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Television Images Identification in the Vision System Basis on the Mathematical Apparatus of Cubic Normalized B-Splines

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Abstract: The solution the task of television image identification is used in industry when creating autonomous robots and systems of technical vision. A similar problem also arises in the development of image analysis systems to function under the influence of various interfering factors in complex observation conditions complicated the registration process and existing when priori information is absent, in background noise type. One of the most important operators is the contour selection operator. Methods and algorithms of processing information from image sensors must take into account the different character of noise associated with images and signals registration. The solution of the task of isolating contours, and in fact of digital differentiation of two-dimensional signals registered against a different character of background noise, is far from trivial. This is due to the fact that such task is incorrect. In modern information systems, methods of numerical differentiation or masks are usually used to solve the task of isolating contours. The paper considers a new method of differentiating measurement results against a noise background using the modern mathematical apparatus of cubic smoothing B-splines. The new high-precision method of digital differentiation of signals using splines is proposed for the first time, without using standard numerical differentiation procedures, to calculate the values of the derivatives with high accuracy. In fact, a method has been developed for calculating the image gradient module using spline differentiation. The method, as proved by experimental studies, and computational experiments has higher noise immunity than algorithms based on standard differentiation procedures using masks.

Keywords: Denoising, Spline, Approximation, Segmentation, Contouring.

1 Introduction

Recently, image identification systems have been intensively developing. It is possible due to the fact that developers have a wide range of high-speed elements of computer technology in microcircuit design at their disposal, which

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allow creating complex multifunctional products with reconfigurable algorithms. It opened up the possibility of digital processing of multidimensional signals, primary scenes from images of objects formed by a variety of technical sensors. At the same time, the volume of stored information and its reliability are significantly increasing, while requirements for the speed processing and useful information retrieval from large image arrays obtained against a noise background being of different intensity are substantially increased [1 – 6].

The solution of the task of identifying television images is used in the industry to create autonomous robots and vision systems, as well as image analysis systems under difficult observation conditions, under the influence of various interfering factors complicating the registration process and in the absence of a priori information on the type of background noise. It means that the methods and algorithms for processing data from image sensors must take into account the presence of noise of a different nature associated with the registration of images and signals in real systems.

To date, most algorithms for extracting outlines in television images are based on differential operators. The basic idea of all these methods is that the two-dimensional color intensity function undergoes a jump at the boundaries of the contours that can be detected by studying the derivatives of the colour intensity function.

Differential methods for selecting contours consist of two stages. At the first stage, intensity changes increase. In the second phase, contour points are chosen when threshold methods are used. It should be noted that differential methods enhance point-like impulse noise. Most methods for isolating image outlines are based on the study of the colour intensity gradient. One of the first methods was proposed by L. Roberts [1] and was based on the use of a cross matrix operator containing finite differences of neighbouring elements. Later the operator Prewitt was proposed on the basis of the concept of central difference [1]. The main disadvantage of this approach is the noise sensitivity.

The most famous of the differential methods of isolating contours are based on the Sobel operator [1]. This approach is also based on central differences, but the weight of the central elements is doubled. The disadvantage of the Sobel operator is the absence of complete rotational symmetry. More complex approaches are based on the choice of a function to determine the weight of the pixel, depending on distance to the central pixel [2]. This method has the additional possibility of slight noise suppression.

Another set of methods for differential selection of contours in images is based on the use of the Laplacian [3], to use this one it is necessary to find the second-order derivatives. In [4], a proposed two-stage algorithm, before applying linear differential operators, the image is split into layers in the Z / 2P ring with the subsequent union of the contours.

As an alternative to differential filters, statistical methods of delimiting boundaries and methods based on wavelet transforms are used. At the same time, well known current algorithms of solving such problems assume the preliminary filtration of two-dimensional signals, and then the solution of the problem isolating the contours. When constructing methods and algorithms ofidentifying two-dimensional signals, priori knowledge of distorting interference characteristics is required. In practice, in most cases, such information is not available or it is approximate. For solving problems, it is necessary to create appropriate new mathematical methods for describing and processing two-dimensional signals, as well as software, for specific issues [6 – 25].

Thus, existing methods and algorithms for processing 2D signals and television images allow solving the problem of reliable processing under the condition that processed priori information is given, which is not always possible [1 – 6]. This requires additional technical solutions, which are quite complex. The solution of the task of isolating contours, and in digital differentiation of two-dimensional signals registered against a background of noises of a different nature is far from trivial. It is due to the fact that such task is incorrect. In modern information systems, methods of numerical differentiation or masks are usually used to solve the task of isolating contours.

The purpose of this work is to develop a method for isolating contours against the background of pulsed noise by means of using the mathematical apparatus of cubic B splines and evaluating the efficiency.

At present, methods based on splines a firm place among the most powerful tools of computational mathematics have been taken into account. In the practice of processing signals and images, a spline approximation of their discrete values is widely used, determined by the smoothness property of the approximating function concerning the derivatives at the boundaries of the sampling intervals [9].

The selection of image contours is done, as a rule, using different masks, that is, in fact, they use methods of numerical differentiation. However, in the presence of intense background noise, this approach is usually unproductive and leads to large errors [9]. Let us consider this in more details.

2 The Proposed Approach

At present, there are a number of problems of signal processing, when a process $S(t)$, is available to direct observation, and its derivative is an informative parameter $\partial S(t)/\partial t$. The known methods of numerical differentiation will work satisfactory only for functions specified at points with a small error.

Let us consider one of the widely used difference relations, for approximate calculation of the derivative of the function $S(t)$, for example:

$$\frac{\partial S(t_k)}{\partial t} \approx S_{t,k} = \frac{S(t_k) - S(t_{k-1})}{h}, \tag{1}$$

where h is step, $S(t_k)$ are selective signal values.

The resulting methodical error of approximation arising as a result of this replacement is characterized by a decomposition:

$$S_{t,k} = \frac{\partial S(t_k)}{\partial t} - \frac{h}{2}\frac{\partial^2 S(\xi^{(j)}{}_k)}{\partial t^2}, \tag{2}$$

where $\xi_k^{(j)}$, $j = 1,2,3,$ are points from the interval (t_{k-1}, t_{k+1}).

The error arises in the calculation of the difference ratios is much higher than the error in the specification of the values of the function $S(t_k)$ and can even increase indefinitely as the grid spacing h tends to zero.

The operation of numerical differentiation, in this case, is incorrect. It is due to the fact that in order to find the approximation $S_{t,k}$ to $\partial S(t_k)/\partial t$ it is necessary when the step h is small. The problem of differentiation can also be solved using Lagrange polynomials, but for high-precision approximation, it is required to use large powers. Practical application of this approach is not found.

The application of the method differentiating the image line on the noise background proposed in [12, 13] allows us to calculate the derivative of the signal with sufficient accuracy. Having information about the behavior of the first derivative, it is possible to determine the local maxima in the image line on the noise background.

The procedure of finding the first derivative of the signal using the proposed new spline differentiation method is as follows:

1. Select the smoothing factor (is usually equal to one, with a higher noise level, you can choose a higher ratio).
2. The matrix of smoothing coefficients is calculated.
3. A system of linear algebraic equations is solved with allowance for the smoothing coefficients and the values of input realization, thereby calculating the coefficients of smoothing cubic B splines.
4. With the help of cubic smoothing parabolic B-splines, the first derivative and the original signal are reconstructed [12, 13].

Let us consider the solution of the problem of extracting the contours of television images using the new spline differentiation method. To this end, we devide the image matrix $S(i,j)$ into rows and columns, to perform differentiation by the proposed way [12, 13], and then compute the contour selection operators. In contrast to the known approaches, the differentiation will take into account the information about the intensity in the entire line of the image. This approach minimizes the harmful effects of noise.

Let the matrix $S(i,j)$ of a black and white image of size $N \times N$ are given. We use the following notation:

$$S_i = [s_{i1},...,s_{ij},...,s_{iN}] \text{ – } i\text{-th matrix string,} \tag{3}$$

$$S_j = \begin{pmatrix} s_{1j} \\ \vdots \\ s_{ij} \\ \vdots \\ s_{Nj} \end{pmatrix} - j\text{-th column,} \tag{4}$$

$S1_i = \dfrac{\partial S_i}{\partial x}$ – vector is the string obtained by differentiating the i-th row of the matrix $S(i,j)$

$$\frac{\partial S(j)_i}{\partial x} = S1(j)_i \; - j\text{-th vector-line element } S1_i = \frac{\partial S_i}{\partial x}, \tag{5}$$

$S1^j = \dfrac{\partial S^j}{\partial y}$ – vector is the column obtained by differentiating the j-th column of the matrix $S(i,j)$

$$\frac{\partial S(i)^j}{\partial y} = S1(i)^j \; - i\text{-th column vector element } S1^j = \frac{\partial S^j}{\partial y}. \tag{6}$$

Then, taking into account the previously developed spline differentiation method [2], the expressions for the derivative concerning rows and columns can be written in the following form:

$$\frac{\partial S_i}{\partial x} = \sum_{i=1}^{N-1}\left(\frac{\chi^2}{2h}(b_{i+2} - 3b_{i+1} + 3b_i - b_{i-1}) + \frac{\chi}{h}(b_{i+1} - 2b_i + b_{i-1}) + \frac{1}{2h}(b_{i+1} - b_{i-1})\right), \tag{7}$$

$$\frac{\partial S^j}{\partial y} = \sum_{i=1}^{N-1}\left(\frac{\Upsilon^2}{2h}(b_{j+2} - 3b_{j+1} + 3b_j - b_{j-1}) + \frac{\Upsilon}{h}(b_{j+1} - 2b_j + b_{j-1}) + \frac{1}{2h}(b_{j+1} - b_{j-1})\right). \tag{8}$$

The intensity gradient is a vector that does not depend on the choice of the coordinate system, in the sense that it retains its magnitude and orientation concerning the underlying image when this image is rotated or shifted. The image contours can be determined by using a gradient.

Let us consider the algorithm for spline differentiation in details. The gradient of the intensity of the investigated image $G(S(i,j))$ can be written in the following form:

$$G(S(i,j))=\left(\begin{array}{l}\left(\sum_{i=1}^{N-1}\left(\frac{\chi^2}{2h}(b_{i+2}-3b_{i+1}+3b_i-b_{i-1})+\frac{\chi}{h}(b_{i+1}-2b_i+b_{i-1})+\frac{1}{2h}(b_{i+1}-b_{i-1})\right)\right)^2+\\ \left(\sum_{j=1}^{N-1}\left(\frac{\Upsilon^2}{2h}(b_{j+2}-3b_{j+1}+3b_j-b_{j-1})+\frac{\Upsilon}{h}(b_{j+1}-2b_j+b_{j-1})+\frac{1}{2h}(b_{j+1}-b_{j-1})\right)\right)^2\end{array}\right)^{\frac{1}{2}}. \quad (9)$$

Thus, this spline-differentiation algorithm will be used further for mathematical modeling.

The most common types of interference are random distributed additive noise, as well as impulse noise, statistically independent of the signal. The impulse noise model can describe the interference occurred when a digital signal is transmitted.

3 Experimental Results

The following is used as quantitative criteria in work:

1. Standard deviation *SD*:

$$SD=\sqrt{\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(MK_{ij}-\hat{MK}_{ij}\right)^2}. \quad (10)$$

In this case, as the test image, a contour image obtained from a noiseless image was detected by the *Canny*. Subsequently, the noise of two types was superimposed on the original image of *S*: impulse noise of “broken pixels”; impulse noise “salt-pepper”. Further, the contours were determined by the proposed method of spline differentiation and the well-known *Sobel* method. Images $\hat{MK}$ were obtained.

2. Peak signal/noise ratio *SNR:*

$$\mu=\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(\hat{MK}_{ij}\right)^2, \quad (11)$$

$$SNR=\frac{255-\mu}{\sqrt{\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(\hat{MK}_{ij}-\mu\right)^2}}, \quad (12)$$

where: μ - average value $\hat{MK}_{ij}$.

3. The *SNRF* peak-to-noise ratio (using the standard deviation background in the calculations):

$$SNRF = \frac{255 - \mu}{\sigma_{\text{background}}}, \tag{13}$$

$$\sigma_{\text{background}} = \sqrt{\frac{1}{\left(N_{\text{background}}\right)^2} \sum_{i=n_1}^{n_1+N_{\text{background}}} \sum_{j=m_1}^{m_1+N_{\text{background}}} \left(\hat{MK}_{ij} - \mu_{\text{background}} \right)^2}, \tag{14}$$

$$\mu_{\text{background}} = \frac{1}{\left(N_{\text{background}}\right)^2} \sum_{i=n_1}^{n_1+N_{\text{background}}} \sum_{j=m_1}^{m_1+N_{\text{background}}} \left(\hat{MK}_{ij} \right), \tag{15}$$

where: $\sigma_{\text{background}}$ – the standard deviation of the background; $\mu_{\text{background}}$ – the average background value; n_1, m_1 – the coordinates of the selected background area are $N_{\text{background}} * N_{\text{background}}$ in the image under study $\hat{MK}_{ij}$,

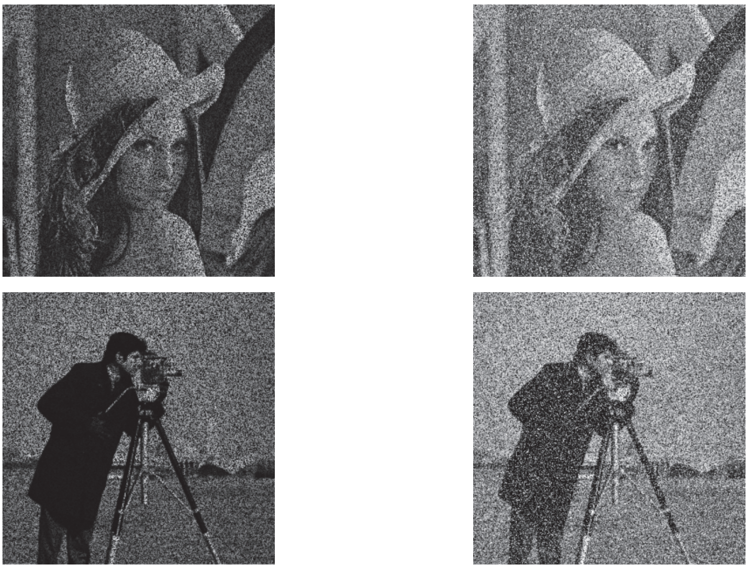
Using three criteria, it will be possible to adequately evaluate the effectiveness of the proposed algorithm in comparison with known methods in future. To verify the adequacy of the developed algorithm [12, 13], we will check its functioning on test images. To do so, we will use a test image of 512×512, which has not been subjected to noise.

(a) (b)

Fig. 1 – *a)* ***Lena*** *and* ***cameraman*** *test images; b) the same images processed by the Canny boundary detector.*

The essence of the computational experiment was as follows. The original *Lena* and *cameraman* images are shown in Fig. 1a were processed by the *Canny* boundary detector from the *Mathcad* 14 package (Fig. 1b). In future, all the resulting images will be compared with these images.

Then the test image was exposed to 2 types of noise: impulse noise of "broken pixels" with probability $p = 0.5$ (Fig. 2a); impulse noise "salt-pepper" with probability $p = 0.5$ (Fig. 2b).



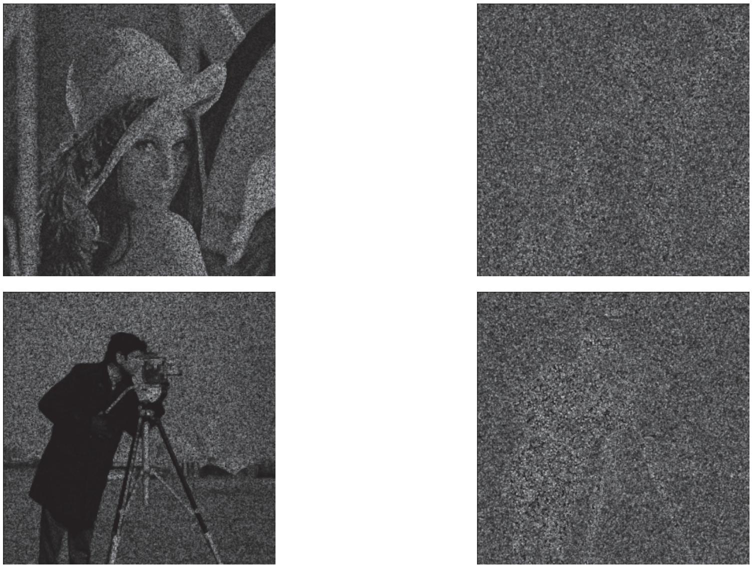
(a) (b)

Fig. 2 – *Test images exposed to noise: a) "broken pixels"; b) "salt and pepper".*

Fig. 3 shows the results of processing by means of *Sobel*'s operator of the images shown in Fig. 2, respectively.

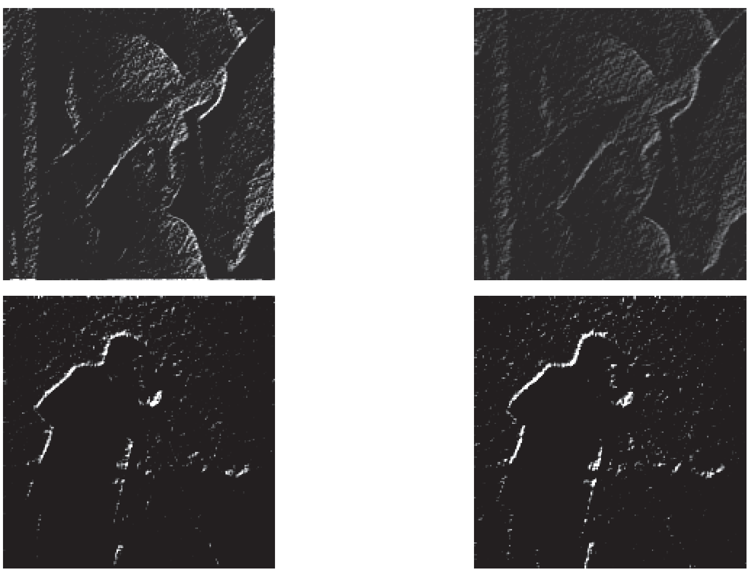
Fig. 4 contains the results of spline-differentiation processing of the images shown in Fig. 2, respectively.

Obviously, the algorithm for isolating contours based on spline differentiation proposed in this paper allows us to solve the problem posed quite effectively. **Tables 1** and **2** show the average values of *SD*, *SNR* and *SNRF* for *Lena* and *cameraman* processed images.



(a) (b)

Fig. 3 – *Results of processing by Sobel operator of a test image exposed to noise: a) "broken pixels"; b) "salt and pepper".*



(a) (b)

Fig. 4 – S*hows the results of spline differentiation processing of a test image exposed to noise: a) "broken pixels"; b) "salt and pepper".*

Table 1

The values are different, SNR and SNRF for the Lena image distorted by impulse noise "broken pixels".

Criterion 1, the gain according to the standard deviation of *SD*, dB									
Noise	SD of the source image	Smoothing coefficient of spline functions							
		1	5	10	50	100	200	300	500
50	83,42	0,96	1,5	1,56	1,6	1,6	1,6	1,6	1,6
100	106,01	0,7	1,43	1,55	1,64	1,65	1,65	1,65	1,65
Criterion 2, the gain against peak signal/noise ratio *SNR* [dB]									
Noise	PSNR of the original image	Smoothing coefficient of spline functions							
		1	5	10	50	100	200	300	500
50	2,51	2,52	5,14	5,85	6,85	7,15	7,59	7,82	8,06
100	3,15	1,74	4,55	5,54	7,26	7,85	8,27	8,45	8,61
Criterion 3, the gain relative to the peak signal/noise by the standard deviation background SNRF [dB]									
Noise	PSNR to the SD background	Smoothing coefficient of spline functions							
		1	5	10	50	100	200	300	500
50	2,85	3,71	6,5	7,36	8,96	9,65	10,57	11,07	11,7
100	3,39	2,78	5,69	6,77	8,69	9,49	10,2	10,57	11

Table 2

The values are different, SNR and SNRF for the Lena image distorted by impulse noise "salt and pepper".

Criterion 1, the gain according to the standard deviation of *SD* [dB]									
Noise	SD of the source image	Smoothing coefficient of spline functions							
		1	5	10	50	100	200	300	500
50	85,48	1,29	1,84	1,92	1,96	1,97	1,97	1,97	1,97
100	108,51	1,65	2,46	2,6	2,72	2,73	2,73	2,74	2,74
Criterion 2, the gain against peak signal/noise ratio *SNR* [dB]									
Noise	PSNR of the original image	Smoothing coefficient of spline functions							
		1	5	10	50	100	200	300	500
50	1,46	3,07	5,47	6,2	7,05	7,34	7,62	7,72	7,83
100	1,21	3,47	6,05	6,89	8,44	8,72	8,98	9,2	9,37
Criterion 3, the gain relative to the peak signal/noise by the standard deviation background. SNRF, [dB]									
Noise	PSNR to the SD background	Smoothing coefficient of spline functions							
		1	5	10	50	100	200	300	500
50	1,56	3,31	5,91	6,86	8,59	9,4	10,18	10,63	11,17
100	1,23	3,58	6,38	7,41	9,62	10,24	10,92	11,43	12,02

4 Conclusion

For *Lena* test image, the gain in decibels was:

– by the standard deviation *SD*: 1,6 ÷ 2,7;

– with respect to the peak *SNR* signal/noise ratio: 8 ÷ 9.4;

– with respect to the peak signal/noise of the standard deviation background *SNRF*: 11 ÷ 12.

Thus, a new method of isolating image contours against the background of additive impulse noise was developed and investigated by using the mathematical apparatus of smoothing cubic B-splines. In fact, a method is proposed for calculating the modulus (square) of an image gradient by using spline differentiation. It allows you to avoid using different masks when selecting image contours, while the use of cubic normalized B splines in the task of differentiating two-dimensional signals has higher noise immunity than algorithms based on the use of standard differentiation procedures.

Providing the requirements for modern vision systems intended for solving high-complexity problems associated with high variability of the working stage, heterogeneity of objects, interference, etc., connected with the task of increasing the efficiency of the digital signal processing process recorded by sensors of vision systems of autonomous robots. In particular, one of the problems of application in priori unknown observation conditions is the presence of noise caused by various factors, such as defects in the recording system, environmental effects, and similar ones. The new high-precision digital signal differentiation method proposed for the first time allows, using nonstandard numerical differentiation procedures, to calculate both the value of the signal itself and the value of its derivative with high accuracy.

The rapid development of microprocessor technology in recent times creates the conditions for emergence of new applications and the expansion of a wide range of problems solved with the help of vision systems indicating the relevance of research in improving the efficiency and stability of methods and algorithms for digital processing of two-dimensional signals.

The method, as shown by experimental studies, has higher noise immunity than algorithms based on the use of standard differentiation procedures.

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