DIGITAL METHODS OF EXPRESS-DIAGNOSTICS QUALITY OF SUBSTANCES OF DIFFERENT PHYSICOCHEMICAL NATURE (summarizing article)

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Abstract. **The present work offers the methods of express diagnostics of quality of substances of different physicochemical nature, recording their color and its changes under influence of various external factors, based on digital image processing. The object of digital processing is digitized using professional flatbed scanners and digital image apparatuses of the investigated substances. Quality assessment of substances and registration of it changes based on building of differential contrast (zero and not zero), the luminance characteristics of intensity profiles, areas of equal contrast and the decomposition of the digitized image by color channels, which allows to quantify the quality and the change of the diagnosed objects, and reduces the subjective factor due to their visual perception. No visually perceive changes in the material are easily registered by the digitizers. Zero differential contrast corresponds to identical images and there is no influence of the investigated factor on this substance. The developed method of quality assessment, registration, changes, research, and visualizations taking place in the substance of the processes, detection of counterfeit products, as comparing with efficiency of different methods, wavelet bases, etc., is easy to implement, has the immediacy, accessibility and tested in the diagnosis of substances of different physicochemical nature.**

Keywords: **substances, diagnostics, digital processing, wavelet analysis, single crystal, image, technique, express analysis, quantitative criteria, color, difference contrast, brightness feature, intensity profile, region of equal contrast, visualization**

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Contents

1. INTRODUCTION

In nature there are almost no substances which during a time and under the influence of various external factors have not changed its physicochemical parameters and characteristics. The speed of these changes is largely determined by the physicochemical nature of the substance, duration and intensity of exposure. In many cases the monitoring of these changes is a major challenge for the national economy, science and technology.

Registration of changes and determination of their speed is achieved by using a variety of methods and techniques, which differ from each other in resolution, sensitivity, complexity of its implementation, rapidity, etc. For registration of any changes it is necessary as a rule, expensive equipment, instruments, qualified professionals and supporting material that is available mainly to large enterprises, research centers and laboratories. Small and medium enterprises can not provide the required level of research and diagnostics and are satisfied by available methods and equipment, relying on the requirements the supplier's quality certificates, and neglect the changes of parameters and characteristics of substances. This approach is not always valid and justified, especially when it comes to quality control of raw materials and food products, medical products, identification of counterfeit products, registration of changes and degradation processes in materials and multilayered structures used in microelectronics, etc. Hence, the task is an improving old and developing new methods and techniques of quality control substances of different physicochemical nature, available for a wide range of researchers [1-25].

For operational research and quality control of various substances the methods with rapidity, simplicity, availability, informativity, and reliability and validity of the obtained data are needed. That is why it not accidentally the big hopes are related on computer and information technology with corresponding software and hardware [6-8, 19-21].

Color is one of the most important characteristics of the substances and is directly connected with change of its physicochemical parameters and characteristics. Thus, registration of changes of color is not perceived visually, may be the basis of methods of express-diagnostics and research of substances of different physicochemical nature in different states of aggregation [11-18, 20]. When comparing between the quality of different images, methods and techniques, changes in matter by various external factors not only qualitative but also quantitative assessments are important. It is significant the ease, reliability and rapidity of assessment, the possibility of its transfer to various objects of study [14, 15, 18, 19, 21, 26-28].

The present work represents a brief review of digital express methods and techniques of quality research substances of different physicochemical nature and changes occurring in them under the effect of external factors. The experimental results of the application of digital processing for diagnosing the quality of single crystals, raw meat, meat products, water, research different methods of meat curing by multi-component mixture, obtained with the use of a common approach in obtaining quantitative information about the investigated object are presented [14-25].

2. THE USED APPROACH, EQUIPMENT AND SOFTWARE

The basis of the digital methods of research and diagnostics of substances of different physicochemical nature, including the registration of color and its changes is them digitizing, using professional equipment and subsequent mathematical processing of the obtained images in specialized programs.

To digitize it can be used flatbed scanners, e.g. Epson Perfection 4890 Photo with an optical resolution of 4800 dpi and a dynamic range of 3.8 D or Epson Perfection V 750 Pro with a resolution of 6400 dpi and a dynamic range of 4.0 D (or similar scanners of other firms with high depth of sharpness).

In particular, when we study the liquid substances, and if it is needed a high resolution it is more preferable as digitizing device, for example, Olympus Camedia C-5060, which is installed with help of optical nozzle on optical microscope. The usage of professional digital cameras with high resolution allows to avoid the application of the optical nozzle.

The test substance is placed in a special cuvette, made of high-quality glass with a thickness of 1 mm, for example, from glass used in the manufacture of photographic plates for nuclear research. The dimensions of cuvettes make provision for simultaneous scanning of several studied samples.

To eliminate the influence on the result of the digitization of the glass shooting of cuvette without test substance is originally held. Next, in the cuvette the test substance is placed in, and again there is the shooting. Then from a digitized image of the cell with a substance the image of an empty cell is subtracted.

Digitizing of interesting areas of substance is carried out in manual mode with the same settings of the scanner and a digital camera with control external lighting and stable lighting of the microscope. It is preferable to carry out the digitization in a darkened room.

To eliminate the influence on the image of various external factors every sample or selected area is digitized at least five times. This allows to exclude or take into account the dispersion further defined in the color characteristics and, therefore, to make the research more objective and reliable.

In the research process, the samples are stored in refrigerators, freezers or in vivo under strictly controlled conditions. For processing of digitized images the professional programs, for example, Image-Pro Plus 6.0, Matlab, Mathcad or similar programs, providing great opportunities compared to the scanner software are used. That is why the primary image, as the original, is scanned at the highest possible hardware characteristics on the resolution and number of quantization levels that is called "as is" and saved in PSD, TIFF, or BMP formats, ensuring minimum losses of useful information. In practice, for a number of objects the changes of color characteristics can be reliably recorded with lower resolutions, resulting in reducing of the size of the digitized image and the time of its further processing (chosen experimentally). The analyzed images must necessarily have the same sizes and format [19-21]. The basic stages of digital processing of the digitized images of the studied objects and defined characteristics are presented in **Fig. 1.**

For digitized images in three color channels (blue, green and red), for example, in Image-Pro Plus 6.0 program, difference contrast (DC), brightness characteristics (BC), an intensity profile (PI) and the area of equal contrast (AEC) are built. It was established experimentally that some substances when comparing their images of the greatest differences caused by the influence of the external factor, are stronger in one of the color channels, which is chosen then as the primary [14, 15, 20, 21].

Difference contrast is the result of subtracting of one image from another one, for example: images before and after any exposure on a substance; images of different samples, if you want to identify them distinctly, each from other in color characteristics; images of the cell with substance and without it, if you want to exclude the influence of the glass cuvette on the result of the digitization, etc. If compared images are identical, the result is a homogeneous background of zero DC. If there are differences, not visually detectable, the DC is not uniform and the background is not equal to zero. Differences of images of the investigated substances and their DC are registered by the building of DC. The luminance characteristics show the distribution of point image intensity: on the abscissa axis

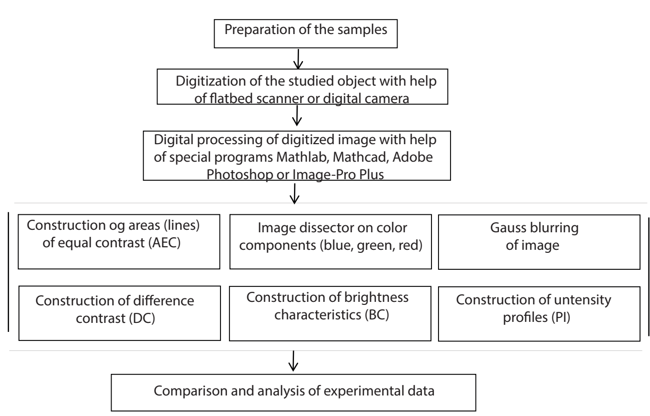


Fig. 1. *The sequence of digital image processing and determined characteristics.*

intensity I in gradation of gray color is putted (for an 8-bit image there are 255 gradations, for 16-bit images there are 65535 gradations), and on the y axis the number of dots N, having a given intensity. Under diagnosing of substances' quality, zero and non-zero DC can be visually indistinguishable, but the maximum value of the BC is securely fixed to the distinction.

The intensity profiles show the intensity variation in the selected direction for construction: along the axis of ordinates the intensity I is putted in gradation of gray, and the abscissa axis is the image size in pixels. The intensity profiles constructed for a zero DC have the appearance of straight horizontal lines, and BC – vertical (**Fig. 2**,a). In the presence of even slight color differences built BC reflects this fact (Fig. 2,b). PI is less informative as compared to BC, but in some methods they are essential to obtain qualitative and quantitative information about the studied object or process.

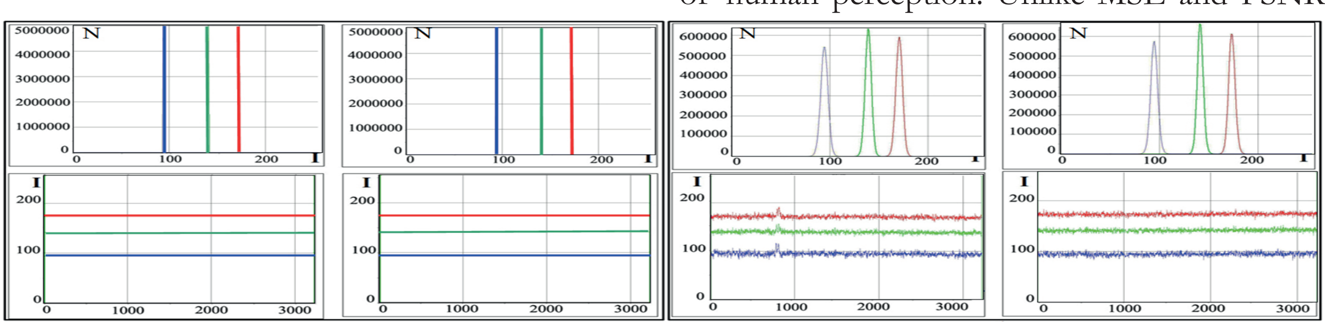
In some cases, to eliminate the influence on the result of digital processing features of experimental contrast, it is advisable to compare BC and PI not of their original digitized images, but their DC and their zero DC [20, 21].

In practice, the image quality and the efficiency of digital processing are evaluated visually and are largely dependent on the skill and visual acuity of specialists, who can have different opinion about the same image, the result of digital processing, the optimality of the choice of a particular technique, etc. To eliminate the subjectivity it is necessary to introduce objective quantitative evaluation criteria images, which can be used, for example, [25-28].

1. The mean-square deviation or standard deviation (MSE) is statistical measure of the dispersion of values of a random variable concerning to its expectation value. This value is dimensionless and equal to the average of the squared errors (differences in the intensity of corresponding pixels) of two images: the original X and treated Y. The lower MSE value, the closer to each other the compared images are.

2. The peak signal-to-noise ratio (PSNR) is often used to measure the level of distortion in compressing images, for comparison of different methods of restoration of signals and to study the effect of various parameters on the performance of a particular algorithm. The value of PSNR in the range of 20-40 and, the closer the processed image to the original, the higher the value of this metric. A high PSNR value does not guarantee that the restored image seems to be of high quality, but means only a certain similarity of the processed and original images. The metrics PSNR and MSE are not absolute values.

3. The index of structural similarity (SSIM) is a metric measuring of the similarity of two images according to three components: luminance similarity, contrast similarity and structural similarity. To measure the quality of the processed image, it is needed to have the original image. This technique (SSIM) was developed as a replacement for the metrics MSE and PSNR that do not take into account the peculiarities of human perception. Unlike MSE and PSNR



a *b*
River water Treated water River water Treated water

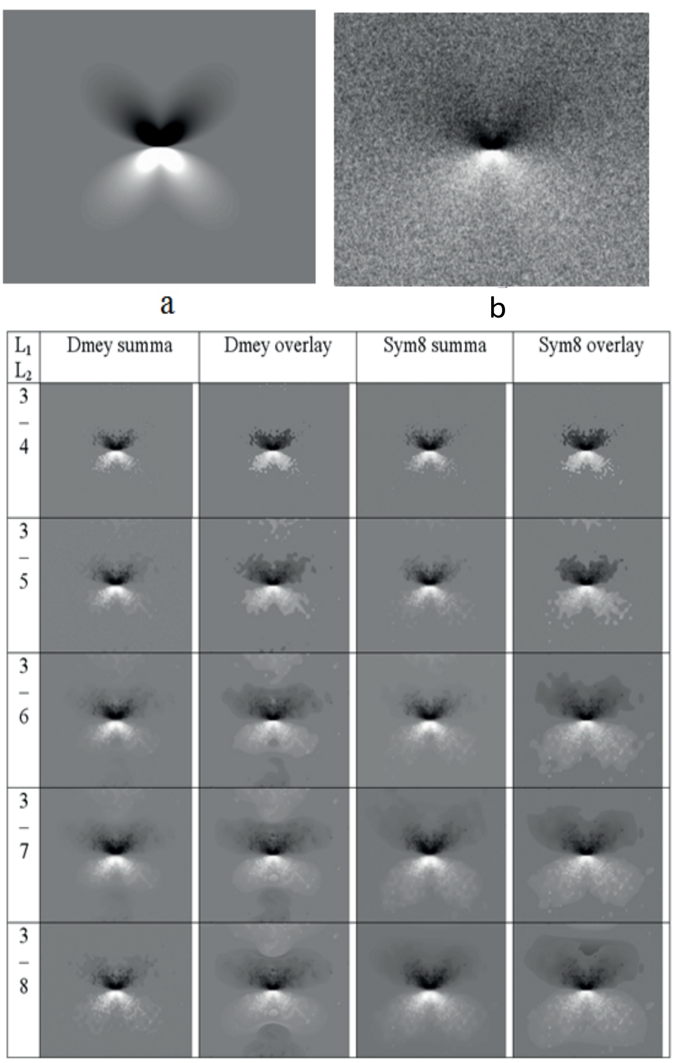
Fig. 2. *BC and PI, constructed in Image-Pro Plus 6.0 program. Images for river and treated water were received by digital camera: a – for zero of DC (river water-river water after treatment); b – river water before and after treatment.*

calculation of the index of structural similarity based on pixel-by-pixel comparison of images, and on comparing blocks of pixels of a certain size, as a rule, these blocks are of 8×8 pixels. Next, the resulting values are combined into the final result. The result of the measurement SSIM is in the range from minus 1 to plus 1. If the value of SSIM is 1, then the compared images are entirely identical [27, 28].

As an example, **Fig. 3** shows the result of applying of these three metrics to measure the quality of restoration by Sym8 and Dmey wavelets of noisy theoretical image of edge dislocation for the single crystal 6H-SiC and different bandwidths.

During the conducted researches it was established that the metric of evaluation of the quality of reconstruction of the digitized images based on structural similarity (SSIM) is more advanced than the metrics PSNR and MSE. The reason is taking into account by the SSIM metric of luminance, contrast and structural features of the compared images. The best results of reconstruction of a noisy image of edge dislocation obtained for wavelet Sym8. The main drawback of these metrics is not a high rapidity, due to the need to perform calculations.

The most simple, effective, and rapid method of quantitative evaluation of image quality based on the construction of DC, BC and PI is proposed by the authors of papers [19, 23].



The processed image	MSE	PSNR	SSIM
Dmey summa (3-4)	262,6938	23,9363	0,9401
Dmey summa (3-5)	194,9144	25,2324	0,9447
Dmey summa (3-6)	111,6201	27,6534	0,9540
Dmey summa (3-7)	80,5342	29,0710	0,9571
Dmey summa (3-8)	88,1790	28,6772	0,9567
Dmey overlay (3-4)	176,2482	25,6696	0,9379
Dmey overlay (3-5)	120,8628	27,3079	0,9344
Dmey overlay (3-6)	128,1268	27,0544	0,9441
Dmey overlay (3-7)	137,4368	26,7498	0,9452
Dmey overlay (3-8)	146,1950	26,4815	0,9405
Sym8 summa (3-4)	192,1072	25,2954	0,9340
Sym8 summa (3-5)	182,1101	25,5275	0,9448
Sym8 summa (3-6)	209,6032	24,9168	0,9477
Sym8 summa (3-7)	95,2864	28,3405	0,9542
Sym8 summa (3-8)	73,0280	29,4959	0,9567
Sym8 overlay (3-4)	142,3848	26,5962	0,9276
Sym8 overlay (3-5)	103,5984	27,9773	0,9291
Sym8 overlay (3-6)	113,7682	27,5706	0,9376
Sym8 overlay (3-7)	119,0258	27,3744	0,9395
Sym8 overlay (3-8)	136,9708	26,7645	0,9372

d

Fig. 3. *The results of the reconstruction by wavelets Dmey and Sym8 and evaluation the effectiveness of restoration metrics MSE, PSNR and SSIM of theoretical noisy image of edge dislocation single in crystal 6H-SiC: a – original image; b – noise image; c – the result of the recovery for different bandwidths, d – effectiveness of evaluation of recovery by all three metrics.*

All the necessary information about the image may be obtained during 30-60 seconds by the specialized for complex signal processing program Image-Pro Plus 6.0. The method was validated by comparison of a large variety of digitized images of substances of different physicochemical nature and showed high efficiency, sensitivity, rapidity and accessibility for a wide range of researchers [14-22].

Let us consider the application of this technique to assess the quality of reconstruction using wavelets Dmey and Sym8 on the theoretical example of a noisy image of screw dislocation in a 6H-SiC single crystal (**Fig. 4**).

Restored by these wavelets the image of screw dislocation visually almost do not differ from each other and pass all the main features of the original theoretical contrast. Built DC of Sym8-source (1) and Dmey-source (2) which are not zero, are also indistinguishable, and therefore, the recovered images are qualitatively different from the original. DC is not null for Sym8 and Dmey (3), but DC are null for original-original, Sym8-Sym8 and Dmey-Dmey (4). The question remains: what wavelet is better restore the noise of image, and which of them is closer to the original?

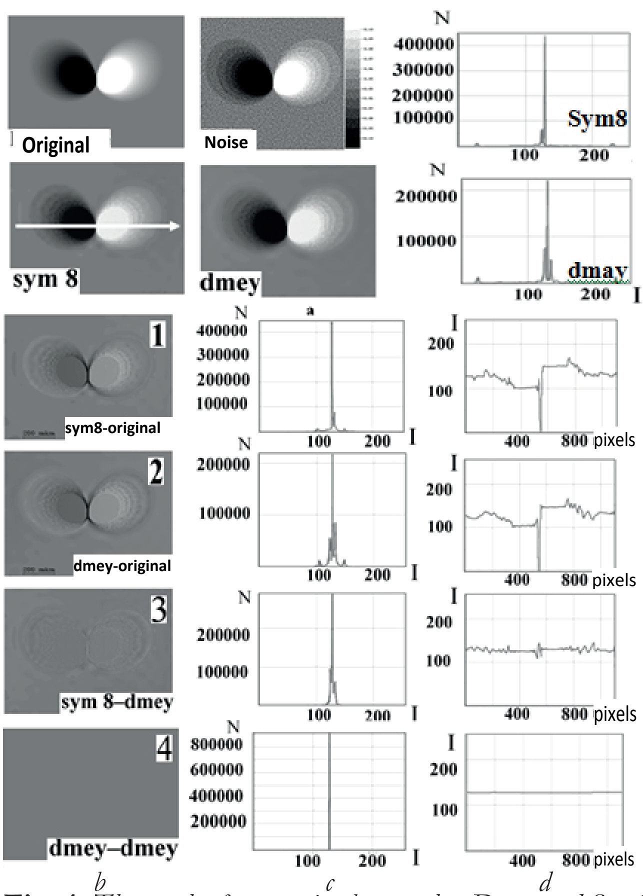


Fig. 4. *The result of processing by wavelets Dmey and Sym8 and evaluation of the effectiveness of restoration (construction of DC, BC and PI) for noisy theoretical image for a screw dislocation of a 6H-SiC single crystal. The arrow shows the direction of construction of the PI.*

All images in Fig. 4 have the same dimensions and format. Quantitative assessment of the quality of the restoration and determination the best wavelet can be given by comparing the maximum values of the BC differential contrast, which are different: for zero of DC (the original-original, Sym8-Sym8 and Dmey-Dmey) is 900000, for non-zero original DC Sym8-original is ~450000, Dmey-original is ~220000 and Sym8-Dmey is ~300000. The maximum value of BC for the original contrast is ~600000, for the Sym8 wavelet is ~450000 and for Dmey is ~220000. Since the maximum value of the BC for wavelet sym8, including the DC Sym8-original is close to original and DC original-original, than it is the most optimal for reconstruction.

The closer the noise image processed by wavelets to its original theoretical image and the smaller the difference between the maximum value of the BC, the higher is quality of digital processing. Therefore, as a quantitative criterion of efficiency of digital processing of different wavelets maximums of BC can be used. For the experimental contrast of 6H-SiC single crystal that contains images of edge dislocations, while eliminating by wavelets Sym8 and Dmey of graininess a similar result was obtained (**Fig. 5**). The Sym8 wavelet has been more effective than the Dmey wavelet, which confirms earlier by results obtained by the processing of a noisy contrast edge dislocation using the metrics MSE, PSNR and SSIM.

Similarly, it is possible to compare the effectiveness of various methods of digital image processing to identify changes in the substance occurring during a time, to control

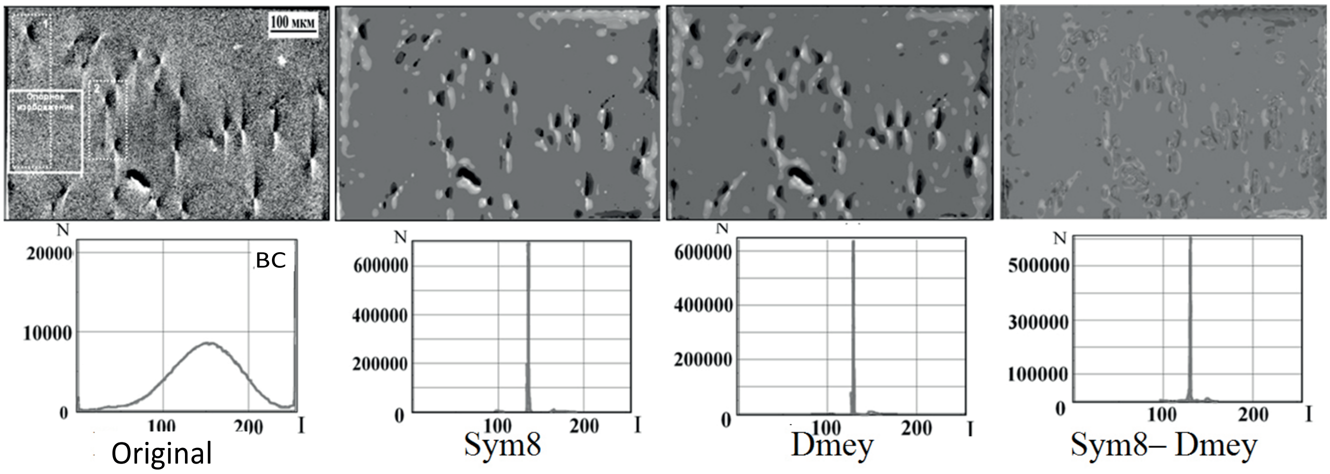


Fig. 5. *Quantitative evaluation of the effectiveness of Sym8 and Dmey wavelets at granularity removing on X-ray topography contrast of the 6H-SiC single crystal.*

technological processes, to identify counterfeit products, falsification paintings, etc. [14-22].

3. ANALYSIS OF THE RESULTS OF DIAGNOSIS QUALITY OF VARIOUS SUBSTANCES

Here there are a few examples of application of the above methods of digital processing for diagnosing the quality of substances of different physicochemical nature, including the registration of their color and its changes, the construction of DC, BC, PI and AEC. We will assess qualitative and quantitative differences compared digitized images and changes in matter.

3.1. Comparison of efficiency of different numerical methods to remove background inhomogeneity of the polarization-optical contrast of single crystal 6H-SiC

Background heterogeneity is manifested in a strong variation of the degree of blackening of various parts of topogram and negatives, which makes the analysis and recording of defects in the structure are difficult [4, 19, 22, 24]. The initial contrast (**Fig. 6**a) has darkened and exposed areas in which detection of defects of patterns of a single crystal is difficult. Using various methods of digital processing based on the brightness analysis (Fig. 6c) or the frequency characteristics (Fig. 6b,d), it is possible to eliminate the background heterogeneity.

Comparing the effectiveness of different methods, but in the case of application of methods 1 and 2 (**Table 1** and Fig. 6b and 6c) it is difficult to give preference to one of them. Analysis of the DC and BC recovered contrasts (Fig. 6b and 6c) shows that despite of large visual similarity, the result of digital image processing polarization-optical image of single crystal 6H-SiC by these methods the quality is different.

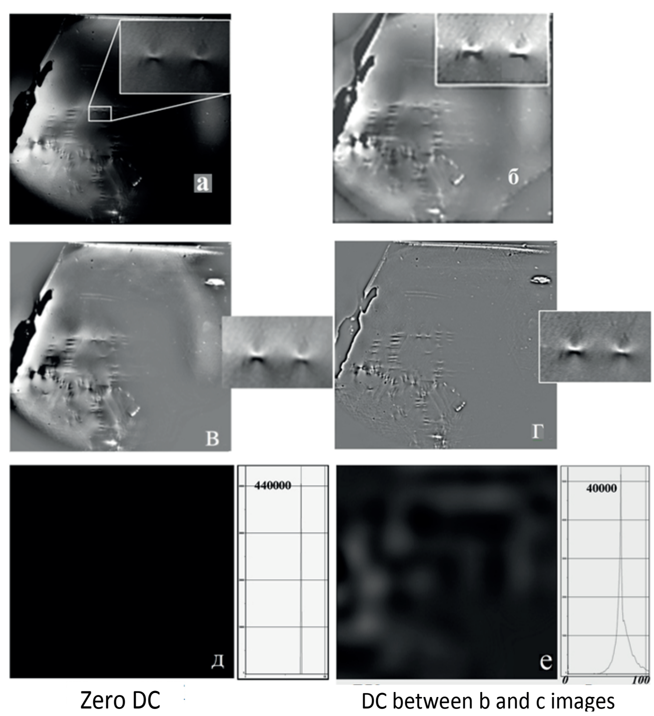


Fig. 6. *The elimination of the background inhomogeneity of the polarization-optical contrast of single crystal 6H-SiC by various digital methods: a – original contrast, b – 1 method, c – 2 method, d – 3 method, e – zero DC and BC; f – DC between contrasts b and c and its BC.*

Table 1

Main stages of digital processing by different methods

Number method	The basis of method	The sequence of digital image processing
1	The discrete wavelet analysis (frequency analysis)	Elimination of the background inhomogeneity is achieved by zeroizing of scale factors on the stage of the reconstruction. In the reconstruction only the detail coefficients of a certain set of the upper levels of decomposition are involved. HF filtering of detailed wavelet coefficients is carried out. At different frequency features of the image and not previously recorded details of defects of structure are identified. The range of levels involved in the reconstruction image, forms the bandwidth of the HF filter. The disadvantage is a great time of ~90-100 seconds and the presence of the phenomenon of aliasing.
2	Analysis of luminance characteristics	**Stage 1.** Gauss-blur of the original image is carried out (chosen experimentally). The image lost a fine detail contrast related to the structural defects. **Stage 2.** DC is built between the blurred and original images. **Stage 3.** The correction of the dynamic range of the received DC is carried out.
3	The discrete wavelet analysis (frequency analysis)	**Stage 1.** At all levels of decomposition the detail coefficients are zeroized. With increasing level of decomposition HF detail image are lost, and LF information starts to dominate. Selecting the optimal level of decomposition, and that, as a rule, the last level. During the reconstruction the processed image is obtained that contains information only about the background heterogeneity. Information about defects on the restored contrast is absent. **Stage 2.** DC is built between two images: the first one is the original contrast, the second contrast is obtained at stage 1 and containing only the background heterogeneity. On received DC an aliasing (intensity fluctuation) is observed depending on the chosen decomposition level. **Stage 3.** The Gaussian blur to DC obtained in step 2 is applied. The blur radius is determined experimentally and is approximately 10-80 pixels. **Stage 4.** Resulting DC between blurred DC and DC obtained in step 2 is constructed, the correction of its dynamic range is carried out. The received DC has a higher elaboration of the details of contrast under almost full suppression of phenomenon of aliasing. The digital processing time is in 10-12 times smaller (8-10 sec) than in the first and second techniques [19, 22, 24].

Digital processing of experimental contrast, containing images of structural defects based on analysis of discrete wavelet analysis gives the better result as compared with digital processing, based on the analysis of luminance characteristics. Most fully application of discrete wavelet analysis based on analysis of the pyramidal algorithm of Mallat and various wavelet bases for solving practical tasks is considered in [19, 22]. Inhomogeneous background and the contrast generated by the structural defects are in different frequency range: inhomogeneous background has low and very low frequencies, and the contrast from defects is at medium and high frequencies. Using the algorithm of discrete wavelet decomposition, it is possible to carry out a separate filtering of low and high frequencies.

In discrete wavelet analysis a decomposition of a two-dimensional signal carries out: decomposition image to a number of basis elements multiplied by certain coefficients that characterize the frequency spectrum of the signal. In general, the processing is the conversion of the obtained coefficients. Under inverse transformation the signal reconstruction restores, which is the final result of digital processing. Wavelet analysis allows to estimate and to separate the frequencies corresponding to the defects and noise factors.

Under decomposition of the signal two types of coefficients are obtained:

– large-scale (approximation) coefficients that give information about low-frequency (LF) component of the image, i.e. about coarse approximation of the image at different scales (levels) of its submission;

– detailed coefficients that give information about high frequency (HF) component of the image, i.e. about the little details of contrast at the analyzed scales, i.e. the structural defects. For two-dimensional signal there is a set of three types of detailed coefficients: horizontal, vertical and diagonal giving features of contrast in these areas. As a basic function in digital image processing of single crystal 6H-SiC (Fig. 6) methods 1 and 3 were used, the wavelet of Symlet was applied with the initial scale of the function equal to 8 (Sym8). Table 1 presents a brief description of three methods used for digital processing of this image.

3.2. Computer diagnostics of quality of meat raw materials and meat products

Scientific and practical interest represents the transfer of a part of the above methods for express-diagnostics of quality of raw meat, foodstuffs, liquid substances, and evaluation factors on their quality of various technological and external effects. Applying methods of computer diagnostics, based on the detection of color and its changes, it is possible to offer methods for assessing the quality and standards of raw meat, meat and other goods coming into reprocessors and trading network. For the studied substances it is possible to create atlases of the reference images with known color characteristics and changed under influence of the controlled external factors. To record qualitative and quantitative differences between the samples before and after external influences it is needed to build DC, PI, BC and AEC. The number of AEC can be varied depending on the required accuracy of registration changes color [14-18, 20, 21].

View of images in black and white format is also used to assess the quality of the substance and making the true decision, but the most convenient for diagnostic are color images. In quality assessing a useful decomposition of the image by color channels is blue, green and red. Meat from different manufacturers, different regions, and morphological parts of the carcass are different in color, and their quality depends on the breed of cattle, forage, diseases, conditions of transportation, storage, slaughtering, external factors, etc. Differences in meat color and quality visually is very difficult to identify. We show the possibility of registering this difference, using the construction of DC, PI, BC and AEC.

To eliminate the influence on the result of diagnosis of glass cuvettes, it is needed to build the DC between the digitized images of the cuvette with the meat and the empty cuvette. To reduce the influence on BC, PI and AEC of fluctuations' intensity, caused by the impact of boundaries between the fibers of the muscle tissue, the original digitized image are subjected to not large Gauss blur (blur radius ~10-20 pixels). Then for the blurry images DC, BC, PI and AEC are built.

Digitization of meat in manual mode and the subsequent digital processing allows to fix surely the color difference characteristics of the studied samples for different manufacturers and for different parts of the carcass. As an example, **Fig. 7** shows the scanned in manual mode under the resolution is 600 dpi, the samples of meat of beef of three different manufacturers: conventionally A, B, and C, taken from the cervical portion of the carcass. During visual inspection the meat color of all samples are virtually identical.

Conditions of storage and transportation, repeated freezing and defrosting of raw meat reduce its quality or change of color, and as a result, reduce the quality of meat products [16, 20, 21]. **Fig. 8** shows the images of beef taken from the outer portion of the hip portion of carcass, which was subjected to freezing at a temperature of minus 18ºC and subsequent defrosting at a temperature of 14° to 16ºC. Change the color of the meat sample, initially not visible to the human eye, surely are fixed in DC (zero and not zero), BC, BC and PI.

Change the color, BC and PI images of boiled sausage "Doktorskaya" (GOST R 52196-2003) depending on time of storage at a temperature of 14° to 16ºC and humidity of 85% is presented in **Fig. 9.** Visually change the color of the sample is not fixed, but DC and BC give qualitative and quantitative assessment of happened in the investigated object changes [17, 20-22].

Using this approach and knowing the color change (high BC) for reference samples of products that were stored under the conditions recommended by the GOST, it is possible to control the storage conditions of the products by state control and state supervision.

When diagnosing the quality of meat raw, meat products and comparison of experimental data for each color channel it is needed to build

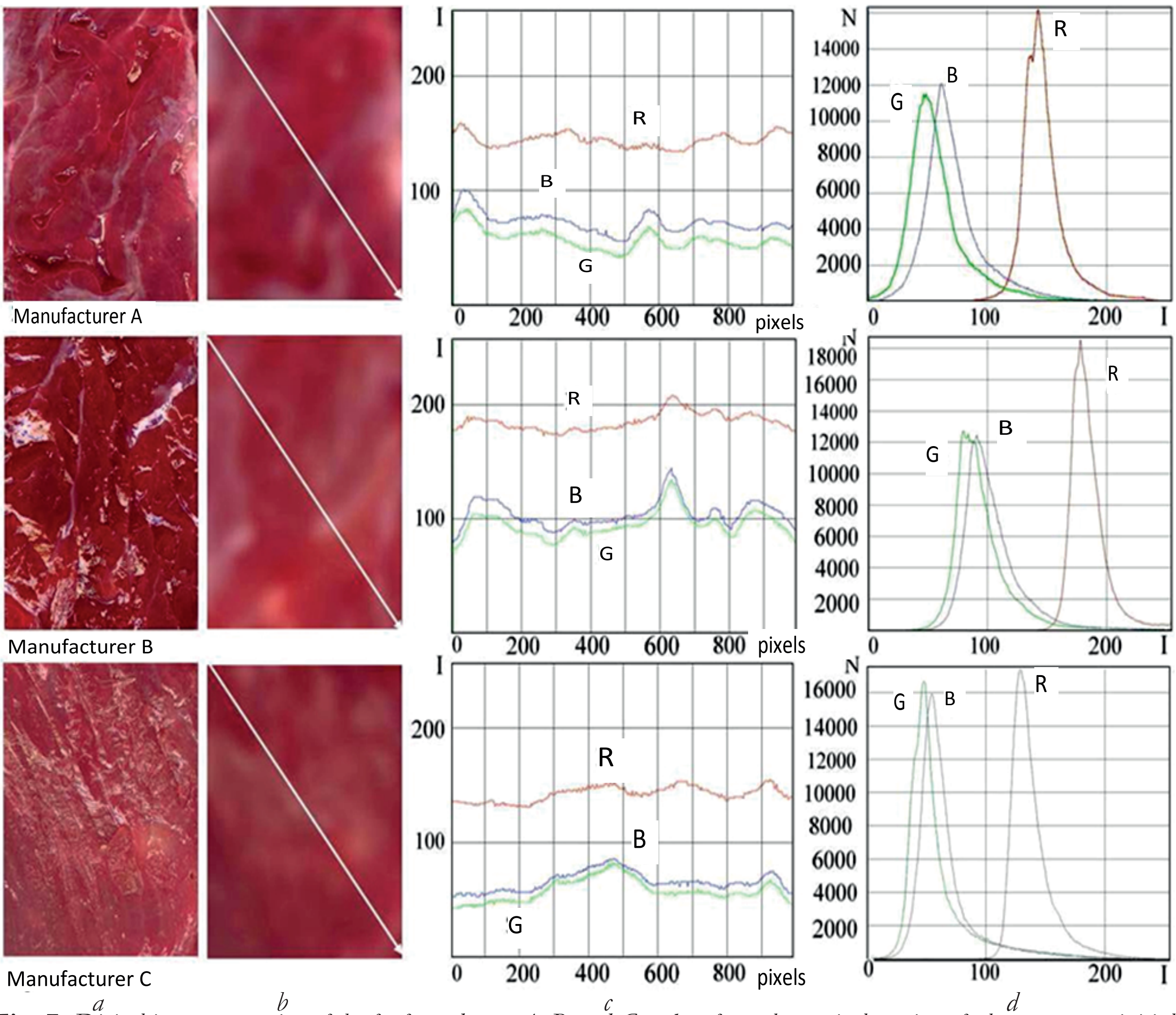


Fig. 7. *Digital image processing of beef of producers A, B and C, taken from the cervical portion of the carcass: a: initial, b: after Gauss-blur (blur radius 20 pixels), c: PI and d: BC taken for red (R), blue (B) and green (G) components.*

the dependences of changes of maximum values of BC from the studied factor. Comparing the obtained dependences similar to selected reference samples it can be evaluated the quality of supplied raw meet and manufactured products from different manufacturers, as well as influence of studied factors on various samples [20-22].

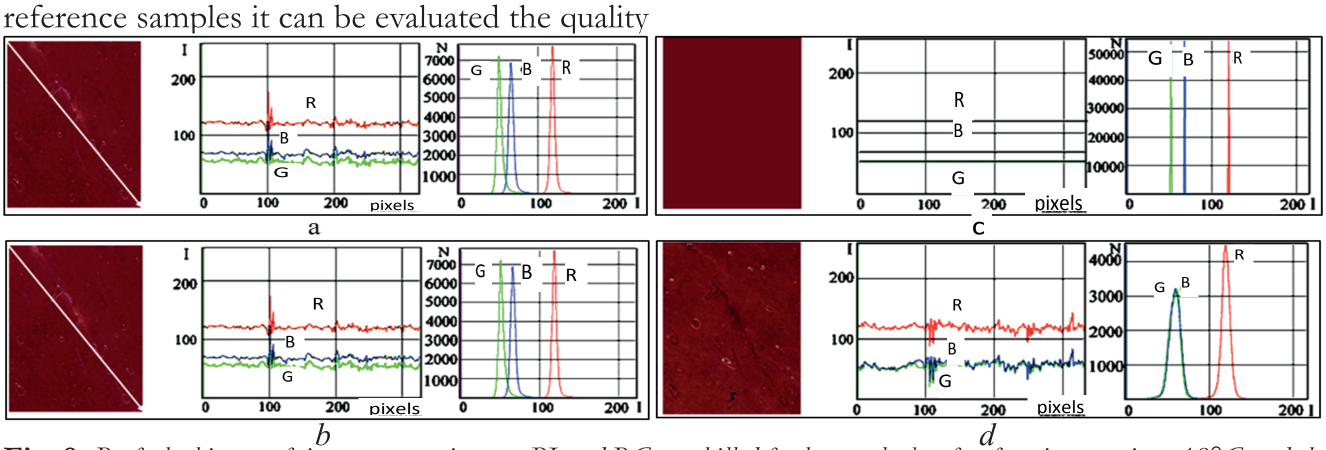


Fig. 8. *Beef the hip cut of its outer part images, PI and BC: a: chilled fresh sample; b: after freezing at minus 18°C and the subsequent defrosting at temperature, equal to 14-16°C, c: zero DC (a–a), d: DC, obtained by subtraction of images b and a.*

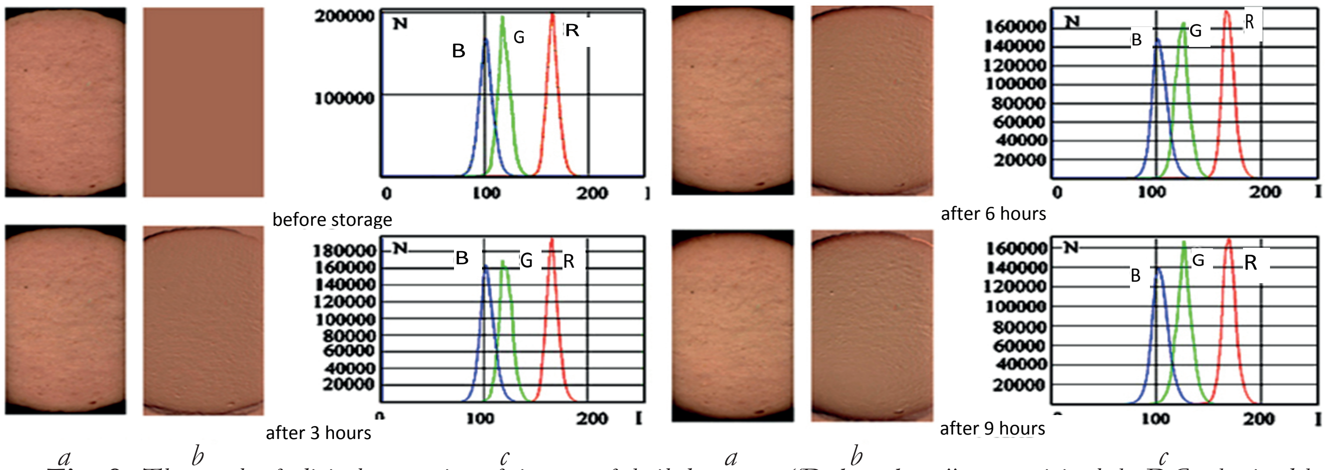


Fig. 9. *The result of digital processing of images of boiled sausage "Doktorskaya": a – original, b: DC, obtained by subtracting the image after storage and the original; c: BC.*

3.3. Computer diagnostics of water quality

In works [14, 15, 20, 21] the results of express-diagnostics of the quality of river and drinking water are given. Applying the above express method it can reliably assess the quality of water and compliance with sanitary standards for the region and the requirements to the water standards. The results of water diagnosis correlate are in good agreement with results obtained by gastronomy techniques in laboratories sewage treatment plants.

To establish relationship between physicochemical parameters of water and its color characteristics, let us consider the following parameters: color, turbidity, pH and alkalinity, which for the entire duration of the experiment of different water samples were greatly varied, shown in **Table 2.** Color and turbidity have the strongest influence on the color change characteristics of the water and especially at BC.

To assess the experimental error of determining the color characteristics of images of the same sample is digitized several times. For each image the DC, BC and PI was constructed. A fixed experimental error did not exceed 1-2% and was mainly stipulated by a change of illumination of an analyte in the sample when digitization.

Table 2

Physicochemical characteristics of water samples

Date	Turbidity, mg/l		Chromaticity, deg		pH		Alkalinity	
Standard SanPiN	1,5		20		6.0-9.0		1.10	
Sample water	*River*	*Purified*	*River*	*Purified*	*River*	*Purified*	*River*	*Purified*
1	6	0.45	77	11	7.54	6.35	1.4	0.46
2	23.8	0.24	70	10	7.36	6.25	1.45	0.48
3	6.1	0.7	105	10	7.5	6.45	1.4	0.65
4	7.2	0.95	117	7	7.15	6.15	1.15	0.31

The points in **Fig. 10** correspond to the maximum values of BC of drinking water for three color channels. For each of the color components, one can select an area that meets the requirements of SanPiN water for the region. If the maximum value of the BC of water samples puts into this region, the water corresponds to the color characteristics of the requirements of SanPiN. If the maximum of BC does not put within this region, the water does not meet the

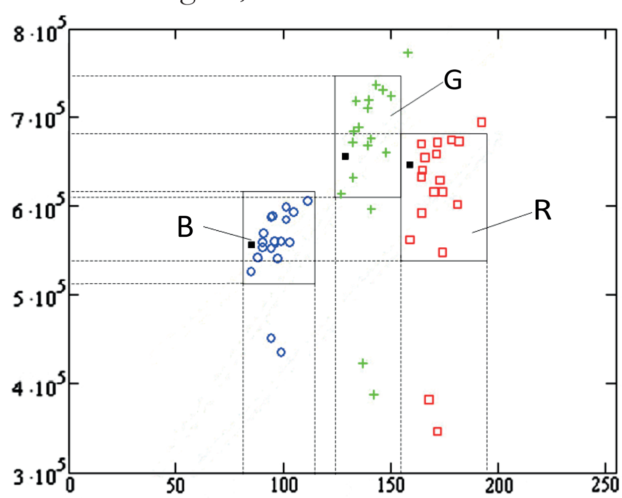


Fig. 10. *The permissible ranges of finding the maximum of the values of BC of drinking water, corresponding SanPiN: R, G and B are red, blue and green color channels. The black dots represent the results of the diagnostics from one of the food enterprises.*

requirements of SanPiN and additional cleaning and monitoring are required.

The experimental data obtained for three color channels coefficients of correlation between some physicochemical parameters and color characteristics of water is calculated, giving in **Table 3**.

Analysis of the obtained results shows that the color of the water is most highly correlated with the values of the BC for the green color channel along the ordinate (**N**) and the red channel on the abscissa (**I**), and the dependence is straight line. With increasing color of the water there is increase the maximum values of BC for green and red channels. The turbidity of water has the most high correlation with the values of the BC for the blue and red channels on **N**. The pH index of water is most strongly correlated with the values of the BC for green channel by **N**, and alkalinity has a good correlation with values for the green channel and red for **I**.

Thus, physicochemical water quality indices have a good correlation with the maximum values of BC for each of the three color channels, and the choice of the BC, as a tool for assessing water quality, is much reasonable and objective.

The most important indicators of the quality of beer and wine in addition to taste is their color, therefore, color registration and its changes can be the basis for digital express methods. This approach was applied by the authors in the study of the different manufacturers in the process of aging, the registration and identification of particles of different physicochemical nature without the use of special dyes, and identification of adulterated beer and wine production [14, 20, 21].

Table 3

Correlation coefficients of physicochemical parameters of water and brightness characteristics of digital images

Index	The correlation coefficient					
	The blue channel		The green channel		The red channel	
	X	Y	X	Y	X	Y
Color	-0.496	-0.234	0.583	0.989	0.882	-0.509
Turbidity	-0.378	0.989	-0.505	0.012	-0.455	0.967
pH	-0.755	-0.179	-0.222	0.961	-0.452	0.080
Alkalinity	-0.790	-0.317	0.105	0.969	0.908	0.141

4. COMPUTER DIAGNOSTICS OF DRY AND WET METHODS OF MEAT SALTING

Development of methods of visualization of the process of salting and determination of its quantitative characteristics (the speed of the process and the depth of penetration of the mixture and its individual components) was conducted on chilled meat of broiler chickens. There were studied dry and wet salting of meat with a mixture of part salt-pepper-garlic in the ratio of 1:0.11:1. In the wet process the salt concentration in the brine was 12%.

For each experiment five samples of meat were collected with the size of approximately, 5×7 cm^2 and a thickness of ~1 cm, which was placed in a glass cuvette. One sample sprinkles on the lateral surface of the curing mixture, the other three components of the mixture, respectively, with salt, pepper and garlic, the fifth sample was a control and evaluated the impact of meat on the external factors. All cuvettes with samples were closed from above by glass. With all methods of salting meat the impregnation took place only on the part of its lateral surface, although in real conditions the process of the saturation goes through the entire surface. In the first hour the digitization of meat was carried out every 15 min, and then every 30 min. In between digitization samples the cuvette was not removed from the scanner glass. In some experiments the samples were kept in refrigerator at temperature of 4-6ºC.

When salting the meat has a change of meat color, which begin from sides and is related with penetration of salt and other components of salt mixture. It is difficult to see a visually a clear boundary between the impregnated and not impregnated areas, as well as to determine the depth of penetration of each mixture component in meat is not possible.

In papers [18, 20, 21] there were discuss four methods of digital visualization of the process of salting and determine its quantitative characteristics that are a good fit to the proposed theoretical model.

4.1. The technique is based on analysis of AEC and PI

The speeds of the process of meat salting by mixture and its individual components in different directions are different from each other [18, 20, 21]. **Fig. 11** shows a theoretical model of the process of salting. The figures shows four directions in which PI was obtained, including the directions along and perpendicular to the muscle fibers (Fig. 11a and 11b). Applying to digital images of a small Gauss-blur you can reduce the influence of muscle fibers on the AEC and PI.

The model is based on registration of changes of digitized color image of the meat during salting. Ideally, PI has the form presented in Fig.11: 1 – initial, 2-4 – for different times of the time salting, at that $t_1<t_2<t_3$ and $l_1<l_2<l_3$, where l is the depth of penetration of the mixture or its components. Any increasing a time of salting leads to a change in contrast and PI. Under construction of AEC the optimal number of gradations of color is chosen, but at least five for a ternary mixture: two grades give the meat and its connective tissue, and three gradations of three components of the curing mixture (conventionally A, B and C). It is proposed that components A, B and C have different diffusion coefficients in the meat. The first area forms a contrast between the components A, B and C; the second between components B and C and the third area – by C component only.

Comparing AEC, PI and knowing the size of the meat, it can be determined the penetration depth of the salting mixture and separately its

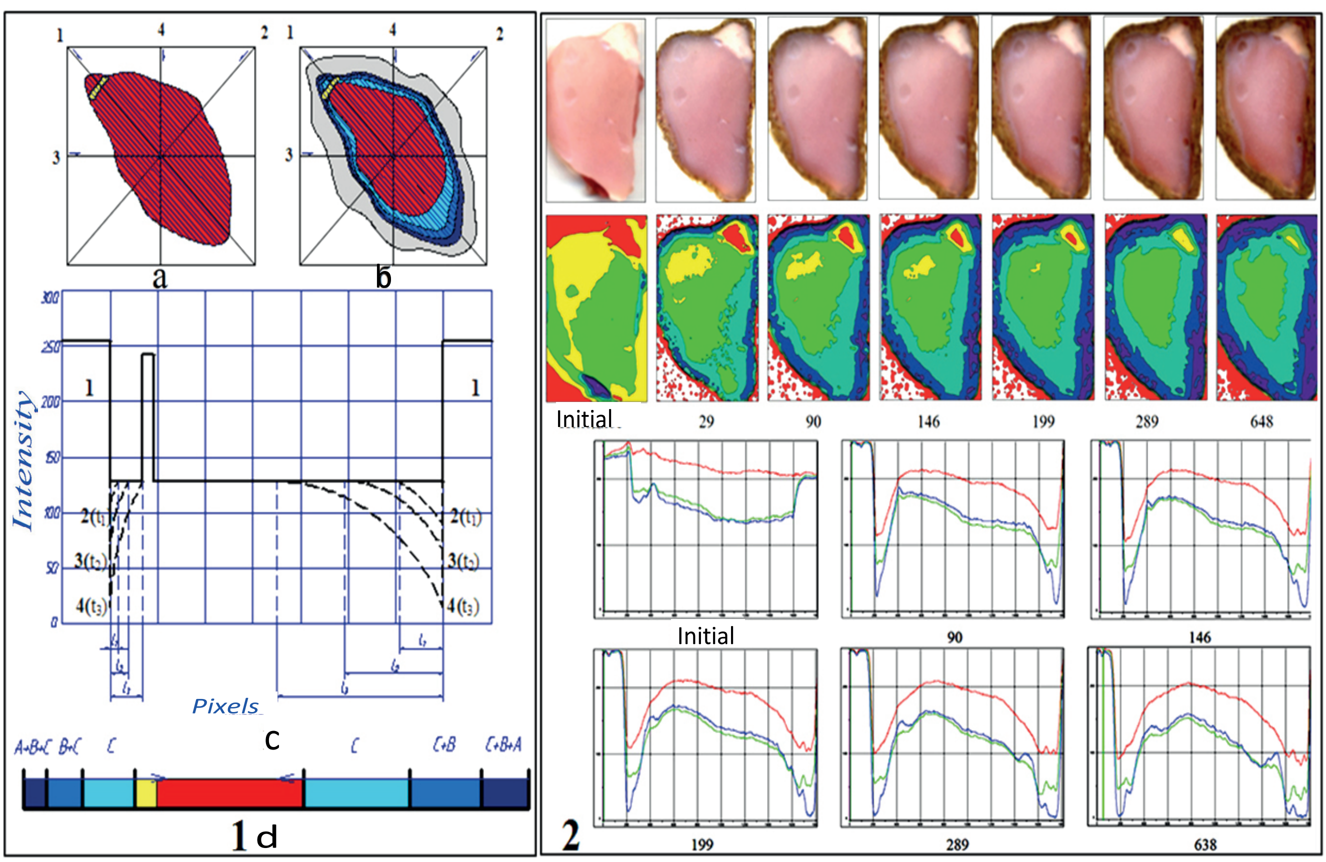


Fig. 11. *Theoretical model* (**1**) *of visualization of the process of salting meat by mixture consisting of three components* **A, B** *and* **C** (**2**)*: a – the original digitized image, numbers 1-4 show the directions of obtaining of the PI, b – AEC at time t of salting, c – PI at the time of salting $t_1<t_2<t_3$ ($l_1<l_2<l_3$ is the depth of the salting); d: contrast in five gradations of color,* **2** *– fuzzy experimental contrast, AEC and PI at different time of salting in minutes.*

individual components. Knowing the time of salting (t_s) and the depth of penetration of (l_p), it is easy to estimate the speed of the process v by the formula:

$$v = l_p/t_s. \quad (1)$$

4.2. The technique based on the decomposition of an image by color channels

The essence of the method is demonstrated on the **Fig. 12**. Not the whole image, but only the most interesting part of it, can be subject of digital processing. The best visualization of the process of salting is observed under processing a whole image of the sample.

This method of digital processing differs from the previous by lack of the Gauss-blur, where insignificant loss of useful information is possible. It is based on the transfer of the digitized color image into black and white format is demonstrated by Fig. 12,c, the AEC, build for him is presented by Fig. 12,d. For better visualization of the process of salting and separation of areas of penetration of the mixture and its individual component the last two figures can be represented in color format (Fig. 12,e). Similarly to the previously proposed method the quantitative characteristics of the process of salting (the depth of penetration of the mixture and its components, etc.) are determined by the AEC and PI.

Digitization of the original image requires some time, during which the meat of broiler chicken is in contact with the mixture, so on

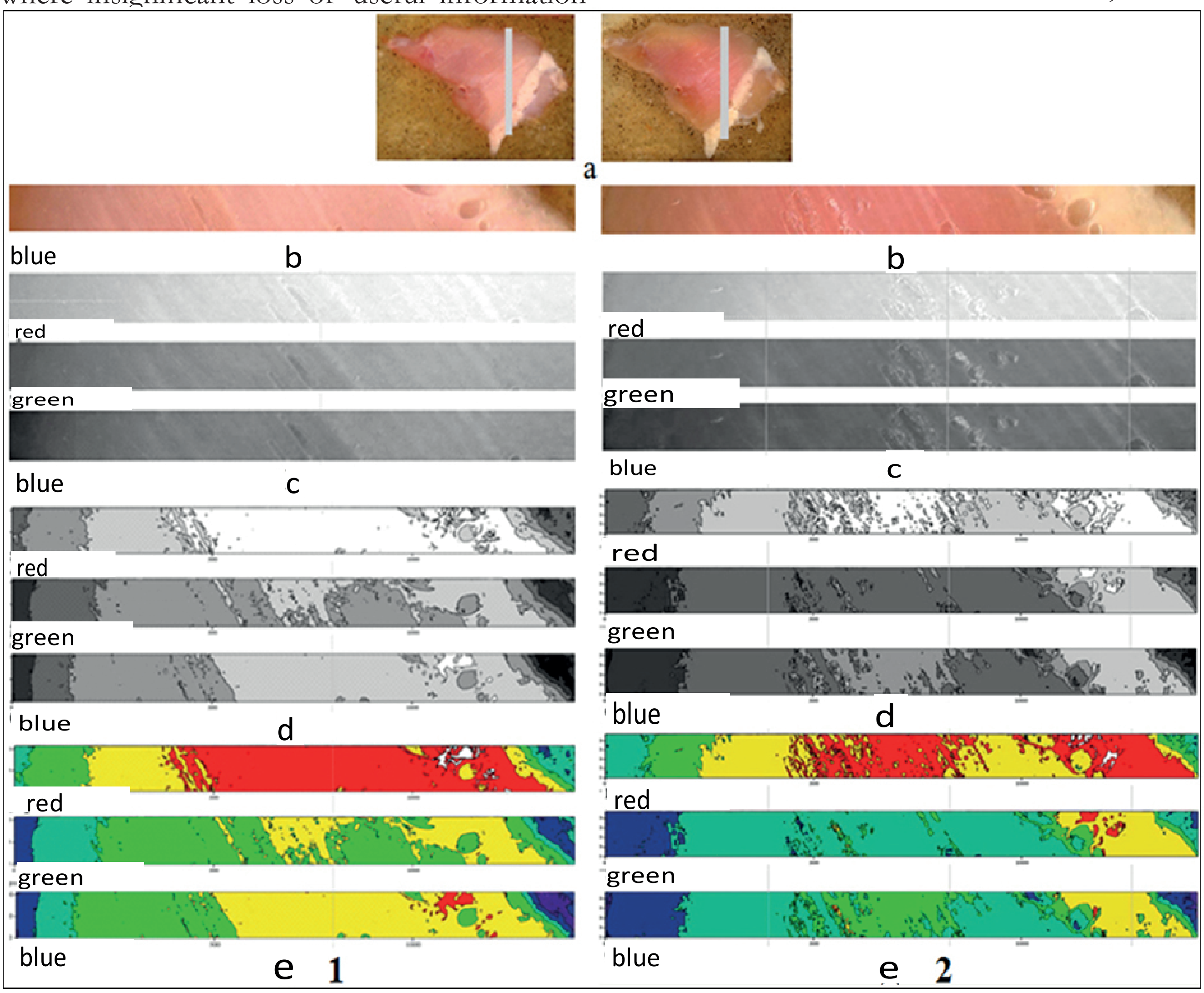


Fig. 12. *The original decomposition* (**1**) *and the wet method of salting within 1050 minutes* (**2**) *images made by color channel: a – original image; b – selected area; in – selected area in black and white and in color channels; c and d – AEC in black and white and color formats, with 5 gradations of color.*

the original image (1) when the AEC is built a thin black or purple layer is fixed, in which the salting mixture entered in (Fig. 12,d and e). By experimental contrast, knowing the sizes of the meat sample and pixel, the penetration depth of the mixture and its individual major components can be calculated. A more accurate determination of the penetration depth of the mixture and its components is achieved when comparing the original and made after curing PI.

4.3. The technique, based on the detection of differential contrast

This technique develops the earlier presented methodology, and is based on the analysis of DC obtained by the subtraction of two images: the original and after curing. If meat has no color changes, there is a zero DC, but PI represents a straight line (**Fig. 13,** profile 1). During curing the salt (mixture) concentration decreases deep into the meat. Constructed DC reflects this fact by changing the color and PI, respectively (Fig. 13, profiles 2-6).

Quantitative characteristics of the process are determined of salting by built DC, AEC, and PI. For example, knowing the time of salting (t_s) and evaluating the depth of penetration (l_p), the speed of the process can be calculated using formula (1).

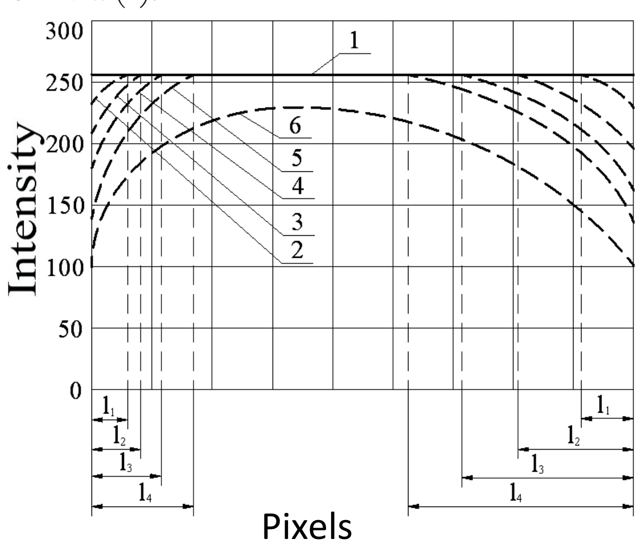


Fig. 13. *PI and their change under salting recorded by the third method: 1 – at zero in DC; 2-6 – after curing for a time* $t_1<t_2<t_3<t_4<t_5<t_6$, l_1-l_4 *– depth of salting (model approximation).*

The use of Gauss-blur of DC allows to reduce the influence of the boundaries between the fibers of the muscle tissue on the AEC and PI and to improve the accuracy of the technique. According to this method, the DC consecutively is recording between the original image and the image of the meat during different times of the salting and in further it is possible to judge about the dynamics of the process, the peculiarities of penetration of the mixture and its components in meat by changes of the DC, AEC and PI. It is possible to define DC, for example, between two images of meat at different time of salting and to evaluate the changes of the color characteristics for a selected period of time.

4.4. A combined methodology

The technique is a combination of the previously described methods and allows a gradual increase in the number of gradations of color to trace the change of the experimental contrast-induced change in the concentration of a component in the meat in a depth. A seeming complication of the technique and increase the time of digital processing are negligible. The profit is in more objective and reliable detection of changes in the color characteristics of the meat during salting and, consequently, specific quantitative parameters of the process are more accurate and objective.

The experimental results obtained by evaluating the speed of curing for the different methods are presented in **Table 4**.

As a result of research for different types of salting the possibility was shown of their visualization, determination of the speed and depth of penetration in a meat of curing mixture

Table 4

Speed of salting for different mixture components, obtained from the analysis of regions of DC and PI, expressed in cm/hour

Salting method / Component of the mix	Dry		Wet	
	along the fibers	perpendicular to the fibers	along the fibers	perpendicular to the fibers
Salt	8-13	6-11	5-9	4-6
Pepper	0.02-0.035	0.015-0.025	0.1-0.18	0.06-0.08
Garlic	0.06-0.11	0.04-0.09	0.18-0.35	0.11-0.23

and separately for each components of salting mixture.

In addition to the examples discussed above the digital techniques were applied for diagnosing the quality of gasoline, milk, honey, baby food, juice, and other substances.

5. CONCLUSION

Analysis of the obtained experimental results have proved a promising of application of the developed digital express-diagnosis methods of quality and quantitative estimation of substances of different physicochemical nature.

Digital methods based on the analysis of luminance and frequency characteristics, can be used effectively for the detection of structure defects of various single crystals, the registration of which is visually complicated by the presence of the noise contrast factors (background inhomogeneity, granularity of emulsion).

Differential contrast (zero and not zero), brightness characteristics, profiles of intensity, and areas of equal contrast can be used as tools for the quantitative and the qualitative assessment of the images, the efficiency of digital processing methods and the selected wavelet basis.

For a large number of substances of different physicochemical nature the color becomes to be one of the most important of their characteristics. Registration of color and its change with time or when exposed to various external factors may be the basis for numerical methods of express-diagnostics of the quality of the substance and identification of faulty product.

The discussed above digital techniques allow to visualize the processes of the meat salting by multicomponent mixtures, to determine the speed and depth of penetration of the mixture, and its separate components, to explore the ageing of beer and other processes carrying out in substance.

Thus, the considered above methods and techniques are promising for substances under exposition on them of external factors and color changes are not visually apparent.

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