j), \quad (3)$$

$$CTWSC(m,n,j) = \sum_{i=0}^{N-1}\varphi_{m,n}(y_i)S(i,j). \quad (4)$$

Then the expression for the gradient square of the matrix $S(i,j)$ shall appear as follows:

$$\left(\frac{\partial S(j)_i}{\partial x}\right)^2 + \left(\frac{\partial S(i)_j}{\partial y}\right)^2 = \left(C_\psi \sum_{m=1}^{NK}\sum_{n=0}^{N-1} CTWSS(m,n,i)\frac{\partial \varphi_{m;n}(x_j)}{\partial x}\right)^2 + \quad (5)$$
$$+\left(C_\psi \sum_{m=1}^{NK}\sum_{n=0}^{N-1} CTWSS(m,n,i)\frac{\partial \varphi_{m;n}(y_i)}{\partial y}\right)^2 =$$
$$= (S1(j)_i)^2 + (S1(i)_j)^2, \quad i = 0...N, \quad j = 0...N.$$

The absolute value of the intensity gradient of image $S(i,j)$ under study in terms of wavelet transformation may be expressed as follows:

$$G(S(i,j)) = \left(\left(C_\Psi \sum_{m=1}^{NK}\sum_{n=0}^{N-1} CTWSS(m,n,i)\frac{\partial \varphi_{m,n}(x_j)}{\partial x}\right)^2 + \quad (6)$$
$$+\left(C_\psi \sum_{m=1}^{NK}\sum_{n=0}^{N-1} CTWSS(m,n,i)\frac{\partial \varphi_{m,n}(y_i)}{\partial y}\right)^2\right)^{1/2}.$$

Novelty of the proposed approach is that in the expression (6) the wavelet functions derivatives of type $\frac{\partial \varphi_{m,n}(x_j)}{\partial x}$ and $\frac{\partial \varphi_{m,n}(y_i)}{\partial y}$ are used in reverse wavelet transformation.

Images in the process of their forming by imaging systems (photographic, holographic, television) are usually affected by different random interferences or noises. The most common type of interferences is random additive noise, statistically independent from signal. The additive noise model well describes the effect of film-grain noise, quantization distortion in analog-to-digital converters, etc. That is the reason why in the course of mathematical simulation we shall use the random numbers generator, whereat the quality evaluation criteria of image edge extraction shall be statistical.

This paper uses the following criteria.

1. Root-mean-square deviation, e_{rmsd} :

$$e_{rmsd} = \sqrt{\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(MT_{ij} - \hat{MK}_{ij}\right)^2} \quad (7)$$

Whereat the image of edges, obtained from a noise-free tested image S by the Canny edge detector, was used as the MT test image. Further on the additive Gaussian noise was superimposed on the source image S, and the edge extraction by the proposed wavelet differentiation method and by the known Sobel method was performed.At that the $\hat{MK}$ images were obtained.

2. Peak signal-to-noise ratio, *SNR1:*

$$\mu = \frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(\hat{MK}_{ij}\right)^2;$$

$$SNR1 = \frac{255-\mu}{\sqrt{\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(\hat{MK}_{ij}-\mu\right)^2}} \quad (8)$$

where μ - mean value of $\hat{MK}_{ij}$.

3. Peak signal-to-noise ratio, SNR2 (with the use of background root-mean-square deviation (RMSD) in calculations):

$$\sigma_{bcgr} = \sqrt{\frac{1}{\left(N_{bcgr}\right)^2} \sum_{i=n_1}^{n_1+N_{фон}} \sum_{j=m_1}^{m_1+N_{bcgr}} \left(M\hat{K}_{ij} - \mu_{bcgr} \right)^2}; \qquad (9)$$

where: σ_{bcgr} - background RMSD;

$\mu_{bcgr} = \frac{1}{\left(N_{bcgr}\right)^2} \sum_{i=n_1}^{n_1+N_{bcgr}} \sum_{j=m_1}^{m_1+N_{bcgr}} \left(\hat{MK}_{ij} \right)$ - mean value of the background;

n_1, m_1 – coordinates of the singled out background area with dimensions $N_{bcgr} \times N_{bcgr}$ on the image $\hat{MK}$ under study,

$$SNR2 = \frac{255 - \mu}{\sigma_{bcgr}}. \qquad (10)$$

Using the three above criteria it shall be further possible to evaluate more adequately the efficiency of the proposed algorithms as compared to those already known.

For qualitative and quantitative evaluation of the developed algorithms let us test their functioning on test images. Whereat we shall study the test images, which were not affected by noise. See the Pictures 2÷7 for the results of mathematical simulation.

The procedure of computing experiment was as follows. The source eight-bit image with dimensions 512*512 “Cameraman” (Fig. 1), was processed with canny edge detector from MathCAD (Fig. 2). Then the “Cameraman” image was treated with the additive Gaussian noise with RMSD σ=5, 20, 30, 40, 50.

See Fig. 3 for the image with RMSD at σ=30. For the results of edge extraction by the known Sobel method see Fig. 4. See Fig. 5÷7 for the research of the proposed algorithms of edge extraction by the use of DOG, WAVE and MATH wavelets at noise background for the models with the mathematical noise expectation m0=0. See Tables 1-3 for the values of e_{rmsd}, SNR1 and SNR2 for the series of the studied test images.

Figure 1. Initial image (8-bit).

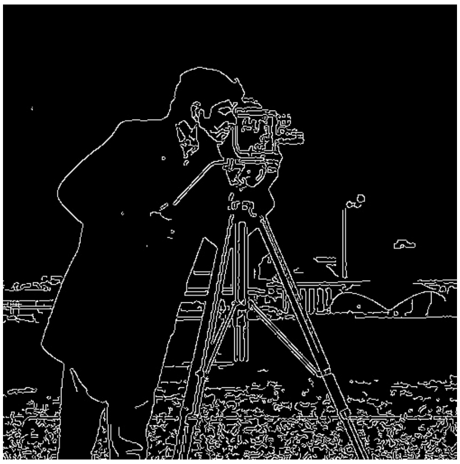

Figure 2. Initial image is processed by Canny edge detector.

Figure 3. Initial image with standard deviation σ=30.

Figure 4. Initial image is processed by Sobel operator.

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Figure 5. Initial image is processed by DOG wavelet.

Figure 6. Initial image is processed by WAVE wavelet.

Figure 7. Initial image is processed by MATH wavelet.

RMSD of the forming noise	RMSD of source image, e_{rmsd}	Algorithms/ Criterion gain, dB		
		Wavelet DOG	Wavelet WAVE	Wavelet MATH
5,00	10,33	3,14	2,81	2,99
20,00	31,37	3,49	3,16	3,21
30,00	39,98	3,70	3,39	3,37
40,00	46,22	4,22	3,96	4,00
50,00	50,77	3,96	3,70	3,57

Table 1. Computing experiments results for criterion "Root-mean-square deviation"

RMSD of the forming noise	Peak signal-to-noise ratio, SNR1 of source image	Algorithms/ Criterion gain, dB		
		Wavelet DOG	Wavelet WAVE	Wavelet MATH
5,00	1,92	5,16	5,20	5,34
20,00	2,63	4,83	4,80	4,91
30,00	3,05	4,89	4,80	4,93
40,00	3,37	5,01	4,89	5,00
50,00	3,63	5,11	4,97	5,06

Table 2. Computing experiments results for criterion "Peak signal-to-noise ratio SNR1"

RMSD of the forming noise	Peak signal-to-noise ratio by RMSD of source image, SNR2	Algorithms/ Criterion gain, dB		
		Wavelet DOG	Wavelet WAVE	Wavelet MATH
5,00	8,11	9,64	8,86	9,59
20,00	5,94	7,51	7,63	7,16
30,00	5,40	7,10	7,32	6,66
40,00	5,07	6,91	7,20	6,43
50,00	4,89	6,81	7,14	6,30

Table 3. Computing experiments results for criterion "Peak signal-to-noise ratio SNR2"

The obtained quantitative results and expert evidence of image edge extraction allow for the conclusion about the advantages of the proposed algorithms as compared to already known. Software implementation of the proposed methods and algorithms allow for the automation of signals and images processing processes, and expand the possibilities of research conduct for development of advanced signals and images processing systems.

3. CONCLUSIONS

Analysis of the images and results of mathematical simulation shown on the figures allows us to make the following conclusions. The proposed method of

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image processing allows to efficiently perform edge extraction of noise distorted images. The new method and the algorithms of wavelet differentiation of images at noise background with the use of discrete wavelet transformation allow to increase the peak signal-to-noise ratio by 4,8÷9,6 dB and in 3÷4 times decrease the error in standard deviation.

In the given case the wavelet transformation allow to refuse from the use of different masks, i.e. to refuse from inefficient methods of numerical differentiation. Using the proposed method the other algorithms of edge extraction on the basis of wavelet differentiation with the use of different wavelet bases may be implemented.

Hence, the scientific mission to elaborate the methods of automated analysis of measurement results for edge extraction of fragments of objects in images with the presence of a background noise is solved. The proposed methods and algorithms may be used at development of the signal processing systems of digital images for industrial application for self-contained robots engineering, for surveillance under the conditions hindering the registration process, and in the absence of a priori information about the type of background noises.

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