This paper focuses on aerospace image analysis methods. Aerospace images are considered for the study of agricultural crops of northern Republic of Kazakhstan belonging to the A. I. Barayev Research and Production Center for Grain Farming. The main goal of the research is the development and implementation of algorithms that make it possible to detect and highlight on aerospace images the factors that negatively affect the growth of crops over the growing seasons. To resolve the problem, the spectral brightness coefficient (SBC), NDVI, clustering, orthogonal transformations are used. Special attention was paid to the development of software tools for selecting characteristics that describe texture differences to segment texture regions into sub-regions. That is, the issue of the applicability of sets of textural features and orthogonal transformations for the analysis of experimental data to identify characteristic areas on aerospace images that can be associated with weeds, pests, etc. in the future was investigated. The questions of signal image processing remain the focus of attention of different specialists. The images act both as a result and as a research object in physics, astronautics, meteorology, forensic medicine and many other areas of science and technology. Furthermore, image processing systems are currently being used to resolve many applied problems.

A program has been implemented in the MATLAB environment that allows performing spectral transformations of six types: 1) cosine; 2) Hadamard of order 2n; 3) Hadamard of order n=p+1, p≡3 (mod4); 4) Haar; 5) slant; 6) Daubechies 4.

Analysis of the data obtained revealed the features of changes in the reflectivity of cultivated crops and weeds in certain periods of the growing season. The data obtained are of great importance for the validation of remote space observations using aerospace images

Keywords: image processing, aerospace images, NDVI, SBC, orthogonal transformations, conceptual model

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IDENTIFICATION OF FACTORS THAT NEGATIVELY AFFECT THE GROWTH OF AGRICULTURAL CROPS BY METHODS OF ORTHOGONAL TRANSFORMATIONS

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1. Introduction

The basis for this study is the features of the growth of agricultural crops during the growing season and the factors that negatively affect their growth in the A. I. Barayev Research and Production Center for Grain Farming. The study is conducted with the aim of implementing grants for young scientists for scientific and (or) technical projects in the Republic of Kazakhstan.

The aim of the study is to create a scientific and technical basis for aerospace image processing [1]. A further objective of the study is to identify factors that adversely affect crop growth, such as weeds, pests and diseases. Now the study of this issue is relevant among scientists of different specialties – agronomists, chemists, biologists, technologists.

In this paper, the main attention is paid to the development of software tools for the analysis of aerospace images, namely programs for textural analysis by NDVI.

To analyze the results of remote sensing of the Earth (ERS) and the underlying surface, as a rule, three intervals of the electromagnetic radiation spectrum are distinguished and considered: visible, infrared and microwave.

In this paper, the brightness values are considered in various intervals of the electromagnetic spectrum, in order to obtain informative intervals for the selection of the object under study, for example, for the selection of vegetation species and damage to crops, namely weeds.

For comparison, statistical methods are used for a large sample of data from two images, which require large computational resources, as well as NDVI indices, and the use of NDVI indices has one drawback: for one NDVI value, there correspond many pairs of SBC values, which entails ambiguity in the results of the study. To circumvent this problem, the following procedure is used: based on the values of the SBC, an NDVI is created – an index image, which also requires additional calculations.

This paper deals with spectral transformations based on orthogonal matrices [2]. In total, 6 types of transformations are considered. It is assumed that the characteristics of textural features, such as the ratio of order/disorder, the proportion of zones with “anomalous” texture, etc., which were obtained for different images, as well as various spectral coefficients, can be further correlated with values characterizing weeds, seedlings, crops, etc. Software products that allow detailed texture analysis can be successfully applied in various fields of science and industry. First of all, these are research institutes in the field of agriculture and agro-industry.

When processing aerospace images, researchers also deal with different textures. It becomes possible to determine whether it is a coniferous or deciduous forest, whether the fields are sown with cereals or legumes, etc. only by textural features. You can also determine whether forests are infested with pests or whether areas are abandoned. Another area of research where these methods can be effectively used is the diagnosis of internal human pathologies, including malignant ones, using images obtained with a thermal imager. The fundamental difference between the ideas of our study and existing analogs lies in the correct application of mathematical methods and in their deeper study. For example, we know of over two hundred textural features, but scientific reviews typically use about fifty types. At the same time, only 3–4 features are commonly used in practice, for example, when processing satellite images. This means that the original images are fully examined. The same can be said about the application of integral transformations. For example, the Haar transform is used in the study of the strength of metals under load to characterize cracking. And also, in the study in the field of crops, the efficiency of spectral transformation was revealed.

The results obtained can be applied in automated image analysis systems, which are used in scientific research and industry. Their use in the industry makes it possible to reduce the cost of fertilizers from the destruction of weeds, and in some cases improve the quality of agriculture.

2. Literature review and problem statement

The paper [3] presents the theoretical and practical results of using orthogonal transformations based on Walsh functions for information compression when transmitting aerospace images over a communication channel. As a result of applying this method to the NDVI image, clustering was not performed by determining the coefficients obtained at low frequencies of the spectrum.

In [4], the effectiveness of orthogonal transformations in compressing documents for storage and transmission in information systems is shown. The authors note that this makes it possible to eliminate the information redundancy of images in them, depending on the purpose of the system and the characteristics of the images being restored. Clustering of the coefficients obtained by applying this method to the NDVI image was not carried out.

In [5], the authors developed a theoretical and methodological framework for applying systems of Vilenkin-Krestenson functions in the smallest possible non-trigonometric form. Based on the rules and conclusions following from the theory of discrete signals on finite intervals, the most appropriate variant of constructing a system of basic functions from all types of Vilenkin-Chrestenson functions is shown. The resulting theoretical and methodological rules were used to filter aerospace images. This work improved the quality of aerospace images and did not single out specific objects, i.e. areas with crops.

In [6], a spectral transformation was used on various orthonormal bases of images obtained with a transparent electron microscope. The efficiency and reactivity of technological processes, porosity, diffusion coefficient, etc. have shown the effectiveness of determining the degree of disorder of plant cell walls from microphotographs. In this paper, methods based on orthogonal bases were performed on electron microscope images, and the effectiveness of aerospace images was not demonstrated.

The paper [7] presents a system design that can detect a suitable location in the vicinity for immediate boarding in case of emergency. The proposed system design consists of two stages. At the first stage, the system takes overviewing images from the onboard camera of the UAV, then the image processing algorithm extracts and clarifies the attributes. In the second stage, the machine learning algorithm evaluates the results of the previous stage, and based on its previous training decides whether the area is visible in the image, good for a safe landing or not. The proposed system design is implemented in MATLAB and the approach used is confirmed by experimental test results data. The proposed system design uses a combination of simple methods, which makes it less resource-intensive, with reduced latency, low cost of implementation and ease of implementation on high-speed real-time equipment in order to determine the properties of plant materials. The method discussed in this paper does not apply to multispectral images.

In [8], a new automatic, hierarchical, multidimensional, histogram-based clustering algorithm is considered. A method for choosing the clustering detailedness in different regions of the vector space of spectral features depending on the average separability of clusters is proposed. The algorithm is applied for the automatic classification of multispectral satellite data in recognizing the land cover. This paper does not compare methods based on orthogonal bases.

The results of experiments [9] on the joint use of spectral and textural features for the classification of vegetation cover on aviation hyperspectral images are considered. The information content of textural features offered in the ENVI package is analyzed in different parts of the spectrum in the range of 400–1000 nm. Examples are given in which the combined use of spectral and textural features makes it possible to increase the classification accuracy. In this work, the analysis of multispectral images and spectral brightness coefficients was not carried out.

Research in the field of image processing, including textural, is carried out in many areas of human activity. Satellite images are studied in space studies of automation and electrometry, optical-electronic satellite systems, as well as image processing methods are actively used in the nuclear, microelectronic, metallurgical and petroleum industries. Abroad, such studies are most developed in the USA, Germany and China. Recognition operations on images of certain objects, as a rule, are preceded by image processing to create conditions that increase the efficiency and quality of the selection and recognition of the desired or studied objects. Image processing methods depend on the research objectives, are quite diverse and may include, for example, highlighting the most informative fragments, enlarging them, increasing the contrast resolution, improving image quality, etc.

A feature of this work is the application of orthogonal transformations to aerospace images. In particular, the effectiveness of these methods in determining factors that negatively affect the growth of crops, i. e. weeds.

of proposed methods, as well as a wide range of textured objects and the different nature of the tasks being solved.

Texture is one of the most important characteristics used to describe the desired areas or properties on the surface of an image based on the dependence of grayscale in space [10]. Despite the presence of textures in images, there is no single and formal approach to the description and strict definition of texture. Texture analysis methods are usually developed individually for each case (Fig. 1).

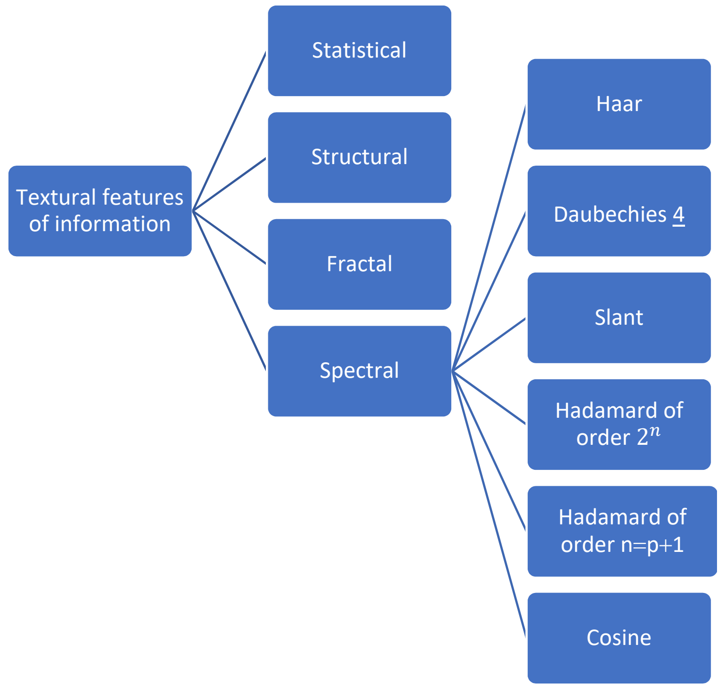


Fig. 1. Textural features

3. The aim and objectives of the study

The aim of the study is to identify factors that negatively affect the growth of agricultural crops by methods of orthogonal transformations based on aerospace images.

To achieve this aim, the following objectives are accomplished:

– to evaluate the efficiency of using methods of orthogonal transformation to the selected area of aerospace images;

– to implement clustering by methods of orthogonal transformations, which makes it possible to determine the percentage ratios for the types of agricultural crops, weeds, by growing seasons.

4. Materials and methods

Recently, a lot of work has been done on the texture analysis of dynamic textures and color images. Analyzing the texture of color images, additional symbols of their characteristics are introduced, based on measuring the intensity levels of each color and their distribution in the image field. When analyzing dynamic structures that change in time, space-time is introduced – the third dimension, which is added to the two spatial coordinates. In this case, all changes in the texture are modeled by moving individual parts that do not change (movement, rotation). The current state of the problem of texture analysis is explained by a variety

However, despite the lack of a formal approach and a strict definition of texture, four approaches can be considered at the stage of definition formation [11]:

– statistical approach: the texture is calculated as a quantitative characteristic of the distribution of intensity values in the image area;

– structural approach: the texture is considered as a set of textured primitive textures arranged in a simple or repetitive order;

– fractal approach: the description of a wide range of processes and phenomena, such as limited diffusion aggregation processes, the formation of sticky fingers in porous media, diffusion processes called leaks and characteristics of clouds, terrestrial and other natural objects, a new direction called fractal geometry was found out. In such methods, the authors consider the object not as a texture, but as a fractal [12]. Many authors state that natural surfaces are isotropic fractals in space, and that the two-dimensional intensity field of such surfaces is fractals;

– spectral approach: Fourier and wavelet analyses are used to work with the texture of the image at different scales. Spectral analysis is a very effective tool for analyzing signals and images. This is because the spectrum is very sensitive to various changes in the structure of signals and images. To perform spectral analysis, one must first divide the signal or image into frequencies. It uses a different set of basic functions. Corresponding algorithmic transformations are: cosine, Hadamard, Haar, italic, etc. called algorithm transformations. The Haar and Daubechies transformations, on the other hand, are simpler types of wavelet transformations. These methods, which are consistent with the theory of signal processing, can be applied to stationary random processes. However, areas can be selected from the images that are conventionally considered stationary (quasi-stationary) and sufficient for analysis to obtain statistically finite results.

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

$$H\vec{u}=\vec{\alpha},$$

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 basis function (harmonic) is represented in the vector $\vec{u}$ (in the original signal). In the two-dimensional case for images, the spectral transformation is written as $HUH^T=A$, 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.

The discrete two-dimensional (matrix) cosine transformation (DCT) is usually given by the formula [13].

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

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

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.

In this case, methods for constructing normalized Hadamard matrices, known as Paley constructions are used [14, 15]. In the studies [16–20], we can find numerous examples of using Hadamard transformation.

Definition. Let p be a prime number, $p\neq 2$, α an arbitrary integer, which can not be divisible by p. The Legendre symbol (α/p) is equal to 1, if the equation $x^2=\alpha(\mathrm{mod}\,p)$ has a solution; otherwise, it will be [21].

As is known [21], the following formula is valid

$$(\alpha/p)=-1^M,\ \ M=\sum\nolimits_{(x=1)}^{(p_1)}[2\alpha x/p],$$

$$p_1=1/2(p-1).$$

Here the square brackets show the whole part of the division. It is necessary to note that this formula is very simple for calculation. Of course, when implemented on a computer, it is necessary to erect in a degree number – 1; it will be enough to control parity M, for example, in such a way. Let us suppose that $R=M-2\left[\frac{M}{2}\right]$. Then it is clear to see that $-1^M=1-2R$.

An orthogonal transformation called slant transform [22] has the following set of features:

– among the basis vectors there is one vector with the same components (constant basis vector);

– the oblique basis vector decreases monotonically from the maximum to the minimum value in jumps of a constant value;

– the transformation matrix has a sequential property.

For vector length $N=2$, the oblique transformation coincides with the second-order Hadamard transformation. In this way

$$S_2=\frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix}.$$

The fourth-order oblique transformation matrix is formed according to the following rule

$$S_4=\frac{1}{\sqrt{2}}\begin{pmatrix}1 & 0 & 1 & 0\\ a_4 & b_4 & -a_4 & b_4\\ 0 & 1 & 0 & -1\\ -b_4 & a_4 & b_4 & a_4\end{pmatrix}\begin{pmatrix}S_2 & 0\\ 0 & S_2\end{pmatrix},$$

or

$$S_4=\frac{1}{\sqrt{4}}\begin{pmatrix}1 & 1 & 1 & 0\\ a_4+b_4 & a_4-b_4 & -a_4+b_4 & -a_4-b_4\\ 1 & -1 & -1 & 1\\ a_4-b_4 & -a_4-b_4 & a_4+b_4 & -a_4+b_4\end{pmatrix},$$

where a_4 and b_4 are real coefficients, which should be chosen so that the matrix S_4 is orthogonal, and the magnitude of the jumps when changing the second oblique basis vector is constant. It can be found from the jump constancy condition that $a_4=2b_4$, from the orthogonality condition $S_4S_4^T=E$ it follows that $b_4=1/\sqrt{5}$. Thus, the fourth-order oblique transformation matrix is as follows

$$S_4=\frac{1}{\sqrt{4}}\begin{pmatrix}1 & 1 & 1 & 0\\ 3/\sqrt{5} & 1/\sqrt{5} & -1/\sqrt{5} & -3/\sqrt{5}\\ 1 & -1 & -1 & 1\\ 1/\sqrt{5} & -3/\sqrt{5} & 3/\sqrt{5} & -1/\sqrt{5}\end{pmatrix}.$$

It is easy to check that the matrix is orthonormal. In addition, it has a sequential property: the number of sign changes increases with the row number from 0 to 3. One can obtain a recursive formula relating matrices of order N and $N/2$.

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

where E_N is a unit matrix of order N.

The constants a_N and b_N can be found from the recurrence relations

$$a_2=1,$$

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

$$a_N = 2b_N a_{N/2},$$

or by formulas

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

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

Modern highly efficient compression algorithms for image processing are based mainly on wavelet analysis methods, among which the classical Haar orthogonal basis occupies a prominent place. The Haar function, like the Walsh function, belongs to the class of piecewise constant functions. Their difference from the Walsh functions is that they are localized on separate parts of the studied interval. Therefore, the Haar functions that allow estimating the local properties of the studied signals are often called Haar wavelets.

The Haar system consists of piecewise constant functions defined on the interval [0, 1]. The Haar transform is based on the orthogonal Haar matrix [23]. The first function of the Haar system is constant:

$$\alpha_0(\theta) = 1, \quad \theta \in [0,1).$$

The remaining functions of the Haar system are conveniently built in groups: the group with numbers m contains 2^n functions.

$$\alpha_{nk}(\theta), \quad n = 1,2,..., \quad k = 0,1,...,2^n - 1.$$

To normalize the Haar function, the following formula is used:

$$\alpha_{nk}(\theta) = \begin{cases} \sqrt{2^n}, \ \theta \in \left[\frac{k}{2^n}, \frac{k+1/2}{2^n}\right), \\ -\sqrt{2^n}, \theta \in \left[\frac{k+1/2}{2^n}, \frac{k+1}{2^n}\right), \\ 0, \ \ \theta \in \left[\frac{k}{2^n}, \frac{k+1}{2^n}\right). \end{cases}$$

Below are examples of fourth- and eighth-order orthonormal Haar matrices

$$H_4 = \frac{1}{\sqrt{4}} \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ \sqrt{2} & -\sqrt{2} & 0 & 0 \\ 0 & 0 & \sqrt{2} & -\sqrt{2} \end{pmatrix},$$

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

Higher-order Haar matrices are built according to the same rules as the H_4 and H_8 matrices. The Haar transform can be viewed as a sampling process of the original signal, in which the sampling step is halved with the transition to the next line.

The Daubechies 4 transform is given [24, 25] by the following matrix

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

Matrix elements are calculated using the formulas below:

$$h_0 = \frac{\left(1+\sqrt{3}\right)}{8}, \quad h_1 = \left(3+\sqrt{3}\right)/8,$$

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

All reasoning remains true if characters in the Galois field are used instead of the Legendre symbols. This allows one to obtain similar matrices in the specified dimensions. Calculating characters manually is extremely difficult and therefore impractical. But it is possible to calculate them on a computer. Let us dwell on this in more detail.

Let p be a prime number. We fix $f(x)$ an irreducible polynomial over J_p – the field of residues module p. If for the polynomial $A(x)$ we have $A(x)=f(x)q(x)+r(x)$, then we think that $A(x)=r(x)(\text{mod} f(x))$, by analogy with the numerical case. If $f(x)$ has a degree, then we can take $r(x)$ degrees no higher than h–1. Therefore, modulo $f(x)$ we have as representatives of the residue classes the polynomials

$$A(x) = a_0 + a_1 x + \ldots + a_{h-1} x^{h-1},$$

where each of α_0, α_1, ..., α_{h-1} can be any of the p elements of the field J_p, i. e. there are residue p^h classes modulo $f(x)$ over J_p. All of them together concerning the natural operations of addition and multiplication form a field called the Galois field, and usually denoted by GF (p^h).

Let now $g(x)$ be the element of the field by GF (p^h), not equal to zero. We put $\chi(g(x))=+1\chi(g(x))=+1$, if (x) – a square and $1\chi(g(x))=-1$, if $g(x)$ – not a square. The function χ – is called the character of the Galois field. Usually also required $\chi(0)=0$. The Legendre symbol is a special case of the character of the Galois field.

Let $q=p^h$ and let $g_0, g_1, ..., g_{p-1}$ be the elements of the field GF (p^h) numbered so that

$$g_0 = 0, \quad g_{q-i} = -g_i, \quad (i = 1,..., p-1).$$

The order matrices $n=p^h+1$, if $p\equiv3$ (mod4) and $n=2$ $(p^h+1)\equiv1$(mod4) are defined in the same way as the order matrices, respectively $m=p+1$, $m=2$ $(p+1)$. The only difference is that in the first case, instead of the relation $\alpha_{ij}=\chi$ $(j-i)$, $(1\leq i, j\leq p, i\neq j)$, we assume $\alpha_{ij}=\chi$ (g_j-g_i), $(1\leq i, j\leq q, i\neq j)$ and in the second case, we make a similar replacement s_{ij}.

5. Results of applying orthogonal transformations to aerospace images

5. 1. Efficiency of using methods of orthogonal transformation to the selected area of aerospace images

The application of 6 orthogonal transformation methods was carried out in the MATLAB software environment. The results of calculations by these methods were stored separately for 6 text files in the area highlighted in the image below (Fig. 2).

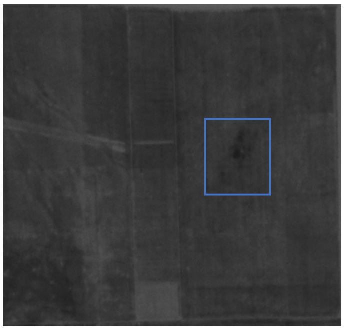
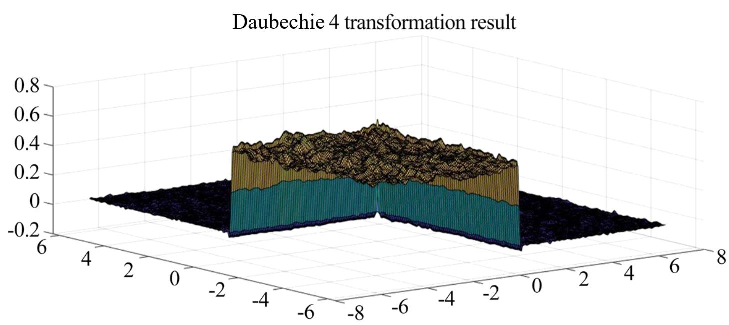


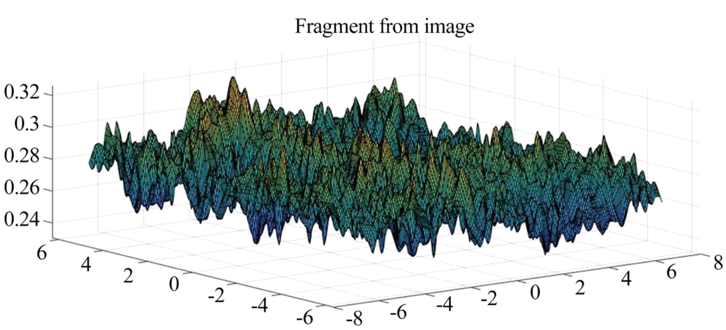
Fig. 2. Calculations made in the selected area

One of them shows the results of the Daubechies 4 method. The presence of a signal in the selected area is reflected by the presence of waves (Fig. 3).

The Daubechies 4 transform is one of the simplest wavelets. Multiplying a vector of this type of matrix can be viewed as scanning two different filters and 4 – element masks, the stride of the original vector is 2. Other wavelets with similar masks but with different elements are used in different areas.



a



b

Fig. 3. Result of Daubechies 4 conversion of selection: *a* — Daubechies 4 transformation result; *b* — fragment from the image

5. 2. Clustering by methods of orthogonal transformas tions for the identification of weeds

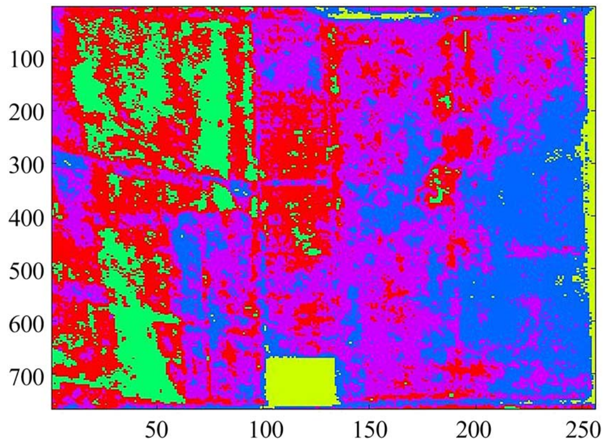
Factors that negatively affect the growth of wheat, in particular, the negative impact of weeds on vegetation belong to the A. I. Barayev Research and Production Center for Grain Farming in the North Kazakhstan region. Images obtained from the Planet.com website about crops belong to this research center (Fig. 4).

Fig. 4. The original image

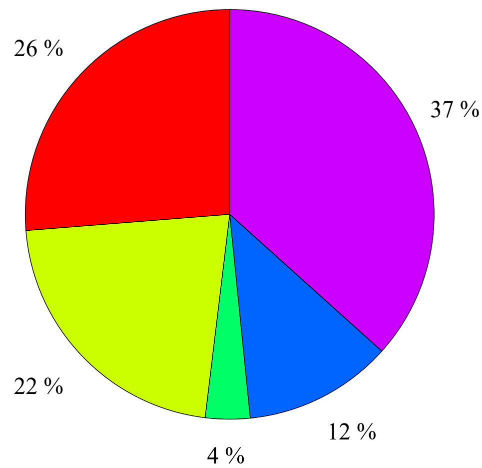
To perform spectral analysis, it is necessary to first decompose the signal or image into frequencies. For this, various sets of basis functions are used. The corresponding algorithms are called transformations: cosine, Hadamard, Haar, slant, etc. Note that the Haar and Daubechies transformations are the simplest wavelet transforms. The program is implemented in the MATLAB environment and allows performing spectral transformations of six types:

1) cosine;
2) Hadamard of order 2^n;
3) Hadamard of order $n=p+1$, $p\equiv 3(\text{mod}4)$, – a simple number, i.e. based on the Legendre symbol;
4) Haar;
5) slant;
6) Daubechies 4.

The calculation is performed in the MATLAB environment and is used for image analysis. The image is divided into separate parts using software. In the study of texture images, various non-standard methods can be used using orthogonal transformation. For example, the original image is divided into non-intersecting square windows. Experiments show that it is better to reduce the window size: 8×8, 16×16, 32×32, etc. We perform an integral transformation on each window. We also set some spectral coefficients to zero, such as high-frequency coefficients or some parts of the spectrum. In the two-dimensional case, the frequency spectra have the form of a matrix. Let us place the elements of the matrix in the form of vectors. For example, consider the rows of a matrix located one after another at the end. In vector data, we subtract the coefficients of the spectra that have been zeroed out from the resulting vector. As a result, we perform the procedure of clustering these vectors. The results of image processing by the methods described above are presented below (Fig. 5).



a



b

Fig. 5. Haar transformation is used, the result of clustering on the lower frequency of the spectrum: *a* — clustering on the lower frequency of the spectrum, the number of clusters 5, Haar transformation was used, window size 8×8; *b* — percentage result of clustering in the form of a diagram

According to agronomists of the A. I. Barayev Research and Production Center for Grain Farming, wheat was grown from 12.05.2021 to 25.05.2021. 17.06.2021 weeds were hybridized and harvested from 18.08.2021. The table below shows the percentage of weeds for different growing seasons (Table 1).

The dynamics of weed growth on orthogonal transformation are considered. One of them, the results of the work on the Haar transformation is shown in the figure below (Fig. 6).

Image analysis based on SBC allows you to recognize the type of plant and changes in plants by growing seasons. Our research allows us to detect whether a plant is healthy, if not, what negative factors have affected the plant: disease, wilting, lack of fertilizers, insect damage, and so on, as well as predict yield.

Fig. 7 shows how it is possible to organize the partitioning of the spectrum of brightness coefficients, for further recognition of the type of crop and its normal growth.

Table 1

Identification of weeds by orthogonal transformations in different growing seasons

Methods	Data				
	10.06.2021	01.07.2021	21.07.2021	06.08.2021	14.09.2021
Haar	37 %	9 %	6 %	9 %	3 %
Daubechies 4	37 %	8 %	5 %	6 %	3 %
Cosine	37 %	10 %	5 %	8 %	3 %
Hadamard of order $n=p+1$, $p\equiv3(\text{mod}4)$ – prime number, i. e. based on Legendre's symbol	37 %	9 %	6 %	9 %	3 %
Hadamard of order 2^n	37 %	9 %	5 %	9 %	2 %
Slant	37 %	9 %	6 %	8 %	3 %

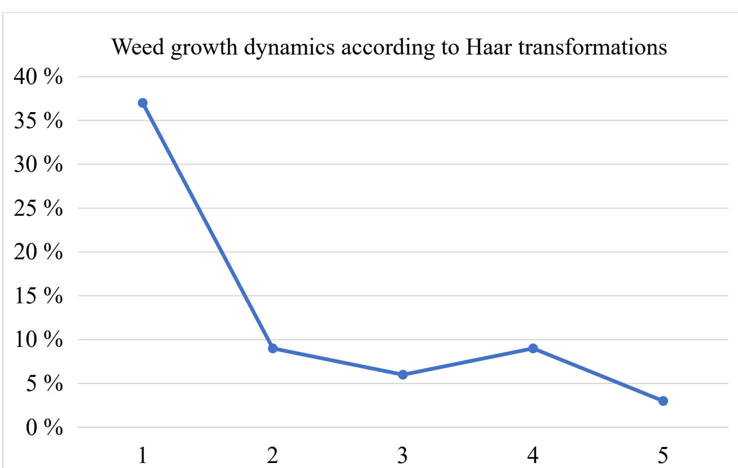


Fig. 6. Weed growth dynamics

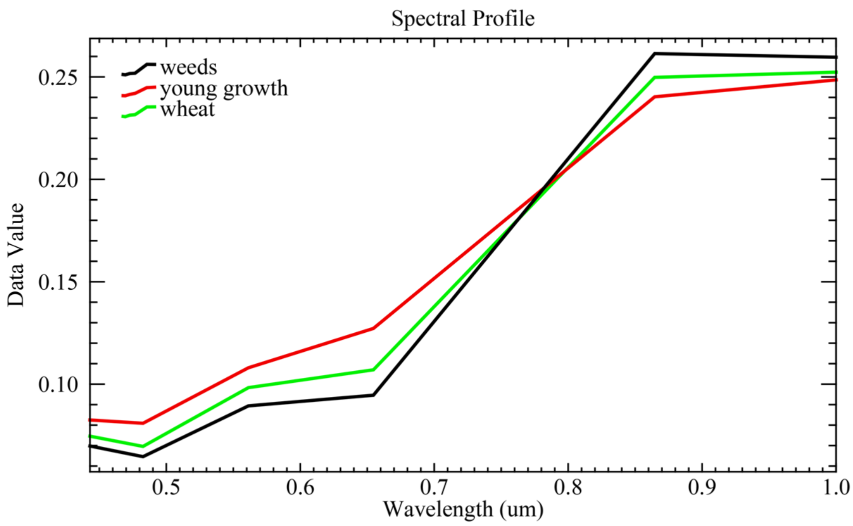


Fig. 7. Spectral brightness coefficients of wheat, weeds, wheat shoots during the growing season 10.06.2021

During the growing season 10.06.2021 in the table below, the percentage of weeds visible by all methods is very high (Table 2).

Table 2

Detection of weeds and millet on orthogonal transformations before the application of herbicides

Method	10.06.2021		
	Weeds	Young growth	Wheat
Haar	37 %	26 %	37 %
Daubechies 4	37 %	28 %	35 %
Slant	37 %	27 %	36 %
Hadamard of order 2^n	37 %	27 %	36 %
Hadamard of order $n=p+1$, $p\equiv 3$ (mod4) – a prime number, i. e., based on the Legendre symbol	37 %	27 %	36 %
Cosine	37 %	27 %	36 %

After hybridization of weeds in different growing seasons, the following graph shows the dynamics of their reduction and increase in productivity (Fig. 8).

On average, all orthogonal transformation methods showed the same result. Changes in the growth dynamics of crops and weeds were identified for each growing season.

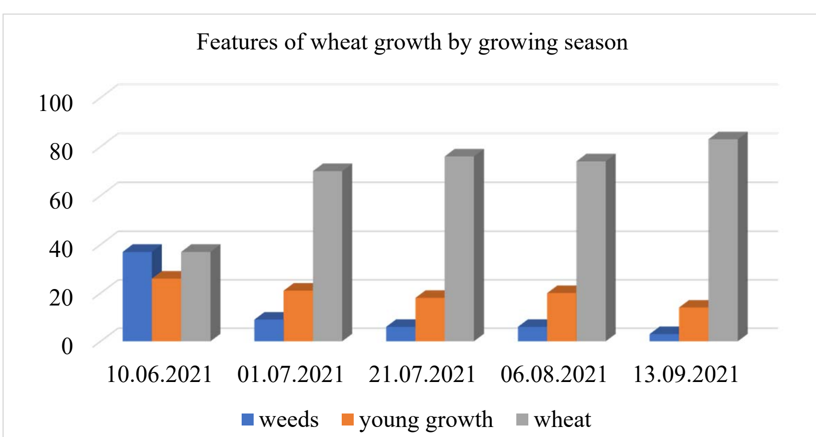


Fig. 8. Wheat growth dynamics

6. Discussion of experimental results of the non-standard approach with the help of informative textural features

The result of applying the k-means clustering method to a gray image (NDVI) was obtained after multispectral image processing. It did not correspond to the data provided by agronomists of the A. I. Barayev Research and Production Center for Grain Farming. However, changes have been observed in the use of orthogonal transformation of textual symbols (Fig. 2).

Orthogonal transformations were used in NDVI images, studying aerospace images obtained on the spectral brightness coefficient. The effectiveness of these methods is shown in Table 5, with changes in each vegetation period, i. e. proving that the orthogonal transformations applied to microscopic images can be applied to aerospace images.

Orthogonal transformation methods showed areas of homogeneity in aerospace images, i.e. the presence of weeds in crops. In the course of the study, according to the actual data provided by the agronomists of the A. I. Barayev Research and Production Center for Grain Farming, the percentage of weeds coincided, and no pests were identified. This is due to the fact that crop pests cannot be detected on aerospace images.

When conducting research, the mathematical description of these methods requires the accuracy and time to process a single image used.

The disadvantage of this method is that it is ineffective in applying to areas of inhomogeneity in aerospace images.

During the study, the mathematical calculations of 6 methods were complicated. To check the accuracy of the calculation, the values of the image in different areas were compared. In the future application, the set of methods will be combined into one function.

7. Conclusions

1. The presence of a signal in the highlighted area was observed as a result of using orthogonal conversion methods to gray image (NDVI) obtained from the processing of the original multispectral image. As a result of all methods, the presence of waves, i.e. the presence of values in the image (Fig. 3, *b*) (0, 0.4] determines the presence of changes.

2. After determining the effectiveness of orthogonal transformation methods in the selected area, these methods were applied to the images obtained for each growing season. As a result, we convert negative or high-frequency values to zero in the values obtained in a two-dimensional matrix and cluster the positive val-

ues. The original image is divided into 8×8 non-intersecting square windows. As a result of the complex transformation of each window, the specificity of the grain was determined, i. e. the presence of weeds in it. In addition, on the images of each growing season, a change in signals was observed, i. e. weed growth dynamics.

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