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THE ANALYSIS OF TEXTURAL IMAGES ON THE BASIS OF ORTHOGONAL TRANSFORMATIONS

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ABSTRACT

The aim of the conducted research is development and search of analysis algorithms of textural images. The software products, which allow analyzing successfully textures in details, can be used in different fields of science and the industry. First of all, it is chemistry and materials science. It is possible to analyze materials of organic origin, cuts of metals and minerals, ceramics, etc. Another field of research, where we can effectively apply these methods, is the diagnosis of internal pathologies of human, including malignant, according to the images received by means of the thermal imager. In this study we are talking about application of spectral decomposition on various orthonormalized bases of images, which were received by the translucent electronic microscopy. The program is implemented in the Matlab environment, which allows spectral transformations of six types: 1) cosine, 2) Hadamard of the 2^n order, 3) Hadamard of the order $n = p+1$, $p \equiv 3 (\mathrm{mod}\, 4) -$ prime number, i.e. based on Legendre's symbol, 4) Haar, 5) slant, 6) Dobeshi-4. Various experiments were made. The algorithms, which were studied in this research, have allowed us to allocate effectively on the analyzed images some fields, which can be characterized by different degrees of structure orderliness. To say more precisely, chemists are interested in the “disorder” areas of structure of materials, for example, during studying the ultrastructure of plant cell walls. This research was made for the Institute for Chemistry of Solids and Mechanochemistry of the Siberian Branch of the Russian Academy of Sciences. The main attention was paid to the development of software tools for the analysis of the above microphotographs. It is supposed that received characteristics for different images - textural signs, as well as various spectral coefficients can be further correlated with values, which characterize the physical and chemical properties of the analyzed material: reactivity, porosity, diffusion coefficient, and so on. For correlation, it will be possible to use algorithms for machine learning, for example, based on the neurocomputer approach.

Keywords: *Image Processing, Textural Images, Orthogonal Transformations, Microphotography Analysis, Electronic Microscopy, Herbal Raw Material.*

1. INTRODUCTION

The basis for conducting this research is the agreement between the Institute for Chemistry of Solids and Mechanochemistry of the SB RAS and A.P. Ershov Institute of Informatics and Computer Systems of the Russian Academy of Sciences Siberian Branch. The study is carried out for the purpose of the implementation of the ISTCS SB RAS grant of the Russian Science Foundation No. 16-13-10200 "Controlled change in the structure and composition of plant raw materials by mechano-chemical methods for the intensification of the extraction of biologically active compounds". The work is also supported by Russian Foundation for Basic Research: grant 18-08-01284.

The aim of the research is to create a scientific and technical foundation in the field of texture image processing [1 - 6]. Another aim of the research is to develop and search algorithms for analysis of images obtained from various sources, for example, with the help of modern electron microscopic methods. Besides, images of ultrastructure of plant cell walls, obtained by transmissive electron microscopy of herbal raw materials, after various physico-chemical, mechanochemical treatment were analyzed. Nowadays, this information is popular among scientists from various fields - chemists, biologists, technologists – but it is still handled manually at a qualitative (rarely semi-quantitative) level. The transition to algorithms, which allow operating large volumes of data, would allow to the mentioned fields of science to make a significant step forward and to improve existing and create new technological processes.

In our case, microphotographs of herbal raw material, milled on special mills are the source, as a rule. The final aim of the work is the definition of porosity, chemical reactivity of the raw material, etc. using photomicrography. In this work, the main focus is on the development of software tools for image analysis, namely, programs for texture analysis. In the previous article we have studied sets of textural signs [7]. Different sets of textural attributes (namely, 19 signs, both classical and modern) were used in order to reach it. Besides, various experiments were carried out on the application of R/S-analysis and fractal analysis [8, 9].

In this work we are talking about spectral transformations based on orthogonal matrices [10 - 15]. In total, 6 types of transformations are considered. It is supposed that the characteristics of texture features (such as entropy, ratio of order/disorder, the proportion of zones with "abnormal" texture, etc., which were received for different images, as well as various spectral coefficients can be further correlated with the values, characterizing the physical and chemical properties of the analyzed material: reactivity, porosity, diffusion coefficient, and the so on. It will be possible to use algorithms for machine learning for the correlation, for example, based on the neurocomputer approach. So, if the system will be trained on a data set, then it will be possible to carry out predictions regarding the physical and chemical properties of materials demanded in the chemical industry. The most interesting part of the project is the application of methods of machine learning, i.e. in fact, methods of artificial intelligence in classically applied methods of physical-chemical analysis. Software products that allow to make detailed analysis of textures can be successfully applied in various fields of science and industry. First of all, it is chemistry and material science. It is possible to analyze materials of organic origin, slices of metals and minerals, ceramics, etc.

The quantity of tasks is not limited only with microphotography analysis. For example, during processing aerospace pictures, researchers also deal with different textures. It becomes possible to determine the coniferous or deciduous forest it is, whether the fields are planted with grain or bean plants, etc. just by using texture features. It is also possible to define whether the woods are affected by pests or deserted territories. Another field of research, where these methods can be used effectively, it is a diagnosis of internal pathologies of a person, including malignant, with the help of images obtained with the help of a thermal imager. The fundamental difference between the ideas of our project and the existing analogues is the correct application of mathematical methods and in their deeper study. For example, we know more than two hundred texture characteristics, but in scientific reviews usually only about fifty kinds are used. At the same time, in practice, only 3-4 features are usually used, for example, during processing space images. That means that original images are explored in the full way. We can say the same about the application of integral transformations. For example, the Haar transformation is used during investigating the strength of metals under loads in order to characterize the fissuring. The question about information that can be obtained on the basis of other transformations is almost not studied. The literature on wood chemistry [8, 9] states the usefulness of R/S analysis and fractal analysis for corresponding studies, but even with this method, information is fragmentary.

It is suggested to approach these questions in a comprehensive way that means to consider a large amount of features, a large number of transformations and to create the algorithms and programs, which will be applicable for the solution of a wide class of tasks. The obtained results can be applied in automated image analysis systems, which are used in scientific research and in industry. Their application in industry makes it possible to simplify and cheapen the analysis of the quality of incoming raw materials and products produced and, in some cases, even to improve the quality.

2. ORTHOGONAL TRANSFORMATIONS

Spectral analysis is a powerful tool for analyzing signals and images, since it was noted long before that the spectrum is very sensitive to various changes in the structure of signals and images.

It is necessary to predefine previously the signal or image by frequency in order to perform a spectral analysis. Different sets of basic functions are used for this purpose. The corresponding algorithms are called transformations: cosine, Hadamard, Haar, inclined, and others. We want to point out that the transformations of Haar and Dobeshi are the simplest wavelet transformations. According to the theory of signal processing, these methods can be applied to stationary random processes, but often we do not have it. However, it is possible to choose for analysis areas, which are considered conditionally stationary (in other words, quasi-stationary) and whose size is sufficient to obtain statistically reasonable results. Another feature, which was found during experiments with such algorithms is that the assessment is more qualitative than quantitative, which also represents a definite value. Often there are no normative tables of the basic parameters of signals or images, as it is, for example, in cardiography. The application of decomposition algorithms to various basic functions can be considered as a transition from one form of information presentation to another, which is more convenient, compact, and informative.

Spectral transformations in a one-dimensional case can be written down in such way as:

$H\vec{u}=\vec{\alpha}$, where H - is the transformation matrix, whose rows form an orthonormal basis in the corresponding linear space; $\vec{u}$ - vector representing the sampling of the original signal; $\vec{\alpha}$ - vector of spectral coefficients, characterizing how much one or another basic function (harmonic) is represented in the vector $\vec{u}$ (that mean in the original signal). In the two-dimensional case f or images, the spectral transformation is written in the form $HUH^T=A$, where H^T is a transposed matrix, U - is a square fragment of the original image, A - a matrix containing spectral coefficients. That is, we believe that the conversion is applied to the image fragment.

Typically, different "wonderful" bases are used, we mean matrix. They allow you to neatly "uncover" the nature of signals and images, that is, makes it possible to understand their structure. Below is a list of these most interesting transformations.

2.1. Cosine transformation

The discrete two-dimensional (matrix) cosine transformation of DCT is usually defined by the formula [15].

$$C_{ij}=\frac{1}{\sqrt{2n}}C_iC_j\sum_{x=0}^{n-1}\sum_{y=0}^{n-1}p_{xy}\cos\left(\frac{(2y+1)j\pi}{2n}\right)\cos\left(\frac{(2x+1)j\pi}{2n}\right)$$

$$C_f=\begin{cases}1/\sqrt{2}, & f=0,\\ 0, & f>0.\end{cases}$$

Here p_{xy} - is the brightness of the pixel with coordinates x, y. That is, this formula immediately represents the result of multiplying the matrices. HUH^T.

2.2. Hadamard transformation

Methods [16, 17] describe methods for constructing normalized Hadamard matrices, known as Pali constructions. In studies [18-22] we can find numerous examples of the use of the Hadamard transformation.

Definition 1. Let *p* be a prime number, *p*≠ 2, α an arbitrary integer, which can not be divisible by *p*. The Legendre symbol (α/p) is equal to 1, if the equation $x^2\equiv\alpha(\mathrm{mod}\,p)$ has a solution; otherwise it will be –1. [16].

As it is known [16], the following formula is valid

$$(\alpha/p)=-1^M,\ M=\sum_{x=1}^{p_1}\left[\tfrac{2\alpha x}{p}\right],\ p_1=\tfrac{1}{2}(p-1).$$

Here the square brackets show the whole part of the division. It is necessary to note that this

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formula is very simple for calculations. Of course, when implementing on a computer it is not necessary to erect in a degree number –1; it will be enough to control parity M, for example, in such way. Let's suppose that $R = M - 2\left[\frac{M}{2}\right]$. Then it is clear to see that $-1^M = 1 - 2R$.

Definition 2. If $A = (\alpha_{ij})$ is $(n \times n)$-matrix, and $B = (b_{ks})$ is $(m \times m)$ - matrix, then Kronecker product $A \times B$ will be called $(nm \times nm)$ matrix

$$A \times B = \begin{pmatrix} \alpha_{00}B & \alpha_{01}B & \dots & \alpha_{0n-1}B \\ \alpha_{10}B & \alpha_{11}B & \dots & \alpha_{1n-1}B \\ \dots & \dots & \dots & \dots \\ \alpha_{n-1,0}B & \alpha_{n-1,1}B & \dots & \alpha_{n-1,n-1}B \end{pmatrix}$$

Let's describe two classes of matrix.

1). Matrices of order $n = 2^k$ are determined by induction.

When $\kappa = 1$ we suppose

$$H_1 = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

If H_k is already defined, then

$$H_{k+1} = H_1 \times H_k.$$

2). Matrices of order $n = p + 1$, $p \equiv 3 (\mathrm{mod}\, 4)$ - are prime numbers.

We suppose $\chi(k) = (k/p)$ and

$$\alpha_{ij} = +1, \ (i = 0 \text{ or } j = 0).$$

$$\alpha_{ij} = \chi(j - i), \quad (1 \le i, j \le p, i \ne j)$$

$$\alpha_{ii} = -1, \quad (1 \le i \le p)$$

Proposition. Such ratios are fair:

a) $\alpha_{ij} = -\alpha_{ij}$, $(i, j \ge 1, i \ne j)$,

b) $\alpha_{ij} = \alpha_{i+k, j+k}$, $(i, j \ge 1, i \ne j)$,

c) $\alpha_{i, i+k} = \chi(k)$, $(i, k \ge 1)$,

d) $\alpha_{i, i+k} = -\alpha_{i, i+p-k}$, $(i, k \ge 1)$.

The proof follows directly from the well-known qualities [16] of the Legendre symbol.

The first equality from this proposition means that matrix A is antisymmetric. The second one shows that on any line, which is parallel to the main diagonal, all elements are equal. The third equality gives first line structure: it is $\langle 1, -1, \chi(1), \chi(2), \dots \rangle$. From the fourth equality comes that: in the first line, if we consider its segment $\langle \alpha_{12}, \alpha_{13}, \dots, \alpha_{1,p-1} \rangle$, which is lying above the main diagonal, then elements equidistant from the ends are opposite in sign.

Thus, the whole segment can be restored by its half.

2.3. Haar transformation

The Haar transform is based on the Haar orthogonal matrix [23]. Below is an example of an orthonormal Haar matrix of eighth order.

$$H_8 = \frac{1}{\sqrt{8}} \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ \sqrt{2} & \sqrt{2} & -\sqrt{2} & -\sqrt{2} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sqrt{2} & \sqrt{2} & -\sqrt{2} & -\sqrt{2} \\ 2 & -2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & -2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & -2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 & -2 \end{pmatrix}$$

Haar matrices of higher order are constructed according to the same rules as matrices H_4 and H_8. The Haar transformation can be considered as the process of digitalization of the source signal, with which, during transition to the next line, the digitalization step twice decreases.

2.4. Slant transform

An orthogonal transformation, which is called slant transform [23] is given as follows:

$$S_N = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \quad 0 & & 1 \quad 0 & \\ & 0 & & 0 \\ a_N \quad b_N & & -a_N \quad b_N & \\ 0 & E_{N/2-2} & 0 & E_{N/2-2} \\ 0 \quad 1 & & 0 \quad -1 & \\ & 0 & & 0 \\ -b_N \quad a_N & & b_N \quad a_N & \\ 0 & E_{N/2-2} & 0 & E_{N/2-2} \end{pmatrix} \begin{pmatrix} S_{N/2} & 0 \\ 0 & S_{N/2} \end{pmatrix}$$

Where E_K is a unit matrix of *K-order.*

Invariable a_N and b_N can be found from recurrence equitation.

$$a_2 = 1,$$

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$$b_N = \left(1 + 4\left(a_{N/2}\right)^2\right)^{-\frac{1}{2}}, \; a_N = 2 b_N a_{N/2}.$$

Or by formulas

$$a_{2N} = \left(\frac{3N^2}{4N^2 - 1}\right)^{\frac{1}{2}}$$

$$b_{2N} = \left(\frac{N^2 - 1}{4N^2 - 1}\right)^{\frac{1}{2}}$$

2.5. Dobeshi-4 transformation

Dobeshi-4 transformation is given [23 - 24] by means of the following matrix.

$$\mathbf{M} = \sqrt{2}\begin{bmatrix} h_0 & h_1 & h_2 & h_3 & & & & \\ & & h_0 & h_1 & h_2 & h_3 & & \\ & & & & h_0 & h_1 & h_2 & h_3 \\ h_2 & h_3 & & & & & h_0 & h_1 \\ h_3 & -h_2 & h_1 & -h_0 & & & & \\ & & h_3 & -h_2 & h_1 & -h_0 & & \\ & & & & h_3 & -h_2 & h_1 & -h_0 \\ h_1 & -h_0 & & & & & h_3 & -h_2 \end{bmatrix}$$

The elements of the matrix are calculated using the formulas given below:

$$h_0 = \left(1 + \sqrt{3}\right)/8, \qquad h_1 = \left(3 + \sqrt{3}\right)/8,$$
$$h_2 = \left(3 - \sqrt{3}\right)/8, \qquad h_3 = \left(1 - \sqrt{3}\right)/8.$$

Dobeshi-4 transformation is one of the simplest wavelets. Multiplying this type of matrix into a vector can be considered as a scan with a step equal to 2 of the original vector with two different filters, set up with masks consisting of 4 elements. Let's pay attention that in other fields, other wavelets given by similar masks, but containing another number of elements, are successfully used. For example, we can specify a study [25]. Some of them are also interesting for us.

3. THE PROGRAM OF CALCULATION OF ORTHOGONAL TRANSFORMATIONS

The program is implemented in the Matlab environment, which allows for the implementation of spectral transformations of six types: 1) cosine, 2) Hadamard of order 2^n, 3) Hadamard of the order $n = p + 1$, $p \equiv 3(\mathrm{mod}\,4)$ –prime number, i.e. based on Legendre's symbol, 4) Haar, 5) slant 6) Dobeshi-4. The working window is selected (Figure 1) before starting the main program with the help of the support program, Namely, a small window appears on the studied image. With the help of this window it can be moved, where necessary, but it is necessary not to change its size, that is, not compress and not expand it. At the top, when the window moves, four numbers are displayed in rectangular brackets. This is the coordinates of the lower left corner and the window size. Then you can take the first two numbers (coordinates x and y) and manually enter them into the second program, which will carry out the calculation. The main program is called main.m.

You can manually insert the entire code of the main program into the Matlab working environment, and immediately there will be results - graphics and 7 text files. The graphs of the transformation results will be presented each in a separate window (Figure 2), and all at the same time in one window. Matlab allows graphics to rotate and view from different sides. In text files, the original data and the results of the mentioned six transformations are automatically saved.

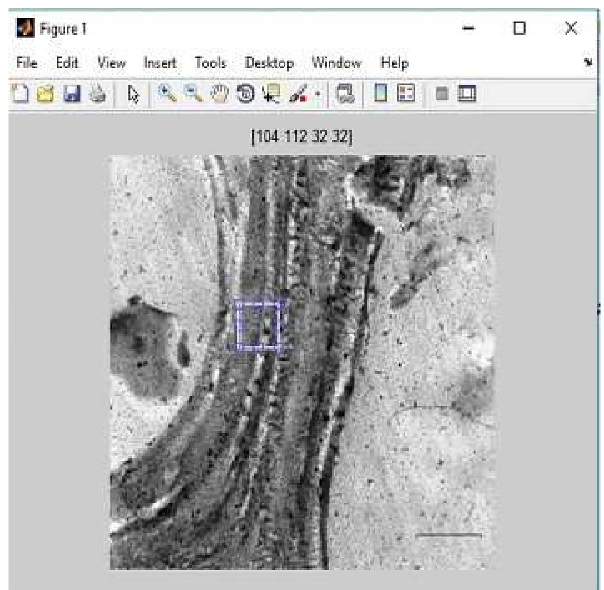

Figure 1. External view of auxiliary program.

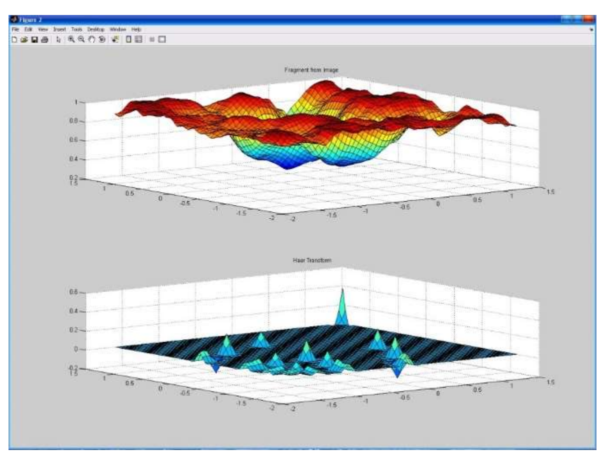

Figure 2. The graph of the initial brightness function in the window and the result of the Haar transformation.

4. OTHER APPLICATION EXPERIENCES OF ORTHOGONAL TRANSFORMATIONS

It is possible to apply different non-standard approaches to the study of textures using orthogonal transformations. For example, the original image is split into non-intersecting square windows. As experiments show, it is expedient to take the size of a window large enough; such as 32 × 32, 64 × 64, etc. Then in each window we make an integral transformation. In this case, some spectral coefficients can be reset, for example, high-frequency, or in several definite parts of the spectrum. In the two-dimensional case, the frequency spectra represent two-dimensional matrices. You can arrange elements of the matrices in vectors. For example, the rows of the matrix can be placed sequentially one after the other. Actually, the positions in the vector in which the spectral coefficients we zeroed can be struck out of the resulting vector. Further, a clustering procedure can be carried out according to the available vectors.

The results of the image processing (Fig. 3, 4) with the help of the described above method are presented below.

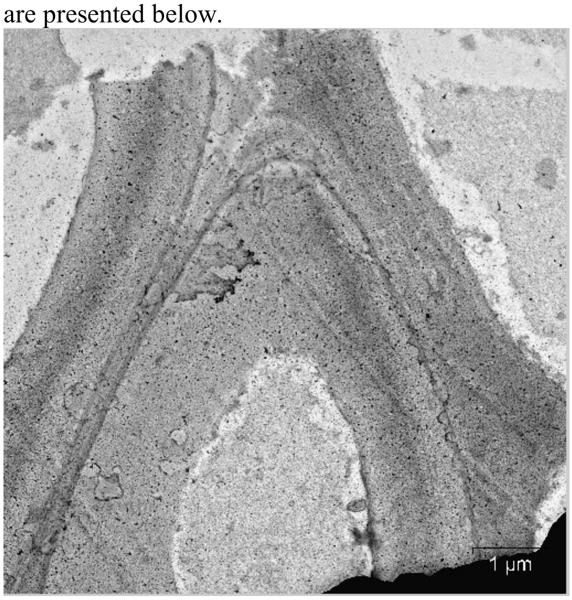

Figure 3. Original image.

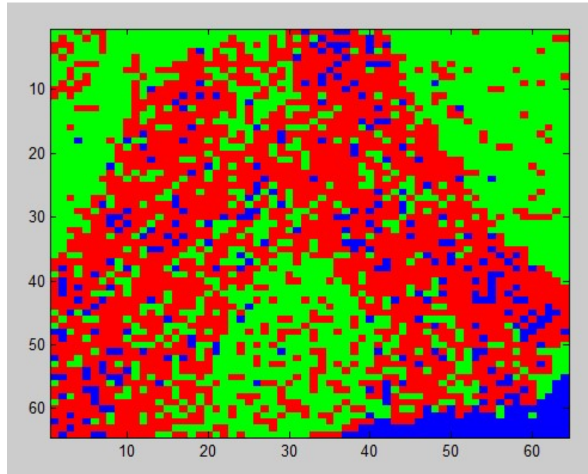

Figure 4. Clusters in the low-frequency part of the spectrum, the number of clusters is 3; the Haar transform is applied; the size of the window is 32x32.

5. WAVELET - DECOMPOSITION OF IMAGES

We can say that the wavelet-decomposition [9] is performed with the help of tree-connected dual-channel filter blocks. At the height of the tree, which is equal to d, it is usually assumed that the signal should have a length equal to 2^d. So, the image accordingly, should have the size $2^d \times 2^d$. If this is not done, then the missing counts are usually added, for example, by adding zero.

At each step of the transformation, the image is split into 4 matrices. One of them represents the image, which is similar to the original, but it is smaller in horizontally and vertically in 2 times. We can say that this is a "rough" version of the original image. In three other matrices, various brightness differences from the original image are "encoded". So, in such way the "detailing" of the information contained in the image occurs.

Values of elements may not fall into the interval {0, …, 255}. For each of the matrices, we find the values of the minimal and maximal elements and display in-line corresponding interval in the interval {0, …, 255}. This allows us to visualize the results in the form of gray images.

The simplest forms of wavelet transformations for images are the Haar and Dobeshi-4 transformations. Below are the results (Fig. 5, 6) of this kind of experiment for the Haar transformation.

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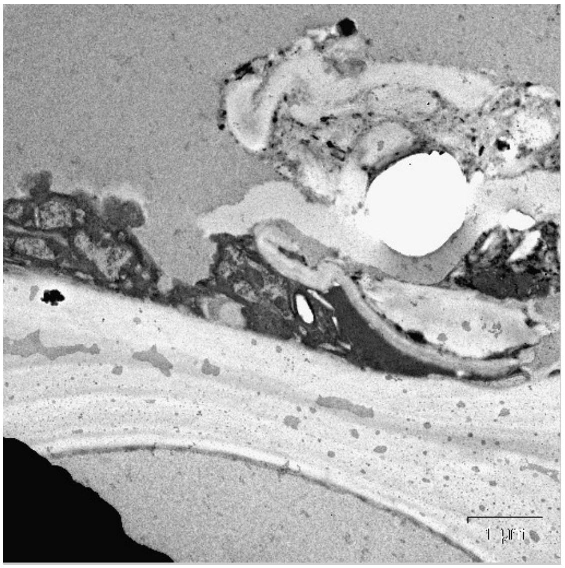

Figure 5. Original image

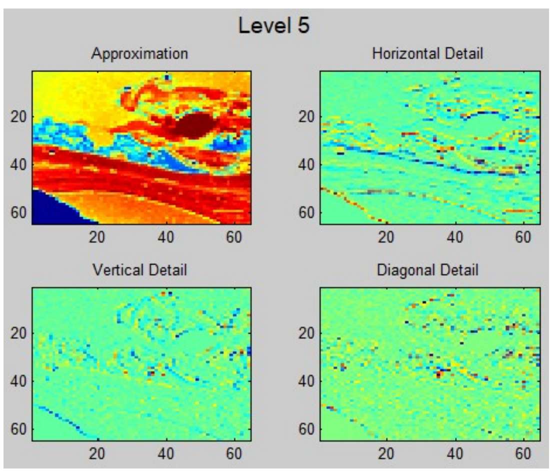

Figure 6. Wavelet - decomposition of the image; the Haar transformation has been applied; the fifth level of detailization.

6. CONCLUSION

This research is devoted to the study of textural images. The source is microphotographs of herbal raw materials, milled on special mills. The work is made for the Institute for Chemistry of Solids and Mechanochemistry (ISSC SB RAS). The main result is the creation of software tools and performed experiments on image processing. The program is implemented in the Matlab environment, which allows for the implementation of spectral transformations of six types: 1) cosine, 2) Hadamard of the order 2^n, 3) Hadamard of the order $n = p + 1$, $p \equiv 3 (\mathrm{mod} 4) -$ prime number, i.e. based on Legendre's symbol, 4) Haar, 5) slant, 6) Dobeshi-4.

The algorithms, which were considered in this work, have allowed us to efficiently isolate the areas in the analyzed images, which are characterized by different degrees of ordering of the structure. To say more precisely, chemists are interested in the areas of "disorderly" structure of materials, for example, during studying the ultrastructure of plant cell walls.

The significance of the project is determined by the development of new models and methods for analyzing textured images. Software products that allow us to make detailed analysis of textures can be successfully applied in different fields of science and industry. First of all, we are talking about chemistry and material science. It is possible to analyze materials of organic origin, slices of metals and minerals, ceramics, etc.

Besides, researchers also deal with different textures during analyze of aerospace images. By texture, it is possible to determine the coniferous or deciduous forest it is, or whether the fields are planted with grain or bean plants, etc. It is also possible to isolate the woods affected by pests or deserted territories.

Thus, the sources of the images can be different. Participants of the project now are interested in microphotographs of the herbal raw materials processed in various physical and chemical conditions. The final aim of the work is the definition of such features of the plant materials as: reactivity, porosity, diffusion coefficient with using photomicrography.

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